Historical introduction

About 36 years ago Bill Scott-Brown suffered a major coronary infarct and being strictly ordered to 'rest' for six months set himself to create, as Editor (not author, because that would have been too strenuous, he thought) this work of his own inspiration. In 1952 I was among the first generation of FRCS candidates for whom it was the Bible. We all revered 'Negus' for the nose and throat (some of us still do) but Scott-Brown, in two volumes as it then was, provided the first post-war text for otolaryngology across the board. SB (as he was known) was probably the only person to be at all surprised by the success of his achievement, and to find himself in due course under notice from Butterworths to prepare a second edition. It was at this stage that he recruited John Ballantyne and myself and the second, third and fourth editions were produced by the two of us under his friendly eye. For the third edition we succumbed to the inevitable by expanding two fat volumes into four (slightly) thinner ones, only to find that the fourth edition in its turn required four fat ones.

Throughout this 20 year period John Ballantyne and I derived constant satisfaction and pleasure from the ongoing association with so many willing friends and contributors past and present. We than them warmly.

We know that the ENT fraternity world-wide has pleasure in the knowledge that SB continued in his retirement still to take satisfaction from the perpetuation of his work. The sad news of his death came just as this new edition went to press. Those who knew him will perhaps see in this Fifth Edition, and the 35th year of his book, a memorial to his achievement.

John Groves
Advisory Editor
Introduction

When I was first invited to edit the Fifth edition of Scott-Brown's Otolaryngology, I thought I was aware of the enormity of the task and my own limitations. As time progressed, I realized that I had misjudged both.

This work has represented the mainstream of British otolaryngological thinking for over thirty years. However, the increase in the breadth and depth of our specialty is such that only a gifted few can be conversant with all aspects of it. Hence, I realized that I could not undertake the task without help. I have been most fortunate in having such a distinguished group of volume editors, all of whom are already well-known in British otolaryngology, and all of whom have been delightful and stimulating colleagues in this work. It has been a joy to work with them.

Modern otolaryngology has widened in recent decades, and procedures are now being performed that are no longer covered by the term 'ear, nose and throat surgery'. This work attempts to embrace all the areas that so-called ear, nose and throat surgeons are covering at the present time, and hence the change of the title to Scott-Brown's Otolaryngology.

For the new edition Scott-Brown has grown from four to six volumes. An entirely new volume has been introduced in recognition of the subspecialty of paediatric otolaryngology and the amount of material in audiological medicine is now great enough to justify its separation from the Ear volume. Although these are now specialties in their own rights, they are also, and will continue to be beyond the lifetime of this edition, part of the routine practice of most British otolaryngologist. To enable these new volumes to stand alone, a certain amount of overlap with other volumes has been necessary.

In any multi-author and multi-volume production, overlap is always necessary if each chapter is to be developed freely, and if there is to be easy reference to subjects dealt with in more than one volume. Consequently, I ask for the reader's indulgence in those sections where overlap has been planned and deliberate. Where it has occurred as a result of my ineptitude, I apologize.

The editorial team have been very pleased at the response of those invited to contribute, although, unfortunately, a few leading members of our specialty were unable to accept the invitation. However, by and large, those asked were both cooperative and energetic in their responses, and have given freely of themselves in their contributions. I have been most impressed by the spirit of goodwill among the otolaryngologists in this country, and I am grateful to them.

In the production of this edition, I have seen myself as custodian of a great British institution. I have always been aware of the privilege and responsibility of my position, and am grateful for the advice I have received from many senior and not so senior members of our specialty. I am particularly indebted to the Advisory Editor, John Groves, and to his formed editorial colleague, John Ballantyne. My respect and admiration for these colleagues has risen, not simply because of the invaluable help they have given so freely in this edition, but because I now realise the enormity of their accomplishment and their contribution to British otolaryngology in editing the last three editions.
I also wish to express my thanks to those in Belfast who have helped with, or suffered because of, the Fifth Edition. Some have done both, and without their backing and encouragement this work would not have been possible. It would be invidious to try to name everyone. Various secretaries have been of enormous help, and without this I could not have produced this edition. My consultant colleagues have advised and encouraged me, and my junior colleagues have given very practical advice in their down-to-earth comments and invaluable help with proof-reading. My family have been both encouraging and remarkably tolerant of the long hours required to edit such a work as this.

The staff at Butterworths were helpful and encouraging throughout. Initially, Peter Richardson set the wheels in motion. He was followed as publisher by Charles Fry, who was assisted by Anne Smith and Jane Bryant. The sub-editors have been Anne Powell and Jane Sugarman. The general spirit of pleasant cooperation and tolerance has been delightful.

I am sufficiently optimistic to believe that there will be a Sixth Edition. I do not know who will be editing it. However, if the reader has any constructive comments or criticisms, I should be pleased to have them ... in writing! I can not guarantee to acknowledge these, but I promise that, if I am the editor, I shall give them due consideration, and, if not, I shall make them available to my successor.

Alan G. Kerr
Preface

I had not originally intended to write anything at the beginning of the book as I thought it likely that it was already too long, and my own contributions by far the worst examples, but seeing the friendly, smiling pink cheeked face of Bill Scott-Brown just a fortnight after his ninetieth birthday made me feel that perhaps I should. It was such a pleasure to see friend who has becomes something of a legend through a book, first published under his editorship in 1952 and now in its fifth edition thirty-five years later, though I have only known him for the last twenty years. Many outside ENT will know him for his painting in oils and watercolours and for his sketches in pastels of scenes in France, London and the beautiful Hampshire countryside and the River Test. His first one-man show was held in London in 1973 and his third only last year. As this edition appears, he will be putting his considerable fishing skills to the test again as a distinguished member of the Houghton Club and I hope he will have another excellent season with many more to come. Last year he celebrated his Diamond wedding anniversary, but sadly his wife Peggy died on 25th May this year. Like Bill, she has enriched the lives of all who knew him.

My second reason for adding further length to the book is to apologise to my fellow authors, for although I have tried desperately to cut my own chapter and keep to length, they have succeeded where I have sadly and somewhat ashamedly failed. Considerable effort has been made to reduce repetition throughout the volume and to try and make it as readable as possible, while trying to retain a book of reference, alas not as comprehensive as it might be. I should be pleased to have constructive criticism or corrections about omissions; we are certain not to have pleased everyone. It has generally been assumed that the student will read the book from start to finish and that those referring to it later will use the index. However to help both, cross-referencing the illustrations in each chapter, particularly between pathology and radiology and the clinical parts of the book, has been used and it is hoped that all readers find this helpful and leading to an easier understanding.

Finally, may I express a very warm vote of thanks to the authors for all their industry, for being so tolerant of their editor, and to their wives and families for allowing them to spend so much time in this way. This volume has gone from first manuscript, through galley to page proof in twelve months and from conception to birth in two years (e.g. the elephant!). This is a fairly remarkable feat which would not have been possible without so much help from the contributors and publishers. I cannot omit a friendly look over my shoulder to the Editor-in-Chief, Alan Kerr, whose encouragement/cajoling I hope I have accepted with good grace. Oh, how I wished over the last two years that I had bought shares in British Telecom; Alan, now known to my family as 'Buzby', has remained remarkably cheerful but even more to be congratulated is his most supportive wife, Paddy. Alan Kerr will have thanked Butterworths and therein, Charles Fry who has been in charge of this edition, Jane Bryant (Senior Sub-editor) who has remained courteous and efficient throughout dealing with six individual editors and no less than one hundred and fifty chapters, and Anne Powell, who has polished up our English! The word 'fetus' has been spelt, by intention, in its original form. Sadly, try as I might, I have failed to convince the publishers about one thing and I mourn the demise of the hyphen-prescribed by the OED but proscribed by them in the name of 'housestyle'. Co-operative they have all certainly been throughout a wholly co-ordinated exercise but finally we have come to coexist!
On 12th July, just six weeks after his wife, 'Bill' Scott-Brown died peacefully at their Hampshire home, leaving the world and his friends sadder but full of the most wonderful memories. I am sure that he wished no more than that they should be together again; now they are reunited in earth and in heaven. A surgeon and friend of the utmost integrity who commanded both respect and affection. 'May we... reject those things which are contrary to our progression and follow all such things as are agreeable to the same...' (part of the collect (ASB) for that day - the fourth Sunday after Trinity). Deo Gratias.

John B. Booth
18 Upper Wimpole Street,
London, W1M 7TB
Chapter 1: Examination of the ear

A. Fitzgerald O'Connor

The practice of medicine demands the taking of an accurate history and carrying out a careful clinical examination. This principle applies to otology as much as to any other branch of medicine, and should not be forgotten in the rush for 'high technology' investigations which may be invasive and add little to the diagnostic process. The symptoms and signs associated with ear disease must be elicited, together with those which the patient may not recognize as being related to disorders of the ear (see also Volume 2, Chapter 6).

History

Symptoms of ear disease include otalgia, discharge, disorders of auditory perception (mainly hearing loss), tinnitus, vertigo and headache.

Otalgia

Pain in the ear may come from pain receptors in the external or middle ear whose afferent fibres lie in the fifth, ninth and tenth cranial nerves and second and third cervical nerves.

As the skin is so closely applied to the meatal and auricular perichondrium, severe pain may be associated with an external otitis having minimal clinical signs. Senturia (1973) stated that severe otitis externa can be one of the most painful disorders known. Note must be taken of long-standing dermatitis, usually of the eczematous type; trauma to remove wax, may predispose to infection but be neglected in the history. Herpes zoster infections of the fifth and seventh cranial nerves or the upper cervical nerves frequently begin with pain, the diagnosis only becoming apparent when the vesicular eruption on the pinna or meatus occurs. Other painful conditions of the external ear include polychondritis helicis (chondrodermatitis nodularis chronica helicis) and squamous carcinoma.

Myringitis bullosa haemorrhagica is a painful condition occurring spontaneously and resolving within several days. A vesicular eruption is seen on the tympanic membrane which may be associated with bleeding and a serious discharge.

Otitis media, although a frequent cause of otalgia, is subject to overdiagnosis (Bluestone and Cantekin, 1979).

Children who have otitis media with effusion (glue ear) may have a history of previous upper respiratory tract infection and earache. Otalgia is said to occur in some children due to eustachian tube dysfunction, when the middle ear pressure is markedly reduced leading to retraction of the tympanic membrane. The pain usually occurs at night when the child has been sleeping and may be due to venous congestion in the eustachian tube area with reduced frequency of swallowing and, consequently, failure of middle ear ventilation. On arising or sitting up the congestion clears, the eustachian tube opens and the pain disappears. Sometimes the child's crying, because of the pain, leads to hyperaemia of the tympanic membrane and misdiagnosis of acute otitis media.
Sudden spontaneous resolution of pain in cases of true otitis media indicates perforation of the tympanic membrane. Pain is not a feature of chronic otitis media unless there is an associated otitis externa, or more ominously dural inflammation. Less frequently, severe pain in a chronically discharging ear may reflect neoplastic change.

Pain may be referred to the ear from other areas supplied by the fifth, ninth and tenth cranial nerves and the upper cervical nerves. Thus when otalgia is a presenting symptom and no local disease is found in the ear, a distant cause must be considered. Usual sources of referred otalgia are dental disease, lesions of the posterior tongue, pharynx and larynx.

**Aural discharge (otorrhoea)**

Otitis externa may present with irritation and a watery odourless discharge. A clear fluid discharge from the ear after trauma may be indicative of a cerebrospinal fluid leak through a dural tear, often over the tegmen tympani and roof of the external auditory meatus.

When discharge contains mucus, it must have arisen from glands within the middle ear cleft, passing into the external auditory meatus either from an open mastoid cavity or through a tympanic membrane perforation.

A thick brown discharge of liquefied wax may occur in an otherwise healthy ear but often heralds an acute otitis media, particularly if it contains blood and pus. In chronic otitis media, the discharge is often long-standing and characterized by a foul smell due to saprophytic organisms. Cholesteatomatous debris may be discharged, such patients frequently presenting because of the embarrassing nature of the smell. In a chronically discharging ear, the onset of bleeding is an ominous sign, indicating the possibility of neoplastic change.

Bleeding from the ear usually follows trauma but in rare cases may occur from glomus tumours or vascular anomalies in the middle ear or external meatus.

**Abnormalities of auditory perception**

Deafness is the term most commonly used by patients to indicate an abnormality or change in their hearing acuity. Some idea of the level of auditory hearing loss can be obtained from the history by asking about their difficulty in varying social situations. Conversation in a quiet environment is conducted around 40 dB hearing level, a door bell output is, on average, 60 dB and conversation on the telephone between 40 and 70 dB within a limited frequency band of 200-1200 Hz. A person with a conductive loss appears to hear better in a noisy environment, usually because the speaker has raised the intensity of the voice. This phenomenon is known as *paracusis Willisii* and is usually associated with otosclerosis. In sensorineural hearing loss, there is reduced discrimination of speech, particularly in background noise. The ability of a person with sensorineural deafness to discriminate speech is not necessarily helped when the speaker raises the intensity of the voice. Indeed the listener may say: 'Don't shout, I'm not deaf'.

*Recruitment* of loudness is characteristic of a cochlear loss. A relatively small increase in the intensity of the auditory stimulus may cause frank discomfort to the listener. Poor
speech discrimination without recruitment, especially if unilateral, suggests auditory nerve damage.

Tonal changes in auditory perception are usually expressed as 'one ear not sounding like the other' or 'tinny'. Diplacusis is the apparent difference in the pitch of a tone between the two ears and is associated with conditions causing endolymphatic hydrops.

Autophony is the abnormal perception of one's own breath and voice sounds and is often associated with a permanently open, or patulous, eustachian tube. The patient may also describe it as sounds echoing in the ear, or as if talking in a reverberating chamber. It indicates eustachian tube dysfunction and examination may occasionally show serous fluid in the middle ear.

Fluctuant hearing loss may result from diseases causing either conductive or sensorineural pathology. The fluctuant nature of the hearing loss associated with upper respiratory tract infections, eustachian tube dysfunction and otitis media with effusion is well known. Ménière's disease is characterized by a fluctuating sensorineural hearing loss, with the hearing deteriorating during each attack and recovering between attacks (Hood, 1980). In a variant of Ménière's disease - Lermoyez's syndrome - the hearing drops before an attack, recovering as the vertigo begins.

Other features associated with the onset of the hearing loss should be noted. In the majority of cases of sudden deafness the cause is unknown, though many are assumed to be due to vascular disease. The deafness may be related to a recent viral infection, as seen in the classical unilateral mumps deafness. Severe infections such as meningitis and, abroad, malaria may pre-date the onset of hearing loss. Sudden deafness may be the presenting feature in up to 10% of patients with acoustic neuroma (Morrison and Booth, 1970) or be associated with a perilymph fistula resulting from an increased venous pressure due to straining or lifting.

Previous otological procedures should be noted, especially stapedectomy, which may have been performed many years previously.

It is important to enquire about a family history of hearing loss since this may reveal a hereditary cause. There may be a history of noise trauma having occurred 20 or 30 years previously which has potentiated the effect of ageing on the cochlea to produce a hearing disability. A clear history of occupational noise exposure and military service is required. In the UK, protection from industrial noise trauma has been supported by legislation for only a relatively short time so that many such cases are still presenting to outpatient clinics. Social noise trauma includes pop music, rifle shooting and motor racing. Some people suffer irreversible hearing loss from relatively minor noise stimuli, whereas others are exposed to major noise trauma with little effect on their hearing.

The patient's past medical history is important since the aminoglycoside antibiotics, used for life-threatening infections, and some of the 'loop' diuretics, are potentially ototoxic (Ballantyne and Ajodhia, 1984). It is generally considered that topical aminoglycoside antibiotics, as used in ear drops, do not cause hearing loss. More recently, the use of cytotoxic therapy in oncology has been implicated as a cause of hearing loss. Salicylates bought 'over
the counter' may be ototoxic to the susceptible user, as is quinine which used to be taken as an antimalarial drug.

In children, a history of poor speech development, lack of communication skills and educational retardation may replace hearing loss as a symptom of ear disease.

**Tinnitus**

Tinnitus, like hearing loss, is a common presenting symptom of aural pathology. The nature of the tinnitus may be helpful in locating the lesion in the auditory pathway. A rhythmic beating or pounding tinnitus, synchronized with the pulse, is suggestive of a vascular lesion such as a glomus tumour. A dull, continuous tinnitus is sometimes found in association with a conductive hearing loss. This may represent normal noise levels in the temporal bone which have now become obvious to the patient because of the absence of the masking effect of environmental sound. Successful treatment of the conductive deafness, for example by stapedectomy, may alleviate this type of tinnitus.

Body sounds transmitted via an abnormally patent (patulous) eustachian tube may be reported as tinnitus, and likewise the noise of a live insect in the ear canal.

Most cases are characterized by rushing, hissing or ringing sounds in the ear or head. The source of these is either in the cochlea, neural pathways or cerebral cortex.

Previous noise exposure and a history of having been given ototoxic drugs (aspirin, quinine, etc) are important aetiological factors (Brown et al, 1981; Meyerhoff et al, 1983). Fluctuant tinnitus may be associated with Ménière's disease and usually increases in intensity prior to a vertiginous attack, returning to its resting intensity in between.

Long-term tinnitus sufferers may well be unable to locate the offending noise in the ears and simply perceive head noise. Recognizable sounds such as voice, music and bells may not be considered to be evidence of ear disease, but more psychological, as in schizophrenia. Tinnitus in general may be caused by all of those agents which produce hearing loss and thus a similar history should always be taken.

**Vertigo**

The definition of vertigo is difficult. It may be defined as an 'hallucination of movement' - that is, the patients feel that they or their environment are moving. Elsewhere in this volume (Chapter 18), it is defined as a 'subjective sense of imbalance'.

The history is of paramount importance in making the diagnosis in cases of balance disorder. In many cases, the diagnosis can be made from the history alone. It is essential to elicit from the patient the exact sensation perceived, since the terms 'dizziness', 'vertigo', or 'lightheadedness' mean different things to different people. The patient may have great difficulty describing the actual phenomenon (Hinchcliffe, 1973). This difficulty in description is a reflection of the small cortical representation of balance perception. The patient needs to rely on the mismatch of positional cues and the associated autonomic vegetative effects for their own description. It is important to identify symptoms not attributable to the vestibular
system, such as the lightheadedness, with blurring of consciousness, which accompanies cerebral anoxia. Anxiety states, in which the patient hyperventilates with resulting hypocarbia, may also produce such symptoms (Evans and Trimm, 1966). The sensation of movement associated with vestibular lesions is most commonly rotatory, but can include swaying or tilting of either the patient or the surroundings. If nystagmus is present, the environment is only perceived during the slow phase and since the images traverse the retina in the opposite direction, the environment appears to spin in the direction of the fast component. This may be useful on some occasions in trying to locate the offending labyrinth.

Peripheral lesions usually produce vertigo of sudden onset which may last for only seconds or up to a few days. In Ménière's disease, the attacks are recurrent and usually associated with fluctuating hearing loss and tinnitus. Movement tends to make vertigo of peripheral origin worse. The best known example of this is the sudden onset of rotatory dizziness associated with certain head movements in patients with benign paroxysmal positional vertigo. Vertigo associated with coughing or sneezing suggests the presence of a perilymph fistula. Tullio's phenomenon is the vertigo caused by loud sounds and may be due to endolymphatic hydrops or a third labyrinthine window, as in a labyrinthine fistula (Kakkar and Hinchcliffe, 1970).

Central lesions tend to produce less intense vertigo. Positional changes have less effect, but the patient tends to have more disturbance of gait.

Vertebrobasilar ischaemia can cause sudden onset vertigo and drop attacks, without loss of consciousness, but usually accompanied by other associated symptoms. A full medical history may reveal long-standing degenerative conditions such as diabetes mellitus or atherosclerosis. Life-threatening infections sometimes require potentially ototoxic antibiotics. Some of these, particularly gentamicin, may damage the vestibular system.

In summary, it is important to ask the patient if he/she remembers the first attack and to describe it accurately. The onset, whether sudden or gradual, precipitating factors, duration of attack and associated symptoms are noted. The frequency and severity of attacks should be enquired about.

**Oscillopsia**

This descriptive term is used when the patient complains that the horizon rotates or jumps in a vertical plane when walking (Ramsden and Ackrill, 1982). Resulting spatial disorientation is corrected by the patient halting, holding on to a solid structure and focusing on a near image. It is due to an imbalance in the vestibulo-ocular reflex, which is necessary to stabilize the retinal image. Oscillopsia may follow loss of peripheral vestibular function, but is also a feature of central lesions, especially when associated with an acquired pendular nystagmus (Rudge, 1984).
Clinical examination

The ear

Congenital absence of the auricle is termed 'anotia' and incomplete development 'microtia'. Anotia is associated with severe malformations of the ear canal, middle and inner ear; with microtia the auricular remnant is usually anteroinferior to the bony ear canal and the presence of a tragus is considered a good prognostic feature for middle ear reconstruction. Accessory auricles may be found and represent separate developments of the second branchial arch remnants. In all cases of congenital external ear dysplasia, a full examination should be made for other features which might allow the identification of a named syndrome.

Acquired lesions on the auricle include gouty tophi, squamous carcinoma, basal cell carcinoma and the painful nodules of chondrodermatitis helicis.

It is important to look behind the auricle for surgical scars. Postauricular incisions may be difficult to see deep in the retroauricular sulcus, and the more posteriorly placed incisions associated with the formation of a Palva flap or excision of an acoustic neuroma may be hidden in the hairline. Endaural incisions can usually be noted in the area between the tragus and helix. Examination behind the auricle may reveal evidence of acute inflammation in the form of erythema, tenderness or abscess formation. In children, a subperiosteal abscess tends to point posterosuperiorly to the external auditory meatus. In adults, the abscess points more posteriorly, reflecting the more extensive mastoid development. Pus from the mastoid may track anteroinferiorly along the sternomastoid muscle presenting as a mass in the neck (Bezold's abscess). Alternatively, it may track medially along the posterior belly of the digastric emerging in the submandibular triangle as Citelli's abscess (Shambaugh, 1967b).

Lymphadenopathy, associated with ear infections, occurs commonly in the preauricular node where it has to be differentiated from an infected preauricular cyst. Swollen, tender postaural nodes also occur, but other sites of primary infection (scalp, etc) should always be considered. Neoplastic infiltration of neck nodes in both anterior and posterior triangles occurs with aural carcinoma and is a grave prognostic feature.

The external auditory meatus is examined using either an auriscope or hand-held speculum and headlight. In the adult, traction on the pinna upwards and backwards helps to straighten the canal and facilitate vision. If the view is obscured by wax this should be removed either by a wax probe or by syringing. Syringing is best avoided if there is a possibility that the tympanic membrane is perforated. It must not be forgotten that syringing can change the appearance of the tympanic membrane. It is often difficult to see the anterior sulcus of the canal because of a prominent anterior meatal wall. Canal stenosis may follow chronic otitis externa or surgery. Meatal osteomata, which are sometimes associated with cold water swimming, appear circumferentially in the bony part of the meatus and may obstruct a clear view of the tympanic membrane.

Tympanic membrane

It is essential to identify the normal anatomical features of the tympanic membrane using either an auriscope or speculum and headlight. The wide-angled lens of a Storz rod may
be helpful and is useful for photography of the tympanic membrane. Some tympanic membranes are difficult to see and in these cases an operating microscope is useful.

If possible, the whole of the tympanic annulus should be seen, along with the handle and lateral process of malleus. In most normal tympanic membranes there is the sharp reflection of the auriscope's light spreading anteroinferiorly in a cone shape. The mobility of the tympanic membrane is assessed by using a pneumatic bulb on the auriscope or Siegle's speculum (Siegle, 1864).

Alternating positive and negative pressures in the ear canal result in the normal tympanic membrane moving inwards and outwards. Where there is a perforation of the tympanic membrane, or fluid in the middle ear, there is loss of normal mobility.

The position of pathological features should be noted in relation to the normal anatomy, that is the pars tens and pars flaccida. A perforation may be central, marginal or attic (in the pars flaccida). It is sometimes difficult to differentiate a retraction pocket from a perforation. In such cases, pneumatic otoscopy with bacteriostatic powder blown on to the tympanic membrane helps to make the diagnosis. Assessment of the retraction pocket's adherence to middle ear structures (usually the incudostapedial joint) is important. If a perforation is present, the state of the middle ear mucosa should be assessed for inflammation, infection and oedema. When the stapes is visible through a perforation, its mobility can be assessed using the operating microscope by stimulating the other ear, if the hearing is normal, with a Barany noise box and looking for a crossed stapedius reflex. This technique may be helpful in the preoperative assessment of cases involving tympanosclerosis.

**Eustachian tube patency**

The following manoeuvres indicate patency of the tube, although not necessarily normal function, as they are non-physiological.

**The Valsalva manoeuvre**

The production of a high nasopharyngeal pressure by blowing out against closed lips and nose normally results in an increase in middle ear pressure with the tympanic membrane bulging outwards. It is important to have the auriscope in place before the patient starts blowing as otherwise trauma to the external meatus may occur with head movement.

**Toynbee's manoeuvre**

This occurs when a swallow is made with the lips and nose closed. A negative pressure in the nasopharynx and middle ear results in an indrawing of the tympanic membrane. This should return to its normal position when swallowing again with an open nose.
Frenzel manoeuvre (nasopharyngeal pressure test)

This manoeuvre was described in 1938 by Hermann Frenzel, a prominent figure in German aviation medicine in World War II, and has been found to be more effective than the Valsalva and Toynbee tests (Frenzel, 1950).

'With the nostrils and glottis closed, the air in the nasopharynx is compressed by the muscles of the floor of the mouth and tongue. The opening of the eustachian tube by this method is facilitated by the convexity of the tongue which places the soft palate and parts of the tube orifice to which it is connected into a more favourable position for opening the tube'.

Its advantage is that it can be performed in any phase of respiration and is independent of intrathoracic pressure. The disadvantage is that the procedure has to be learned, but once acquired it soon becomes no longer necessary to hold the nostrils as these close automatically. This has an obvious advantage for those wearing a flying helmet, oxygen mask or both.

The subject has to acquire a feel for voluntary closing of the glottis and Frenzel suggested 'the repeated production of a silent "ah" while expiring after a moderate inspiration'. Davison (1962) suggests:

'... having the subject close the glottis after a moderate inspiration and then attempt to make an oral "ka" sound. If the subject partially compresses his nostrils while performing this manoeuvre, he can feel and hear the rush of air out of the anterior nares, thus demonstrating that the manoeuvre does diminish the volume of the nasopharyngeal space'.

Patulous eustachian tube

This is a not uncommon ear condition which frequently goes undiagnosed and is managed incorrectly (Bull, 1976). The patient complains of a sensation of blockage in the ear, but denies any hearing loss. The sensation of blockage disappears on lying down and may alter with certain positions of the head. Patients may also say that they hear the noise of themselves talking, eating or breathing.

The tympanic membrane is normal, but may in some cases be seen to move with respiration. If the patient is asked to breathe in and out through the nose with the mouth open, air flow through a patulous tube is accentuated and the tympanic membrane movement is more easily visible (O'Connor and Shea, 1981).

The condition is often missed and treated as a eustachian tube obstruction with topical and systemic decongestants. These may make matters worse. The condition is common in people who have lost weight suddenly, usually from strict dieting, those on the contraceptive pill and in pregnancy. It may also be found in older patients given diuretics.

Treatment is usually unnecessary if the condition is explained to the patient and reassurance given that there is nothing seriously wrong. Some people obtain relief after
insertion of a ventilation tube and, in rare instances, injection of Teflon paste around the eustachian cushion may help.

**Fistula sign**

If, following a pressure increase in the external auditory meatus, vertigo and nystagmus result, a positive fistula sign is said to be present. Such a pressure change can be achieved by simply compressing the tragus into the external auditory meatus. A similar effect can be obtained by using a pneumatic otoscope, Siegle's speculum or the air pump of a tympanometer. In cases of chronic suppurative otitis media, a positive fistula sign indicates the presence of a third window into the perilymphatic space enabling gross movement of the inner ear fluids and stimulation of the vestibular end organs (Schuknecht, 1974). In ears with such disease, palpation of a fistula while probing the ear results in a violent vertiginous response.

**Hennebert's sign**

Hennebert's sign occurs when there is a positive fistula test with an intact tympanic membrane and no evidence of middle ear disease. The pathophysiology of this sign is unclear, but is thought to be due either to adhesions in the vestibule or to the presence of a third window somewhere in the labyrinth caused by osteitis (Schuknecht, 1974). It is seen most commonly in congenital or late tertiary syphilis, but is sometimes found in other conditions causing endolymphatic hydrops such as Ménière's disease. Hennebert's sign is seen most clearly using the slow, sustained negative pressure change of the tympanometer.

The normal caloric response due to air currents that occurs during suction to the meatus or mastoid cavity should be recognized and not interpreted as a fistula sign.

**Auscultation of the ear and temporal bone**

This part of the examination is useful in some cases. The stethoscope is used, placing the bells over the ear canal and then lightly on the mastoid process; bruits from vascular anomalies or glomus tumours may be heard (Moffat and O'Connor, 1980). Recently, perception of cochlear emissions, which may or may not be associated with subjective tinnitus, have been reported (Harrison, 1986). In cases of patulous eustachian tube, a stethoscope end inserted into the meatus will pick up the transmitted voice sounds from the nasopharynx.

**Examination of the eyes**

Inspection of the eyes may reveal features, such hypertelorism or coloboma, associated with congenital hearing disorder syndromes. The presence of blue sclera (osteogenesis imperfecta) and interstitial keratitis (congenital syphilis, Cogan's disease) should be noted.

**Fundal examination**

Examination of the fundus of the eye must be performed when there is a possibility of an intracranial lesion. Papilloedema may be seen with a space-occupying lesion, such as
a cerebellopontine angle tumour or temporal lobe abscess, and also in otitis hydrocephalus
where it is often chronic (O'Connor and Moffat, 1978). Optic nerve atrophy follows
demyelinating conditions which may present with auditory or vestibular disturbances.

When looking at the fundus it is important to use optimum conditions, including a
darkened room and mydriatic drops in order to see the fundus clearly. Remember,
ophthalmologists regularly use these conditions; it would be wise for the infrequent
'ophthalmologist' to do the same.

**Eye movements**

Nystagmus is involuntary eye movement. Patients with nystagmus may describe an
inability to focus on a still object or, when associated with rotational vertigo, movement of
the visual field in the same direction as the nystagmus. Nystagmus is most easily seen in good
light with the patient looking to the front (spectacles on, if usually worn!) and the observer
viewing slightly from the side. Visual fixation is obtained by placing a finger central to the
eyes and at least 45 cm from the nose. The presence or absence of nystagmus is noted and
the finger moved laterally in the same horizontal plane 30° to either side, asking the patient
to follow the finger.

Congenital nystagmus is characteristically pendular in type, when viewed in the
'neutral' central position and usually associated with visual defects.

Vestibular nystagmus may be horizontal or rotatory and has two components, a slow
phase with a fast corrective phase in the opposite direction. The slow phase reflects an
imbalance of input to the vestibular nuclei and the fast phase is a central righting response.
The direction of the nystagmus is conventionally defined in terms of the direction of the fast
phase. The intensity of the nystagmus is described in terms of the direction of gaze. Thus, a
first degree nystagmus is visible only when the eyes are deviated to the side which is also the
direction of the fast phase. A second degree nystagmus is visible in the above position and
also with the eyes in the 'neutral', straight ahead position. A third degree nystagmus means
that the nystagmus is present in all directions of gaze. If nystagmus changes in direction with
the gaze it is termed 'direction changing' and may be indicative of a central lesion. Visual
fixation should then be reduced using Frenzel's glasses (spectacles having a focal length of
infinity, and illumination so that the eye movements are clearly visible to the observer). It is
also possible to abolish fixation by using a dark room where eye movements may be seen
with an infra-red viewer. In general, removal of visual fixation enhances the nystagmus due
to peripheral lesions but reduces that due to central lesions. These clinical techniques correlate
well with the findings when electronystagmography is used.

If spontaneous nystagmus as described above is absent, nystagmus may be induced by
positional changes, rotational or caloric stimulation. Nystagmus induced by changes in
position may be associated with benign positional vertigo and is characterized by a brief delay
in onset following the change of position (latent period), rotational or horizontal nystagmus
directed towards the undermost ear, which lasts no longer than 20-30 seconds and is
fatiguable. It is thought to be due to a 'benign' pathological process affecting the peripheral
vestibular system (Schuknecht, 1969). A positionally induced nystagmus, that has no latent
period, remains present while the patient is in the provocative position and is direction
changing according to head position, is suggestive of a central lesion. If a benign positional nystagmus has atypical features, the presence of a central lesion must be considered.

Caloric stimulation may be achieved in the clinic with cold water. Ten millilitres of ice-cold water are introduced into the deep external auditory meatus by means of a soft Portex tube (intravenous infusion catheter). Nystagmus is viewed using Frenzel's glasses and, if present, indicates significant labyrinthine function, the direction of the nystagmus being away from the stimulated ear. This technique cannot differentiate a canal paresis from a directional preponderance.

**Examination of cranial nerves III-VI**

Voluntary eye movement is examined by exercising all six oculomotor muscles in turn, observing any paresis and enquiring about diplopia associated with specific movements. Failure of lateral gaze with diplopia indicates an abducens nerve palsy. This nerve has a long intracranial course and it is therefore often difficult to localize lesions affecting it. Paralysis of the abducens nerve may be associated with lesions of the petrous apex such as congenital cholesteatoma or Gradenigo's syndrome (aural discharge, pain and sixth nerve palsy).

**Pupillary reflexes**

The reflexes mediated through the Edinger Westphal nucleus of the parasympathetic system are examined by asking the patient to look to infinity and then focus an object at their normal focal length. This process - accommodation, should cause pupillary constriction. This is followed by stimulating the eye with a bright light and once again looking for pupillary constriction. In congenital or tertiary syphilis, the pupil constricts in response to accommodation but not to light - the so-called Argyll Robertson pupil.

**Visual fields examination**

The visual fields of each eye are examined clinically by asking the patient to observe the movement of the clinician's fingers placed at the focal distance, with the eyes in the neutral position. The fingers are then moved to map out the visual fields. Central visual field loss may be associated with papilloedema (perhaps due to cerebellopontine angle lesions or otitic hydrocephalus). With an otogenic temporal lobe abscess, an homonymous quadratic hemianopia may be found due to disruption of the optic radiation.

**Corneal reflexes**

The cornea is touched from the side with a fine wisp of cotton wool (note - it is sufficient to touch the sclera). The normal response is a blink. The response of each cornea should be noted and compared. The loss of corneal reflex is said to be the most sensitive indication of a lesion involving the trigeminal nerve, but is usually a late sign in acoustic neuroma, indicating a large tumour which has expanded sufficiently so as to compress the nerve.
Facial nerve (VII)

Motor function

It is important to differentiate between an upper and lower motor neuron lesion. An upper motor neuron lesion paralyses only the lower part of the face, the forehead being spared as it has bilateral cortical representation. A lower motor neuron palsy involves all of that side of the face. The patient is asked to frown with the observer's thumb placed firmly in the midline to prevent muscle movement from the other side simulating movement of the affected side. The patient is then asked to close and open the eyes, bearing in mind that the levator palpebrae muscle is partially innervated by the oculomotor nerve. The midface is examined by nose twitching and the lower face by smiling or showing the teeth. Various conversations have been suggested to quantify partial facial palsy, but all are open to observer differences. However, it should always be clearly stated whether the palsy is partial or complete.

Somatic sensory function

Touch sensation of the floor of the external auditory meatus has been noted to be absent in some cases of acoustic neuroma (Hitselberger's sign).

Parasympathetic secretomotor function

Fibres passing in the nervus intermedius and then in the greater superficial petrosal nerve to the lacrimal gland may be tested by the tearing on a strip of filter paper placed over the lower lid (Schirmer's test). Only a gross difference between abnormal and normal sides is significant.

Special sensation

Taste from the anterior two-thirds of the tongue is examined, either by the use of test substances (salt, sugar and citric acid) or by electrogustometry. In this technique, a quantitative assessment may be obtained in terms of the electric current needed to elicit a metallic taste in the mouth; both methods are prone to false positives due to the hyposensitivity of many patients' taste buds.

Cranial nerves IX-XII

Glossopharyngeal nerve (IX) function is tested by touching the wall of the oropharynx or posterior one-third of the tongue. This is the afferent arm of the gag reflex whose efferent arm is mediated through the vagus, producing elevation of the palate and generalized movement of the oro- and hypopharynx. The palate should be examined in cases of clicking tinnitus in order to exclude palatal myoclonus.

Indirect laryngoscopy will permit an assessment of vocal cord movement (vagus nerve - X). To test accessory nerve (XI) function, the patient is asked to rotate the head against the observer's hand and the tension in the contralateral sternocleidomastoid muscle is felt. Shoulder shrugging is tested on each side.
Following hypoglossal nerve (XII) palsy, protrusion of the tongue from the mouth may lead to deviation towards the side of the lesion.

**Examination of the nose and throat**

A full examination of the nose and throat must always be carried out. Inspection of the nose may reveal rhinitis or sinusitis which is responsible for eustachian tube dysfunction. The postnasal space is examined using a mirror placed in the oropharynx. This necessitates the use of a tongue depressor and head mirror or headlamp. The development of the fibreoptic rhinopharyngoscope permits the nasopharynx to be examined from the posterior choanae. Where there is evidence of a middle ear effusion, without an obvious explanation, the postnasal space must be examined, even if a general anaesthetic is needed.

The rest of the upper air and food passages should be examined for the cause of a referred otalgia, for example carcinoma of the pyriform fossa.

**Clinical tests of hearing**

During the history taking and examination, the clinician should be making an assessment of the hearing threshold. The clinician should alter the voice level and avoid giving visual clues, and in this way gain an impression of how well the patient hears. This is of special importance in patients who are thought to have a non-organic hearing loss. An estimation of the hearing thresholds in each ear may be obtained with masking of the contralateral side by gently rubbing the orifice of the external auditory meatus with a finger.

**Tuning fork tests**

These tests are a most important part of any clinical examination of hearing and should be performed carefully. They are discussed in considerable detail in Volume 2. The tuning fork used most commonly has a frequency of 512 Hz. The note of the higher frequency forks tends to decay quickly, not allowing sufficient time for the Rinne test to be performed. The lower frequency forks tend to enhance perception by vibration sensation.

**The Rinne test**

Essentially this test consists of comparing the auditory acuity of each ear to bone and air conduction. The tuning fork is struck gently so as not to produce overtones and dysharmonics (usually by striking it on a bony prominence, belonging to the examiner not the patient!). The fork is placed firmly on the mastoid with the observer's hand steadying the head. Care is taken, especially in children, to have the fork placed firmly on bone and not on the sternomastoid muscle. The patient is asked to indicate when the sound disappears and the fork is then immediately placed erect and in line with the external auditory meatus about 2 cm from the orifice. If the patient still hears the note when the fork is placed in front of the ear the patient is termed 'Rinne positive' (air conduction being better than bone conduction). If he/she does not still hear it the patient is 'Rinne negative' (bone conduction better than air conduction). Alternatively, and more usually, in routine clinical practice, the patient is asked to compare the sound intensity of the fork in the mastoid position (bone conduction) with that in the meatal position (air conduction). If there is a significant sensorineural deafness, the fork
will not be heard by bone conduction at all, but only by air conduction, and obviously in severe cases not by air conduction either. A conductive deafness of greater than 25 dB usually gives a negative Rinne test with a 512-Hz fork. However, with a 256- or 128-Hz fork, this may be reduced to 10-15 dB and, with the higher frequency forks (1028, 2048 and 4096 Hz), the conductive deafness needs to be greater than 25, 30 and 35 dB, respectively (Shambaugh, 1967a).

**False negative Rinne**

This is an important concept and its possibility should never be missed by the otologist. If the patient has no hearing in the test ear, the bone conduction stimulus may be perceived by the contralateral (non-test) ear, although the patient often says that he/she hears it in the test ear. As there is no hearing by air conduction, the test result is labelled Rinne negative suggesting that the deafness is conductive in nature. This mistaken impression of function in a non-functioning ear is called a false negative Rinne. In such cases the diagnosis is given by a combination of the Rinne and the Weber test. In addition, the non-test ear can be masked by a Barany noise box (a clockwork-driven sound generator of about 90 dB). This phenomenon occurs because the interaural attenuation for bone conduction is less than 5 dB, that is sound passes freely across the skull stimulating both ears equally, regardless of where the tuning fork is placed.

**Weber test**

The tuning fork is struck and the base placed on either the forehead, vertex or upper incisor teeth. The patient is asked where the sound is heard loudest. In a normal hearing person, the sound is related to the midline. In a patient with unilateral sensorineural deafness, it is referred to the good ear and in a patient with a conductive deafness to the affected ear. In cases of asymmetrical mixed (conductive plus sensorineural deafness, no definite rules can be made, but the result interpreted in conjunction with the Rinne test. Obviously the Weber test is a great help in recognizing a false negative Rinne as it will be referred to the good ear. In long-standing cases of sensorineural deafness, the Weber test tends not to lateralize. A lateralized Weber in a conductive deafness may indicate a hearing loss of only 10-15 dB.

It should be understood that the abnormal test results in conductive deafness are not explained by the lack of environmental masking, as they also occur in anechoic (soundless) chambers. Several theories have been put forward and it seems likely that the explanation differs in different types of conductive loss (Tonndorf, 1966).

**Modified Schwabach test (absolute bone conduction test)**

This compares the bone conduction of the patient with the bone conduction of a normal hearing person. The tuning fork is placed on the patient's mastoid with the meatus blocked and, when the patient no longer hears it, the fork is placed on the normal hearing person's mastoid (usually the examiner's), again with the meatus blocked. If the examiner hears the note, the patient's bone conduction is said to be reduced. The Schwabach test is carried out in the same way but without occluding the meatus.
Several other tests are available which use the principle that, in a normal ear when the sound conducting mechanism of the external and/or middle ear is reduced, the bone conduction stimulus will be enhanced. If there is already a conductive deafness, there will be no change in the perception of the bone conduction stimulus.

**Gellé test**

The air pressure in the external auditory meatus is altered using a Siegle's speculum. In the normal individual, or those with a sensorineural loss, increasing the meatal pressure results in a decreased sensation of loudness from a bone-conducted stimulus. No alteration of bone-conduction thresholds indicates fixation of the stapes.

**Bing test**

Increased loudness for bone-conducted stimuli, less than 2 kHz, occurs in the normal patient or those with a sensorineural loss when the external meatus is occluded without altering meatal pressure. There is no change when a conductive deafness is present.

**Tuning fork tests in non-organic deafness**

**Stenger test**

Principle: if sounds of identical frequency but different intensity are presented simultaneously to each ear, only the louder sound will be perceived. The test can be performed either with a pure-tone audiometer or tuning forks.

The examiner stands behind the patient. A tuning fork is struck and held 20 cm from the 'good ear' - the patient hears the sound. The fork is then removed and placed 5 cm from the 'bad ear' - the patient denies hearing the sound. Another fork is then held 15 cm from the good ear without the patient noticing. If there is a genuine hearing loss the patient will hear the fork in the good ear, but if there is a non-organic hearing loss the patient will not be able to hear the fork in the good ear because the fork which is closer, and therefore of louder intensity, is being heard in the bad ear.

**Chimani-Moos test**

This is a modification of the Weber test. When the tuning fork is placed on the vertex, the patient indicates that he hears it in the good ear and not in the deaf ear. The meatus of the good ear is then occluded. A genuinely deaf patient will still lateralize the sound to the good ear, the malingerer will usually deny hearing the sound at all.

Both of these tests should be used in conjunction with the clinical history (Is there a question of litigation? Was trauma involved?), and the clinical assessment of hearing during the examination.
Clinical tests of balance

Normal body position is a function of the neural input into the cerebellum and brainstem from the receptors in the semicircular canals, the macula of the utricle, the proprioceptive and joint position sensors and the eyes. Thus, in the clinical examination, each component of the system should be tested individually. If hypofunction of one input occurs, then compensation by the others usually takes place. However, when such compensation is removed, for example by closing the eyes, the resultant deficiency usually becomes obvious.

Romberg's test

The patient is asked to stand erect looking forwards with the feet together. If the patient is stable, he/she is asked to close the eyes. With a labyrinthine lesion the patient will sway often to the side of the lesion, a feature which is accentuated by closing the eyes. A central lesion in the cerebellum results in symmetrical swaying that is less affected by eye closure. If the patient falls backwards in a rigid pose, but is able to regain balance before falling to the ground, there is a non-organic disturbance such as malingering or hysteria.

Unterberger's test

This test aims to reduce the input from the proprioceptive organs. The patient is asked to stand as for the Romberg test, but with the hands outstretched, and march on the spot with the eyes closed. The patient will rotate towards the side of a paralytic labyrinthine lesion. In the presence of an active irritative lesion, the balance disturbance is so significant that the patient cannot perform the test for more than a few seconds.

The gait test

The patient is asked to walk in a straight line between two points and then quickly turn to return on the same line. Patients with labyrinthine lesions deviate to the side of the lesion whereas marked imbalance on turning indicates a cerebellar lesion. The sensitivity of the test may be increased by asking the patient to walk on a bed of foam.

Caloric test

The minimal cold water caloric test has been described previously. The classical Fitzgerald-Hallpike bithermal caloric test is the generally accepted method of evaluating vestibular function by caloric stimulation (Fitzgerald and Hallpike, 1942).

The patient is placed supine on a couch with the head elevated to an angle of 30° to the horizontal. This brings the lateral semicircular canal into the vertical plane. Both ears are checked for wax or the presence of a perforation, as the latter would preclude caloric testing by this technique. Each ear is irrigated by water at 44°C and 30°C (7°C above and below normal body temperature) for 40 seconds. Warm water is used first and the tympanic membrane checked for an hyperaemic blush which indicates adequate irrigation. The volume of water used is checked and should be about 300 mL. The eyes are observed for nystagmus with the patient focusing on a near object. The end point of the nystagmus is noted and its
duration recorded. Frenzel's glasses are then used to reduce visual fixation and, if the nystagmus reappears, the new end point is noted. A normal caloric reaction results in nystagmus being visible between 90 and 140 seconds after the onset of irrigation, and prolongation by a further 60 seconds following the reduction of visual fixation. The affected ear is stimulated with warm water, then with cold, and the test concluded by cold water irrigation of the affected ear. Between each irrigation a rest period of 7 minutes is allowed.

Cold water produces a nystagmus away from the stimulated ear (away cold = AC) and warm water towards the stimulated ear (towards hot = TH), thus the mnemonic ACTH.

Following bithermal caloric stimulation of a paretic labyrinth, nystagmus may be absent or decreased in amplitude and duration. Care should be taken to look for the end point prior to the reduction of visual fixation, which may prolong the nystagmus into the normal range. When the nystagmus in one direction is significantly greater after bithermal testing, it is termed 'directional preponderance'. The significance of this is not fully understood.

Other tests for cerebellar dysfunction

Dysmetria and past pointing

The patient is asked to touch his nose and the examiner's finger alternately. The examiner's finger should be placed in front of the patient at a distance which necessitates very full extension of the patient's arms. The target finger is moved around. Failure by the patient to touch the examiner's finger or his own nose suggests the presence of a cerebellar lesion. If the test is performed satisfactorily the patient is asked to close the eyes and continue pointing. Straying from the targets now suggests a peripheral vascular lesion (Marshall and Attia, 1983).

Asynergia

The patient is asked to tap the back of each hand in turn with the other hand. With the cerebellar lesions the accuracy of the tap and the discrete area of contact are lost.

Dysdiadochokinesis

In cerebellar lesions, asymmetry occurs when the patient is asked to pronate and supinate the hand on the side of the lesion.

Rebound

The patient's hands and arms are held out rigidly in front and the examiner pushes from above on one hand and from below on the other. The hands are then released. With a cerebellar lesion the patient's arms are unable to compensate for the change in resistance and move wildly.
Chapter 2: Radiology of the ear

P. D. Phelps

The petrous temporal bone is a complex structure containing important tiny bony objects such as the crura of the stapes and canals such as the vestibular aqueduct, which are less than 1 mm in diameter. These are close to the limits of resolution by imaging techniques. Good spatial resolution to allow adequate demonstration of these bony structures in the middle and inner ears has been an important requirement of radiographic equipment for many years. Spatial and density resolution are discussed in Volume 1, Chapter 17.

The major disadvantage of plain films is caused by overlap of structures which makes interpretation difficult. Historically, a great range of views has been described to try to overcome this problem. These specialized projections have now been almost entirely superseded by sectional imaging techniques, and only a few standard projections are required in practice.

Plain X-ray examination

The author rarely uses any plain film views other than the first four basic projections. The two that show both sides on one film are standard skull views with the field size reduced.

Lateral view

Since the temporal bones are symmetrically placed, a true lateral view results in superimposition of the two sides; it is therefore necessary to angle the incident ray, or alternatively the skull, in order to prevent this. The greater the tilt, the more the attic (epitympanic recess) and antrum will be thrown clear of the mass of bone around the labyrinth, but this is offset by increased distortion. As shown in Figure 2.a, the lateral projection of the petromastoid is obtained by placing the head in a true lateral position and angling the tube caudally 15°, thus preventing superimposition of the mastoid processes. The incident beam is centred 5 cm above the uppermost external auditory meatus. The angled lateral view results in superimposition of the petrous bone on the mastoid process and similarly of the internal and external auditory canals (Figures 2.1b and c). The view allows assessment of the degree of pneumatization of the mastoid, the state of translucence of the air cells and the position of the sigmoid sinus and its relation to the tegmen tympani. The attic, aditus and mastoid antrum are also visible. Erosion of the attico-antral region and of the bony bridge formed by the outer attic wall can be shown, but only when this is extensive.

Oblique posteroanterior (Stenvers') view

In this view, the whole length of the petrous bone is demonstrated by placing it parallel to the X-ray film with the incident ray passing at right angles. When a 'skull-table' is used, the patient sits erect facing the film. With the radiographic baseline horizontal, the sagittal plane of the skull is rotated through 35° and tilted 15° away from the side to be examined (Figure 2.2a). The incident ray is inclined at an angle of 12° cranially and is centred on a point 2 cm medial to the tip of the mastoid process. A radiograph of Stenvers'
position should demonstrate the petrous tip and internal auditory meatus, the semicircular canals (superior and lateral), the middle ear cleft, the mastoid antrum and the mastoid process (Figures 2.2b and c). Erosion of the petrous tip and widening of the internal auditory (acoustic) meatus may be shown on this projection, although these changes are generally better demonstrated by tomography.

Submentovertical (axial or base) view

This is an important item in the X-ray examination of the ear, and no study by plain radiography is complete without it. In the classical position, the baseline is parallel to the film, and the incident beam centred at a point midway between the angles of the mandible. If the centring point is too far anterior or the head insufficiently extended, the angle of the jaw is projected over the middle ear and obscures it. To avoid this, a centring point slightly lower than that used in the classical position is recommended (Figure 2.3a). The radiograph demonstrates the middle ear, the external and internal auditory meatus and the bony eustachian canal (Figures 2.3b and c). This plain view of the middle ear provides the best plain X-ray assessment of its air content, the degree of translucence, and of the ossicular chain. The malleus and incus may be clearly visible; the cochlea should also be identified.

Half-axial (Towne's) view

The reversed Towne's view (Figure 2.4a) should be used whenever possible because of the large radiation dose to the eyes in the classical position. The internal auditory meatus, most of the labyrinth and middle ear are shown, together with enlargement and erosion of the attic and antrum (Figures 2.4b and c).

Periorbital view

This is the best view of the internal auditory meatus if tomography is unavailable and should be carried out in the posteroanterior position to avoid radiation to the eyes. The orbitomeatal line is at right angles to the film. The tube is angled 5-10° caudally, centring between the orbits (Figure 2.5a). The petrous pyramids and internal auditory meatus are thus projected through the orbits (Figure 2.5b).

Jugular foramen view

A symmetrical bilateral projection showing the margins of the jugular fossa can be obtained with the patient lying supine with the head extended so that the baseline is at 45° to the table top (Figure 2.6). This view is needed when a glomus jugulare tumour is suspected.

Conventional tomography

Although linear tomography is still used for the examination of the petromastoid, it is generally less satisfactory than complex motion tomography using a hypocycloidal or spiral movement of the X-ray tube. This gives even blurring of structures outside the plane of the section and cuts approximately 1 mm thick. Good technique and limitation of radiation to the
eyes by use of shields or the prone position are necessary. Rigorous beam collimation will both reduce radiation dose and improve definition. The technical factors are discussed in Volume 1, Chapter 17.

**Coronal sections**

These are taken with the orbitomeatal line at right angles to the film and table-top. For routine examination, tomographs are obtained at 2-mm separation of the sections. These should cover the full extent of the labyrinth from the apical turn of the cochlea to the posterior semicircular canal and allow comparison between the two sides. Four or five films are usually sufficient to show the internal auditory meatus, labyrinth, oval window (fenestra vestibuli), ossicles and the descending portion of the facial nerve.

There are two sections in the coronal plane that are important and must be recognized; these pass through the centre of the cochlea and vestibule respectively (Figure 2.7). The cochlear cut shows the modiolus or central bony spiral as a 'curl', while above the cochlea is the pit for the geniculate ganglion of the facial nerve. The ossicle shown in the middle ear cavity is the malleus. The vestibular cut, 3 or 4 mm posteriorly, shows the oval window and also the full length of the internal auditory meatus. The ossicle is the incus and sometimes the stapes may be demonstrated. The outer attic wall, which also forms the roof of the deep part of the bony external auditory meatus is, because of its appearance, called 'the spur'. The carotid canal and jugular fossa are shown in the cochlear and vestibular cuts respectively, below the labyrinth.

In the author's opinion polytomography in the coronal plane, especially the vestibular cut, provides the most satisfactory demonstration of the state of the bony margins of the internal auditory meatus. A two- or three-film examination, using lead shields on the patient's eye, provides one of the quickest, cheapest and most reliable screening examinations in the search for an acoustic neuroma. Lateral tomography can help to confirm whether any widening of 2 mm or more, shown on the coronal sections, is the result of expansion by a neuroma or merely asymmetry.

**Lateral tomography**

For sections in the sagittal plane, the head is placed in the true lateral position; they are made at 2-mm intervals through the petrous pyramid, middle ear and external auditory meatus, depending on the site of the pathological change. The labyrinth is not well visualized, but an appropriate section through the middle ear will demonstrate the bodies of the malleus and incus (Figure 2.8) as well as the descending portion of the facial nerve. Tomography of the middle ear in the true lateral position results in an image of the malleus and incus which has been likened to the appearance of a 'molar tooth'. The head of the malleus and the body of the incus combine to represent the crown of the tooth, the handle of the malleus forms the anterior root and the long process of the incus, the posterior root. The crown should normally appear as a solid shadow; any disruption of this image either in the form of separation of its two components, or their misalignment, indicates a dislocation. Divarication of the roots of the image also indicates displacement of the incus. A lateral projection is used to assess the cross-sectional appearances of the internal auditory meatus and any erosion of its posterior wall.
Lateral tomography is particularly important because of the difficulties encountered with computerized tomographic (CT) scanning in the sagittal plane. Such CT images must be obtained either with the patient in an uncomfortable position or by reformatting from axial slices when much spatial resolution is lost; this is the result of intrinsic distortion and partial volume averaging, as well as motion which may occur not only during scanning but also during the interscan time. Sagittal sections through the jugular fossa and carotid canal are a most important part of the examination to differentiate glomus tumours and other vascular masses and anomalies in the middle ear (Phelps and Lloyd, 1986). A smoothly outlined jugular fossa with an intact spur or crest of bone separating it from the carotid canal (Figure 2.9) virtually excludes a glomus jugular tumour, but not a glomus tympanicum or high jugular bulb (see below).

Another important structure best demonstrated by lateral tomography is the vestibular aqueduct. The rather variable course of the vestibular aqueduct means that further sections in a slightly off-lateral position may be required (Stahle and Wilbrand, 1974). This usually means elevating the chin of the patient about 20° if the underside temporal bone is being examined. The key to the correct level for identifying the vestibular aqueduct is the crus commune of the superior and posterior semicircular canals (Figure 2.10). Stahle and Wilbrand (1974) reported that Ménière's disease is often associated with absence of periaqueductal pneumatization. They classified periaqueductal pneumatization into three types:

1. large air cells
2. small air cells
3. absence of periaqueductal pneumatization.

They found that 75% of patients with Ménière's disease are type 3. More recently Valvassori and Dobben (1984) and Arenberg et al (1984) have discussed the demonstration of the vestibular aqueduct by both tomography and CT. In practice, these techniques appear to be of value only in the preoperative assessment for endolymphatic sac surgery, particularly for showing the position of the jugular bulb and sigmoid sinus. A high jugular bulb with diverticulum may even cause endolymphatic hydrops by compressing the endolymphatic duct (Jahrsdoerfer, Cail and Cantrell, 1981). (See the section on vascular anomalies.)

**Modified coronal section tomography**

**Zonography** (see Figure 2.5)

As an alternative to the evaluation of the internal auditory meatus by coronal hypocycloidal tomography, thick section tomography or zonography using a circular motion of the tube can be employed. Usually two or three zonograms suffice to give adequate visualization of the internal auditory meatus on both sides. The result is, in effect, a superior version of the periorbital view described in the section on plain X-ray technique.

**Semi-axial or Guillen projection (Figure 2.11)**

Another modification of tomography in the true coronal plane is the position corresponding to the Guillen projection on plain X-ray. The middle ear cavity, and in
particular its medial wall, incline medially as they run forward to the eustachian tube. Consequently, for optimal demonstration of the important region of the oval window and promontory, 15° of rotation from the coronal plane are necessary. In order to achieve this, the head is turned from the coronal plane 15° towards the side to be tomographed. The small canal containing the second part of the facial nerve is demonstrated in cross-section below the lateral semicircular canal on this view. The appearance of the section differs little from that of similar coronal section and, consequently, the author rarely uses this projection. Its main drawback is that both petrous bones need to be tomographed separately.

For full evaluation of the cochlea it is necessary to demonstrate the individual coils. To do this, the long axis of the modiolus or central bony spur must be in the plane of the section. Two projections fulfil this condition: the base and the axial-pyramidal. For the latter, the head is turned 45° towards the side to be examined.

**Computerized tomography**

The ability of CT to show intracranial lesions was its first and most important contribution to diagnostic imaging. For the otologist, the premier role of CT is the demonstration of intracranial complications of suppurative ear disease, such as brain abscess, and the intracranial extension of tumours of the petrous temporal bone, such as glomus and acoustic neuroma. Normal brain scan techniques with contrast enhancement are required. Since the introduction of high resolution thin-section computerized tomography, it has become the optimum technique for the study of the temporal bone. The bony portions of the petromastoid are depicted with approximately the same resolution as with complex motion tomography, but the better contrast, freedom from spurious shadows, and fewer problems with soft tissue silhouetting, make the pictures much easier for the non-expert to interpret, as well as being much easier to reproduce as illustrations (see Volume 1, Chapter 17). It is, however, the ability of CT to depict the soft tissue components within and adjacent to the temporal bone that has provided the major advance. Contrast enhancement of masses may be helpful in the diagnosis but, generally, tissue characterization in the middle ear particularly has been disappointing and relies on the anatomical configuration and situation of the mass. Thus, a profound knowledge of temporal bone anatomy is mandatory for the interpretation of these sectional images.

Although many planes, equivalent to those formerly described for conventional tomography, are advocated by some European authorities (Zonneveld et al, 1984), these must add enormously to cost, patient irradiation and examination time. In most institutions, only sections in the axial (base or horizontal) plane supplemented by frontal views in the coronal plane are used. Section thickness may vary between 1.5 and 5.0 mm, depending on the machine and a wide window setting should be used; contiguous sections cover the whole temporal bone. Sections at 1 mm intervals are not normally required unless reformatting in other planes is envisaged.

There are two important sections in the axial plane which may be labelled the cochlear and vestibular cuts. The cochlear cut shows the individual coils and is equivalent to the mid-modiolar section of the histologists. The vestibular cut shows the vestibule and lateral semicircular canal as a ‘signet ring’ (*Figure 2.12*). The posterior semicircular canal is an
important landmark for the surgeon operating on an acoustic neuroma. Lower sections in the axial plane show the whole length of the basal coil, the hook and round window niche (Figure 2.13). Below the basal turn, lie the carotid canal and jugular fossa with a crest of bone between them (Figure 2.14). The head of malleus and body and short process of incus, as well as the joint space are best visualized in the vestibular cut, while their long processes are seen in lower sections. The crura of the stapes may sometimes be seen in the cochlear cut.

Axial scans are followed by sections made with the patient's head extended as near as possible in the true coronal plane, and for this a machine with a tilting gantry is a distinct advantage. Once again, the two most important sections may be labelled the cochlear and vestibular cuts. In the coronal plane, the cochlear cut does not show the individual coils as well as the axial plane but depicts the central bony spiral as a small 'curl'. The vestibular cut, about 4 mm posteriorly, shows the oval window and the lateral and superior semicircular canals. The malleus is demonstrated in the cochlear cut and the incus in the vestibular cut. The carotid canal and jugular fossa are also shown in the cochlear and vestibular cuts respectively.

Two further sections behind the vestibular cut are important. Immediately behind the incudo-stapedial region, the pyramidal eminence lies between the facial recess and sinus tympani and appears as a small blob of bone (Figure 2.15). The cochlear aqueduct is found at this level but usually only the wider medial part can be identified. Further back still, the descending part of the facial nerve canal can be seen (Figure 2.16). The internal auditory meatus is best seen in the vestibular cut in either axial or coronal planes.

Air meatography - the demonstration of the contents of the internal auditory meatus and cerebellopontine angle

Cost and limitations on scan time in the UK mean screening large numbers of patients for an acoustic neuroma using conventional radiography and tomography. Polytomography provides a quick, cheap assessment of the bony margins of the internal auditory meatus, but an equivalent demonstration is given by axial or coronal high resolution CT and all tumours larger than 1.5 cm should be demonstrable in the cerebellopontine angle by an enhanced posterior fossa brain scan. Nevertheless, to show the normal contents of the internal auditory meatus and angle and to demonstrate a small acoustic neuroma confined to the internal auditory meatus or extending only slightly into the cerebellopontine angle, introduction of an intrathecal contrast agent is necessary. At present, this is also the only certain way to exclude a small tumour.

Air-CT meatography is a simple and effective procedure, which the author believes causes no more morbidity or unpleasantness for the patient than a simple lumbar puncture. It is usually carried out on an outpatient basis. The technique is described below.

The patient lies on his side on the scanner table with the ear to be examined uppermost; a lumbar puncture is performed and cerebrospinal fluid sent for differential protein estimation. The patient is positioned at a sufficient spinal gradient to allow 3 mL of air introduced via the cannula to pass into the cervical region. After 2 minutes, the head is elevated, momentarily, to allow the air to pass through the foramen magnum and into the
cerebellopontine angle. The first section is made at the level of the internal auditory meatus and if air is demonstrated in the meatus, then the examination is terminated (Figure 2.17).

The seventh and eighth cranial nerves and the loop of the anterior inferior cerebellar artery can usually be recognized (Figure 2.18). Air may enter the medial aperture of the cochlear aqueduct - a feature of negligible importance so long as this is not thought by the observer to be the porus of the internal auditory meatus.

Other intrathecal contrast agents are rarely used in otoradiology. Large extra-axial masses in the posterior cranial fossa are not satisfactorily demonstrated by air CT studies, and if not clearly defined on the enhanced CT scan and magnetic resonance (MR) is not available, they are best outlined by positive intrathecal enhancing agents such as Iopamidol (Niopam), which can show the relation of the tumour to the brainstem. An example of this is cholesteatoma of congenital origin in the cerebellopontine angle (Figure 2.19).

Magnetic resonance

Bone produces a negligible signal on MR scans and so both the bone of the petromastoid and the air in the middle ear cleft and mastoid cell system appear as black areas on the scan, devoid of any of the bone detail so well demonstrated by tomography and high resolution CT. Thus, only soft tissue structures within the petrous temporal bone are imaged and this can be an advantage for the demonstration of the cranial nerves passing through the skull base, as the nerve itself will be shown, not the canal in which it lies. However, these techniques are still being developed and really need the application of surface coils to improve the definition. In contrast to the non-signal of compact bone, marrow spaces, which are very variable in extent but occur mostly in the petrous apex, give an intense signal because of their large fat content.

So far MR has been used almost solely in otology for the demonstration of an acoustic neuroma. Superior density resolution without contrast enhancement, absence of artefacts, and the potential for three-plane imaging mean that MR is already beginning to replace CT for the demonstration of masses in the posterior cranial fossa. Intra-axial masses are particularly well shown (see Volume 1, Chapter 17). It is also possible to show a small acoustic tumour within the internal meatus (Figure 2.20 and see Figures 21.13c and d), and MR may well eventually replace both the enhanced posterior fossa CT scans and the air-CT meatogram. Paramagnetic agents have been used to enhance these tumours in the same way that iodine-containing substances are given intravenously with CT. The response has been variable and the possibilities for tissue characterization are still being assessed (Curati et al, 1986).

Similarly, it is hoped that a high intensity signal (long $T_2$) in $T_2$ weighted images, characteristic of cholesteatoma, may make it possible to differentiate this from fluid, cholesterol granuloma and other causes of soft tissue opacification.

Angiography

Carotid or vertebral angiograms are usually of diagnostic value only in glomus jugulare tumours but may be required to show the vascular supply and the relation of other lesions, particularly a neuroma or meningioma (see Volume 1, Chapter 17). A carotid
angiogram may be used to demonstrate the very rare abnormal course of the internal carotid artery through the middle ear. Digital vascular imaging and therapeutic embolization techniques are considered briefly in Volume 1, Chapter 17.

Retrograde jugulography has been advocated to diagnose and show the extent of small glomus tumours of the jugular bulb. In the author's opinion, however, this examination is nearly always superfluous if good quality pictures are obtained with subtraction angiography. Rarely is jugulography required to confirm a high jugular bulb and diverticulum. Such vascular anomalies can usually be sufficiently well demonstrated by non-invasive techniques (see below).

**Demonstration of the facial nerve canal**

The facial nerve runs a complicated course through the temporal bone. From the lateral end of the internal auditory meatus to the stylomastoid foramen, the facial canal is divided into three parts, corresponding to their directions (see Figures 24.3, 24.4 and 24.5). These are difficult to demonstrate with conventional radiography and the Stenvers' view, which may show the descending part, is probably the only projection of value.

**Labyrinthine part**

Starting at the anterosuperior aspect of the lateral end of the internal auditory meatus, this short segment swings anteriorly above the cochlea to the pit for the geniculate ganglion, where the nerve turns sharply backwards to become the second part. This short length of canal may be shown by axial CT (see Figure 2.17), but the sulcus for the geniculate ganglion is well demonstrated in coronal sections (see Figures 2.7 and 2.12).

**Tympanic part**

From the geniculate ganglion to the second bend, the nerve runs backwards above the oval window and below the lateral semicircular canal which overhangs it. It is surrounded by a thin bony sheath which may be dehiscent. Its course is somewhat oblique (Figure 2.21) and the bony canal is, therefore, best seen in cross-section on the semi-axial projection (see Figure 2.11).

**Mastoid or descending part**

The third part of the nerve runs downwards from the second bend at the level of the pyramidal eminence to the stylomastoid foramen. Its length is partly dependent on the shape of the temporal bone and partly on the extent of pneumatization of the mastoid. Its width varies considerably. The bony canal is best demonstrated by coronal section and lateral tomograms, and CT (see Figures 2.8 and 2.16). Recognition is easy where the nerve passes through solid bone, but may be difficult where there is much pneumatization. In children with congenital ear lesions, it is important not to confuse the facial nerve canal with other dehiscences such as the tympanomastoid fissure.
Choice of investigation by imaging techniques

There are no 'routine' investigations of the temporal bone; all should be undertaken to try to solve a problem in diagnosis or to define the extent of a lesion. Our commonest examination is the study of the internal auditory meatus in patients with symptoms and signs of eighth nerve dysfunction who might have an acoustic neuroma. Examination by complex motion tomography is preferred and such coronal sections usually comprise the initial temporal bone investigation. Most centres would use a few plain film projections.

High resolution CT is now established as the most useful and versatile procedure for showing bone detail in the petrous pyramid, soft tissue abnormalities in the middle ear and extension of disease into the cranial cavity. It is supplanting all other imaging modalities and restricting the use of angiography. However, the extensive use of CT for almost all lesions of the petromastoid seems excessive, on grounds of cost and radiation dose to the patient. If the eyes are rigorously avoided, the good beam collimation of CT results in a corneal dose almost as low as polytomography with eyeshields. However, 20-25 slices, which included the orbits, were found to result in a considerable dose of radiation (12-15 cGy) using the most recent machine of a major manufacturer (see Volume 1, Chapter 17).

Otitis media is essentially a clinical diagnosis. Radiology shows only non-specific opacity of the middle ear cleft and is rarely required. It may however be useful for showing evidence of bone erosion in mastoiditis or alternatively for confirming that the air cells are indeed air containing. Similarly, the diagnosis of an acquired cholesteatoma with attic perforation is clinical, the treatment is surgical exploration, and radiology largely irrelevant, although it is now being claimed that cholesteatomata as small as 3 mm in size can be diagnosed much earlier by the use of CT (Schwartz, 1984). For cholesteatoma behind an intact eardrum, radiology is as important as it is for vascular masses in the middle ear cavity (see below). The demonstration of rarefaction of the labyrinthine capsule is sometimes useful to confirm the presence of otospongiosis.

A brief review of imaging techniques in some of these pathological processes is given below.

Congenital malformations

Congenital malformations of the inner, middle and external ear almost always present in childhood and are considered in Volume 6 (see Figures 25.4 and 25.5). This does not, however, apply to vascular anomalies which are usually discovered in late childhood or adulthood. The differential diagnosis of these vascular anomalies and their distinction from vascular neoplasms, especially glomus tumours is almost entirely dependent upon radiology (Phelps and Lloyd, 1986).

Vascular anomalies

Angiography has been considered the definitive investigation and in many cases is mandatory when there appears to be a vascular mass behind the eardrum. Exceedingly rare abnormalities are a persistent stapedial artery or an aneurysm of the internal carotid artery (Glasscock et al, 1980; Moffat and O'Connor, 1980). These can only be recognized by
angiography. This discussion concerns aberrations in position of the internal carotid artery and jugular bulb.

The anatomy of the jugular bulb is variable, the right usually being larger than the left. Not infrequently, it extends above the inferior rim of the bony annulus, with or without a bony covering. The anatomy has been comprehensively reviewed by Graham (1974), who quoted dissections by other authors showing the jugular bulb extending above the inferior rim of the annulus in 6% of specimens, and a similar percentage showing dehiscence in the bony floor of the middle ear cavity.

When the jugular bulb is small, it is separated from the floor of the middle ear by a comparatively thick layer of bone, which is usually compact, but may contain air cells. Anteriorly the bulb is in relationship with the internal carotid artery. A spur or crest of bone separates the jugular fossa from the carotid canal at the skull base (see Figure 2.9). When the jugular bulb is very large, it can extend up into the mesotympanum with a thin bony covering, which can easily be damaged at surgery (Figure 2.22). When there is dehiscence of this bony covering the exposed jugular bulb is at even greater risk. The soft tissue mass of a dehiscent jugular bulb cannot be adequately shown by conventional and tomographic imaging, but is well shown by CT, especially in the coronal plane, and by retrograde jugular venography (Figure 2.23).

Another aspect of the large jugular bulb is encroachment on inner ear structures. The internal auditory meatus, vestibular aqueduct and posterior semicircular canal may be affected, especially if there is an associated diverticulum from the bulb (Phelps and Lloyd, 1983b).

Aberrations in the course of the internal carotid artery through the petrous temporal bone are extremely rare. Normally the artery ascends vertically, medial and anterior to the middle ear cavity before bending sharply anterior and medially below the eustachian tube and cochlea; it then passes through the foramen lacerum into the cranial cavity. A thin bony septum separates the artery from the hypotympanum (see Figure 2.12). There is said to be dehiscence in 1% of people (Glasscock et al, 1980), but the true incidence is probably much less than this. If the ascending part of the artery is more posteriorly placed than usual with a very acute bend, it is more likely to be dehiscent (Figure 2.24), although the spur between the carotid and the jugular bulb remains intact. In more severe aberrations, a soft tissue mass will be shown in the middle ear by CT (Figure 2.25), but the important differentiating feature on coronal CT is absence of the normal carotid canal and a laterally and more posteriorly placed vertical canal (Figure 2.26). These features need to be confirmed by angiography and no attempt at surgical interference should be made (Figure 2.27).

**Differential diagnosis**

Enlargement of the jugular fossa may be demonstrated on plain X-ray by a transoral view or an undertilted submentovertical projection. It may also be demonstrated on coronal hypocycloidal tomography, but lateral hypocycloidal tomography is the more important projection at this stage of the investigation and will demonstrate either a high jugular bulb, or enlargement of the jugular fossa in an anterior direction, when it is likely that the jugular bulb will encroach on the middle ear. However, the best method of demonstrating this
anomaly is by high resolution CT scan when the jugular bulb can be seen as a rounded or
dome-shaped opacity encroaching upon the middle ear space (Figure 2.28). High resolution
CT in the axial plane will also show both the enlargement of the jugular bulb and the
integrity of the cortex at the margin of the jugular fossa. This allows a distinction to be made
between a large jugular bulb and the enlargement that takes place in the presence of a glomus
ejugulare tumour. In the anomaly of an aberrant carotid artery, it can be shown from
angiographic studies that the vessel lies both more lateral than normal and more posteriorly.
In this way, it may come to lie under the promontory in the middle ear, sometimes producing
a small indentation. CT is again the definitive investigation since it is possible to show both
the soft tissue mass of the vessel in the middle ear and also the abnormal course of the
carotid canal.

Trauma

The value of radiology for injuries involving the petrous temporal bone may be
summarized:

1. to confirm the presence of a fracture line
2. to show the site of injury to the facial nerve
3. to demonstrate and confirm the pathway of a cerebrospinal fluid fistula
4. to show foreign bodies
5. in the late management of persistent conductive deafness ossicular dislocations may
   be shown.

The radiological investigation should relate to and depend upon the clinical picture.
To demonstrate a fracture, the X-ray beam must be in or close to the plane of the fracture line
and several projections in different planes are necessary. Tomography or high resolution CT
will show more fractures than will plain films and are valuable for demonstrating more
precisely their path and extent. The examination needs to be performed in at least two planes.

Although fractures of the petrous temporal bone follow no set pattern, they are usually
classified with reference to the long axis of the petrous pyramid as longitudinal or transverse
(see Figure 24.5).

The fracture line in the commoner longitudinal type is in the long axis of the petrous
bone and, typically, it extends from the squama across the superior aspect of the bony
external auditory meatus and through the tegmen (Figure 2.29). The fracture line then passes
in front of or behind the labyrinth (see also Figure 7.2).

Anterior longitudinal fractures usually involve the horizontal portion of the facial nerve
canal in the region of the geniculate ganglion (Figure 2.30). Posterior fractures involving the
vertical portion of the canal or the posterior genu then proceed either along the roof of the
eustachian tube or to one of the nearby foramina (the foramen lacerum, jugular foramen or
internal auditory meatus).

Longitudinal fractures are best shown by axial CT when the whole length of the
fracture line can be shown, and by lateral tomography or reformatted lateral CT. The
reformatting technique is particularly well suited to the demonstration of longitudinal fractures
when the cross-sectional reconstruction can be made precisely in the plane of the fracture shown on the axial views.

Transverse fractures run at right angles to the long axis of the petrous bone. As classically described, this type of fracture affects the pyramid, with the fracture line passing across the labyrinth or internal auditory meatus. It produces facial palsy and sensorineural deafness which may be complete and permanent. Some fractures, however, pass laterally to the pyramid, through the middle ear or external meatus and, because they are in the same plane, should strictly be classified as 'transverse', although the conductive deafness and other features make them very similar to the longitudinal type.

Transverse fractures are also best demonstrated by axial CT but they can usually be shown also by simple plain film views in the periorbital or Stenvers' projections (Figure 2.31). Coronal CT sections will show the fluid level of a cerebrospinal fluid fistula.

**Ossicular dislocations**

When a head injury is followed by conductive deafness, it is most commonly the result of a simple haemotympanum or a traumatic rupture of the drum. However, if hearing loss remains after the drumhead has healed, then disruption of the ossicular chain must be suspected.

Unfortunately, the commonest dislocation, namely of the incudostapedial joint, cannot be satisfactorily demonstrated by tomographic methods. Displacement of the incus, rarely the malleus, and separation of the incudomalleolar joint can be demonstrated by axial and coronal tomograms or high resolution CT (Figure 2.32). Loss of the normal 'molar tooth' sign on the lateral tomograms is another important sign of major ossicular displacement (see above).

**Inflammatory disease**

Acute otitis media and its complications are essentially diseases of childhood, and are considered in Volume 6 (see also Figure 9.3).

Chronic suppurative otitis media is usually described as:

1. the non-cholesteatomatous tubotympanic type in which radiology has a negligible role

2. the attico-antral type with cholesteatoma.

Adhesive otitis media involves the development of adhesions and tympanosclerosis, that is calcification in areas of hyaline degeneration. The only importance of tympanosclerosis, from an imaging point of view, is to be aware of its existence to avoid misinterpretation of plaques of calcification in the middle ear.
Radiology of complications of middle ear infection

These may follow any form of middle ear infection but, most commonly, acute mastoiditis and cholesteatomatous chronic suppurative otitis media.

Labyrinthitis

The symptoms of vertigo in the presence of acute or chronic suppurative otitis media indicate the presence of labyrinthitis due to involvement of the labyrinthine fluids in the inflammatory process. Spread of the infection to the labyrinth may be via the intact oval window, the round window membrane or via an erosion in the labyrinth capsule, the latter being usually produced by a cholesteatoma. Radiology is likely to be informative only in cholesteatomatous disease, where the most common abnormality is an erosion of the bony capsule of the lateral semicircular canal, demonstrable on a Stenvers' projection, coronal section tomography or CT. Suppurative labyrinthitis can also result from spread of infection from the blood stream or meninges. Following an episode of purulent labyrinthitis, which results in total destruction of the membranous labyrinth, the bony labyrinth may become filled with granulation tissue which often undergoes varying degrees of ossification. This so-called 'labyrinthitis obliterans' is, primarily, a histopathological diagnosis but the ossification is readily detectable by tomography (see Figures 17.2, 25.2 and 25.3).

Partial obliteration of the bony labyrinth is probably a characteristic tomographic feature with a clear-cut margin seen between the parts obliterated by bone and portions seemingly unaffected. This appearance distinguishes post-suppurative labyrinthitis obliterans from advanced otosclerosis, in which the bone encroachment is much more diffuse.

Intracranial complications

These comprise one or more of the following extradural abscess, subdural abscess, temporal lobe abscess, cerebellar abscess, meningitis and hydrocephalus. Suspicion of their presence is par excellence the indication for computerized tomography in acute or chronic suppurative otitis media.

The radiological diagnosis of brain abscess is based on the demonstration of a localized area of low attenuation and, after injection of contrast medium, a surrounding area of high attenuation. Distortion or displacement of the ventricles may be present if the lesion is large. Serial CT scans allow the development of a lesion to be monitored and give warning of incipient rupture into ventricle, or they may be used to assess postoperative progress of the cavity. It is important to remember that up to 15% of brain abscesses or otitic origin are multiple. Occasionally, an abscess which is clinically silent may be demonstrated.

Extradural and subdural collections of pus may show a peripheral rim of low attenuation and contrast enhancement. Not infrequently, however, extradural abscesses are very shallow and not well demonstrated by computerized tomography, unless by chance a tomographic section passes through the centre of the pathological area.
Tuberculous otitis media in adults most commonly occurs in association with advanced pulmonary tuberculosis, but in children it may occur in isolation. Extensive ragged destruction in the mastoid and middle ear rather than sclerosis is a typical radiographic feature.

**Malignant otitis externa**

Malignant otitis externa is a rare condition in which an otitis externa, usually due to Pseudomonas infection in a diabetic patient, spreads wide, leading to osteomyelitis of the temporal bone cranial nerve lesions according to the precise area of spread may also occur and occasionally death (Prasad, 1976).

Radiologically there is a typical appearance of rarefaction of the bone spreading symmetrically and centrifugally from the external auditory meatus. In an analysis of nine cases of diabetic malignant otitis externa, Mendez et al (1979) found that when there was a unilateral facial paralysis or a jugular foramen syndrome, bone destruction was always demonstrable. Five cases had evidence of jugular fossa destruction, but only one had a jugular foramen syndrome. Retrograde jugular venography confirmed the presence of high degree of venous obstruction at the jugular bulb.

A good demonstration of the extent of the disease is given by CT (*Figure 2.33*), but probably more important are isotope studies to show the degree of activity of the infective process (Mendez et al, 1979). Nevertheless, early diagnosis is essential as prognosis seems to be related directly to the stage that the disease has reached at the onset of treatment (Mills, 1986).

**Cholesteatoma**

The aetiology of this characteristic epidermoid cyst containing keratin is not fully understood. Two types are recognized, although they do not differ histologically.

(1) Congenital cholesteatoma originating from ectodermal cell rests. This may arise in any of the cranial bones, the petrous temporal being the most commonly affected, or within the cranial cavity.

(2) Acquired cholesteatoma, in which there is ingrowth of the surface epithelium of the tympanic membrane.

In the vast majority the diagnosis is readily made on clinical grounds.

**Congenital cholesteatoma**

Congenital cholesteatoma may arise anywhere within the petrous temporal bone but may be conveniently classified into:

(1) cholesteatoma of the cerebellopontine angle

(2) cholesteatoma arising deep within the petrous pyramid
(3) cholesteatoma arising in the jugular fossa region

(4) congenital cholesteatoma of the middle ear cleft.

Classically, these lesions present in middle age with severe sensorineural deafness and facial spasm or weakness. This involvement of the facial nerve is a characteristic feature.

Cholesteatoma is the third most common tumour of the cerebellopontine angle, after acoustic neuroma and meningioma. The brain scan shows an area of low attenuation (see Figure 2.19).

**In the petrous pyramid**

A large erosion is usually evident on plain films in a patient with cholesteatoma of the pyramid or petrous apex. Tomograms show a clearly defined 'punched out' area of bone destruction. The clear-cut margins may be scalloped and the labyrinth is destroyed by a 'steam roller' effect, although individual coils of the cochlea and the modiolus may be identified after invasion of the cochlea has taken place. There may be thinning and elevation of the superior petrous ridge (Valvassori, 1974) (Figure 2.34). A CT scan will demonstrate a non-enhancing mass of low attenuation, and high-resolution CT demonstrates the characteristic expansile cyst-like lesion (Figure 2.35). The congenital cholesteatoma occurring in an extensively pneumatized pyramid can be difficult to diagnose radiologically.

**In the jugular fossa**

A cholesteatoma arising in the region of the jugular fossa or skull base may mimic a glomus tumour, both radiologically and clinically. Although the destruction may be extensive, it is usually less ragged than that caused by a glomus tumour. A CT scan should differentiate between the two lesions, if intravenous contrast enhancement is used, but angiography will be decisive.

**In the middle ear and mastoid**

It is uncertain what proportion of the much more common cholesteatomata arising in the attico-antral region have a congenital origin but the percentage is probably small and they are, ultimately, indistinguishable from acquired cholesteatoma.

There are two criteria which help to distinguish a cholesteatoma of the middle ear cleft which ha a congenital rather than an acquired origin. These are:

1. an intact eardrum with no evidence of a previous perforation
2. an intact spur.

**Acquired cholesteatoma**

The vast majority of cholesteatomata arise from either the pars flaccida or the posterior segment of the tympanic membrane. From here they extend into any part of the tympanic
cavity and backwards into the mastoid antrum and air cells. There is associated erosion of the walls of the middle ear cleft.

The most important single plain radiographic projection in the management of typical cholesteatoma is the lateral view, with the incident beam tilted $20^\circ$ caudally. This will show the extent of pneumatization and erosion of the outer attic wall. The other mastoid projections will only demonstrate large erosions. Pneumatization is usually poor or absent and the mastoid sclerotic, but cholesteatoma may be encountered, with minimal bone destruction, in an extensive air-cell system.

Tomography in the coronal plane was formerly the optimum method for demonstrating small cholesteatomata in the attic and antrum. The tomographic evaluation of cholesteatoma is based mainly on the detection of bone erosion (Figure 2.36).

In the attic the following signs indicate the presence of a cholesteatoma:

1. destruction of the lateral spur of bone formed by the junction of the lateral boundary of the attic and the roof of the external auditory canal
2. bone destruction of the lateral attic wall
3. destruction of the ossicles
4. erosion of the medial attic wall. This is a less common sign, but may lead to involvement of the facial canal or a labyrinthine fistula. It should be noted that the presence of a fistula can only be confidently predicted if the lesion is present on two or more slices.

Similar erosive changes can be discerned on coronal CT, but its ability to depict precisely small soft tissue masses in the middle ear makes CT the best overall method of imaging cholesteatoma. Acquired cholesteatomata are diagnosed on CT by the presence of a non-dependent homogeneous soft tissue mass in an appropriate location (Schwartz, 1984). It is important to remember that CT imaging is unable to distinguish the soft tissues of a cholesteatomata from polyps, granulation tissue mucosa, cholesterol cysts or fluid, by tissue characterization (Figure 2.37).

If a lesion is adequately assessed clinically, and a versatile surgical technique applied in the treatment, then radiological assessment is necessary only in those cases with unusual clinical features, for example suspicion of intracranial complications, facial palsy, positive fistula sign, and severe sensorineural deafness or disease in an only hearing ear.

A cholesteatoma may not, however, always be apparent on first inspection. House and Sheehy (1980) reported 41 cases of cholesteatoma with an intact eardrum (3.7% of their series). Cholesteatomata may also be associated with a central type of perforation. Such a true perforation is usually a feature of the safe tubotympanic type of disease, but it may also result from breakdown of a retraction pocket with the resultant isolation of squamous epithelium in the middle ear. Often polyps and granulation tissue obscure both types of disease. Invasion of the labyrinth by a cholesteatoma is not necessarily immediately associated with a dead ear, presumably due to a sealing off of the disease process. When there is a small fistula present
in a semicircular canal, a piece of cholesteatoma matrix may be left over the defect in the hope of preserving the remaining cochlear function. In these circumstances, tomographic demonstration of the site of invasion of the labyrinthine capsule provides useful preoperative information (Figure 2.38).

Preservation of cochlear function in the labyrinth invaded by cholesteatoma, first described by Phelps in 1969, is now a well-recognized, though unusual phenomenon. Bagger-Sjobach and Phelps (1985) recently reviewed reported cases of this phenomenon and added three more (Figure 2.39).

To summarize, therefore, the radiological demonstration of cholesteatoma affecting the petrous temporal bone depends on the anatomical site and configuration of a soft tissue mass in the middle ear or petrous pyramid producing characteristic clear-cut bone erosion. These features are well shown by CT but tissue characterization has been unsatisfactory. Magnetic resonance does not demonstrate the bony features and very limited experience suggests tissue characterization may not be much more satisfactory (Figure 2.40). The differing MR signal seen with cholesteatomata appears to be related to the variable amounts of fat found in these lesions (Latack et al, 1985).

Tumours of the middle ear and petrous temporal bone

Tumours may involve the middle ear, the mastoid and the petrous parts of the temporal bone - primarily, metastatically or by extension from adjacent sites such as the postnasal space, external auditory meatus, parotid gland or even from structures within the cranial cavity. Acoustic neuroma is the most common tumour to erode the temporal bone, but it is most unusual for this to cause any radiologic abnormality other than expansion of the internal auditory meatus. Primary neoplasms of the middle ear region are extremely rare, the most common being the glomus jugulare tumour (benign) and squamous cell carcinoma (malignant).

Benign neoplasms

A compact osteoma appears as a well-defined usually single, although occasionally lobulated, bony mass of high density. Cancellous osteomata are more rare and present as a less dense, defined mass. They occur in the following situations:

1. external auditory canal - where they are asymptomatic unless they become large enough to cause obstruction, with consequent hearing loss or retention of wax and skin debris

2. squama of the temporal bone - where they cause a hard bulge above and behind the pinna

3. mastoid - where they are asymptomatic unless encroaching upon the facial nerve canal, causing paralysis

4. petrous pyramid - where they can occur in the region of the porus of the internal auditory meatus (Beale and Phelps, 1986)
(5) middle ear - where they may impinge upon the ossicular chain, causing a conductive hearing loss (*Figure 2.41*).

**Glomus tumours**

Sometimes called chemodectomata or paragangliomata, these arise from small structures called glomus bodies. The tumours are usually classified as glomus jugulare, vagale or tympanicum, depending on the site of origin. The glomus tympanicum may be entirely confined to the middle ear cavity but, usually, the tumour has reached such a size by the time of presentation that it is difficult to determine exactly where in the base of the skull or upper part of the neck, it has arisen.

The glomus jugulare tumours located in the jugular bulb has ready access to various parts of the temporal bone and the foramina at the base of the skull, since they spread along the lines of least resistance. Intracranial extension, therefore, can be along the carotid artery, through cranial nerve foramina, into the nasopharynx, intravascularly into the sigmoid sinus and superior petrosal sinus, through the tempore bone air-cell system to the petrous apex, or retrofacially into the mastoid process (*see Figure 23.1*).

Classically, large tumours demonstrate ragged erosion of the base of the skull in the region of the jugular fossa and posteroinferior aspect of the petrous pyramid, with extension into the mastoid and adjacent occipital bone (*Figure 2.42*).

The first radiographic indication of a glomus jugulare tumour is an abnormality of the jugular foramen and fossa. The lateral (vascular) part of the fossa will be affected rather than the medial (nervous) part. The two fossae are rarely symmetrical and expansion may be difficult to assess. It is most important, therefore, to look for evidence of bone erosion of the margins of the foramen (*see Figure 2.6*). More extensive lesions show a ragged and irregular outline; this is more clearly defined than the erosion produced by an infiltrating lesion such as a carcinoma but not as smooth as the margin of a congenital cholesteatoma or neuroma.

Computerized tomography is superior to plain films, not only for assessment of the extent of bone destruction, but also for demonstrating the presence of a mass in the middle ear cavity. Minor erosion of the walls of the cavity and, especially, the promontory, by small glomus tympanicum tumours may also be shown. Tomography or CT will demonstrate the presence or absence of the floor of the middle ear cavity, an important point when trying to decide whether a mass behind the eardrum is coming from the jugular bulb. The initial radiological investigation for a suspected glomus tumour should include routine views of the skull and mastoid, together with a special view of the jugular foramen and coronal section tomograms. Further assessment can then be made by tomography in other planes, especially the lateral (*Figure 2.43*), by axial and coronal CT, and by arteriography and jugular venography. The role of these special investigations will now be considered in more detail.

Computerized tomography is the investigation of choice. It is used to show both the intracranial extent of a glomus tumour and its downward extension into the neck. The intracranial tumour is well demonstrated on the enhanced scan (*Figure 2.44*). In the soft tissues, glomus tumours do not show marked contrast enhancement except in the early
vascular phase. In this respect, their behaviour is similar to that of a juvenile angiofibroma and one explanation would seem to be that there is little tumour tissue present, much of its volume being made up of vascular spaces. There is, therefore, little extravasation of contrast medium into the extracellular spaces. Demonstration of the tumour requires scanning immediately after a bolus injection or, better still, during continuous infusion. 'Dynamic CT' is a more scientific way of showing the characteristic immediate enhancement followed by rapid 'wash-out' of contrast (see Volume 1, Chapter 17).

High resolution CT may be used to show both the soft-tissue mass of the tumour and the bone erosion on a single scan and, in the axial view, this is now the optimum method for showing the forward extension from the jugular fossa into the middle ear cleft and external auditory meatus (Figure 2.45). (See also Volume 1, Figure 17.8).

For glomus tympanicum tumours originating in the middle ear, high-resolution CT is even more valuable diagnostically and is now the method of choice (Phelps and Lloyd, 1983a). In conjunction with the characteristic clinical signs, the appearance of a soft-tissue mass arising from the promontory (Figure 2.46) is virtually diagnostic of tympanic body tumour; the discrete nature of the mass and the absence of involvement of the jugular fossa serve to distinguish it from the glomus jugulare tumour, especially if air can be demonstrated between the mass and the intact floor of the middle ear (Figure 2.47; see also Figure 23.2b-c).

**Arteriography**

Digital vascular imaging will confirm the presence of all but the smallest glomus tumours. Arteriography is almost always necessary to demonstrate the extent of these tumours and their complete vascularization, as well as their not infrequent multiplicity. The angiographic appearance is nearly always characteristic (Figure 2.48; see also Figure 23.3) with large vascular spaces, arteriovenous connections and dense homogeneous tumour staining. The blood supply is principally from the ascending pharyngeal artery which is the first branch of the external carotid. Other collaterals from both external and internal carotid systems develop as the tumour enlarges and eventually there may be an additional supply from the vertebral system. The initial injection, therefore should be into the common carotid artery with subsequent selective catheterization and vertebral injection as required. Subtraction films are necessary.

Recently, percutaneous catheter embolization has been used for large tumours. Embolization aims at blocking the vascular bed of the tumour, causing thrombosis and preventing the establishment of collateral channels as long as obliteration of the vascular bed is maintained. Selective angiography of the external carotid artery is an indispensable prerequisite to embolization. The vessels feeding the tumour are identified. The catheter should be advanced as close as possible to the lesion before emboli are introduced. This will reduce the chances of reflux of emboli back into the carotid bifurcation where stray emboli may enter the internal carotid artery (see Figure 23.4).
Jugular venography

Adequate demonstration of the jugular bulb is often obtained in the venous phase of the arteriogram. However, a better demonstration of the jugular bulb and a glomus tumour invading it, may be obtained by retrograde catheterization of the internal jugular vein in the neck (Figure 2.49). Where there is extensive involvement of this system, the upper and lower limits of the tumour may be ascertained by the two types of venography, that is run-off phase of the arteriogram for the upper end, and retrograde jugulography for the lower.

To summarize, therefore, the most important diagnostic feature for glomus jugulare tumours is the demonstration by plain films or CT of ragged erosion and loss of the normal cortical margin of jugular foramen. Loss of the normal crest of bone between the carotid canal and the jugular fossa on lateral views is a particularly good sign of a jugulare tumour (see Figure 2.43). Angiography with subtraction is mandatory for the confirmation of glomus jugulare tumours and an aberrant carotid artery; may not be necessary for a small tympanicum tumour confined to the promontory; and should not be necessary for a high jugular bulb. Magnetic resonance, which shows no bone detail, has little to offer, as the flowing blood in these vascular lesions will appear as black areas of no signal.

Neuroma

Neuromata, more correctly called schwannomata, may arise from any of the cranial nerves but have a peculiar tendency to occur in the vestibular components of the eighth nerve within the internal auditory meatus. They are the commonest tumour of the petrous temporal bone.

Neuromata of the facial nerve are slow-growing rare tumours which may arise on any part of the facial nerve, and although they usually present with facial palsy, this is not always a feature.

Radiological diagnosis depends on the demonstration of localized erosion or expansion in the course of the facial nerve canal. The lesions are usually rounded or somewhat elongated (Figure 2.50). The whole length of the canal should be examined and an air meatogram is usually indicated to show the proximal limit of the tumour, either in the internal auditory meatus or cerebellopontine angle. The region of the geniculate ganglion is often involved (Latack et al, 1983) and so the pit for the geniculate ganglion above the cochlea should be carefully assessed on the coronal CT cochlear cut for any erosion. Facial neuromata arising in the internal auditory meatus are virtually indistinguishable from acoustic tumours.

Acoustic neuromata

Most acoustic neuromata arise in the lateral one-third of the internal auditory meatus. Tumour growth takes place medially following the line of least resistance and causes remodelling and expansion of the internal auditory meatus. Extension out through the porus into the cerebellopontine angle then occurs.

A battery of clinical tests is available for the detection of acoustic neuromata but none is completely reliable nor indicates the size of the lesion. Radiological studies are therefore
the definitive investigation for demonstrating or excluding the presence of a tumour on the eighth nerve. However, while most authorities agree with the desirability of demonstrating small tumours a few millimetres in size, the decision of whether or not surgical removal is indicated becomes difficult, given the tumour's variable rate of growth. This decision will depend to a large extent on the age of the patient.

Traditionally there has been great reliance placed on the demonstration of the bony margins of the internal auditory meatus. Where limitations of scan time and cost preclude the investigation by CT of patients with minimal symptoms and signs, plain films or polytomography still provide a valuable screening examination (see above). Computerized tomography provides the means of imaging all acoustic neuromata large and small but, unfortunately, not without the use of intravenous and intrathecal contrast agents.

The ability of magnetic resonance to distinguish brain tissue and tumours from cerebrospinal fluid makes it the potential investigation of choice for identifying all acoustic neuromata both large and small (see Figure 2.20). It is the only modality which will define the lateral and the medial extent of a small lesion confined to the internal auditory meatus. However, the time seems far distant when all patients with mild sensorineural deafness and some unsteadiness will have an MR scan to exclude an acoustic neuroma (see also Figures 21.3 and 21.13).

Bone studies

The classic criteria of abnormality in the internal auditory meatus as shown by tomography (Valvassori, 1969) are still applicable:

1. erosion of the cortical line surrounding the lumen of the canal seen in the lateral tomograms

2. widening of 2 mm or more of any portion of the internal auditory meatus when compared with the corresponding segment of the opposite canal

3. shortening of the posterior wall of the canal at least 3 mm in comparison with the opposite side

4. demonstration of the crista falciformis running closer to the inferior than to the superior wall. The crista should normally be located at or above the midpoint of the vertical diameter of the canal.

Lateral tomographic views obtain a better assessment of the degree of expansion.

A less common but more pathognomonic appearance of the internal auditory meatus occurs when there is irregular and pronounced destruction of the walls of the meatus (Figure 2.51). Why a minority of neuromata should produce this type of bone erosion instead of the more usual expansion of the internal auditory meatus, is unknown.
Computerized tomography with intravenous contrast

Acoustic neuromata show variable attenuation. In about 50% this is similar to that of normal brain but may be more, less, or mixed. However, almost all acoustic neuromata show some degree of contrast enhancement and should appear on the scan if they are of sufficient size (Figure 2.52). Indirect signs, such as displacement of the brainstem and fourth ventricle, obliteration and widening of the cisterns and ventricular dilatation from obstructive hydrocephalus, indicate the presence of a space-occupying lesion. Improvements in scanner technology have lessened the problem of posterior-fossa artefacts caused by the dense bone of the petrous pyramids. Typically, acoustic neuromata are round or lobulated, often with non-homogenous areas of enhancement. Areas of low attenuation may be due to cystic change within the tumour (see Figure 21.12).

Modern scanners should show almost all neuromata in the angle larger than 1.5 cm and often give a convincing demonstration of smaller lesions.

Air CT meatography

Pitfalls with air studies and their interpretation are usually due to incomplete filling of the internal auditory meatus or partial volume averaging on the sections (see Volume 1, Chapter 17). Unless a filling defect with a convex medial margin can be reliably and repeatedly demonstrated, a firm diagnosis of a neuroma should not be made, as failure to fill fully the internal auditory meatus with air may be due to the 'tomato ketchup effect', with air not completely replacing cerebrospinal fluid. This is a particular problem with a normal or narrow internal auditory meatus. The examination should be repeated after repositioning and shaking the patient's head. Examining the other side may help. Excessive pneumatization around the internal auditory meatus may make expansion of the meatus difficult to demonstrate on plain films, and tomography or CT give a better assessment. Pneumatization can also be a problem with air studies in deciding which is air already present in the air cells, and which is that introduced intrathecally (Figure 2.53). Usually the appearances of small acoustic neuromata are characteristic (Figures 2.54 and see Figure 2.18).

Other tumours within the cerebellopontine angle

Acoustic neuromata account for 90% of tumours within the cerebellopontine angle. The differential diagnosis of large tumours is primarily the differentiation of masses in the posterior cranial fossa (see Figure 21.14).

Meningioma

Meningiomas are the next most common neoplasms that occur in the cerebellopontine angle. Several differentiating features have been described. Unlike acoustic neuromata, meningiomas often calcify. Acoustic neuromata expand mainly posteriorly and medially and rarely have a broad attachment to the petrous bone. Meningiomas may be oval, which is unusual with acoustic tumours; surrounding oedema is said to occur more often with acoustic neuromata. Changes in the internal auditory meatus are rare with meningioma and frequent with neuromata. Dense homogeneous enhancement, a smooth outline (Figure 2.55)
and sometimes, hyperostosis of the petrous ridge, are other features of a meningioma in the posterior fossa, although bony changes occur less often than when they arise in the region of the sphenoid ridge.

**Cholesteatoma**

Cholesteatoma occurs in the angle or, more anteriorly, alongside the petrous apex. Non-enhancement of the lesion and low or even negative attenuation values, are characteristic features (see above).

**Glioma**

Gliomata, or large glomus jugulare tumours from below, may appear as enhancing masses in the region of the cerebellopontine angle. The pattern of bone erosion of the petrous pyramid will, however, suggest an extrinsic mass.

**Neuroma**

Neuromata arising from the trigeminal nerve or from the ninth, tenth and eleventh nerves in the jugular fossa, may also extend up into the cerebellopontine angle. Neuromata of the last four cranial nerves involve the jugular foramen and cause expansion. It is usually impossible to determine the exact nerve of origin of these tumours at surgery, since the mass generally envelops them all. Radiologically, these tumours of the lower cranial nerves need to be differentiated from both glomus jugulare tumours and from acoustic neuromata. They differ, radiologically, from glomus jugulare tumours in three respects: the contour of the bone is smooth and well defined with a neuroma, but poorly defined and irregular when the jugular fossa is expanded by a glomus tumour; a neuroma does not usually erode into the middle ear; and expansion of the hypoglossal canal is almost pathognomonic of a neuroma of the twelfth cranial nerve.

**Malignant neoplasms**

Carcinoma arising in the cartilaginous auditory meatus tends to spread into the parotid gland and the postauricular sulcus, whereas a tumour arising from the deep bony meatus may perforate the eardrum at an early stage. It is, therefore, often impossible to assess the exact site of origin of the tumour or to decide whether it has arisen from the deep meatus or the middle ear cleft (Figure 2.56).

The diagnosis of carcinoma in the mastoid is usually made while performing a mastoidectomy in an effort to control presumed chronic mastoiditis, since preceding chronic ear infection is to be expected in at least 40% of patients (Phelps and Lloyd, 1981). Sclerosis of the mastoid and clouding of the cells are therefore radiological signs of little value, but the presence of ragged erosion, usually extensive or in an unusual site, suggests neoplastic change (Figure 2.57). An important sign, on the lateral mastoid view, is erosion of the articular fossa of the temporomandibular joint. This was present on the initial radiographs in 30% of the author's cases. Much better demonstration of erosion of the bony external auditory meatus and back of the temporomandibular joint was given by lateral tomograms.
The hard avascular bone of the labyrinthine capsule is relatively unaffected by carcinoma, and erosion of the capsule with direct invasion of the inner ear is a late radiological feature only present with extensive surrounding bone destruction. There are two important modes of spread of carcinoma of the middle ear (Figure 2.58; see also Figures 2.21 and 2.22). First, the tumour extends anteriorly and penetrates the bony septum separating the middle ear cavity from the carotid artery. It then spreads around the artery and extends down around the eustachian tube towards the postnasal space. Erosion of the carotid septum margins of the bony eustachian tube and even soft-tissue extension of the tumour anteriorly can be demonstrated by CT. Second, the tumour may spread upwards through the tegmen tympani and backwards through the mastoid air cells, then through the thin plate of bone forming the posterior wall of the petrous pyramid and underlying the lateral sinus. Erosion of these thin bony structures may also be demonstrated radiologically.

Otosclerosis and bone dysplasias

The otic capsule forming the bony labyrinth of the inner ear is composed of hard, poorly vascularized, endochondral bone which is metabolically inert and therefore relatively unaffected by systemic bone diseases. Widespread bone disorders such as Paget’s disease, hyperparathyroidism, rickets, osteogenesis imperfecta and fibrous dysplasia, may eventually affect the labyrinthine capsule causing sensorineural deafness, but the periosteal bone forming the remainder of the petrous temporal bone and base of skull is affected first in these disease. The rare congenital dysplasias which are present at birth or appear during childhood are considered in Volume 6. Otosclerosis, the most common bone disorder causing deafness, affects only the labyrinthine capsule.

Otosclerosis

Otosclerosis is a localized disease of the bony labyrinth in which new bone, initially spongy and later denser, replaces the endochondral bone of the otic capsule and may cause ankylosis of the footplate of the stapes. The French term 'otospongiose' is more descriptive.

This immature woven bone of increased thickness, vascularity and cellularity has a lower radiographic density than that of the otic capsule. The focus becomes less active and more sclerotic with increasing maturity (and probably, also as a result of fluoride therapy).

Tomographic or CT demonstration of otosclerotic bone deposits depends mainly on the distortion of the normal clear-cut outline of the labyrinthine capsule. Otosclerotic foci must be large enough - 1 mm in diameter or more - to become radiographically visible. The normal labyrinthine capsule is the most dense bone in the body. It cannot become more radiopaque but, eventually, only thicker by apposition of otosclerotic bone.

Fenestral otosclerosis is essentially a clinical diagnosis based on the audiometric findings and only when severe will narrowing or obliteration of the oval window niche be shown. Follow-up of patients after stapedectomy will be of more value to show displacement of a prosthesis (Figure 2.59).

Similarly, tomography can be used to show the position of a prosthetic cochlear implant (Figure 2.60). Such metallic objects cannot be demonstrated satisfactorily by CT.
Capsular otosclerosis, or more particularly otospongiosis of the bony cochlea, will appear as areas of rarefaction around the coils (Figure 2.61). In theory, CT with its improved density resolution should be better able to depict these areas of bone rarefaction, but in practice they have been demonstrated equally well by CT and polytomography (see also Figures 14.27a and b).

**Paget's disease (osteitis deformans)**

The radiological appearance of the petrous pyramids is pathognomonic (Figure 2.62). The periosteal bone is affected first and the extensive demineralization that occurs makes the labyrinthine capsule stand out more clearly than normal in the initial stage, osteoporosis circumscripta (see Figure 15.5). When the labyrinthine capsule becomes involved, the affected parts become almost impossible to identify, as they are replaced by amorphous bone (see Figure 15.6). The remaining unaffected parts of the labyrinth may give the impression of floating in this grey, featureless, homogeneous, pagetoid bone. The medial ends of the petrous pyramids become tilted upwards due to bone softening and platybasia. Secondary degenerative changes in the cochlear duct seem to be the main cause of the deafness rather than narrowing of the internal auditory meatus. The margins of the meatus become difficult or impossible to define on the tomograms when surrounded by pagetoid bone. Finally, all recognizable features of the inner ear may be lost as progressive sclerosis occurs (see Figure 15.7). The cause of the conductive component of the deafness seems to be involvement of the ossicles rather than stapedial ankylosis.

**Fibrous dysplasia**

Although monostotic fibrous dysplasia is not infrequently found affecting the facial bones, only a handful of cases have been reported in the petrous temporal region. These usually present with conductive deafness caused by a bony mass obstructing or occluding the external auditory meatus. Fibrous dysplasia of the petrous pyramid rather than the external ear is even rarer (Figure 2.63).

Although fibrous dysplasia, like Paget's disease, causes expansion of bone and affects the periosteal bone of the skull base rather than the labyrinthine capsule, the radiological differentiation is usually not difficult. Fibrous dysplasia occurs in a younger age group and the distinctive 'ground glass' appearance of fibrous dysplasia is unlike pagetoid bone (see Figures 15.8 and 15.9).

**Primary basilar impression (craniocervical dysplasia)**

Primary basilar impression is the upward displacement of the skull base and upper cervical vertebrae into the cranial vault. It is a radiological diagnosis based upon Chamberlain's supposition that all parts of the axis and atlas lie caudal to the base of the skull. Elies and Plester (1980) suggested that such craniocervical dysplasia may result in a symptom-complex that in itself presents as a differential diagnosis from Ménière's disease. They were able to display radiological evidence of primary basilar impression in 16% of patients presenting with non-specific dizziness and sensorineural deafness.
Chamberlain's distance is the perpendicular length between the tip of the odontoid peg and a straight line (Chamberlain's line) drawn from the dorsal margin of the hard palate to the dorsal tip of the foramen magnum (Figure 2.64). Chamberlain's distance was considered positive if the odontoid peg was cephalad to Chamberlain's line, and negative if it was caudad. Kane, O'Connor and Morrison (1982) using this measurement showed a proclivity to basilar impression in patients with Ménière's disease.

Secondary basilar impression may occur as a result of bone-softening pathologies, for example Paget's disease; the anterolateral impression is best measured by Bull's angle (Bull, Nixon and Pratt, 1955).

**Acknowledgements**

Chapter 3: Pathology of inflammatory conditions of the external
and middle ear

G. G. Browning

Anatomy and pathology of the squamous epithelium of the external ear

The pinna and external auditory meatus are lined with keratinized squamous epithelium that is identical to that which covers the body. The deeper or basal cells are cuboidal in shape and rest upon a basement membrane. This layer is constantly undergoing cell division and the progeny of the original cells gradually move towards the surface becoming flatter in the process. As they reach the top layer the cells shrink, lose their nucleus, and die. When dry the surface cells contain a tough protein called keratin, hence the name keratinized squamous epithelium. Finally the surface cells are shed.

In the external auditory meatus, the epithelium varies in thickness, being thickest in the cartilaginous portion where there are rete pegs, thinner in the bony portion where there are no pegs and thinnest of all on the tympanic membrane where the number of layers of cells is considerably reduced. Interestingly, the number of cell layers here is similar to that in a cholesteatoma (Michaels, 1987).

As squamous epithelium, the skin of the meatus obeys the well recognized laws of repair. If a break occurs in the basal layer due to either trauma or inflammation, the cells migrate until they meet another epithelial surface; this may be either epithelium of the same or of a different type. Hence, if a tympanic membrane defect occurs, the squamous epithelium will advance and one of three things may happen: the gap may be bridged resulting in a healed tympanic membrane; the epithelium may fail to bridge the defect and join at some position with the middle ear mucosa, although this need not necessarily be at the edge of the defect; and finally, it may not meet up with middle ear mucosa in the region of the tympanic membrane, perhaps because the mucosa has been destroyed, but grows into the middle ear until it finally does so. Why the ear should heal in one way rather than another is uncertain, but it is probably related to how much epithelium is lost and over which structures the epithelium has to migrate. These may be normal anatomical structures such as the middle ear mucosal folds, pathological tissue, such as granulations, secretions or pus, or perhaps a surgically inserted graft.

Anatomy and pathology of the mucosa of the middle ear and mastoid

The ciliated, pseudostratified columnar epithelium of the respiratory tract extends up the eustachian tube as far as the anterior part of the middle ear cavity. These cells are capable of producing mucus. In addition there are goblet cells and mucus-secreting glands. More posteriorly, the mucosa changes patchily into a simple cuboidal or stratified epithelium with no secretory elements. The medial aspect of the tympanic membrane and the mastoid air cells are lined by a single layer of cells ranging in shape from cuboidal to flat.

In the early stages of inflammation, whatever its cause, there is vasodilatation of the submucosal tissues. Glandular secretion is stimulated with the production of a thin mucoid fluid. Some of the epithelial cells die and the bacteria that are normally in the area multiply.
in the denuded areas and aggravate the condition. A polymorphonuclear reaction occurs from the neutrophils in the blood and a mucopurulent discharge results which may remain stagnant within the middle ear and mastoid air cell system because of loss or immobility of the cilia including those of the eustachian tube.

Most frequently, resolution will occur but if the condition is prolonged for some reason, such as the inability of the secretions to drain down the eustachian tube, the number of glands and goblet cells will increase and the areas formerly covered by cuboidal or flat epithelium will change into a similar but perhaps less well differentiated pseudostratified columnar epithelium. Differentiation into squamous epithelium, most frequently non-keratinized, can also occur.

Granulation tissue is an end result of non-resolution of an inflammatory process. Localized areas of the mucosa become hyperplastic with invasion of fibroblasts and chronic round cells such as macrophages, plasma cells and lymphocytes. Granulation tissue can be covered by all the variations in mucosal types described above but is also frequently ulcerated so that it does not have a mucosal covering.

**Bacteriology of the external and middle ear**

Like skin elsewhere, that of the external auditory meatus has a normal commensal flora such as *Staphylococcus epidermidis* (*albus*), and *Corynebacterium* spp (diphtheroids). In addition *Staph aureus* and *Streptococcus viridans* can frequently be present without causing any ill effects (Sipila et al, 1981). When the skin's natural defence mechanism breaks down, such as in otitis externa, the resident bacteria multiply because of the more favourable environment and other organisms such as *Proteus* and *Pseudomonas* spp, which are normal commensals of other parts of the body, may then flourish. The fact that these bacteria can be isolated is more likely to imply that they are secondary invaders rather than the cause of the condition. Naturally their local multiplication will increase the degree of the inflammatory response, but what is less certain is whether their elimination, say by antibiotic therapy, will be of material, clinical benefit.

In normal individuals with an intact tympanic membrane, the culture of swabs taken from the middle ear mucosa will not usually grow any bacteria. In some, however, an upper respiratory tract flora such as *Streptococcus* and *Pneumococcus* spp may be isolated and this should not be considered surprising because of the continuity of the middle ear with the nasopharynx. If, however, skin commensals such as *Staph epidermidis* or *Corynebacterium* spp are isolated then they are most likely to be contaminants picked up during the sampling of the middle ear.

When a tympanic membrane defect is present the normal flora of the external auditory meatus has easy access to the middle ear. In most instances, the mucosa should be no less able than that of the nose or throat to deal with such contamination. In some, however, if the mucosa is more susceptible or already inflamed for some other reason, bacterial colonization is likely to occur both with the normal skin commensals and the bowel-type flora normally found around the body. When this occurs, the question has to be asked: What part do the bacteria have in the condition? The fact that an average of two different species of bacteria
can be isolated from active ears (Sweeney, Picozzi and Browning, 1982) would suggest that secondary colonization rather than primary infection is a strong possibility.

The role of antibiotic therapy in inflammatory conditions of the external auditory meatus is controversial, but the needless prescribing of them should be condemned on bacteriological grounds because of the likelihood of the development of resistant strains particularly those that produce beta-lactamase. The penicillins (including ampicillin) and the cephalosporins are only effective because they have a beta-lactam ring to which various chemical radicals can be added to make different antibiotics. Bacteria can develop resistance to these antibiotics by producing beta-lactamase (previously called penicillinase) and what is of concern is that the genetic ability to do so can be passed relatively easily from one bacterial species to another. The indiscriminate prescribing of the penicillins and the cephalosporins will increase the number of resistant strains within the population. This might be of little consequence in the management of ear disease but is of considerable importance for infections else where in the body.

**Otitis externa**

**Definition**

The term 'otitis externa' covers any inflammatory condition of the skin of the external auditory canal, but when used in an unqualified manner it implies diffuse dermatitis/eczema of the canal skin. (In dermatological terms there is no difference between dermatitis and eczema.)

**Classification**

Several different classifications have been used (Mawson, 1963; Peterkin, 1973) which are based on fine clinical distinctions concerning the appearance of the lesion and the likely aetiological factors. Unfortunately, there is no histological or other quantifiable distinction in these classification systems. An alternative is to classify otitis externa as to the extent of the lesion (*Table 3.1*).

**Incidence**

Little data apart from anecdote appear to be available concerning the incidence of the various forms of otitis externa but perhaps the commonest type in both general and hospital practice is diffuse otitis externa. Furunculosis is also fairly common but invasive otitis externa and keratosis obturans are rare.

**Localized otitis externa**

The most common form is a boil (furunculosis) of one of the sebaceous glands of the outer third of the canal where the skin is hair bearing. Pathologically, there is no difference between boils in this site and anywhere else in the skin.
Diffuse otitis externa

Here the pathological process is initially limited to the skin of the cartilaginous portion of the external auditory meatus and perhaps the concha. With more extensive involvement, the bony canal and tympanic membrane become affected.

Table 3.1. Classification of otitis externa

<table>
<thead>
<tr>
<th>Classification</th>
<th>Subclassification</th>
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<tr>
<td>Localized (furunculosis)</td>
<td>Idiopathic</td>
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<tr>
<td>Diffuse otitis externa</td>
<td><em>Traumatic</em></td>
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<td></td>
<td><em>Irritant</em></td>
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<td></td>
<td><em>Bacterial/fungal</em></td>
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<td></td>
<td><em>Climatic/environmental</em></td>
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<td></td>
<td><em>Other</em></td>
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<tr>
<td>Part of generalized skin condition</td>
<td><em>Seborrhoeic dermatitis</em></td>
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<td></td>
<td><em>Allergic dermatitis</em></td>
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<td><em>Atopic dermatitis</em></td>
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<td><em>Psoriasis</em></td>
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<td>Invasive (granulomatous/necrotizing/malignant)</td>
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<tr>
<td>Other (keratosis obturans)</td>
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Aetiology

Idiopathic

In most instances, there will be no obvious reason why diffuse otitis externa has developed and it must therefore be considered idiopathic. In most instances, it is likely to be due to a combination of factors superimposed upon a breakdown, for some as yet unknown reason, in the skin's natural defence mechanism and in particular of the sebaceous and ceruminous glands whose lipid secretions coat the squamous epithelium of the meatus. It then requires only the addition of another minor factor, such as trauma, for the condition to commence.

Traumatic

It is a natural reaction to poke or scratch an itchy ear with whatever is available (fingernail, matchstick, paper or hair clip). Though this might give patient satisfaction, it could break the skin and allow, for example, secondary infection to occur. In addition, the poking instrument itself might cause an irritant or allergic reaction (see below).

Irritant

Many chemicals when applied to the skin will cause an irritant rather than an allergic reaction. The difference between the two reactions is that the former will occur in everyone if the application of the irritant is sufficiently prolonged and its concentration is high enough.
Irritant reactions are more severe if the skin surface is moist and its natural defence mechanism is compromised. Allergic reactions only occur in some individuals who develop a type IV hypersensitivity after a period of sensitization to the allergen.

Irritants are frequently instilled into the ear in the form of solvents (for example propylene glycol, triethanolamine oleyl polypeptide) in wax softeners and in some medicinal ear drops. Sixty per cent of hospital patients with otitis externa will have an irritant reaction to such agents when they are applied in the same concentration as in the propriety preparation (Holmes et al, 1982).

**Allergic**

In most instances where an allergy is present, it is to topical medications which have been instilled into the meatus and under these circumstances they must be considered potentiators rather than initiators of the condition. The commonest allergens are the antibiotics (for example neomycin, framycetin, gentamicin, polymyxin), antibacterials (for example clioquinol) (Holmes et al, 1982) and antihistamines. Other potent sensitizers are metals and in particular nickel which is often present in paper and hair clips which may be used to scratch the ear. In addition, some of the constituents in fingernail varnish, cosmetics and hair preparations can cause allergic reactions. It has been estimated that in about one-third of patients attending a hospital clinic with otitis externa, there will be an allergic component, mainly to topical medications (Rasmussen, 1974).

**Bacterial/fungal**

The role of bacteria in uncomplicated otitis externa is controversial. Normally only diphtheroids and *Staph epidermidis* can be cultured from the canal skin, but in otitis externa, potentially pathogenic organisms can be cultured from at least 75% of ears (Leventon et al, 1967). The identity of the most common organism varies between published series but the most prevalent would appear to be *Pseudomonas* spp, coliforms, *Proteus* spp and *Staphylococcus aureus* in that order (Singer et al, 1952; Leventon et al, 1967). However, the fact that these organisms are isolated does not mean that they are responsible. In unilateral otitis externa, approximately 40% of the non-affected ears will grow similar, potentially pathogenic bacteria; this is significantly more common than the figure of approximately 3% in normal ears (Leventon et al, 1967). Bacteria frequently colonize any inflamed skin surface, for example burns, and once the otitis externa has resolved clinically, approximately 40% will still have the same type of flora (Leventon et al, 1967). Though the bacteria most commonly isolated are bowel commensals, it is unlikely that they colonize the skin of the ear because of poor personal hygiene and the non-washing of hands. Bowel-type flora can be isolated from anywhere on body skin after a night in bed and the fact that they persist in the external auditory meatus is more likely to be due to a loss of the normal skin protective mechanisms allowing secondary colonization.

Otitis externa is often found in association with active chronic otitis media and some have postulated that this is due to an allergic reaction to the bacteria in the mucopus rather than a direct irritant reaction to the moist discharge. There is no evidence to support this concept and the organisms isolated are well-adapted commensals elsewhere in the body.
Fungi, though not infrequently seen growing in the debris of the meatus, in non-tropical countries are secondary invaders usually following the use of antibiotic-steroid ear drops. This is confirmed by the ease with which they can be eliminated by removing the debris and ceasing medication.

Climatic/environmental

Those who have worked in hot and humid climates will state that otitis externa is much more frequent there than in cold climates. There are many potential reasons for this, one being that more individuals go swimming in hot weather and, if the skin defence mechanism is already compromised, the combination of getting their ears wet and perhaps irritated by the chemicals in the pool water causes the condition to erupt. This is confirmed in swimmers; the incidence of otitis externa is related to the time spent swimming (Calderon and Mood, 1982). Whether the ears become infected with the swimming water is doubtful as the water is usually not contaminated with bacteria when patients develop otitis externa (Calderon and Mood, 1982) and the bacteria isolated are the same in swimmers and non-swimmers alike (Feinmesser et al, 1982). If, however, a patient develops otitis externa while swimming in a pool that is contaminated with, for example, \textit{Pseudomonas} spp, then the ear will understandably become colonized with that organism (Seyfried and Fraser, 1978).

Other

It has been suggested that a negative middle ear pressure may be a contributory factor and this is based on the tympanometric finding of mildly abnormal middle ear pressure in patients when they have the condition (Morrison and Mackay, 1976; Khalifa, Abdel Nabi and Labib, 1984). This could just be a reflection of the fact that the tympanic membrane is affected by the otitis externa. Further controlled studies are needed.

Pathology

The basic pathology of diffuse otitis externa is that of dermatitis (eczema) anywhere in the skin and it is impossible to distinguish on histological grounds between one clinical type or aetiology and another.

There are several stages through which the lesions can pass. First, there is an acute stage with hyperaemia and intercellular oedema (spongiosis). As the oedema increases small vesicles develop which contain serous fluid within which are some inflammatory cells. In the next stage, the vesicles rupture and serous fluid exudes onto the skin surface. The distinction between the stratum granulosum and corneum is lost with the production of nucleated keratotic cells (parakeratosis) which scale off. Though the condition is usually reversible it can pass into a chronic fibrotic and indurated phase.

Though secondary damage to the ceruminous glands with loss of their protective secretions is postulated as one reason for failure of resolution of the condition in some patients, no histological evidence has been presented to support this. In other inflammatory dermatological conditions there is no loss of pilosebaceous cell function; indeed it is often the reverse and there may be hyperplasia.
Generalized skin conditions

In every patient with otitis externa, it is important to look for evidence of more extensive skin involvement particularly behind the ear, on the scalp or face and neck. Dermatologists, on the basis of their own experience, may attribute other disease labels, but the aetiological factors are just the same as for diffuse otitis externa, that is they are most commonly known.

Seborrhoeic dermatitis

This is a non-specific term used to describe any dermatitis that is neither irritant nor allergic in origin which affects the sebum-producing areas such as the scalp, face, and the back of the neck; dandruff is a mild form. The condition is often made worse when it affects a moist area between two areas of skin that are in contact, for example in the postauricular sulcus. Intertrigo is a more specific name to attach to this and is obviously akin to diffuse otitis externa. There is some evidence from specific antifungal therapy that yeasts of *Pityrosporum* spp may be an important factor in seborrhoeic dermatitis (Ford et al, 1984), but their role in otitis externa would not appear to have been studied.

Allergic dermatitis

There is no pathological difference between irritant and allergic reactions that are confined to the ear and those that are part of a more general reaction. The reaction need not always be confined to the area with which the allergen is in contact; satellite lesions can occur, for example on the neck.

Atopic dermatitis

In atopic children with the triad of dermatitis, allergic rhinitis and bronchitis, the external auditory meatus can be involved, but the distinction from classical otitis externa should be easy to make. Topical medications are more likely to cause irritant (but not allergic) reactions in atopic as opposed to other children.

Psoriasis

Psoriasis affects in the region of 25 of Caucasians, and a lesser proportion of other ethnic groups, at some time in their life. Histologically, it is distinguishable from dermatitis by the presence of nucleated keratinized squames (parakeratosis) and elongation of the rete pegs. The lesions are white and scaly because the transit time of cells from the basal layer to the surface is about 3 days compared with the normal 28 days. Rubbing the lesion with a spatula will cause the skin to produce scales leaving some fine bleeding points. When the ear is affected the lesion is primarily of the concha and the adjacent cartilaginous canal. The differential diagnosis is not difficult because of the almost invariable presence of other psoriatic lesions.
**Invasive (granulomatous/necrotizing/malignant) otitis externa**

Many different names have been ascribed to this condition which almost invariably presents with granulation tissue in the external auditory meatus initially at the junction of the cartilaginous and bony parts.

**Pathology**

Invasive otitis externa is considered to be due to an opportunistic infection with *Pseudomonal aeruginosa* though there are often multiple bacteria. It usually affects those over 50 years of age and most patients have evidence of microvascular disease. Most, though by no means all, have diabetes mellitus which may or may not be insulin dependent and well or poorly controlled (Editorial, 1982).

The term 'necrotizing' is used because in many there is necrosis of the adjacent cartilage or bone of the meatus. The granulomatous condition may then spread through the soft tissues to the base of the skull where it can involve the lower cranial nerves. Alternatively, *Pseudomonas aeruginosa* may spread via the mastoid bone to affect the facial nerve or go on to give rise to intracranial complications. How the pathology spreads is often confused by the fact that a high proportion of patients have had some form of earlier mastoid surgery, commonly resulting in an open cavity.

The term 'malignant' is used because there is a high mortality if the disease process spreads outside the external auditory meatus (Chandler, 1977).

The condition is assumed by many to originate in the external auditory meatus, but in some reports the condition appears to have arisen from acute otitis media (six out of 15 patients reported by Meyerhoff, Gater and Montalbo, 1977) or is associated with active chronic otitis media (four out of 11 patients where the tympanic membrane was described by Doroghazi et al, 1981).

**Keratosis obturans**

This uncommon condition is often clinically confused with a cholesteatoma of the external auditory meatus (Piepergerdes, Kramer and Behnke, 1980) and reports of the condition from the 1950s should be treated with caution because almost certainly some are a description of impacted wax in children (Black and Chaytor, 1958). In one report from an English suburban town, an association with bronchiectasis in children was noted (Morrison, 1956).

Pathologically there is retention within the deeper canal of a tight keratin plug without any obvious reason such as narrowing (Naiberg, Berger and Hawke, 1984. Associated with this is hyperplasia of the skin and chronic inflammation in the subcutaneous tissues.
Acute otitis media

Definition

The term 'acute otitis media' is usually taken to imply a bacterial infection which affects the mucosal lining of the middle ear and mastoid air cell system.

Incidence

Acute otitis media is reported to be the commonest otological condition in childhood, with an incidence of nearly 50% in the first year of life. The incidence remains high in the first 5 years of life, but thereafter tails off to become relatively infrequent in teenagers. There appears to be a marginally higher incidence in boys. Such figures are reported from the community by non-specialists and as such have to be treated with caution as they are likely to include many children who have otalgia for other reasons, less than half of those with otalgia being considered to have acute otitis media when seen by specialists (Ingvarsson, 1982).

Acute otitis media is more frequent in the colder months of the year when upper respiratory tract infections are also more frequent, in children from urban as opposed to rural homes, in those attending nursery school as opposed to those staying at home, and in non-breast-fed infants as opposed to breast-fed infants (Pukander, Sipila and Karma, 1984).

The incidence in industrial countries appears to be declining and this is almost certainly independent of the use of antibiotics as the trend started before their introduction. It is more likely to be due to improved socio-economic conditions. Complications would now also appear to be rare, the risk of clinically developing acute mastoiditis currently being about 0.04% (van Buchem, Peeters and Van't Hof, 1985).

Aetiology

Relationship with otitis media with effusion

In attempting to identify the aetiological factors that might be responsible for acute otitis media, it is becoming increasingly difficult to do so because many authors fail to distinguish between acute otitis media and otitis media with effusion. Thus, for example, in some papers on bacteriology it is difficult to determine which condition(s) is being investigated (Brook, 1979). It could well be that acute otitis media and otitis media with effusion are at the two ends of a continuous spectrum, but this has still to be proven (see Otitis media with effusion). Clinically, two distinct conditions exist and the fact that some children have had episodes of both does not mean that they are aetiologically related.

Viral and bacterial infections

Most children have a history of a preceding upper respiratory tract infection, which initially will be viral and will affect not only the mucosa of the respiratory passages but also that of the eustachian tube and middle ear. Second, bacterial infection can then occur and, if the eustachian tube is functionally blocked by oedema, a middle ear abscess will result. The
bacteria involved are almost invariably those normally resident in the upper respiratory tract and in one-third of patients more than one organism will be cultured. Table 3.2 lists the frequency of isolation of various bacteria in one series (Dadswell, 1967), others being similar. Haemophilus influenzae is seldom isolated from individuals over the age of 10 years. In those with acute otitis media under the age of 5 years, Haemophilus influenzae will be isolated from one-third, but more frequently along with other potentially pathogenic organisms rather than on its own.

Table 3.2. Frequency of isolation of various bacteria in acute otitis media

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Percentage frequency of isolation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta-haemolytic streptococcus</td>
<td>28</td>
</tr>
<tr>
<td>+ other organisms</td>
<td>13</td>
</tr>
<tr>
<td>Staphylococcus aureus</td>
<td>19</td>
</tr>
<tr>
<td>+ other organisms</td>
<td>2</td>
</tr>
<tr>
<td>Streptococcus pneumoniae</td>
<td>10</td>
</tr>
<tr>
<td>+ other organisms</td>
<td>3</td>
</tr>
<tr>
<td>Haemophilus influenzae</td>
<td>8</td>
</tr>
<tr>
<td>+ other organisms</td>
<td>13</td>
</tr>
<tr>
<td>Other organisms alone</td>
<td>3</td>
</tr>
</tbody>
</table>

From Dadswell, 1967.

Eustachian tube

The eustachian tube has two main functions: to maintain the middle ear pressure at atmospheric pressure and to allow the normal secretions of the respiratory type mucosa, with which it and part of the middle ear are lined, to pass on into the nasopharynx. It achieves this during swallowing by the muscular contraction of the levator palati dilating the pharyngeal opening and the tensor palati opening the cartilaginous tube (Honjo, Okazaki and Kumazawa, 1980). It seems reasonable to postulate that the adynamic bony part could be physically blocked by the mucosal oedema associated with an upper respiratory tract infection and be an aetiological factor in acute otitis media.

It is known that normal 3-year-old children are less able than adults to equalize an artificially induced negative middle ear pressure. This inability gradually disappears, until by about the age of 12 an adult ability has developed (Bylander, 1980). The reason for this is unknown, as it is difficult to conjecture why the relative shortness and horizontal position of the eustachian tube in childhood should affect its function. However, the more horizontal position of the tube might allow easier access of bacteria from the nasopharynx to the middle ear. This could be combined with poor tubal function which allows children to create a high negative middle ear pressure by sniffing (Magnuson, 1981a) so sucking a bolus of infected mucus into the middle ear. The fact that acute otitis media is more frequent in children with Down's syndrome and those with cleft palates would support some role for eustachian tube dysfunction.
**Allergy**

Though it might be expected that allergic oedema of the eustachian tube would make acute otitis media more likely, conflicting scientific evidence has been presented as to whether atopic children are more likely than normal children to have acute otitis media.

**Pathology**

The earliest stage is hyperaemia of the middle ear and eustachian tube mucosa which is followed by a serous exudate with polymorphonuclear leucocytes (neutrophils). The lining mucosa of the middle ear hypertrophies and there is metaplasia with conversion from simple cuboidal epithelium to one with mucus-producing cells. The metaplastic process can extend to the mastoid air cells. The air in the middle ear and mastoid spaces is absorbed and replaced by an inflammatory exudate, under increasing tension, of mucus, serum, leucocytes and bacteria. The tympanic membrane bulges and, in about 30% of untreated cases, will rupture spontaneously through a small hole in the pars tensa (Ingvarsson, 1982). This perforation may be difficult to see because of the associated oedema.

In the majority of children, acute otitis media resolves spontaneously and this is independent of whether the tympanic membrane ruptures or antibiotic therapy is given (van Buchem, Dunk and Van't Hof, 1981). In up to one-third of ears there will still be sufficient middle ear fluid 4 weeks later to give a 20 dB conductive hearing impairment but this again would appear to be independent of whether a myringotomy has been performed or antibiotics have been given. It is often said that the incidence of residual fluid is higher if courses of antibiotics have not been completed but this remains to be proven and indeed the evidence is against it, the incidence being no different whether 3 or 10 days of antibiotics are prescribed (Chaput de Saintonge et al, 1982; Bain, Murphy and Ross, 1985). The incidence of long-term middle ear fluid is very low, 95% of children having no otoscopic evidence of fluid and a normal tympanogram 11 weeks later (Wheeler, 1986). In the majority, the tympanic membrane will heal without any sequelae but, in some, tympanosclerosis will develop (see below). The middle ear and mastoid spaces will return to normal but, in some, cholesterol granulomata will form and fibrous sclerosis of the air cells occurs (see below).

In a few children, for some as yet unknown reason, the process can take a more destructive course with the development of acute mastoiditis. Though the mastoid mucosa will almost invariably be affected in acute otitis media, it is only when the infected material is prevented from draining from the mastoid air cells, most probably because of oedema around the ossicular chain, that clinical symptoms related to the mastoid develop. In some, this will progress to what, in effect, is osteomyelitis with bone resorption and remodelling by osteoclasts. The mastoid abscess will probably either rupture externally through the cortex or intracranially if it is not drained surgically. The infection can spread to the venous sinuses (thrombophlebitis) or to the inner ear (labyrinthitis). A facial nerve palsy may develop because of pressure.
**Bullous myringitis**

*Definition*

Bullous myringitis (myringitis bullosa haemorrhagica is a clinical diagnosis based on finding serous fluid containing vesicles (blebs in the superficial layer of the tympanic membrane.

*Incidence*

Vesicles on the tympanic membrane are not uncommon in children and young adults presenting with symptoms suggestive of acute otitis media.

*Aetiology*

It has long been assumed that the blebs on the tympanic membrane are due to a viral infection, but in the majority a virus cannot be isolated (Roberts, 1980). The sole evidence then for a viral aetiology rests upon the commonly reported association with an upper respiratory tract infection and the occasional association with a cranial nerve palsy. The alternative is that the blebs are a manifestation of acute otitis media since bacteria can be isolated from middle ear aspirates as frequently and is of a similar type to those isolated in acute otitis media (Coffey, 1966). Contrary to some suggestions the mycoplasmas do not appear to be isolated more frequently.

*Pathology*

The histological appearances do not appear to have been described.

**Granular myringitis**

*Definition*

In granular myringitis, there are areas of granulation tissue on the tympanic membrane sometimes, but not invariably, in association with middle ear pathology.

*Pathology*

The pathological findings are of non-specific granulation tissue affecting the superficial epithelial layers of the tympanic membrane to a variable extent (Khalifa et al, 1982). In some, the process gradually extends to the skin of the meatus and a fibrotic stenosis results. In some, the granulation tissue is a manifestation of acute or chronic otitis media with a small tympanic membrane defect which cannot be seen because of the granulations (Hoshino et al, 1982).
Otitis media with effusion

Definition

Many different terms have been used for the chronic condition where there is an accumulation of non-purulent fluid in the middle ear. None of them has achieved universal recognition mainly because each can be criticized etymologically. Chronic otitis media with effusion is a clumsy term and can be confused with the standard usage of chronic otitis media. The term 'effusion' does not differentiate between purulent and non-purulent effusions. Otitis media with effusion is slightly better but still clumsy. Secretory otitis media assumes that the middle ear fluid is a secretin which it may not be. Serous otitis media is incorrect because the fluid is not serum. Glue ear is a good lay description but the fluid is not an adhesive. Non-purulent otitis media is considered incorrect by some because bacteria can sometimes be isolated. Of them all, otitis media with effusion is perhaps the best and for consistency this term will be used.

The time that the fluid has to be present in the middle ear for the condition to be considered chronic is usually taken as 12 weeks (Bluestone, 1984).

Incidence

Many sequential studies have reported that between 2% and 50% of children will have an episode of otitis media with effusion at some time between the ages of 3 and 10 years. For example, of 404, 3-year-old children followed up over a winter 6-month period and using strict tympanometric and acoustic reflex criteria for diagnosis, 42% had the problem (Fiellau-Nikolajsen, 1983). In 94% of these children, the condition had resolved within 3 months, but in the 6% in whom it persisted, spontaneous resolution over the following 3 months was unlikely.

Aetiology in children

Genetic/environmental

As with acute otitis media, children from the lower socio-economic groups have the highest incidence of otitis media with effusion though surgery is more frequently performed in those in the higher groups. The specific reasons why the lower socio-economic groups are more frequently affected are unknown, but poor general health, overcrowded housing and tobacco smoking parents have been implicated.

An age-old question is whether a sclerotic mastoid predisposes a child to having recurrent episodes because the lesser air reservoir is unable to compensate for changes in middle ear pressure. Children who have had otitis media with effusion have smaller mastoids than children that have not, but there is a considerable overlap in size (Tos and Stangerup, 1984. Over a 5-year period, the mastoid air cell system will increase in size in only 40% of ears that have been affected by the condition (Hussl and Welzl-Mueller, 1980). What is required is a longitudinal study in children from birth correlating episodes of otitis media with effusion with the radiological size of the mastoid.
**Eustachian tube malfunction**

As was discussed under Acute otitis media, children have poorer eustachian tube function than adults but there is some evidence that it is even poorer in those with otitis media with effusion. However, it could just be that the eustachian tube malfunction is a result of the frequently associated mucosal oedema rather than because of poor muscle function (see below). There is a considerable evidence that once the otitis media settles the eustachian tube function improves markedly (Poulsen and Tos, 1977; Virtanen, 1983) which would argue for its being a secondary phenomenon.

It is known that children with a cleft palate have a higher incidence than normal of otitis media with effusion but this does not mean that their poor eustachian tube function need be the reason. Not all children with a cleft palate have the problem (Bess, Schwartz and Redfield, 1976), so even in those who do there must be a combination of factors which makes them more susceptible to otitis media with effusion.

It has been argued that the problem with the eustachian tube is not that it does not open, but that it opens too easily. If air does not get up the tube, the air within the middle ear will be absorbed but this alone does not create a negative middle ear pressure of the magnitude seen in established cases. Many children are habitual sniffers and this itself will cause negative middle ear pressure (Magnuson, 1981a). The ability to create a negative middle ear pressure is partly related to good eustachian tube function (Bylander, 1980) and unfortunately in children with unilateral otitis media with effusion, sniff-positive ears (that is those in whom the pressure could be changed by sniffing) were as common in the normal as in the pathological ears (Magnuson, 1981b).

Perhaps the main reason why it has not been possible to prove that eustachian tube function has a role is that the tests are often unrepeatable; they assess the ear in artificial situation and only when the child has the condition.

The consensus, but by no means all the evidence, is that children with otitis media with effusion have poorer muscular function than normal but they can still maintain an adequate middle ear pressure under normal conditions (Bylander et al, 1983. It just makes them a population at risk for some additional aetiological factor(s).

**Adenoid hypertrophy**

The role of adenoid hypertrophy has been much debated, the most commonly suggested mechanism being displacement of the eustachian tube orifice rather than its obstruction. In addition, some consider that, together with the tonsils, the adenoids constitute a reservoir of infection. In children, the adenoids are almost invariably enlarged and there is little evidence to suggest that large adenoids are more frequently associated with otitis media with effusion than with normal ears (Hibbert, 1982; Maw, Jeans and Cable, 1983). If there were unequivocal evidence that surgical removal of the adenoids had an effect then their role would have been proven. Unfortunately, there is a disagreement about adenoidectomy in otitis media with effusion though recent evidence from controlled studies appears to suggest that it is beneficial (Maw, 1983).
Unresolved acute otitis media

It has been suggested that in many instances the condition is the result of acute otitis media having failed to resolve. In support of this, it is stated that the incidence of both acute otitis media and otitis media with effusion is high in the first few years of life and that they both have a similar seasonal incidence. Though this is suggestive, it could just as easily be that they have aetiological factors in common such as poor general health.

There is no doubt that fluid can remain in the middle ear following an episode of acute otitis media, but prospective studies would suggest that only about 5% will have middle ear fluid after 12 weeks and none will have any 8 months later (Wheeler, 1986). It is suggested that the incidence of non-resolution is not helped by non-compliance in taking antibiotics, but there is no evidence to support this and indeed it is to the contrary. It appears to make little difference to the incidence of retained fluid 4 weeks later whether antibiotics were prescribed or not (van Buchem, Dunk and Van't Hof, 1981) and, when they were, whether it is for short (3 day) or long (10 day) periods ( Chaput de Saintonge et al, 1982; Bain, Murphy and Ross, 1985).

Not all children with otitis media with effusion have a past history of acute otitis media but it is suggested that in those that have not, there may have been a subclinical infection. If bacteria that are likely to be contaminants from the external auditory canal are excluded, culture of middle ear fluid will isolate an upper respiratory tract flora in 10-20% of ears (for example Pelton et al, 1980). The types of flora are similar to those isolated in young children with acute otitis media, predominantly beta-haemolytic streptococcus and Haemophilus influenzae, but their isolation does not mean that there is a cause-effect relationship. Similar bacteria have been isolated from ears with otosclerosis (Sipila et al, 1981). Antibodies to bacteria within the middle ear fluid have been looked for and do not always correspond to the bacteria which are isolated at the same time (Bernstein et al, 1980). Even if antibodies are isolated, this does not mean that bacterial infection is the cause as they will also be produced when the bacteria are saprophytes.

Allergy

The question as to whether allergy is an important factor is controversial, but the balance of scientific evidence is that it is not.

Atopic allergy in the form of asthma, rhinitis and dermatitis has been calculated to affect about one-third of children at some time in the first 10 years of life when otitis media with effusion is also common. It is vital then that, when the incidence of allergy is being investigated in children with this condition, a comparison be made with a well-matched control group. There is some evidence which suggests that the incidence of otitis media with effusion is marginally higher in children with an allergic diathesis, but even this does not mean that in these children, the problem is an allergic one. It could just be that they are more prone to develop otitis media with effusion, for example because of the eustachian tube oedema associated with their rhinitis.

If otitis media with effusion were to have an allergic basis it would be expected that the level of IgE in the middle ear fluid would be higher than in the serum. This does not
appear to be the case in children with no allergic diathesis (Lim, 1979) and raised levels are found in only approximately 15% of children with allergic rhinitis (Bernstein et al, 1983).

**Aetiology in adults**

**Idiopathic**

In adults it is important to consider a postnasal space tumour but fortunately this is not a common cause of otitis media with effusion except in the Chinese when resident in certain parts of the world. The problem has been studied considerably less in adults than in children and, in most, no cause can be found. Even a history of an upper respiratory tract infection may be irrelevant because of its prevalence in the community.

**Barotrauma**

On descent in an aeroplane, it can sometimes be difficult to equalize the negative middle ear pressure by autoinflation and, if the negative pressure is prolonged, a mild serous transudate may result.

**Nasopharyngeal carcinoma**

Two-thirds of patients with a nasopharyngeal tumour will have otitis media with effusion but it is incorrect to think that this is the sole presenting symptom. Symptoms and signs are most frequently multiple (Table 3.3).

**Table 3.3. The most frequent clinical signs of nasopharyngeal tumours**

<table>
<thead>
<tr>
<th>Sign(s)</th>
<th>Percentage incidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical adenopathy</td>
<td>86</td>
</tr>
<tr>
<td>Auditory</td>
<td>67</td>
</tr>
<tr>
<td>Nasal obstruction</td>
<td>67</td>
</tr>
<tr>
<td>Epistaxis</td>
<td>64</td>
</tr>
<tr>
<td>Neurological</td>
<td>28</td>
</tr>
</tbody>
</table>

From Cammoun, Vogt Hoerner and Mourali, 1974.

**Radiotherapy**

Radiotherapy can cause fibrosis around the eustachian tube resulting in its malfunction. As the most frequent reason to give radiotherapy in this area is for a nasopharyngeal tumour, separating the two aetiologies can be difficult.

**Pathology**

The changes that occur in the middle ear, mastoid and eustachian tube mucosa in otitis media with effusion have been well described in biopsy specimens from the middle ear (Lim and Birck, 1971; Bremond and Coquin, 1972; Gunderson and Gluck, 1972; Tos, 1980; Palva,
Makinen and Rinne, 1981 and temporal bone sections (Ishii, Toriyama and Suzuki, 1980; Tos, 1980). Once otitis media with effusion has become established the normal flat cuboidal middle ear and mastoid mucosa is patchily replaced by thickened pseudostratified mucus-secreting epithelium with varying degrees of specialization, such as the development cilia. Goblet cells are frequently present and sometimes mucus-secreting glands are formed. The ciliary lining would appear to be less efficient at moving the secretions into the nasopharynx than normal, but whether this is a primary or secondary phenomenon is unknown (Karja, Nuutinen and Karjalainen, 1983. Certainly, children with a primary abnormality of the cilia, such as that in Kartagener's syndrome, frequently develop otitis media with effusion (Editorial, 1980), but in general, ciliary dysfunction is more likely to be secondary. The submucosa is oedematous and inflamed with dilated blood vessels and an increased number of macrophages, plasma cells and lymphocytes. The same histological findings pertain to otitis media with effusion in cleft palate children, in animals when it is produced experimentally and in adults with nasopharyngeal tumours.

What is frequently debated is the origin of the fluid within the middle ear and mastoid air cell system. In surgical practice, this is usually categorized by its consistency as being either serous or mucoid. This is obviously a gross simplification of the situation as there will be a full spectrum of fluid types made up of a mixture of the secretions of the epithelial cells, the goblet cells and the mucous glands along with the inflammatory exudate/transudate which comes through the intercellular spaces from the inflamed submucosa.

The cells which are often present in the middle ear fluid have been analysed in the hope that this may give some indication of the aetiology. Bacteria are sometimes isolated (see above), as are all types of inflammatory cells (neutrophils, lymphocytes and monocytes. The types of cells isolated vary considerably between patients and there would appear to be no correlation with the aetiology. For example, atopic individuals and those with cleft palate have similar proportions of cells (Sipala and Karma, 1982).

The biochemical constituents of the middle ear fluid have also been analysed in an attempt to determine whether it is a transudate or a secretion and if it is part of an immunological reaction. In general, the total protein concentration is higher than in serum in both serous and mucoid effusions (Juhn, 1984). This is primarily because of the local production of enzymes and antibodies, but there is nothing unexpected in this because this will occur in an inflammatory reaction irrespective of the aetiology. The only aspect that biochemical studies appear to have answered is that an IgE (allergic) response is not a major cause of the fluid (Lim, 1979).

In the majority of children, the condition resolves and the middle ear mucosa returns to normal. In some, the sequelae of any type of inflammation in the middle ear cleft, such as chalk patches, tympanosclerosis, and cholesterol granuloma can occur. What perhaps is more relevant is the formation of permanent retraction (atelectatic) pockets which may or may not be adherent to the middle ear structures. However, it is doubted whether these can occur in the absence of associated episodes of acute otitis media (Sade and Berco, 1976).
Congenital cholesteatoma

Definition

Congenital (primary) cholesteatomata are squamous epithelial cysts that can arise anywhere within the temporal bone. Aetio logically they have no relationship to acquired cholesteatoma.

Incidence

The incidence of congenital cholesteatoma is unrecorded but in clinical practice they are rare. It might be expected that because they are congenital in origin, they would present in the neonatal period. This is not the case as it takes time for them to grow to a sufficient size to cause symptoms. There are two common ages and modes of presentation. If they arise within the middle ear cleft, they present with a hearing loss in childhood when it affects the ossicular chain. Alternatively, if their origin is within the petrous apex of the temporal bone, they present in adulthood when they press on the facial nerve or brainstem.

Aetiology

Fairly convincing histological evidence has now been presented from serially sectioned temporal bones that squamous epithelial cell rests are a frequent finding in the antral mucosa in 12-week-old embryos (Michaels, 1986). It is assumed that, in the majority, these rests disappear but occasionally they may persist to form a congenital cholesteatoma.

Pathology

Histologically, a congenital cholesteatoma is identical to an epithelial retention cyst and is not usually associated with active mucosal disease.

Chronic suppurative otitis media

Definitions

Over the years many different terms have been used for the different clinical types of chronic suppurative otitis media. Inevitably this has led to confusion and has made it difficult for the trainee to understand. In the early days of otology, when the tympanic membrane could only be seen by using reflected sunlight, the main distinction that could be made was whether the disease affected the pars tensa or the pars flaccida. This anatomical distinction led to the use of the terms 'tubotympanic' and 'atticoantral', respectively. Another anatomical distinction that was relatively easy to make was whether the tympanic membrane defect was central or extended to the margin of the meatus, especially in the posterior superior quadrant. Today, these anatomical terms are less frequently used for diagnostic purposes mainly because of increased ability to assess the ear, especially with an operating microscope, and to determine not only where the pathology is, but what type of disease is present. Thus, when the disease affects the attic, it is usually possible to decide whether or not a cholesteatoma is present. Therefore, pathological definitions are increasingly being used in preference to anatomical ones and are those which are used in this chapter.
**Inactive chronic otitis media**

Here there is otoscopic evidence of previous active disease but at the time of examination there is no evidence of acute inflammation. The tympanic membrane may be in its normal position but abnormal because of the presence of tympanosclerotic plaques or a replacement membrane. Alternatively, there may be a permanent defect or a retraction (atelectatic) pocket in the tympanic membrane or the pars flaccida. The ossicular chain may be eroded or fixed.

**Active mucosal chronic otitis media**

In addition to there being a permanent defect in the pars tensa or flaccida in this condition, the middle ear and/or mastoid air cell mucosa is inflamed and this can hypertrophy to form granulation tissue or a polyp.

**Active chronic otitis media with cholesteatoma**

Here, in addition to the active mucosal disease defined above, there is an acquired cholesteatoma (keratoma, cholesteoid, epidermoid cholesteatoma, epidermoidosis). The reason that the term 'acquired' is used is to emphasize the fact that the cholesteatoma is a 'secondary' pathologically process as distinct from the congenital variety. When the term 'cholesteatoma' is used without qualification it is an acquired cholesteatoma which is being discussed. It is unusual to have a cholesteatoma in the absence of active mucosal disease.

**Prevalence**

The majority of reports of the incidence of chronic otitis media are from clinic data. This tends to reflect the referral pattern to that clinic rather than the prevalence in the general population. The British Medical Research Council National Study of Hearing appears to be the only one to date that has looked at adults randomly selected from the general population and the preliminary report suggests that 5% have chronic otitis media and, in these, 1.8% will be active at any one time (Browning and Davis, 1983). In clinical practice, up to 50% of ears with chronic otitis media will be associated with a cholesteatoma (Smyth, 1976).

**Aetiology: general**

**Environmental**

As with many medical conditions, there is a close correlation between patients with chronic otitis media and socio-economic group, the lower groups having a higher incidence. It is not known why this is the case, but almost certainly it relates to general health, diet, and overcrowding in the home. When investigating such factors it is difficult to allow for others such as genetics, climate, method of screening and previous management of the condition (Hinchcliffe, 1977). Perhaps the most persuasive evidence that the environment is important is that in Eskimos the incidence of all forms of chronic otitis media has increased since they became 'civilized' (Baxter and Ling, 1974). However, there is some evidence to the contrary, such as the finding that the incidence of chronic otitis media is the same in reservation-raised, as opposed to adopted, Apache children (Spivey and Hirschorn, 1977).
Genetic

The question as to whether one race is more predisposed to chronic otitis media remains unanswered, mainly because of the inability to control for many of the factors mentioned above. It is, for example, suggested that American Negroes are less likely to have the condition than White Americans (Harell, Pennington and Morrison, 1982) but this could simply be due to different patterns of attendance for medical treatment.

The importance of genetic factors was much debated earlier this century, in particular whether the incidence was related to the size of the mastoid air cell system which was considered to be genetically determined (Diamant, 1982). The mastoid air cell system is smaller in individuals with otitis media, but it is not known whether this is a primary or secondary event. Histologically, there is no doubt that with repeated inflammation, the mastoid air cell system becomes progressively more sclerotic (see above). The degree of initial mastoid aeration may be a predisposing factor, but once the condition has developed the cell system will decrease in size.

Previous otitis media

It appears to be generally held that chronic otitis media is a sequel of acute otitis media and/or otitis media with effusion, but it is not known what factors make one ear, and not another, progress to the chronic condition. It has been suggested that with the chronic retraction of the tympanic membrane which is associated with otitis media with effusion, there is a loss of the fibrous layer (Smith, 1980) which will not heal if there is a subsequent acute perforation. Though this theory might initially appear attractive, there is little evidence to support it and destruction of fibrous tissue by unspecified enzymes in the middle ear fluid is pathologically unlikely.

Unfortunately, there is little evidence that surgical or medical management of these childhood conditions makes any difference to the incidence of chronic otitis media. It could even be that surgery makes the matter worse, particularly by the creation of tympanosclerotic patches in the tympanic membrane (Ambegoakar, Brown and Richards, 1978).

Infective

Bacteria can almost invariably be isolated from the mucopus or from the mucosa of the middle ear in active chronic otitis media provided that the correct culture methods are used. The proportion of the different organisms varies between series but they are mainly Gram-negative, bowel-type flora and often several different organisms will be cultured from the one ear. Contrary to an opinion that is often expressed, the types of flora are no different if a cholesteatoma is present (Sweeney, Picozzi and Browning, 1982). The fact that organisms can be isolated so frequently is usually taken to imply that bacterial infection of the mucosa is the main reason for the continued activity. However, the role of bacteria can be questioned for several reasons. When the tympanic membrane is intact, bacteriological cultures taken from the middle ear can, on occasion, isolate organisms which are unlikely to be contaminants from the external auditory canal (Sipila et al, 1981). In addition, in nearly 50% of ears with inactive chronic otitis media, an identical flora to that isolated from active ears can be cultured (Picozzi et al, 1982). Another finding is that although anaerobic organisms can be
isolated from at least 40% of ears, their elimination by metronidazole therapy does not cause the ear to become inactive (Browning et al, 1983). Thus, it could be argued that the bacteria in ears with chronic otitis media are secondary invaders of a mucosa which is inflamed because of other factors, rather than that they are the primary cause of the disease.

Tuberculosis is much less common than formerly but should be considered when active disease does not respond to medical or surgical management. The route of infection can be haematogenous from another focus such as the lungs or via the eustachian tube, for example from the ingestion of infected milk.

**Upper respiratory tract infections**

Though it has not been studied scientifically, many patients will state that their ear starts to discharge after an upper respiratory tract infection. The postulate, here, would be that the viral infection would also affect the mucosa of the middle ear making it less resistant to the organisms that are normally in the middle ear, allowing bacterial overgrowth.

Tradition would also suggest that patients with chronic otitis media frequently have chronic disease of the respiratory tract, such as sinusitis. The frequency with which this occurs has not been reported, but clinical experience in the 1980s would suggest that it is uncommon. It remains a reasonable postulate that, if one area of the respiratory tract mucosa is affected, there is an increased likelihood that another part will also be affected, but it does not mean that management of one condition is necessary before the other can be successful.

**Allergic**

Though postulated by some as an important factor, it remains to be proven that allergic individuals have a higher incidence of chronic otitis media than non-allergic subjects. In some, allergy to the antibiotics in ear drops or to the bacteria or their toxins is an interesting but as yet unproven possibility.

**Eustachian tube malfunction**

In active chronic otitis media, the eustachian tube is frequently blocked by oedema but whether this is a primary or secondary phenomenon is unknown. Certainly reconstructive surgery is frequently successful in such ears which would suggest that, in these ears at least, it was a secondary event. In inactive ears, various methods have been used to evaluate eustachian tube function and most would suggest that the tube is unable to return a negative pressure to normal.

**Aetiology: acquired cholesteatoma**

There has been considerable debate about the aetiology of cholesteatoma and the question still remains unanswered as it was 80 years ago. The protagonists of each of the three main theories are vociferous in support of their own cause, but the answer is almost certainly that they are all relevant, some applying more to a specific patient than others. The way to answer the debate is to follow-up several thousand children over many years and, if this were to be combined with an assessment of the effect of surgery, many important
questions could be answered. Until then, opinions as to the aetiology are based on clinical impressions as animal models and studies in vitro, though innovative and interesting, are of questionable relevance to the human situation.

**Negative middle ear pressure**

It is suggested that continued negative middle ear pressure, which is often associated with childhood otitis media with effusion, will cause the pars flaccida to retract resulting in a squamous epithelial-lined pocket; this, due to its position in the attic and the presence there of mucosal folds, will have a narrow isthmus, which it is suggested will cause retention of epithelial debris, and will subsequently become infected and expand under tension. The retraction pocket will eventually block off the antrum and produce an inflammatory reaction with osseous sclerosis of the mastoid akin to that seen in chickens when the ostium of their pneumatized humerus is occluded (Beaumont, 1966).

Evidence to support this concept comes from the high rate of recurrent retraction pockets in individuals who have been operated upon for cholesteatoma and in whom the defect has been grafted. This would suggest that these patients do indeed have poorly functioning eustachian tubes but the majority of these retractions do not progress to a cholesteatoma. When a cholesteatoma occurs after surgery, it is most likely to be due to squamous epithelium being left behind the graft. Several other arguments would suggest that negative pressure is unlikely to be the sole aetiology. One is that the pressure is unlikely ever to be great enough to cause indrawing of the normal pars flaccida and the otoscopic progression of an attic retraction to a cholesteatoma does not appear to have been documented. In addition, the surgical management of retraction pockets with ventilation tubes does not appear to influence their long-term position. Some will return to a normal position without and others will remain retracted with management (Sade, Avraham and Brown, 1982). However, part of the reason for this could be adhesions rather than eustachian tube function being irrelevant.

**Invasion**

Two main ways have been postulated as to how an abnormal growth of the squamous epithelium of the skin of the external auditory meatus or tympanic membrane may cause a cholesteatoma. The more widely held concept is that the epithelium takes advantage of a temporary defect in the pars flaccida, caused by an episode of acute otitis media, to grow into the attic. For some as yet undiscovered reason, the epithelium is thought not to obey the normal reparative laws of contact inhibition so that when it meets the middle ear mucosa it continues to invade.

The evidence to support this concept is tenuous. It is easy to see how a temporary defect in the pars flaccida could allow a retraction pocket to occur but the evidence is lacking for an invasive quality for the epithelium in a retracted area. The histology of the epithelium within a cholesteatoma is identical to that of the meatus and shows no evidence of increased mitoses or early neoplasia. Some histological material has been presented which shows squamous epithelium below middle ear mucosa, but this could easily be an artefact of the angle of section of the material. This material is also not in keeping with the clinical appearances of a cholesteatoma, which is that of a retraction pocket rather than a neoplastic
process. Tissue culture techniques may show slightly different patterns of epithelial growth (Proops, Hawke and Parkinson, 1984) but the method is such an artificial one that its relevance has been doubted (Editorial, 1986). Some will attempt to draw a parallel with inclusion dermoids which can occur when squamous epithelium is left behind a tympanomeatal skin flap or a tympanic membrane graft. These, like residual parts of a cholesteatoma which may form a 'pearl', are histologically distinct from cholesteatoma and are more akin to inclusion epithelial dermoids which can occur anywhere in the body subsequent to implantation.

The alternative concept of invasion is that the epithelium itself is normal but its direction of migration, instead of being out, is inwards which causes a retraction pocket to continue to expand. The normal pattern of migration of the epithelium from the centre of the tympanic membrane towards the external auditory meatus has been well documented (Litton, 1963; Alberti, 1964) and is most likely to be due to the radial pattern of the fibrous layer as this is what generally directs the pattern of growth of squamous epithelium. What could be postulated is that once a retraction pocket forms, the normal direction of outward growth is lost due to an absence of direction of any remaining fibres and is replaced by an inward growth pattern which would cause the retraction pocket to expand. If this were to be the case, it is not necessary to invoke a pathological nature for the epithelium.

Metaplasia

It is postulated that secondary to episodes of inflammation, areas of metaplasia to squamous epithelium occur in the middle ear mucosa and these expand to create cysts, as is known to occur with surgically implanted squamous epithelium. These cysts, it is postulated, enlarge and then burst through the pars flaccida, or less frequently the pars tensa, to create a cholesteatoma. Metaplasia of mucosa into a squamous epithelium, which is sometimes keratinized, is not uncommon in the lower respiratory tract secondary to irritation and the fact that this also occurs in the ear is shown by the frequent finding of squamous epithelium in granulation tissue and aural polyps, even when there is no evidence of a cholesteatoma (Palva and Makinen, 1983).

Though metaplasia may be the mechanism in congenital cholesteatoma, the evidence to support it as a cause in acquired cholesteatoma is less persuasive. Animal experiments have shown that artificially induced inflammation in the middle ear will be associated with metaplasia into a squamous epithelium, but the finding of epithelial cysts in chronic mucosal otitis media has not been recorded, unless there has been previous surgery when implantation may have occurred. It is also difficult to conjecture why these metaplastic area, if they were to create cysts, should preferentially affect the attic.

Non-specific pathology: potentially present in all types of chronic otitis media

Typanosclerosis

Typanosclerosis is a long-term irreversible result of continued inflammation in the middle ear cleft which is present histologically in one-quarter of ears with chronic otitis media, irrespective of type (Meyerhoff, Kim and Paparella, 19770. Pathologically,
tympanosclerosis is the end result of a healing process in which the collagen in fibrous tissue hyalinizes, loses its structure and becomes fused into a homogeneous mass (Schuknecht, 1974). Thereafter calcification and perhaps ossification may occur to a variable extent. Tympanosclerosis most frequently affects the tympanic membrane, but the ossicular ligaments, interosseous joints, muscle tendons and submucosal space can also be affected causing varying degrees of immobility of the ossicular chain (Igarashi et al, 1970). Clinical reports of surgical findings suggest that tympanosclerosis is rare in active ears (Gristwood and Venables, 1982) and particularly in ears with a cholesteatoma (Plester, 1971), but pathological studies of temporal bones would not support this distinction (Meyerhoff, Kim and Paparella, 1977).

Ossicular erosion

There is now general agreement that erosion of the ossicular chain is a non-specific result of the hyperaemia associated with mucosal inflammation, rather than due to ischaemia. In any condition where there is an area of inflammation in contact with bone, resorption and remodelling will occur. Granulation tissue is found more frequently around the ossicular chain than anywhere else in the middle ear cleft, and this could be a result of the mucosal folds directing the spread of inflammation (Proctor, 1964) as well as their position in the antrum, where even a mild degree of oedema will block secretions within the mastoid air cells. The reason that the long process of the incus and the stapes superstructure are the parts of the chain which are most frequently affected is likely to be due to their delicate structure, rather than their tenuous blood supply (Thomsen et al, 1974).

It is no longer generally considered that it is the squamous epithelium in a cholesteatoma which erodes bone, but rather the underlying hyperaemic inflamed tissue that is invariably associated with it, which is responsible (Thomsen et al, 1974; Tos, 1979; Sade et al, 1981). Although the ossicular chain is perhaps more frequently eroded when there is cholesteatoma in association with active mucosal chronic otitis media, it is probably a function of where it is located rather than the pathology itself. It is unlikely that the squamous epithelial lining of a cholesteatoma secretes any noxious substance or enzyme which destroys bone, though this is contested (Abramson, Moriyama and Huang, 1984).

Fibrous sclerosis

During the reparative phase of any inflammation, fibrous tissue is laid down by fibroblasts and, in the middle ear and mastoid air cells, this can result in adhesions between the tympanic membrane, ossicles and the middle ear mucosa.

Mastoid sclerosis

In the mastoid, a secondary effect of fibrous sclerosis is the creation of mucosa-lined retention cysts - fibrocystic sclerosis. Subsequent to this, there is remodelling and deposition of new bone mainly by the action of osteoblasts which results in a sclerotic mastoid. Interestingly, if the external opening of the pneumatized humerus in a chicken is blocked off, fibrocystic sclerosis and new bone formation, which is histologically similar to mastoid sclerosis, will result (Ojala, 1957; Beaumont, 1966).
Cholesterol granuloma

This is primarily a histological rather than a clinical term for a pathological process which can occur anywhere in the middle ear cleft and is independent of whether the ear is active or inactive and whether or not a cholesteatoma is present. Histologically, there is a giant cell reaction around cholesterol crystals indicating an inflammatory reaction of the middle ear mucosa to them. The origin of the cholesterol crystals is debated, but it has been suggested that they are due to the breakdown of extravasated blood cells as iron deposits are often found in association (Friedmann, 1959). On the other hand, it is argued that middle ear secretions, in particular those associated with otitis media with effusion, contain cholesterol and gross haemorrhage is not a common feature of otitis media (Sade and Teitz, 1982).

Otologists often use the term 'cholesterol granuloma' when they find a thick yellow fluid in the mastoid or middle ear space at surgery. The latter can often be suspected otoscopically by the presence of a blue drum (Ranger, 1949). This yellow fluid will indeed contain cholesterol, but it is wrong to call it a cholesterol granuloma because this is a mucosal pathology. In such ears, there will be cholesterol granulomata in the mucosa, but they will also be found in inactive ears where the otologist would never thing of applying the term. The better clinical term to use would be 'cholesteatosis'.

Specific pathology

Inactive chronic otitis media

By definition, the tympanic membrane is abnormal in inactive chronic otitis media and the clinical appearance depends on the method of healing, but in all instances there is a loss of the fibrous tissue layer of the tympanic membrane. Thus, in the replacement, there is a membrane bridging the defect composed only of an outer layer of squamous epithelium and an inner mucosal one. When a perforation is present, the squamous epithelium of the outer tympanic membrane meets the middle ear mucosa at a variable position, frequently within the middle ear. This has practical implications for myringoplasty. If there is any residual drum, there may be a tympanosclerotic plaque in the fibrous layer.

Clinically what constitutes a marginal as opposed to a central perforation is confusing, some equating a marginal perforation with one that extends to the bony meatus. Others would equate it with disease which is primarily located in the posterosuperior quadrant and therefore more likely to be associated with a cholesteatoma. Pathologically, the difference has not been clearly defined but some would suggest that it depends on whether or not the annulus is destroyed.

Active mucosal disease (including polyps)

The extent to which the mucosa of the middle ear and mastoid is affected varies. Areas that usually have a non-secreting lining are replaced by a respiratory type, mucus-secreting mucosa with goblet cells. The mucosa is generally hyperaemic with an underlying inflammatory response. Areas of granulation tissue may form especially in non-draining areas, such as around the ossicles. Depending on its severity, there can be active resorption and
remodelling of bone, irrespective of whether a cholesteatoma is present, which can lead to a
fistula of the semicircular canal(s) and dehiscence of the fallopian canal.

For some as yet unknown reason polyps can sometimes arise from this hyperaemic inflamed mucosa and progressively enlarge so that they block off drainage via the external auditory meatus. Their surface can be ulcerated, covered in a hyperaemic respiratory type mucosa or have areas of squamous metaplasia.

**Active chronic otitis media with cholesteatoma**

A cholesteatoma has nothing whatsoever to do with cholesterol. It is a keratinized, squamous epithelial-lined pocket containing keratinous debris which it would be histologically more correct to call a keratoma (Schuknecht, 1974. A cholesteatoma is distinguished from a retraction pocket or areas of squamous metaplasia (*see below*) by its retention of keratinous debris.

Histologically, there would appear to be little difference between the squamous epithelium of a cholesteatoma and that of skin, all the recognized layers being present. The number of Langerhans' cells may be increased but this is taken to be a result of the underlying inflammation rather than a finding which is specific to a cholesteatoma (Lim and Saunders, 1972). Almost invariably when keratinous debris is retained, there will be an associated inflammatory response in the subepithelial connective tissue, but whether the two are connected is uncertain. Granulation tissue will often develop in association with a cholesteatoma and this may present at its margins and even develop into an aural polyp.

**Pathology following surgery**

**Homo/autograft ossicles: prostheses**

The method whereby repositioned ossicles become integrated into the ear appears to be independent of how they have been preserved, if at all, or whether they are homografts or autografts. They become covered by a layer of mucosa and most commonly the general structure of the ossicle remains, but as dead bone with few, if any, osteocytes. Usually there is a slight degree of inflammation and vascularization of the haversian canals along with some erosion or new bone growth on the surface. Ceramics are incorporated in the same manner.

Implants that have a lattice structure, such as porous polyethylene (Plastipore), allow the ingrowth of fibrous tissue but often this is associated with a chronic giant cell inflammatory reaction which encourages their extrusion.

**Mastoid cavity**

An open mastoid cavity that has healed and is inactive is usually lined by keratinized squamous epithelium on a layer of fibrous sclerosis that extends into any residual mastoid air cells. If an area remains active, it is because of superficial granulation tissue which may take on a polypoidal character rather than because of continued activity in the air cells or osteitis in the underlying bone (Pettigrew, 1980).
If part of a cholesteatoma is left within a closed middle ear cleft, one of two things may happen. The first, and perhaps the more likely, is that the squamous epithelium undergoes metaplasia to middle ear-type mucosa. The evidence for this comes from surgical operations where part of the cholesteatoma matrix has been left over a semicircular canal fistula and, when the ears have been re-explored many months later, there has been no evidence of squamous epithelium (Smyth, 1980). The alternative is that a 'cholesteatoma pearl' will develop. Histologically, the main difference between such squamous epithelial retention cysts and an acquired cholesteatoma is that there is no external opening and the associated inflammation is considerably less. As such they more closely resemble congenital rather than acquired cholesteatomata. The natural history of these cysts is unknown, but they can disappear spontaneously. However, some fear that if they are not removed surgically they may become a cholesteatoma.

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Chapter 4: Pathology of the cochlea

I. Friedmann

The delicate structures of the ear are housed in a comparatively inaccessible part of the skull as Du Verney, a French pioneer in this field, has so aptly described in a postscript to his great thesis *Traité De L'Organe De L'Ouie* (1683): 'Of all the Organs assign'd to the Use of Animals, we have the least knowledge of those of the Senses: but there is none more obscure than that of Hearing; the Minuteness and Delicacy of the Parts which compose it, being inclos'd by other Parts render Enquiries into them more difficult, and their Structure so intricate, that there is much trouble in explaining as there was in discovering them' (Asherson, 1979).

The sensory organ of hearing was first described by Alfonso Corti who was born at Gambarana, near Pavia in Lombardy, Italy, on 15 June, 1822 and died in 1876 at his villa in Mazzolino. He was 19 when he entered medical school at the University of Pavia, but did not complete his course because, at the age of 23, he was attracted by the growing fame of Vienna University where he later received his medical degree. There he attended the Institute of Anatomy and, guided by the great anatomist Joseph Hyrtl, Corti concentrated on the research of the anatomy of the inner ear. Subsequently working with Albert von Kölliker at the University of Würzburg, he was the first to describe the sensory epithelium of the inner ear.

In his experiments, Corti used material as fresh as possible and placed tissue specimens with a diameter of a few millimetres between two slides bonding them with a mastic material. He then allowed a fixative to run between the slides and after fixation, he stained his preparations with a carmine solution. Thus, he was the first to use carmine in histology. In his studies, Corti used a light microscope allowing magnifications of 20-500 times.

Applying this procedure, Corti was not only the first to recognize the bipolar cells of the spiral ganglion, but was able to describe in some detail the basilar membrane, the inner spiral sulcus cells, the pillar cells, as well as the foramina nervosa. Furthermore, he detected the three rows of the outer hair cells and he was the first to describe the tectorial membrane and the stria vascularis in his paper *Recherches sur l'organe des mammifères* in 1851. In spite of the great advances in our knowledge of the organ of Corti, much of the outline given by Corti has remained valid and the organ justly bears his name (Kley, 1986).

Remarkably little has been written about Ernst Reissner (1824-1878) who discovered the vestibular membrane in the cochlear duct. His thesis published in 1851 under the title: *De Auris Internae Formatione* was based on a meticulous study of the fowl embryo ear at different stages of development (Nsamba, 1979).

It is interesting to note that recent intensive research on the fowl and mammalian embryo otocyst mainly in tissue culture, essentially reflects Reissner's method (Fell, 1929; Friedmann, 1959; Orr, 1965; van de Water and Ruben, 1971; Sobkowicz, Bereman and Rose, 1975).
Development of the labyrinth

From the medial aspect of the otocyst, there appears a hollow diverticulum which becomes elongated to form the endolymphatic canal. The otocyst itself divides into the pars superior or vestibular (utricular) pouch and the pars inferior or cochleosaccular pouch. From the vestibular pouch develop three semicircular canals: first, the superior, followed by the posterior and lateral or horizontal canals. The cochlear duct appears around the fifth week as a diverticulum of the cochlear pouch and the saccule develops from its upper portion. This rapid development of the inner ear takes place between the twenty-sixth and the forty-second days: a comparatively short period of time which seems to suffice to transform the simple otocyst into the complicated structures of the membranous labyrinth. After this period, the speed of growth slows down considerably. At this vital period the embryo is most susceptible to teratogenic damage.

The structural differentiation of the cochlea is completed by the third month (length of embryo 25-70 mm). The cochlear nerve fibres induce the sensory epithelium on the inner wall to proliferate, whereas the outer wall continues its longitudinal growth; as a result of this uneven growth the cochlea develops into a spiral organ of two and half coils.

The complete cytological differentiation of the cochlea and the ossification of the otic capsule may be completed between the fourth to the sixth month (embryo length approximately 70-200 mm). It reaches completion with the formation of the three rows of outer hair cells and the single row of inner hair cells with their supporting cells. An area of resorption between the internal and external hair cells leads to the formation of the tunnel of Corti.

Gross anatomy

The inner ear is located in the petrous portion of the temporal bone and is protected by the toughest part of the skull, the otic capsule. The labyrinth, an essential part of the auditory organ, is a complex structure. It consists of a membranous tube lined by epithelium (membranous labyrinth) filled with endolymph and is contained within a bony tube, the osseous labyrinth which is of corresponding complexity of shape and contains the perilymph. The membranous labyrinth is supplied by branches of the auditory nerve and its cochlear branch passes to the organ of Corti.

Classification of hearing loss

The classification of hearing loss has remained complicated and the simple division into conductive, sensorineural and mixed types contrasts sharply with the elaborate schemes developed by various authors.

In trying to distinguish between congenital and acquired deafness, the progress made in recent years has to be considered. The isolation of the rubella virus by Weller and Neva (1962) marked a turning point in the laboratory diagnosis of this condition. This and other advances in virology have thrown some light on the causes of deafness. Furthermore, the rapid progress of genetic and chromosome studies has been contributing to a better
understanding of the genetic influences playing such an important role in the causation of hearing loss.

**Pathogenesis**

Hearing loss in the newborn may be caused by failure to develop one or more parts of the auditory system or to an interruption at any stage in the process of development. It may also be the result of some factor which disturbs or causes the degeneration of the already wholly or partly developed hearing mechanism. Ormerod (1960) tabulated the pathology of congenital deafness as follows:

(1) failure to develop or interruption of development as the result of genetic factors, or toxic influence caused by certain forms of maternal illness during the first 3 months of pregnancy (aplasia)

(2) interruption of development

(3) degeneration of parts of the auditory apparatus which have already developed in some degree or have reached maturity (abiotrophy):

   (a) of the cochlear duct or scala media

   (b) of the sensory end organs

   (c) of the nerve elements.

The pathology of deafness may be conveniently classified according to the following scheme. No new categories are proposed, all have been selected from previous writings on the subject (Friedmann, 1974), although there may be differences of opinion about the interpretation of some of the syndromes.

(1) Pathology of deafness of genetic origin
   lesions of the conductive apparatus
   lesions of the sensorineural apparatus
   aplasia
   abiotrophy (heredodegenerative lesions)
   chromosome aberrations

(2) Embryopathies
   antenatal: rubella, syphilis, toxoplasmosis; other infections - viral and bacterial; hormonal;
   perinatal: infections; asphyxia; kernicterus; toxic; hormonal; metabolic
   postnatal: infection - viral and bacterial; neoplasms; hormonal; environmental - exposure to noise; ageing; toxic.
**Aplasia**

These are hereditary lesions of a degenerative nature, not apparent at birth but revealed at a later period of life, of a progressive nature and associated with deafness. Several classical types are recognized (Schuknecht, 1967):

1. Michel type (complete failure of development of the inner ear)
2. Mondini type (incomplete development of the bony and membranous labyrinth)
3. Scheibe type (cochleosaccular aplasia)
4. Alexander type (membranous cochlear aplasia).

Membranous cochleosaccular aplasia as described by Scheibe (1892) is the most common pathological lesion in congenital sensorineural deafness of any cause.

Suehiro and Sando (1979) developed a new elaborate classification of labyrinthine anomalies which, however, has not been widely applied and may prove complicated to otologists.

**Heredodegeneration (abiotrophy)**

These conditions are of considerable general interest. Heredodegenerative deafness occurs alone or in combination with other abnormalities in which case they are known as 'syndromes'. There are about 70 phenotypically-distinct types of syndrome which may be classified as mesodermal, ectodermal and neuroectodermal, according to the combination of anomalies which are present:

1. occurring alone: in infants or in adults
2. associated with other abnormalities
   - essentially mesodermal, for example Alport's syndrome; Jervell-Lange-Nielsen (cardioauditory) syndrome; Pendred's syndrome; Hurler's syndrome (gargoylism); Marfan's syndrome
   - essentially neuroectodermal, for example von Recklinghausen's disease; Refsum's syndrome; Jamaica neuropathy.

Chromosomal aberrations are responsible for a number of severe anomalies. The presence of an extra chromosome (trisomy) may lead to anomalies associated with deafness.

**Pathology**

The investigation of the pathology of the cochlea requires the application of a wide range of scientific methods. Histochemical and immunological studies as well as both transmission and scanning electron microscopy have provided an increasing amount of
information on the morphology of the inner ear in health and diseases (Lim and Lane, 1969; Engstrom and Ades, 1973; Hunter-Duvar, 1978). The pathological changes of the different constituents of the inner ear can be assessed in familiar general pathological terms (Table 4.1).
Table 4.1. Histopathology of the cochlea and of the organ of Corti

<table>
<thead>
<tr>
<th>Site</th>
<th>Lesion</th>
<th>Aetiology of deafness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensory epithelium</td>
<td>Total absence or loss (abiotrophy)</td>
<td>Congenital: ageing</td>
</tr>
<tr>
<td></td>
<td>Partial absence or degeneration of the sensory and supporting cells</td>
<td>Noise</td>
</tr>
<tr>
<td>Tectorial membrane</td>
<td>Shrinkage: retraction: adhesions</td>
<td>Drugs</td>
</tr>
<tr>
<td>Reissner's membrane</td>
<td>Distension</td>
<td>Congenital</td>
</tr>
<tr>
<td></td>
<td>Collapse</td>
<td>Viral (rubella, measles and mumps)</td>
</tr>
<tr>
<td></td>
<td>Rupture</td>
<td>Anencephaly</td>
</tr>
<tr>
<td>Stria vascularis</td>
<td>Atrophy</td>
<td>Ménière's disease</td>
</tr>
<tr>
<td></td>
<td>Congestion and hyalinization</td>
<td>Anencephaly</td>
</tr>
<tr>
<td></td>
<td>PAS-positive deposits</td>
<td>Meningitis</td>
</tr>
<tr>
<td></td>
<td>Concrements</td>
<td>Trisomy 22</td>
</tr>
<tr>
<td></td>
<td>Cystic degeneration</td>
<td>Otosclerosis</td>
</tr>
<tr>
<td>Spiral limbus</td>
<td>Vacuolation</td>
<td>Ageing, presbyacusis</td>
</tr>
<tr>
<td>Otic capsule</td>
<td>Granulations</td>
<td>Diabetes mellitus</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Jervell-Lange-Nielsen syndrome</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Toxoplasmosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Budd-Chiari syndrome</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alport's syndrome</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Otoxic agents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Noise</td>
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<tr>
<td></td>
<td></td>
<td>Cytotoxic agents</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Viral (rubella, measles)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Woven bone formation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ossification of scalae</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Otosclerosis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paget's disease</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meningitis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Congenital syphilis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pendred's syndrome</td>
</tr>
</tbody>
</table>

Changes of the sensory epithelium may be complex (Friedmann, 1974). The neuroepithelium of the organ of Corti may be totally absent, as in various congenital syndromes, or there may be partial degeneration or absence of the hair cells and supporting cells. Basophilic deposits form in the stria vascularis, the nature of which has remained obscure. The tectorial membrane may be deformed and the ultrastructural changes of the sensory epithelium of the inner ear can be extensive. The cytoplasm of hair cells may show protrusions or ballooning followed by rupture of the outer cell membrane, distension of the rough endoplasmic reticulum with multiple Hensen bodies and marked reduction in the number of the ribosomes. Dense bodies and phagosomes may be present (Table 4.2).
### Table 4.2. Ultrastructural changes

<table>
<thead>
<tr>
<th>Component</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cytoplasm of hair cells</td>
<td>Protrusion-rupture of outer cell membrane</td>
</tr>
<tr>
<td></td>
<td>Distension of rough endoplasmic reticulum</td>
</tr>
<tr>
<td></td>
<td>Hyperplasia of smooth endoplasmic reticulum</td>
</tr>
<tr>
<td></td>
<td>Multiple Hensen bodies</td>
</tr>
<tr>
<td></td>
<td>Dense bodies +++</td>
</tr>
<tr>
<td></td>
<td>Phagosomes +++</td>
</tr>
<tr>
<td></td>
<td>Golgi apparatus - concentration of ototoxic secretory and toxic substances</td>
</tr>
<tr>
<td>Ototoxic antibiotics</td>
<td></td>
</tr>
<tr>
<td>Mitochondria</td>
<td>Damage and rupture of cristae</td>
</tr>
<tr>
<td></td>
<td>Vacuolation and vesiculation</td>
</tr>
<tr>
<td>Nucleus</td>
<td>Aggregation of chromatin</td>
</tr>
<tr>
<td>Ribosomes</td>
<td>Reduction</td>
</tr>
<tr>
<td>Nerves</td>
<td>Bulging and rupture - myelin inclusions, atrophy</td>
</tr>
<tr>
<td>Neurons</td>
<td>Lipofuchsin</td>
</tr>
<tr>
<td></td>
<td>Lysosomes</td>
</tr>
<tr>
<td></td>
<td>Vacuolation</td>
</tr>
<tr>
<td></td>
<td>Nissl substance - reduced</td>
</tr>
<tr>
<td></td>
<td>Protein crystalline inclusions</td>
</tr>
<tr>
<td>Basal lamina</td>
<td>Multiplication and production of long-spaced collagen</td>
</tr>
</tbody>
</table>

The mitochondria are damaged and contain ruptured cristae. Peripheral aggregations of chromatin and intranuclear viral inclusions may be present. Crystalline laminated or striated inclusions may be seen in the hair cells (Friedmann, Cawthorne and Bird, 1965a; Slepecky, Hamernik and Henderson, 1980, 1981).

The stria vascularis forming the lateral wall of the cochlear duct is the site of various well-defined pathological lesions associated with several syndromes and diseases: atrophy in ageing and presbyacusis (Schuknecht, 1974); congestion and hyalinization in diabetes; periodic acid-Schiff (PAS) positive deposits in the Jervell-Lange-Nielsen syndrome; calcification and adhesions in the Budd-Chiari syndrome, toxoplasmosis and Alport's syndrome; vacuolation caused by ototoxic substances and by noise and inflammatory granulations in viral diseases (rubella, measles).

Basophilic deposits in the stria vascularis were studied by Zaytoun (1983). In 42 temporal bones from 22 patients with hearing loss, atrophy of the stria was seen in 12 cases and substrial fibrosis in three; cystic structures were noted in four and the stria appeared to be normal in seven cases.

In 18 cases, bilateral deposits were noted and there were deposits in two or all three coils of the cochlea; the middle coil was the most common site. The deposits presented in the marginal zone of the stria vascularis and protruded into the endolymphatic space. The organ of Corti often showed mild to severe loss of the hair cells and/or total degeneration.
Microscopically, the deposits showed a striking variation of size and shape. Some were elongated or crescent-shaped, others were rounded or polygonal with a concentric lamellar pattern. Still others exhibited a fibrillar pattern. Occasionally, the deposits caused the stria vascularis to be detached from the spiral ligament. In some, the deposits showed a crystalline pattern with sharp edges and fine spicules as described in a case of long-standing profound sensorineural deafness (Nadol and Burgess, 1982) and in Jervell-Lange-Nielsen syndrome (Friedmann, Fraser and Foggatt, 1966; Friedmann, Foggatt and Fraser, 1968).

**Ectodermal syndromes**

**Waardenburg’s syndrome**

In 1951, P. J. Waardenburg, a Dutch ophthalmologist, described a genetically determined (autosomal dominant) syndrome of which unilateral deafness is a feature. The partial albinism of the hair of the scalp has given the condition one of its names - white forelock syndrome. The commonest and most important feature is sensorineural deafness with eyelid deformity and heterochromia or deep blue eyes.

The histopathology of the temporal bones of a child with Waardenburg’s syndrome studied by the author showed total absence of the organ of Corti, atrophy of the stria vascularis and absence of the neurons of the spiral ganglion (Friedmann, 1974).

Since the original description over 1200 cases of the syndrome have been reported, not only in patients of Dutch extraction but also in English, American, African, Indian, Oriental and Black persons (Hageman, 1977; Wang, Karmody and Pashayan, 1981; Galich, 1985). Waardenburg’s syndrome seems to consist of two genetically distinct entities, which can be differentiated clinically into Waardenburg’s syndrome with or without dystopia canthorum (type 1 and type 2 respectively). Congenital deafness in both ears may occur in about 25% of the patients with Waardenburg’s syndrome type 1 and in about 50% of those with type 2.

**Usher’s syndrome**

This consists of retinitis pigmentosa and sensorineural deafness. The histopathological findings include malformation of the cochlea, cochleosaccular dysplasia and degeneration of the spiral ganglion (Usher, 1914).

**Cogan’s syndrome**

Non-syphilitic interstitial keratitis associated with vestibuloaditory dysfunction was first described by Cogan in 1945. Twenty-seven cases were reviewed by Cody and Williams (1960) and two cases were added by Bellucci, Grobeisen and Sah (1974). Fifty-three cases have been reviewed by Cheson, Bluming and Alroy (1976) (including one of their own). In 72% of the affected patients there was an underlying systemic, often vascular, process. Ten per cent had fatal or near fatal aortic valvular disease, which proved to be amenable to surgical intervention. Other systemic manifestations have included congestive heart failure, gastrointestinal haemorrhage, adenopathy, splenomegaly, hypertension, musculoskeletal involvement and eosinophilia.
The aetiology and pathology of the syndrome remain obscure. It has been suggested that the syndrome is a manifestation of polyarteritis nodosa (Cheson, Bluming and Alroy, 1976). The pattern of multisystem involvement can be almost identical in these entities and, in fact, sudden nerve deafness may occur in polyarteritis nodosa.

The clinical course of Cogan's syndrome is as variable as its modes of presentation. Some patients have died within months of onset; others have lived up to 15 years after diagnosis. Most patients regain and retain good vision, but permanent hearing loss is the rule (Wolff et al, 1965) (see Chapter 15).

Histopathology

Necrotizing vasculitis, affecting many organs may be present, affecting the heart, aorta, kidneys and gastrointestinal system. The inner ear shows degeneration of the organ of Corti and of the spiral ganglion. Endolymphatic hydrops and ossification of the labyrinth may occur.

Mesodermal syndromes

Alport's syndrome

This can be defined as familial nephropathy, usually accompanied by sensorineural deafness (Alport, 1927; McDonald, Anderson and Ott, 1978). It is inherited as an autosomal dominant trait and is more severe in males. The disease begins in childhood, usually with haematuria following an acute upper respiratory infection. Hearing loss is slowly progressive and asymmetrical. The discrimination score remains normal until severe hearing loss ensues.

Histopathology

The changes in the stria vascularis range from mild perivascular oedema with thickening of the capillary walls and fragmentation or splitting of the basement membrane, to complete degeneration and atrophy. The spiral prominence is less affected, although severe perivascular oedema may be present. In cases of severe deafness there is a loss of inner and outer hair cells and of ganglion cells, particularly in the basal turn. Non-specific basophilic deposits may occur (Gregg and Becker, 1963; Crawford and Toghill, 1968; Nadol and Arnold, 1987).

However, according to Fujita and Hayden (1969), consistent inner ear pathology is conspicuous by the absence of any characteristic histological findings. A normal organ of Corti with a normal spiral ganglion and acoustic nerve was found in some cases (Wood and Knight, 1966; Arnold, personal communication). It has been suggested that many of the degenerative changes noted in the hair cells of the organ of Corti could be attributed to autolysis (Miller et al, 1970).

The pathogenesis of the inner ear hearing loss is not completely understood. It is not clear whether this undoubted congenital disorder is based on the primary degeneration of the inner ear or whether the sensorineural hearing loss resulted from a special type of glomerulonephritis (Arnold, 1984). Since deafness has been reversed after renal transplantation
(McDonald, Anderson and Ott, 1978), the mechanism causing hearing loss may be considered to be secondary to renal disease.

The renal changes combine various features of chronic glomerulonephritis, pyelonephritis and interstitial nephritis. Lipid-laden foam cells are present in the tissues, often forming long rows and clusters in the renal cortex, a characteristic feature of hereditary nephritis (Krickstein, Gloor and Balough, 1966).

The association of certain clinical problems existing simultaneously in the kidney and the ear has been recognized (Bergstrom et al, 1973). The ultrastructural organization of both these organ displays certain similarities of functional importance. Evidence of a shared antigenicity between the two organs has been noted, suggesting an immunological basis for Alport's syndrome (Quick, Fish and Brown, 1973).

**Jervell-Lange-Nielsen syndrome**

The Jervell-Lange-Nielsen, or cardioauditory, syndrome consists of congenital deafness with an abnormal electrocardiogram and fainting attacks, frequently causing the sudden death of a child so affected. This rare syndrome was first described, in 1957, by Jervell and Lange-Nielsen in four of six siblings of a Norwegian family (Jervell, Thingstad and Thor-Østen, 1966). The fainting attacks had originated in childhood and three of the children had died at the ages of 4, 5 and 9 years respectively. The deaf children showed striking abnormalities of the electrocardiogram, previously undescribed, and characterized mainly by a gross prolongation of the Q-T interval. Levine and Woodworth (1958), during the screening of several thousand deaf persons, described the syndrome in a boy of Finnish ancestry who died suddenly at the age of 13. Nine further cases in Britain and Ireland were ascertained (Friedmann, Fraser and Froggatt, 1966; Friedmann, Froggatt and Fraser, 1968). The attacks are considered to be syncopal as a result of cardiac insufficiency secondary to cardiac arrest or some transient arrhythmia, and the syndrome is inherited in an autosomal recessive manner.

**Histopathology**

The most common finding is a widespread degeneration of the sensory end organs of the cochlea and of the vestibular apparatus; Reissner's membrane is collapsed and adheres to the stria vascularis, to the tectorial membrane and/or the remnants of the organ of Corti. The stria vascularis in every coil contains unusual spherical inclusions of some eosinophilic hyaline matter which seem to be most abundant in the apical coils. The deposits filling distended vessels protrude into the cochlear duct. The ragged surface of the stria vascularis appears to have been ruptured by the underlying fibrillar or crystalline material forming the deposit or inclusion. The deposited material is PAS-positive. This suggests that it contains mucopolysaccharides or allied substances.

Special investigation of the conducting system of the heart revealed considerable narrowing of the sinuatrial artery with intimal hyperplasia. The gradual narrowing of this artery and its intraneural branches may result in arrhythmia; should this become uncontrollable, death may ensue during a fainting attack.
**Pendred's syndrome**

Pendred's syndrome consists usually of bilateral profound childhood deafness and the development in childhood of diffuse or nodular colloid goitre. The mental and physical development of the child is otherwise normal. Histopathology of the ear shows malformed cochlear structures and degenerative changes in the inner ear.

Hvidberg-Hansen and Jorgensen (1968) described the temporal bone findings from a 60-year-old man who had been born deaf and from about the age of 25 had developed a goitre which was first removed at the age of 49. The histological diagnosis was of a colloid nodular goitre. At the age of 60, the recurrent goitre had to be removed after unsuccessful replacement therapy.

**Histopathology**

The bilateral developmental arrest of the labyrinth was of the Mondini type. Apart from this malformation, however, there were also signs of atrophy of the organ of Corti and of the tectorial membrane, endolymphatic hydrops, connective tissue formation in the sacculle and utricle, and an increased amount of periotic connective tissue with endosteal ossification of the cochlea.

A recent study by Johnsen, Jorgensen and Johnsen (1986) of five temporal bones from four patients with Pendred's syndrome has confirmed an earlier finding that the malformed cochlea resembled a Mondini-type cochlea.

**Mucopolysaccharidoses**

These form a group of lysosomal storage diseases caused by inherited deficiency of an enzyme capable of degrading glycosaminoglycans. Hurler's disease (mucopolysaccharidosis (MPS I)) is an autosomal recessively inherited lysosomal storage disease caused by alpha-L-iduronidase deficiency. Therefore, in Hurler's disease, glycosaminoglycans (mucopolysaccharides) accumulate in the tissues and are excreted in the urine. Hurler's disease is distinct from the X-linked recessively inherited Hunter's disease (MPS II), the severe variants of which superficially resemble the former clinically.

Deafness is a well-recognized component of the clinical phenotype in both Hurler's and Hunter's diseases (Hurler, 1919; Kittel, 1963). Although both of these diseases are invariably fatal, deafness often makes an appreciable contribution to the overall morbidity in the earlier stages of their clinical evolution. Hearing loss is also an important practical problem in the clinically milder syndromes associated with alpha-L-iduronidase deficiency (Scheie disease MPS IS) and Hurler Scheie disease (MPS IH/S) and in the mild variants of Hunter's disease. The intellect is well preserved relative to the non-neurological manifestations in both these groups, so that handicaps such as deafness are particularly important in relation to the individual patient's quality of life.
**Histopathology**

Characteristic vacuolated Hurler or gargoyl cells were noted disrupting the fascicles of the vestibulocochlear nerve within the temporal bone in two cases of Hurler's disease (Schachern, Shea and Paparella, 1984; Friedmann et al, 1985). The perivascular spaces of the mastoid process contained many vacuolated cells, and large areas of the mastoid process were replaced by accumulated Hurler cells. The neuroradiological features in these cases were described by Watts et al (1981) and post-mortem biochemical and general pathological studies were reported by Crow et al (1983).

**Idiopathic sudden sensorineural hearing loss**

The challenging diagnostic and therapeutic problems of idiopathic sudden sensorineural hearing loss have attracted a great deal of attention. The condition can be defined as spontaneous sudden hearing loss in patients with apparently no previous otological problems. Its pathogenesis has remained speculative despite some, mainly empirical, improvement in its clinical management.

The pathology has been extensively studied by Schuknecht and Donovan (1986).

**Histopathology**

The pathological changes resemble those occurring in labyrinthitis of known viral aetiology.

The principal histopathological changes involve the organ of Corti and the tectorial membrane with less frequent and less severe lesions of the stria vascularis and of vestibular labyrinth.

In two of the 12 cases studied, the severe hearing loss was attributed to the atrophy of the tectorial membrane and one of the cases showed atrophy of the cochlear neurons as the probable cause.

A histological study of sudden deafness resulting from rupture of cochlear membranes first in the left ear, and then 3 years later in the right ear, in a patient with vertebrobasilar arteriosclerosis was reported by Gussen (1983). Two healed ruptures were shown on the right side, one in the hook portion of the cochlea, and one in the area of the promontory; the latter was adherent to the saccule, distorting it inferiorly. In the left temporal bone, a healed rupture was shown. Although the patient's vertebrobasilar artery disease and her sudden deafness are considered separate entities, one must at least consider whether such long-standing vascular insufficiency might predispose to more readily ruptured membranes with sudden pressure changes in the inner ear.

**Viral diseases**

The ear is potentially open to infection by any of the respiratory viruses and it is a widely accepted assumption that bacterial otitis is often preceded by viral otitis. Although
some respiratory viruses have been isolated from the middle ear, on occasions, there is no
evidence that any of them could invade the middle ear and cause a pure viral otitis media.

Various viruses can cause fetal damage and congenital malformations affecting the ear, and the role of certain specific viruses is well established; for example rubella, cytomegalovirus, herpes simplex, varicella-zoster, influenza, mumps and measles.

**The ear in maternal rubella**

The special vulnerability of the eye, ear and heart of the developing fetus in maternal rubella during the first trimester of pregnancy is well recognized and, although the period of greatest danger to the fetus from rubella is in the first trimester, infection in the second and third trimester can cause deafness.

**Histopathology**

By contrast with the rapid progress of the epidemiology and virology, new knowledge of the histopathology of rubella deafness has remained fragmentary, because of the relatively small number of temporal bone specimens available (Friedmann and Wright, 1966; Lindsay, 1973).

Microscopy of the cochlea showed partial collapse of Reissner's membrane with adherence of the membrane to the stria vascularis and organ of Corti. Small granulomata may be present between the stria vascularis and Reissner's membrane. The tectorial membrane was found to be rolled up lying in the internal sulcus. Collapse of the saccule was observed, and the membrane was found to be collapsed and adherent to the macula sacculi suggestive of a recent acute inflammatory process. Few changes were present in the organ of Corti, in the examined cases. The hair cells were plentiful, as were the pillar cells, and appeared to be normal. There were some areas of cystic dilatation at the junction of Reissner's membrane and the spiral ligament.

The granulomatous lesions described by several authors appear to have occurred when the organ of Corti had reached morphological maturation (Friedmann and Wright, 1966; Bordley and Hardy, 1969; Brookhauser and Bordley, 1973; Lindsay, 1973). This could be interpreted as consistent with the degeneration of the preformed neuroepithelial structures, reflecting continued virus cell interaction, as suggested by other stigmata of the rubella syndrome.

Prenatal rubella is recognized as a cause of congenital deafness but its importance may not be fully appreciated (Brookhauser and Bordley, 1973). One reason is that a woman may have a silent rubella infection during pregnancy and pass the virus to the fetus without any clinical evidence of her own infection (Menser, Dods and Harley, 1967). Out of 84 pregnant women infected with the rubella virus, but without clinical disease, 10 gave birth to children from whom the virus was isolated (Bordley et al, 1968).

A study of the effect of rubella on the frequency of congenital deafness for 5 years after an epidemic in 1960, in an island population, revealed that of 87 congenitally deaf children born the year after the epidemic, 86 had suffered deafness as the only demonstrable
congenital abnormality. Only 20 gave a history of first trimester rubella, so by the usual classification, the remaining 67 cases would be labelled as idiopathic, all known causes having been ruled out. However, serological tests for rubella antibodies on 30 of the 'idiopathic' deaf children were positive in 74% compared with 30% in a control group born within the same year (Karmody, 1968).

In the investigation of congenital deafness in a child, a test for rubella antibodies should be performed. With increasing age a positive result becomes less significant, but the absence of rubella antibodies would exclude the virus as a cause and focus attention on other factors.

**Herpes zoster oticus**

The classical syndrome, described by Ramsay Hunt in 1907, is not common, and it is a more complicated disease than the original conception of 'geniculate ganglionitis' would indicate. Multiple cranial nerves may be affected, but the facial nerve and its ganglion is perhaps the most commonly involved.

The case described by Blackley, Friedmann and Wright (1967) involved the seventh and eighth cranial nerves. The patient, a 69-year-old woman who complained of sudden deafness and right facial palsy, died of carbon-monoxide poisoning some 214 days from the onset of herpes zoster of the ear.

**Histopathology**

The most striking feature of the histopathology was the presence, 7 months after the herpetic eruption, of intense perivascular, perineural and intraneural round cell aggregations in the facial nerve, the auditory nerve, the cochlea and in the mastoid process. The organ of Corti was damaged and, with the atrophic stria vascularis, covered by the collapsed Reissner's membrane.

Sections of the temporal bone of the clinically affected side contained extensive lymphocytic or round cell infiltration of the facial nerve throughout its length and also of the auditory nerve. There was considerable perivascular 'cuffing' by lymphocytes in the modiolus, in the perineural tissue of the facial nerve, the chorda tympani and the skin of the external auditory meatus. The vestibular, spiral and geniculate ganglia contained numerous apparently normal neurons, although there was scattered lymphocytic infiltration of the surrounding nerve tissue. These findings were in complete accordance with the main histopathological findings of the four cases previously described: that is profuse and widespread lymphocytic infiltration in the facial nerve which is in striking contrast to the microscopical findings in Bell's palsy (Friedmann, 1974).

**Mumps**

Mumps appears to be the virus infection most commonly associated with sudden deafness. It may be a more frequent cause of deafness since mumps infection without parotitis is not uncommon and can remain undiagnosed.
Measles

Endolymphatic labyrinthitis caused by infection with measles virus is well recognized. The virus may reach the endolymphatic system from the blood stream and cause destruction of the neuroepithelium.

Lindsay and Hemenway (1954) described the histopathological findings in the temporal bones of a 7-month-old deaf child following measles infection.

Viral encephalopathy

Viral labyrinthitis may be associated with viral encephalitis. The temporal bones of three children between the ages of 12 months and 13 years have been studied and the microscopical changes included various degrees of degeneration of the organ of Corti and of the stria vascularis. There was marked round cell infiltration of the modiolus (Karmody, 1983).

Syphilis

Invasion of the central nervous system by Treponema pallidum occurs during the early stages of infection. Deafness may occur in both acquired and congenital syphilis.

Congenital syphilis

The stillborn or young infant may exhibit syphilitic changes in the middle ear and cochlea which may become ossified. Severe endolymphatic hydrops and degeneration of the organ of Corti and spiral ganglion have also been described (Karmody and Schuknecht, 1966).

Acquired syphilis

The pathology of the deafness is obscure. The principal lesions are those of the tertiary stage of the disease, which may become manifest within a few or many years after infection. The skin and cartilage of the external ear may be affected. The middle ear and temporal bone may be the sites of destructive gummatous processes of tertiary syphilis.

Deafness associated with chromosomal aberrations

Chromosomal aberrations are responsible for many severe anomalies (Friedmann, 1974). The presence of an extra chromosome (trisomy) may lead to anomalies associated with deafness (Suehiro and Sando, 1979). Cochlear anomalies associated with the presence of the additional chromosome in trisomy 13-15 include Patau syndrome, characterized by deafness, ocular defects and absence of the olfactory bulbs and tracts. Deafness is common in Down's syndrome (trisomy 21). Multiple malformations of the ear were described in trisomy 18 (Edward's syndrome) (Suehiro and Sando, 1979) and trisomy 22 (Nadol and Arnold, 1986). Anatomical details of the affected inner ear have been summarized by Suehiro and Sando (1979). Here, only the description of the cochlear changes will be mentioned.
Trisomy 13-15 syndrome

The changes in the cochlea include: absence of hook portion, absence of apical and middle turns, rudimentary and deformed cochlea, shortened cochlea, anteriorly situated cochlea, malformed scala vestibuli, underdeveloped modiolus, absence of Rosenthal canal in lower basal turn, absence of lumen of osseous spiral lamina in lower basal turn, scala communis between apical and middle turns, scala communis between middle and basal turns, wide cochlear aqueduct, tectorial membrane rolled up and covered by single epithelial layer.

Trisomy 18 syndrome

Alterations found in the cochlea include: absence of apical turn; deformity of cochlea; scala communis between apical and middle turns; wide cochlear aqueduct; absence of cochlear duct; underdeveloped stria vascularis.

Trisomy 21 syndrome

A shortened cochlea may be found.

Hearing loss due to noise

The effect of noise or any acoustic trauma is of immense industrial and public health importance. Repeated exposure to high levels of noise is a potent cause of deafness, particularly in certain industrial occupations and in places of public or private entertainment where there is overamplification of sound. Proximity to explosions or to gunfire is also liable to result in deafness. Noise induced degenerative patterns in the human ear exhibit a characteristic 'knife-sharp' demarcation line between the damaged and undamaged areas.

Acoustic trauma may cause sensory cell damage by direct mechanical action, by metabolic disturbances resulting from impaired blood circulation, or as a result of the altered permeability of the cell membrane. The inner hair cells are more resistant to acoustic trauma regardless of their site (Bohne, 1976), but greater hearing loss is caused by the loss of the inner than the outer hair cells. By contrast, the outer hair cells display a varied susceptibility in different coils of the cochlea. The morphological changes include proliferation and vacuolation of the endoplasmic reticulum, swelling of the mitochondria, degeneration of the cuticular plate. The swollen sensory cell may rupture and perish.

The sensory cells are joined by attachment zones and gap junctions as first described in tissue cultures of the otocyst (Friedmann and Bird, 1961a). Subsequently it has been shown that the cell junctions of the organ of Corti are disrupted by noise (Beagley, 1965).

The hair cells and the cochlear nerve endings can degenerate within days following excessive exposure to sound. In the cochlear nucleus, the small cochlear nerve endings are especially susceptible to acoustic trauma. It is noteworthy that there is evidence for both a differential sensitivity of inner and outer hair cells and for a selective susceptibility of different auditory pathways in the central nervous system to acoustic overstimulation (Kent and Bohne, 1983).
Even lower levels (below 100 dB) of noise may damage the outer hair cells. High intensity sound (noise) produces considerable changes in the cilia, which may be converted into large complex 'giant' structures affecting the function of the sensory cells. Lim (1986), in a recent comprehensive review, has drawn renewed attention to the important role of the ciliary apparatus in the normal transduction of sound and any damage may considerably impair its function. Various stereociliary changes may be caused by acoustic trauma (also by ototoxic agents). These have been described as floppy, fanned-out, fractured, fused, giant and dissolved cilia. Following mechanical overstimulation or acoustic trauma, the stereocilia show a reduction in stiffness, as measured directly in isolated organs of Corti. They may return to their pre-exposure stiffness in about 15 minutes, following mechanical stimulation (Miller, Canlon and Flock, 1985; Saunders and Flock, 1985).

Splayed (fanned-out) stereocilia may be caused by the tightening of the contractile proteins that are attached to the rootlets in the cuticular plate (Friedmann, Cawthorne and Bird, 1965b; Slepecky, Hamernik and Henderson, 1980, 1981). Another mechanism could be the result of the altered consistency of the cuticular plate because of depolymerization, leading to an exaggerated pivoting of the rootlets. Such macromolecular changes may represent the underlying mechanism of the reduction of stereociliary stiffness by mechanical overstimulation or acoustic trauma. Seemingly minor changes of the stereociliar-cuticular plate complex have a profound effect on the auditory and/or vestibular function (Friedmann, Cawthorne and Bird, 1965b; Lim, 1986).

**Ototoxic drugs**

There is a wide range of drugs which are capable of causing deafness and/or dizziness, either by causing toxic degeneration of the inner ear, or of the higher centres of hearing and equilibrium. The peculiar sensitivity of the eighth nerve has not yet been satisfactorily explained. Many ototoxic drugs have no apparent chemical similarity (for instance thalidomide, ethacrynic acid and atoxyl), but most ototoxic antibiotics belong to the 'useful but unruly' family of basic streptomyces antibiotics (Hawkins, 1959), or aminoglycoside antibiotics and to the so-called 'loop diuretics'.

**Histopathology**

It has been shown that the effect of some ototoxic antibiotics differed from that of acoustic trauma which usually started at the base of the cochlea extending to its apex. This applies equally to neomycin, gentamicin and kanamycin. Neomycin seemed to act initially upon the hook area and apical coil, whereas gentamicin and kanamycin would initially cause simultaneous destruction of the outer hair cells in the upper basal coil and in the hook area. Neomycin may also act on the apical inner hair cells which are only seldom damaged by gentamicin or kanamycin (Hawkins, 1959; Friedmann and Bird, 1961b; Friedmann, Dadswell and Bird, 1966). The lesions caused by atoxyl usually start at the apex (Anniko, 1976; Anniko and Wersall, 1976).

There exist great variations among individual animals (and humans) in their reaction to the ototoxic antibiotics necessitating the evaluation of the hair cell population of each animal (human) individually.
Transmission electron microscopy

As has been shown in animals and in tissue culture ototoxic antibiotics are ribosomal and mitochondrial poisons (Friedmann and Bird, 1961b).

The earliest ultrastructural signs of degeneration of the organ of Corti, regardless of the antibiotic administered, occur in the outer hair cells. The cisternae along the outer cell membrane become distended and dense bodies accumulate in the subcuticular cytoplasm of the hair cells. Subsequently the distended cisternae become vacuolated and eventually the outer cytoplasmic membrane will rupture. The intracellular organelles are expelled into Nuel's space leading to their complete disintegration.

Sensorineural deafness may be caused by the 'loop diuretics', frusemide and ethacrynic acid, which inhibit cellular metabolism and the enzymes participating in electrolyte transport. Ethacrynic acid causes oedema and cystic degeneration of the stria vascularis. Studies of the combined effect of kanamycin and ethacrynic acid show that the concurrent administration of two or more ototoxic drugs has an enhanced toxic effect on the inner ear. On the other hand, the selective ototoxicity of atoxyl can be employed as a model system for comparative studies of various ototoxic agents (Anniko, 1976; Anniko and Wersall, 1976).

The effect of prussic acid on neurons has been demonstrated on tissue cultures of the isolated fowl embryo otocyst exposed to sodium cyanide (Friedmann and Bird, 1972). The degenerative changes observed were comparable to those observed in patients with the kassava syndrome. Kassava root is a widely consumed food in Africa, which contains a cyanogenic compound, linamarin; and it has been recognized that multiple neuropathy associated with deafness might ensue in persons consuming this otherwise simple food.

Scanning electron microscopy

The effect of gentamicin has been studied by scanning electron microscopy on guinea-pigs (Forge, 1985; Lim, 1986). A variety of lesions have been noted at the hair cell apex. The stereocilia were fused or foreshortened, apparently disintegrating. The surfaces of the outer hair cells where stereocilia were almost completely destroyed appeared to be roughened. The cuticular surfaces were bulging and became detached from the reticular lamina.

'Crooked' rootlets with bent stereocilia, floppy cilia, fusion of stereocilia and giant cilia have been observed on cochlear hair cells exposed to ototoxic agents.

The detached hair cell remnant could be seen beneath the surfaces of the expanded or swollen supporting cell, possessing microvilli, and occluding the space beneath the vanishing hair cell debris (Forge, 1985; Lim, 1986). This process is probably electrochemical in nature and acts through the gap junctions linking the two cell groups. This type of necrosis of the cell has been linked by Forge (1985) to the 'apoptosis' occurring in developing organs which require a programmed regularly timed cell death (Wyllie, 1981).

A partial or total loss of outer hair cells alone, in a given segment of the cochlea, was not associated with any corresponding rarefaction or loss of neurons. When the inner hair cells had also degenerated, the number of neurons in the spiral ganglion and spiral osseous
lamina was markedly reduced, provided the survival time was long enough for degeneration to have run its course. The secondary degeneration of first order neurons following any damage to the organ of Corti, appeared to be a delayed phenomenon; its full development was not apparent until at least 4 weeks after the cessation of treatment with gentamicin.

**Ageing and hearing loss**

Hearing loss and degeneration of balance control in the aged is of gradual onset and forms part of the progressive deterioration of the physiological functions associated with the ageing process. These are of a general nature, affecting any cell of any tissue or organ, although different cell systems may become vulnerable in particular ways.

The true nature of the pathogenesis of hearing loss of the aged (presbyacusis) has remained obscure. Two principal lesions may be recognized: a loss of neurons and nerve fibres of the spiral ganglion and spiral nerve, and vascular changes and atrophy affecting the stria vascularis (Schuknecht, 1974; Suga and Lindsay, 1976; Nadol and Arnold, 1987).

Four distinct clinical patterns have been recognized in the ageing population with typical histopathological correlates:

1. degeneration and loss of neural elements or 'neural presbyacusis'
2. degeneration and loss of hair cells or 'sensory presbyacusis'
3. inner ear biochemical defect or 'metabolic presbyacusis'
4. degeneration or inefficiency of inner ear supportive elements or 'mechanical presbyacusis'.

**Neural presbyacusis**

Early degeneration affects the dendritic processes of the osseous spiral lamina. In areas of severe degeneration there may be marked loss of spiral ganglion cells and afferent axons.

**Sensory presbyacusis**

There is a loss of inner and outer hair cells in the basal turn. Secondary cochlear neuronal degeneration is common. In cases of severe degeneration, the supporting elements may be missing and the organ of Corti may be replaced by a single layer of flat 1/1 epithelial cells.

**Metabolic presbyacusis**

Schuknecht (1964) described a common type of sensorineural hearing loss which has its onset in middle age, is slowly progressive, and is characterized by a flat audiometric pattern. It is associated with degenerative changes of the stria vascularis of the middle and apical turns of the cochlea. Atrophy of the stria vascularis is an important cause of sensorineural hearing loss of ageing. The pathological changes consist of degeneration of all
three layers of the stria vascularis, most prominently in the apical region of the cochlea, affecting most severely the marginal cells, then the intermediate and least severely, the basal cells.

There are other cellular and subcellular processes participating in various degenerative syndromes which find expression in extreme old age. The hair cell population decreases with age in parallel with atrophy of the spiral nerves. The vestibular end organs may also be affected and there is an age-related progressive reduction of the number of vestibular sensory cells and nerve fibres over the age of 40 years. The cells contain a great deal of lipofuchsin yet the physiological ability of such persons may not be substantially impaired, probably as a result of compensation by the surviving cells.

**Mechanical presbyacusis**

**Microscopy**

The observed loss of hair cells, neuronal elements and stria vascularis is insufficient to explain the degree of hearing loss. In such cases a variety of abnormalities of supporting elements of the inner ear has been found. These include degeneration of the spiral ligament and rupture or thickening of the basilar membrane (Nadol and Arnold, 1986).

**Vascular diseases causing hearing loss**

Progressive or sudden hearing loss can be caused by localized or systemic vascular disease. In the first category, the vessels of the stria vascularis and the internal auditory artery and its branches which are terminal arteries, play a significant role for example in diabetes mellitus and in various congenital syndromes associated with deafness. The vestibular end organs appear to be more resistant than the organ of Corti to the effects of surgical severance of the labyrinthine artery.

The cause of so-called idiopathic sudden deafness varies. A vascular disorder such as spasm, oedema or arteritis, or a combination of several vascular factors, have been incriminated. Polyarteritis nodosa and Wegener's granulomatosis involving the ear may cause deafness (Friedmann and Bauer, 1973).

**Delayed effects of ionizing radiation on the ear**

Patients with cancer of the brain, nasopharynx, tonsil, and parotid are often treated with doses of radiation which range from 5000-7000 cGy over a period of 5-7 weeks. Depending on the size and site of the tumour, one or both temporal bones may receive a nearly equivalent dose of radiation. Several studies have shown that some patients so treated developed hearing difficulties during therapy (Bohne, Marks and Glasgow, 1985).

The question of damage to the ear from exposure to ionizing radiation was studied by exposing groups of chinchillas to fractional doses of radiation (200 cGy per day) for total doses ranging from 4000-9000 cGy. In order to allow any delayed effects of radiation to become manifest, the animals were sacrificed 2 years after completion of treatment and their temporal bones examined. The most pronounced effect of treatment was degeneration of
sensory and supporting cells and the loss of eighth nerve fibres in the organ of Corti. The degree of damage found in many of these ears was of sufficient magnitude to produce a permanent sensorineural hearing loss.

**Anencephaly**

Anencephaly is probably the result of failure of the closure of the neural groove and consequent failure of development of the forebrain. Histopathological studies of the temporal bones of six anencephalics have yielded some interesting findings (Wright, Phelps and Friedmann, 1976; Friedmann, Wright and Phelps, 1980).

The cochlea was malformed and showed Mondini-type malformation as described by Gussen (1968). A short, poorly developed modiolus reached the malformed basal coil opening into a wide-open bulbous or pear-shaped space replacing the upper coils and forming a scala communis. The overall size of the cochlea appeared to be considerably reduced and the otic capsule showed enhanced ossification.

The neuroepithelial elements of the organ of Corti appeared to be well differentiated where preserved, but the cochlear duct was distended as in Ménière's disease. Reissner's membrane was bulging or collapsed onto the tectorial membrane and onto the epithelium of the organ of Corti. There was some evidence of rupture and repair.

**Systemic bone diseases affecting the ear**

The temporal bone is affected by systemic or local diseases of the bone. These include developmental abnormalities, inflammatory conditions, otosclerosis, metabolic and endocrine conditions, achondroplasia, osteogenesis imperfecta, Paget's disease, osteopetrosis, histiocytosis X, fibrous dysplasia, lipidoses involving bone, tumours of bone (see Table 15.2).

**Osteogenesis imperfecta**

Osteogenesis imperfecta is a rare condition characterized by fragility of the bones, leading to multiple fractures associated with blue sclerae and deafness. The temporal bone may be affected by this generalized skeletal abnormality, which may result from a specific dominant gene abnormality.

The lesions may present in two forms: as osteogenesis imperfecta congenita at birth, and as osteogenesis imperfecta tarda, when the changes become evident during childhood or adolescence (Seedorff, 1949).

**Histopathology**

In the congenital form the lamellar bone is replaced by a spongy network of non-lamellar bone, which permeates the entire temporal bone or the otic capsule, and may involve the oval window region and stapes, when it can be difficult to distinguish from otosclerosis. In older individuals, the bones are brittle ('fragilitas ossium'). The histological features display no characteristic pattern that might be of differential diagnostic significance. The changes may be regarded as the result of a functional abnormality of osteoblasts.
**Paget's disease of the temporal bone**

The aetiology of Paget's disease has remained obscure. Cytoplasmic inclusions morphologically similar to the nucleocapsids of the paramyxoviridae family have been identified under the electron microscope. Evidence has been presented by Mills et al (1984) in support of the hypothesis that Paget's disease of bone is a slow viral infection of the paramyxoviridae family.

Paget's disease affecting the skull may cause obstruction of the external auditory meatus, inducing conductive deafness. Obliteration of the labyrinth and sensorineural deafness are less common symptoms. Some of the features which distinguish it from otosclerosis include the later age of onset, lack of family history, sensorineural deafness showing rapid deterioration, tinnitus, radiological evidence of Paget's disease of the skull.

**Histopathology**

Histologically there is evidence of disordered and very active reconstruction of the bone (Friedmann, 1974). There are, in the active phase, numerous multinucleate osteoclasts, lying in the perivascular fibrous tissue or in the deep lacunae they have produced. Elsewhere, chains of osteoblasts are prominent, lining newly formed bony trabeculae. Alternating resorption and apposition of bone culminates in the classical mosaic of irregular cements lines. In the inactive lesion, remodelled bone, displaying the characteristic mosaic pattern of cement lines, has been formed. This must not be confused with the similar pattern observed in the sclerotic mastoid bone following chronic infective diseases. The author has studied the temporal bones of a woman who died at the age of 81. The petrous temporal bones were almost totally affected by the process. Her deafness was, in fact, only moderate and it had been easy to communicate with her. The process obstructed the external auditory meatus and obliterated the tympanic cavity but not the cochlea; the organ of Corti was present. There is a similarity with otosclerosis, in that there is a sharp zone of demarcation between the disease and the normal bone.

**Fibrous dysplasia of bone**

No less than 33 different names had been used by various authors to describe this disease before the term fibrous dysplasia was introduced by Lichtenstein (1938). The disease is characterized by the development in one or more bones of circumscribed lesions consisting of bone-forming tissue: monostotic or polyostotic fibrous dysplasia. The aetiology is obscure.

Fibrous dysplasia usually occurs as lesions of long bones, but it is not uncommon in the skull, and particularly in the maxilla. It may affect the temporal bone alone.

The primary histological component consists of connective tissue with metaplastic new bone formation; the bone is of woven pattern and a lamellar organization is usually lacking. There are relatively slender trabeculae of immature bone containing many immature osteoblasts staining unevenly and surrounded by fibrous connective tissue. Osteoclasts can be seen tunnelling into the mineralized interior of trabeculae scalloping and fragmenting them. The resorbed areas become filled with a cellular fibrous tissue.
**Osteopetrosis (marble bone disease or Albers-Schönberg disease)**

This is a rare disease, only about 300 cases have been reported (Hamersma, 1970). Recurrent progressive facial palsy and deafness are frequently encountered. Acute recurrent attacks of facial palsy identical with Bell's palsy usually start in childhood. The disease is probably the result of a congenital metabolic disorder of bone resulting in a failure of resorption of cartilage and mature bone.

**Histopathology**

The abnormality is caused by a failure of adult bone formation and the failure of resorption or replacement of primitive bone. Myers and Stool (1969) examined the temporal bones of a 2.5-year-old Negro girl who died of the sequelae of osteopetrosis (anaemia and pulmonary haemorrhage). Sections of the temporal bones showed that the enchondral layer was most severely affected and there was bony obliteration of the mastoid air cell system. There were no inner ear changes attributable directly to the abnormal bone.

**Xanthoma of the ear**

Xanthomatous deposits in the temporal bone (or mastoid process) are rare (Friedmann, 1974) but may imitate chronic mastoiditis. Their aetiology is unknown. Clinically or pathologically recognizable deposits of cholesterol and other fats in the skin, tendons and bone occur in many diseases, such as diabetes. Groups of foam cells may be seen in inflammatory granulation tissue or in the exudate of otitis media.

The xanthomatoses may be the result of metabolic disturbances of steroid metabolism, lipid metabolism or both, and are associated respectively with high levels of cholesterol and high levels of neutral fats in the blood; they may, however, be found in the absence of any detectable alteration in blood chemistry.

The pathological lesions are formed by the accumulation of lipid-laden macrophages in the affected tissues. The cytoplasm of these macrophages has a foamy appearance, caused by the presence of finely dispersed droplets. At operation, much creamy fluid may be noted in the temporal bone.

*Idiopathic histiocytosis (non-lipid histiocytosis, histiocytosis X or Langerhans cell histiocytosis)*

This non-committal title describes a triad of diseases: Letterer-Siwe disease, Schuller-Christian disease and eosinophilic granuloma of bone. All these conditions have in common focal accumulations or large macrophages in various organs. These cells often contain cholesterol, especially in the more chronic forms of the condition, but this is apparently secondary (Ornvold, Nielsen and Clausen, 1985).

*Eosinophilic granuloma of bone*

Solitary eosinophilic granuloma is frequently localized in the temporal bone of children and the presenting symptoms and signs may be interpreted as chronic otitis media
(Friedmann, 1974). There is discharge from the ear, and polypoid granulations may be found in the external auditory meatus. In other cases, the granuloma presents as a painful, bony swelling infiltrating the postauricular area and it has to be distinguished from a malignant neoplasm. Radiologically, an area of destruction may be noted.

**Histopathology**

A network of proliferating histiocytes encloses large numbers of eosinophils containing Charcot-Leyden crystals. There are occasional foam cells or xanthomatous cells, accompanied by multinucleated giant cells. Recently S-100 protein has been recognized in the cytoplasm and in the nuclei of the proliferating histiocytosis X cells of eosinophilic granulomata. Although the demonstration of Birbeck granules by electron microscopy is considered to be diagnostic for histiocytosis X, the immunohistochemical detection of S-100 protein can serve as a helpful marker.

**Sensorineural deafness and otosclerosis**

Large otosclerotic foci may reach the cochlea and damage the spiral ligament; Kelemen and Linthicum (1969) suggested a correlation between the atrophy of the spiral ligament and the extent of the sensorineural hearing loss, subsequently confirmed by others. Schuknecht and Barber (1985) have cast doubt on the significance of the involvement of the cochlear endosteum on inner ear function. However, they reported one case where they accept that otosclerosis has resulted in sensorineural deafness without stapes fixation.

**Immunology**

Immunological mechanisms may play an aetiological role in ear diseases, many of which have been considered to be of idiopathic nature (Arnold, Altermatt and Gebbers, 1984). Various cellular constituents of the immune system, as well as immunoglobulines, have been identified within the inner ear, suggesting that it may possess an active immune system. While it is possible that many of the idiopathic diseases will eventually prove not to be immunologically mediated, the result of the intensive investigations carried out will assist in a better understanding of some of the basic mechanisms of host immunity involved in ear disease.

**Miscellaneous infective and neoplastic causes of deafness**

Purulent labyrinthitis complicating acute or chronic otitis media and purulent meningitis may lead to partial or complete ossification of the cochlea.

Schwannomata may form satellite tumours in the cochlea and various malignant neoplasms can spread to the cochlea for example rhabdomyosarcoma, malignant paraganglioma, malignant melanoma, malignant lymphoma. Leukaemic deposits may occur.

(The so-called acoustic neuroma is a misnomer but, because of custom and surgical practice, is being used throughout this work. The most precise histopathological term is vestibular schwannoma as it most commonly arises from the Schwann cells of the vestibular
division of the eighth cranial nerve. Strictly speaking a neuroma is a non-neoplastic overgrowth of nerve fibres, Schwann cells and other components of scar tissue.)
Chapter 5: Pathology of the vestibular system

Richard R. Gacek

Knowledge of the pathophysiology of vestibular disorders is essential for a logical accurate evaluation and management of the vertiginous patient. The diagnosis of vestibular system disease, particularly of peripheral disorders, depends primarily on a carefully obtained history with some assistance from tests of hearing function and vestibular sensitivity (caloric, positional tests). Radiological tests (computerized tomography, magnetic resonance imaging) are helpful in the evaluation of neoplastic and inflammatory disorders which affect the labyrinth, eighth cranial nerve and central nervous system (posterior fossa). A reliable body of information necessary to derive an accurate diagnosis of such disease comes from the study of temporal bones from patients with vestibular disorders.

Vertigo or dysequilibrium is a result of an asymmetry in the peripheral or central portions of the vestibular system. The severity of the dysequilibrium depends on the magnitude and speed of onset of the asymmetry. Compensatory mechanisms usually correct for small asymmetries, thus rendering the patient almost asymptomatic. However, recurrent and progressive asymmetries produce troublesome vestibular symptoms. Since other sensory modalities also participate in spatial orientation, pathologies involves the visual, proprioceptive systems, cerebellum and reticular formation may also be responsible for dysequilibrium. However, the present discussion will be limited to pathologies involving the input from vestibular labyrinthine sense organs which project to the brainstem forming important motor reflex connections. The asymmetries in the vestibular pathway may be located in the sense organ, the first order vestibular neuron, the vestibular nuclei and their connections to the extracocular muscles, contralateral vestibular nuclei, and the vestibulocerebellar and the vestibulospinal tracts. It is appropriate to discuss these pathologies at the peripheral and central levels. A number of clinical reports have emphasized that the majority of clinical disorders producing vertigo are located peripherally, that is in the sense organ or the first order vestibular neuron. Central vestibular pathways are less frequently responsible for dysequilibrium.

Peripheral vestibular system

Significantly more information is available about the pathology affecting vestibular sense organs and their nerve supply than any other segment of the vestibular pathway. The vulnerability of the peripheral vestibular system to various intrinsic and extrinsic pathologies along with a more complete histopathological documentation of these disorders are responsible for our present level of knowledge. Pathology in the peripheral vestibular system produces clinical symptoms by significant alteration of the action potentials directed through the vestibular nerve into the brainstem. It may be useful therefore to subdivide further the peripheral pathologies into those that affect the sense organ and those that affect the first order neuron. A helpful approach for discussing these for diagnostic and therapeutic reasons, is from the viewpoint of the pathophysiological mechanism responsible for vestibular asymmetry.
End organ pathology

Mechanical stimulation

Several pathological situations may be responsible for recurrent or chronic dysequilibrium by mechanical stimulation of the vestibular sense organs in an unphysiological fashion. Essentially this mechanism produces an unphysiological change in the action potentials leading from a specific end organ by such mechanical stimulation. There are several well known clinical examples of this form of pathology.

Erosion of the bony labyrinth

Erosion of the bony labyrinth capsule by cholesteatoma may occur as a result of pressure from the enlarging sac and/or a chemical process of bone erosion probably mediated through collagenolytic enzymes (Abramson, 1969; Abramson and Gross, 1971). When fenestration of the bony labyrinth capsule has occurred, an opportunity for the transmission of pressure from the ear canal to the membranous labyrinth is present. True fistulization of the perilymphatic space and the middle ear space through such bony fistulae is extremely rare. Of course, the transmission of positive or negative pressure in the ear canal thereby displacing the cupula of the fenestrated bony canal will activate the vestibulo-ocular reflex accompanied by the symptoms of rotatory vertigo. The lateral, superior and posterior semicircular canals may be involved by this pathology in decreasing order of frequency (Ritter, 1970; Gacek, 1974). The bony wall of the cochlea may also be eroded or fistulized by cholesteatoma or chronic osteitis. Such erosion is usually in association with fistulization of the bony vestibular labyrinth and is manifested by a sensorineural hearing loss which may assume a descending or flat threshold pattern. The most frequent location of erosion of the cochlear wall is over the basal end (promontory) (Gacek, 1974). Since fistulization of the cochlear wall is not indicated by a specific diagnostic test, the condition is usually recognized during surgery for cholesteatoma; it should be suspected in all cases undergoing surgery for extensive disease.

It should be mentioned that along with the bony fistulization of the labyrinth capsule, varying degrees of a localized inflammatory process occur along the endosteal membrane and perilymphatic space adjacent to the fistula. Undoubtedly such inflammatory reactions are also responsible for dysequilibrium, in addition to the vertigo produced by activating the fistula mechanically. Therefore, this pathological circumstance has an inflammatory as well as a mechanical mechanism.

Since the cholesteatoma membrane is pathological tissue, surgical removal is a desirable goal. A general rule suggests that the cholesteatoma matrix can usually be removed safely from a small fistula (< 2 mm) without tearing the underlying endosteal membrane (Gacek, 1974). Safe removal of the cholesteatoma is usually not possible over a larger fistula because of the greater duration of the pathological erosion, with a greater degree of adherence by fibrous tissue to the membranous labyrinth. However, this is not an inviolate rule.

Hennebert's sign

A positive vestibulo-ocular response with clinical symptoms may also occur in the presence of a normal tympanic membrane and middle ear space when positive or negative
pressure is applied to the tympanic membrane. Dysequilibrium and ocular deviation in the absence of clinical middle ear disease is referred to as Hennebert's sign and can be explained on the basis of mechanical stimulation of vestibular sense organs by depression and withdrawal of the stapes footplate in the oval window (Nadol, 1977). The mechanical stimulation depends on distension of the membranous wall of vestibular sense organs especially the saccular wall, which may contact the undersurface of the stapes footplate. A pushing or pulling effect on the membranous walls by the footplate initiates the mechanical displacement. Contact with other vestibular sense organs (cristae ampullaris) may then allow transmission of pressure introduced through the ossicular chain producing vestibular stimulation and ocular deviation.

**Ossicular stimulation of the vestibular sense organs**

Mechanical stimulation of the vestibular sense organs may occur as a result of a stapedectomy procedure used to correct the hearing loss caused by otosclerosis. Because the utricular macula lies close to the oval window in the vestibule, it may be contacted by a prosthesis which extends excessively beyond the level of the window. Particularly in the case of the piston type prosthesis which must be inserted beyond the level of the window to prevent refixation by bony and fibrous tissue, an excessively long prosthesis may make contact with the utricular macula. Depression of the incus during surgery while the patient is under local anaesthesia can be used to determine the proper length of the prosthesis. The long prosthesis syndrome is usually manifested by ataxia exacerbated by the Valsalva manoeuvre, heavy lifting or bending over, and often takes the form of dysequilibrium or ataxia rather than rotatory vertigo. Unrelieved mechanical stimulation by a stapes prosthesis in this manner may ultimately result in a sensorineural hearing loss because of the traumatic labyrinthitis which is produced.

**Cupulolithiasis**

Cupulolithiasis is a well-known form of pathology responsible for paroxysmal positional vertigo (type III Aschan). The accumulated histopathological evidence indicates that the posterior semicircular canal is responsible for the vertigo and nystagmus produced in the head down position with the Hallpike manoeuvre (Gacek, 1985). This nystagmus is rotatory and directed toward the undermost ear (clockwise with left ear down, counter-clockwise with right ear down) which is visible with the unaided eye 1-3 seconds after the provocative position has been assumed. The duration of nystagmus is short (20-25 seconds), reappears briefly in reversed direction when the sitting position is resumed and fatigues on repeated provocation (Hallpike, 1949). The neural pathways from the posterior canal sense organ which input to the brainstem and extraocular muscles explain the direction of nystagmus provoked in this position by a gravity sensitive cupula and also that resulting from selective ablation of the innervation of the posterior canal crista.

Histopathological observations (Schuknecht, 1969; Schuknecht and Ruby, 1973) of the posterior canal crista in patients with benign paroxysmal positional vertigo revealed basophilic deposits embedded into the cupula of the posterior semicircular canal of the undermost ear in the provocative position. Presumably these deposits are derived from the otoconial blanket located over the utricular macula, the probable source for otoconia in the pars superior of the labyrinth. These otoconia are thought to be dislodged from the utricular macula as a result of
head trauma, acute and chronic inflammatory conditions, ageing, or surgical insult to the labyrinth. The otoconia gravitating into the most dependent portion of the labyrinth (that is posterior canal ampulla) are most likely to become embedded into the cupula of the posterior canal rendering it gravity-sensitive during the positional test. Clinical proof that the posterior canal crista is responsible for the symptomatology in this syndrome is available in the form of the complete relief afforded by selective denervation of the posterior canal in the undermost ear (Gacek, 1985). Experimental evidence that increasing the specific gravity of the cupula allows it to respond to gravity has been produced by using deuterium oxide to increase the specific gravity of the cupula (Money and Myles, 1974). In both the experimental animal and human subjects, this resulted in positional nystagmus of the peripheral type.

**Inflammation**

Inflammation of the labyrinth is termed labyrinthitis and may be classified as either bacterial or viral. Bacterial labyrinthitis may occur as an extension of infection from the middle ear space or the intracranial cavity. Acute or chronic bacterial otitis media may extend into the labyrinth either through a fistula of the bony labyrinth associated with cholesteatoma, or via the round window membrane or oval window. Suppurative labyrinthitis may also occur as an extension of bacterial meningitis along the fluid pathways that connect the subarachnoid space and the perilymphatic space of the cochlea; these are the cochlear aqueduct or the cribrose area in the base of the modiolus of the cochlea.

Bacterial labyrinthitis can be classified into four stages (Schuknecht, 1974a):

1. acute or toxic (serous)
2. acute suppurative
3. chronic suppurative
4. fibrosseous.

The acute toxic or serous form of labyrinthitis will occur as a result of chemical changes in the perilymphatic space caused by a toxic or suppurative process which impinges on a membrane barrier of the labyrinth, such as the round window membrane, or the membrane covering a bony fistula. During this stage, chemical changes in the perilymphatic space may occur without the invasion of bacterial organisms and the inflammatory cell component which accompanies bacterial invasion. Although vertigo with nystagmus may be present at this stage, the disturbance in vestibular physiology is reversible if the toxic (inflammatory) process adjoining the vestibular labyrinth is controlled medically or surgically.

The second stage of acute suppurative labyrinthitis develops when invasion of the perilymphatic space by bacterial organisms has occurred with an accompanying response from the host organism in the form of inflammatory cells and fibrocytes. At this stage, irreversible destruction of auditory and vestibular function has occurred and the goal of treatment is to control the extension of infection so that invasion of the subarachnoid space is prevented. Adequate treatment with chemotherapeutic agents may suffice to control acute suppurative disease, but surgical drainage may also be necessary.

The third stage in suppurative labyrinthitis is the chronic stage where involvement of the labyrinth by bacterial organisms with an inflammatory tissue response has occurred over
a long period of time usually as an extension of chronic inflammatory middle ear and mastoid disease. Complete irreversible loss of vestibular and auditory function invariably occurs and the primary goal is to eradicate the inflammatory process in order to prevent intracranial extension.

The final or healed stage of suppurative labyrinthitis is the fibrosseous response that is generated by the host organism as the inflammatory process has been successfully controlled. At first, a dense fibrous tissue response occurs to obliterate the labyrinthine spaces with a resultant complete loss of auditory and vestibular function and then ultimately calcification and osteoneogenesis may occur to obliterate some or all of the labyrinthine spaces (labyrinthitis ossificans).

The most common bacterial organisms responsible for acute serous or suppurative labyrinthitis are pneumococci, streptococci, and Haemophilus influenzae, while the chronic form is caused by a mixture of Gram-negative bacilli (Pseudomonas, Proteus, Escherichia coli).

A more common form of labyrinthitis is that which is seen as a result of invasion by viral agents (Bordley, Brookhauser and Worthington, 1972). Viruses such as mumps, the influenza viruses, adenoviruses and other viral agents have been associated with an acute disturbance of auditory and vestibular function manifested as sustained vertigo and nystagmus lasting 3-5 days with a gradual lessening of the spontaneous nystagmus and vagal symptoms. As these symptoms abate and the patient recovers balance by use of the compensatory mechanisms, varying degrees of residual permanent loss of auditory and vestibular function may be seen. The viraemia reaches the fluid pathways of the labyrinth either directly from the bloodstream or by way of the subarachnoid space. The viral agents probably affect the structures located within the scala media and the sense organs of the vestibular labyrinth (Karmody, 1983). Hair cells of the organ of Corti as well as the strial vascularis and spiral ganglion may be affected by the viral infection. Cystic degeneration, hair cell loss, and round cell infiltrates are the characteristic findings in the end organs of both the auditory and vestibular labyrinth.

Of course, viral labyrinthitis is beyond the presently available therapeutic management programmes. However, steroids have been shown to be of some benefit to hearing recovery in those patients where the loss is not greater than 90 dB (Wilson, Byl and Laird, 1980). Recovery from vestibular symptoms after viral labyrinthitis is gradual and depends primarily on compensatory mechanisms involving the visual, proprioceptive and cerebellar pathways. Fortunately, viral labyrinthitis is usually unilateral and therefore function of the contralateral ear is sufficient to enable a patient to manage reasonably well.

Degeneration

Degeneration of the sensory cells of the vestibular sense organs is associated with vestibular symptoms and eventually may lead to a loss of vestibular sensitivity. Since the hair cell is the transducer by which the mechanical stimulation of the sense organ is transformed into an electrical impulse (action potential) in the vestibular nerve fibres, deterioration of these sensory cells is important in the normal function of the vestibular apparatus. Two well-known causes of vestibular sensory cell degeneration are ototoxic drugs, and the ageing process.
**Ototoxicity**

Most therapeutic agents, particularly the aminoglycosides, that are harmful to the labyrinth will cause degeneration of the vestibular sensory cells as well as severe toxic effects on the organ of Corti. Streptomycin (McGee and Olszewski, 1962; Wersall and Hawkins, 1962) and gentamicin (Lundquist and Wersall, 1967) are unique because of their ability to affect the vestibular hair cells before affecting those of the organ of Corti. Therefore, these drugs are potent vestibulotoxic agents. Since the hair cells are surrounded in a perilymph fluid environment, blood-borne chemicals will reach the sensory cells of the vestibular and auditory neuroepithelium by way of perilymph which is a derivative of blood. A large number of animal experiments supported by clinical trials in patients treated for vestibular disorders (Schuknecht, 1957) have demonstrated that streptomycin sulphate administered parenterally will cause degeneration of the hair cells of the cristae and the maculae of the labyrinth. This effect will be manifested clinically by ataxia after approximately 20-25 g of streptomycin and will usually result in a loss of vestibular function as measured by absence of the vestibulo-ocular reflex at 30-40 g total dosage. If the streptomycin is discontinued at the point where the vestibulo-ocular reflex is absent following a strong ice-water stimulus, no auditory deficit will occur. Therefore this method of destroying vestibular hair cells is useful in the management of patients with disabling Ménière's disease or in patients who have Ménière's disease in an only hearing ear. The temporal bones of patients treated with streptomycin sulphate have demonstrated almost complete loss of vestibular hair cells in the cristae with a partial loss in the maculae. The vestibulotoxic effect therefore appears to be more severe on the sense organs of the semicircular canals. Patients who have been treated with streptomycin sulphate and have bilateral vestibular hair cell ablation, compensate well, not only because of other equilibrium systems, but also because residual hair cell function in the maculae serve as an important vestibular input.

**Ageing**

The ageing process probably has a degenerative effect on the vestibular sense organs, although direct histopathological documentation of this effect has not been presented. The probability of this effect is based on clinical experience, animal experiments, and some brief reports of ageing effects in the human sense organs (Schuknecht, Igarashi and Gacek, 1965; Johnsson, 1971). Clinical experience based on older patients often reveals complaints of dysequilibrium either of a rotatory or positional nature that occur periodically, particularly with rapid changes in position. Nevertheless, tests of vestibular function, auditory function and radiological tests are usually normal for age in these patients. It seems reasonable to suspect pathology in either the peripheral or central nervous system. However, in many aged patients with dysequilibrium the absence of other central nervous system abnormalities points toward a peripheral aetiology. Animal studies have revealed changes (loss or deformed otoliths) in the otoconial blanket, and the accumulation of lipofuchsin pigment within the sense organs of the vestibular labyrinth. This pigment is known to accumulate with age. Degeneration of the vestibular neurons and sensory cells as well as the make-up of the otoconial blanket of the macular sense organs occur in the ageing ear. The syndrome of cupulolithiasis is known to occur in the aged patient probably as a result of loss of otoconia from the utricular macula leading to benign paroxysmal positional vertigo. In addition to the gravity-sensitive change in the cupula of the posterior canal sense organ, the loss of a significant portion of the otoconial blanket of the utricular macula prevents the utricle from exerting an inhibitory effect.
on the semicircular canal input, thereby allowing an increased neural input from the excited crista. These clinical and histopathological observations point to ageing degenerative processes affecting the vestibular system similar to that in the auditory sense organ with increasing age.

**Trauma**

Trauma to the temporal bone and the vestibular sense organs may occur in several forms. Usually the injury results from fracture through the bony labyrinthine capsule or disruption of the fibrous and bony barriers in the oval or round windows of the labyrinth. Before discussing these categories of direct and indirect trauma to the vestibular labyrinth, it should be noted that injury to the vestibular labyrinth with clinical symptoms may occur in the absence of any disruption of the bony vestibular labyrinth. Labyrinthine concussion as a result of head injury is a well-known clinical phenomenon resulting in dysequilibrium, vertigo and positional vertigo (Barany, 1921; Dix and Hallpike, 1952). The histopathology of this injury is not well documented because of the absence of temporal bone material procured at the time of such injury. However, experimental evidence indicates that injury to the otoconial blanket of the macular sense organs with disruption of otoconia is one effect that follows concussion (Schuknecht, 1962). A release of a significant number of otoconia which then become embedded into the posterior canal cupula may produce the condition known as cupulolithiasis. Furthermore, bleeding into the perilymphatic space is known to occur following head blows in the experimental animal (Schuknecht and Davison, 1956). The chemical change in the perilymphatic fluid resulting from blood causing a chemical labyrinthitis is also a possible explanation for dysequilibrium.

**Temporal bone fractures**

Temporal bone fractures are divided into longitudinal and transverse. Although the more common (80%) longitudinal fracture frequently involves the middle ear, ossicular chain, and facial nerve canal, it does not usually directly involve the vestibular labyrinth. However, transverse fracture of the petrous portion of the temporal bone as a result of severe injury to the base of the skull frequently produces a fracture line through the bony labyrinth and/or the internal auditory canal (Stenger, 1909). This occurs because it is the weakest point in the petrous segment of the temporal bone. The fracture through the vestibular labyrinth will produce the clinical signs of severe labyrinthine injury with vertigo and a sustained spontaneous nystagmus which gradually resolves over the period of several days to a week. The injury to the blood supply and the membranous structures of the labyrinth results in a degeneration of the vestibular sense organs and ultimately in fibrosseous obliteration of the vestibular labyrinth.

Vestibular symptoms gradually subside as the loss of vestibular and auditory function becomes complete. If residual vestibular function is present, it may be responsible for persistent dysequilibrium. Complete ablation in the form of labyrinthectomy or vestibular nerve section may be required to relieve symptoms. An unusual, but potentially significant long-term complication of temporal bone fracture which extends through the external auditory canal is cholesteatoma which develops from entrapped stratified squamous epithelium in the fracture line. Such cholesteatomata may reach considerable size eventually destroying both labyrinthine and facial nerve function.
**Surgical fistulization**

Surgical fistulization of the vestibular labyrinth usually involves the lateral semicircular canal prominence. Such fistulization is caused by inadequate awareness of landmarks in a temporal bone obscured not only by pathology, but also by a poorly developed air cell system. Should such injury occur, a serous and serofibrinous labyrinthitis with ultimate degeneration of the vestibular and auditory sense organs will follow if preventive measures are not taken (Altmann, 1946). These preventive measures may be a form of firm sealing of the surgical bony fistula using bone wax or tissue to prevent a persistent communication between the fluid spaces of the labyrinth and the middle ear.

**Direct penetrating injury**

Direct penetrating injury to the oval window may occur from a slender instrument introduced into the ear canal and through the tympanic membrane. Such accidental introduction of a penetrating instrument may sublux or fracture the stapes footplate producing an oval window to middle ear fistula. The perilymphatic fistula results in a serous and serofibrinous labyrinthitis with various degrees of dysequilibrium and vertigo. The dysequilibrium gradually subsides even if there is degeneration of the vestibular system. However, auditory function will eventually be lost if the fistula is not repaired as soon as possible after the injury (Arragg and Paparella, 1964).

**Perilymph to middle ear fistula**

A perilymph to middle ear fistula may occur through either the oval or round windows as a result of indirect injury to the window membranes. Such indirect injury occurs as a result of abrupt severe changes in middle ear or subarachnoid space (cerebrospinal fluid) pressure (Pullen, 1972; Goodhill, 1971). Injuries such as these are associated with severe barotrauma, extreme physical exertion or impact noise. Symptoms associated with perilymph fistula may include a variety of vestibular and auditory symptoms and findings. The fistula test is often negative and therefore not always helpful in identification. The persistence of vertigo and nystagmus with or without auditory deficit over a prolonged period of time (1-2 weeks) following an injury associated with sudden pressure changes should raise the suspicion of perilymph fistula. Repair of the fistula is essential to achieve reversal of the serous labyrinthitis before progression to fibrinous or degenerative labyrinthitis has occurred. However, clear identification of a membrane defect by adequate surgical exposure is a prerequisite to accurate diagnosis and successful repair with an appropriately placed tissue graft.

**Vascular injury**

Vascular injury to the vestibular and auditory labyrinth can be divided into those that result from occlusion of the blood supply to the labyrinth and those that occur as a result of excessive bleeding into the labyrinth.
Occlusion of vascular supply

Occlusion of arterial vessels to the vestibular labyrinth can produce degeneration of both the neural and sensory components of the vestibular labyrinth. The best known example of this is occlusion of the anterior vestibular artery (Lindsay and Hemenway, 1956). The clinical manifestations of this event are the acute onset of vertigo which is sustained over several days with spontaneous resolution. Loss of function of the sense organs supplied by the superior division of the vestibular nerve occurs while hearing remains unaffected if cochlear branches are not occluded.

The histopathology of this condition shows degeneration of the superior division of the vestibular nerve and its branches along with the sense organs supplied by the superior vestibular division. Although complete compensation of this partial vestibular deficit usually occurs, persistent vestibular symptoms in the form of paroxysmal positional vertigo may result if the otocorial loss from the utricular macula is large and becomes embedded into the cupula of the posterior canal.

Excessive bleeding into the labyrinth

Excessive bleeding into the vestibular labyrinth has been documented as a result of subarachnoid haemorrhage or spontaneous intralabyrinthine bleeding secondary to a major blood dyscrasia. Massive bleeding into the subarachnoid space along with increased subarachnoid pressure may force significant amounts of blood elements into the perilymphatic spaces of both the vestibular and the auditory labyrinth along the communicating channels between perilymph and cerebrospinal fluid (Perlman and Lindsay, 1939; Holden and Schuknecht, 1968). These channels are the cochlear aqueduct, the cribrose area of the cochlea and other channels that surround the vestibular nerve fibres as they penetrate the otic capsule. Massive bleeding into the perilymphatic space is responsible for sustained dysequilibrium and hearing loss probably as a result of a chemical alteration in the perilymphatic environment surrounding the vestibular and auditory nerve fibres.

Bleeding into the perilymphatic space may also occur as a result of spontaneous haemorrhage associated with a blood dyscrasia. A well known example of such haematological disorder is leukaemia, where extensive bleeding into the perilymphatic spaces of the vestibular and auditory labyrinth may cause sustained vertigo and nystagmus with loss of auditory function (Schuknecht, Igarashi and Chasin, 1965). The ultimate loss of labyrinth function resulted from the chemical labyrinthitis caused by the massive infusion of blood elements in the perilymphatic compartments.

Neoplasia

Neoplasia originating in the vestibular labyrinth has been reported in the form of neural tumors or schwannomata arising from the peripheral branches of the vestibular nerve or the cochlear nerve within the bony labyrinth. Intralabyrinthine neuromata (schwannomata) have been described by several authors (Wanamaker, 1972; Stewart, Liland and Schuknecht, 1975; DeLozier, Gacek and Dana, 1979). Unlike the intracanalicular form of neuroma, those of the intralabyrinthine vestibular type produce significant vestibular symptoms resembling those seen in Ménière's disease. Recurrent episodic vertigo and fluctuating sensorineural
hearing loss have been the usual clinical symptoms associated with this entity. The preoperative clinical diagnosis of a surgically proven intralabyrinthine neuroma has been Ménière's or atypical Ménière's disease.

The histopathological picture consists of a schwannoma arising from the myelinated labyrinthine segments of the vestibular and auditory nerves which then expands to occupy the perilymphatic compartment of the vestibule. The tumours which arise from the cochlear nerve proliferate into the scale tympani but are also associated with episodic vertigo and sensorineural hearing loss. The episodic vertigo may be the result of chemical changes produced by the tumour which then affect the vestibular nerve fibres. It is also possible that the episodic vertigo is a result of progressive endolymphatic hydrops caused by tumour obstruction of the drainage system (ductus reuniens). Endolymphatic hydrops has also been observed in the temporal bones containing an intralabyrinthine neuroma. Since the vestibular ganglion is remotely located in the internal auditory canal and therefore not affected by the enlarging tumour, the vestibular nerve to the brainstem remains capable of transmitting pathological input thereby accounting for the severity of vestibular symptoms with this form of neuroma.

Other forms of neoplasia which may involve the labyrinth include malignancies such as squamous cell carcinoma or adenocarcinoma which may destroy the bony otic capsule and eventually affect the vestibular labyrinth. However, the otic capsule is generally resistant to neoplastic invasion from an extrinsic source and is violated only late in the course of metastatic disease.

Metabolic alteration

This category includes vestibular pathologies which result in labyrinthine symptoms because of chemical or ionic changes in the fluid environment of the labyrinth, namely the perilymphatic and endolymphatic compartments. Normal function of the labyrinth depends on the maintenance of normal ionic and chemical composition of endolymph and perilymph. The vastly different ionic composition of endolymph and perilymph (endolymph - high in potassium, low in sodium; perilymph - low in potassium, high in sodium) permits a standing potential differential of approximately 120 mV to exist between endolymph and the compartment surrounding the hair cells and nerve fibres (perilymph). An alteration in this chemical composition will lead to dysfunction and dysequilibrium because of a change in the action potentials of the vestibular nerve. Such changes are more likely to occur in the perilymphatic fluid since it is the compartment most easily affected by various inflammatory or traumatic insults to the otic capsule or its natural fenestrae (oval and round windows). Furthermore, this is the fluid environment which is critical for normal hair cell and vestibular nerve function.

Common examples of an alteration in perilymph composition affecting vestibular physiology are:

(1) the serous labyrinthitis which occurs following oval window surgery (Hohmann, 1962)
(2) sensorineural hearing loss with vertigo associated with chronic inflammatory disease in the round window niche.

Following stapedectomy, dysequilibrium (especially positional) and sensorineural hearing loss are common for several days. Gradual resolution of symptoms with return of cochlear function parallels the readjustment in clinical changes produced by the surgery. A similar resolution of labyrinthine symptoms occurs when chronic inflammatory middle ear disease is surgically controlled. The term 'serous labyrinthitis' is used to describe such reversible forms of labyrinthine irritation.

A second example of labyrinthine physiology distributed by chemical alteration in the fluid compartments is that responsible for the clinical symptoms of Ménière's disease. It is now established that the pathological correlate of Ménière's disease is progressive endolymphatic hydrops as a result of endolymphatic sac dysfunction. This pathology has been demonstrated in human temporal bone material (Hallpike and Cairns, 1938; Lindsay, 1942; Schuknecht, Benitez and Beekhuis, 1962 as well as in the experimental animal (Kimura, 1967; Schuknecht, Northrop and Igarashi, 1968). The progressive endolymphatic hydrops may require various time intervals in different species to develop following sac dysfunction (destruction). Eventually progressive distension of the endolymph compartment leads to disruption of the membranous walls of either the pars inferior or the pars superior of the labyrinth. Theoretical (Lawrence and McCabe, 1959; Dohlman, 1965), as well as experimental evidence (Silverstein, 1970), indicates that these events permit release of high potassium endolymph which drastically alters the ionic composition of perilymph by raising the potassium level. High potassium levels in the perilymph diminish the standing action potentials in the vestibular nerve resulting in a sudden asymmetry of input to the vestibular nuclei. Clinically these changes are manifested by dysequilibrium and nystagmus. After the membrane breaks heal, ion composition in perilymph gradually returns to a normal level. Nerve action potentials also recover to a normal pattern resulting in symmetry of input to the brainstem. The resolution of vestibular symptoms follows.

The sensorineural hearing loss which occurs in Ménière's disease can be accounted for by a similar pathophysiological mechanism. Early in the development of endolymphatic hydrops when hearing loss is the earliest presenting symptom, a low frequency sensory pattern of loss is seen. The accumulation of endolymph in scala media with the gradient being greatest at the apical turn and less at the basal turn is consistent with the ascending threshold elevation pattern. Furthermore, changes in endolymphatic volume are consistent with the fluctuations in threshold sensitivity which are characteristic of Ménière's disease. Long durations of endolymphatic hydrops with episodic vertigo are commonly associated with increased sensorineural hearing loss frequently with speech discrimination loss. Although light microscopic evaluation of the organ of Corti fails to reveal corresponding sensory lesions to account for the sensory and neural deficits, degeneration of apical spiral ganglion cells has been observed in Ménière's disease (Lindsay, Kohut and Sciarra, 1962). It seems possible that ultrastructured degenerative changes in auditory nerve terminals within the organ of Corti may also help to explain some of the permanent neural auditory deficits (speech discrimination loss) seen in later stages of the disease. Such nerve terminal injury could result from repeated potassium intoxication following membrane ruptures of pars inferior.
In a similar way, morphological changes in terminal portions of vestibular neurons may occur following repeated insults from potassium contamination of the surrounding perilymph. Degeneration of vestibular ganglion cells has not been observed in temporal bones from patients with Ménière's disease. However, it is well known that vestibular ganglion cells do not degenerate readily following injury to their axonal processes while cochlear ganglion cells are very susceptible to such injury. Therefore, the decreased vestibular sensitivity often seen later in the course of Ménière's disease may be explained by the ultrastructural morphological changes in peripheral terminal portions of vestibular neurons.

**Neural (first order vestibular neuron) pathology**

**Inflammation**

The vestibular ganglion located in the internal auditory canal may be affected by various viral agents resulting in the condition called vestibular neuritis (neuronitis). Vestibular neuritis is manifested clinically by a sudden onset of sustained vertigo and dysequilibrium accompanied by a spontaneous nystagmus lasting from 3 to 7 days followed by gradual resolution. These vestibular signs and symptoms usually occur in the absence of involvement of the auditory system, thus supporting the supposition that the selective involvement of the vestibular system is extralabyrinthine, that is at the vestibular nerve level. Clinical supporting evidence that viral agents are responsible for this condition is based on epidemiological evidence of an increased incidence of this vestibular syndrome during an epidemic of viral infections and clinical evidence than an upper respiratory viral disorder frequently precedes the vestibular syndrome (Stahle, 1966; Coats, 1969).

Vestibular neuritis may take one of two clinical forms - acute or chronic. The acute form is manifested by a single prolonged vestibular disorder which does not recur after resolution. The chronic form includes those patients who have recurrent vestibular attacks without hearing loss following the initial episode (Dix and Hallpike, 1952). These recurring attacks of episodic vertigo may be of varying duration. Although the vestibular attacks usually last one or more days, they may occasionally resemble the original episode. Nevertheless, the episodes are longer in duration than the attacks which are observed in Ménière's disease. The clinical diagnosis is based upon a history of a preceding viral episode, the length of the attacks, the exclusion of auditory symptoms and a reduced vestibular sensitivity in one ear in the presence of normal hearing. Although vestibular neuritis is usually unilateral, bilateral vestibular neuritis may occur in a small number of cases.

The histopathological observations in this disorder demonstrate degeneration of the vestibular ganglion and its processes in the presence of a normal auditory end organ and nerve. In addition to the reduced number of vestibular ganglion cells and nerve fibres, a round cell infiltrate is frequently observed surrounding the vestibular nerve fibres in the internal auditory canal. Treatment of vestibular neuritis may be necessary only for the chronic form. A progressive degeneration of the vestibular nerve in the chronic form will usually permit episodes of diminishing severity which may be managed non-surgically. However, occasionally severity of symptoms and the magnitude of disability may justify selective vestibular ablation in a particular patient.
Degeneration

Degeneration of the vestibular nerve may be caused by non-inflammatory agents. Demyelination and degeneration of vestibular neurons has been observed in carcinomatous encephalopathy (Schuknecht, 1974b) and diabetes mellitus (Naufal and Schuknecht, 1972). The degeneration of the first order vestibular neuron is responsible for varying severities and forms of dysequilibrium ranging from episodic vertigo to ataxia. A persistent or recurring dysequilibrium frequently having a duration of days or weeks is usually seen with these forms of degenerative neuropathy. The degenerative process may also involve the auditory nerve or may involve primarily the vestibular nerve. Histopathological documentation exists in the form of degeneration of the vestibular nerve and its ganglion in the presence of normal sense organs. Decreased vestibular sensitivity determined by the caloric test is the clinical correlate of this degenerative process. Demyelination of the vestibular nerve has not been documented in demyelinating disorders such as multiple sclerosis and amyotrophic lateral sclerosis where dysequilibrium and ataxia are common clinical features. It is presumed that the vestibular system and other equilibrium modalities are affected centrally in these neurological disorders. Degeneration of the vestibular nerve may also occur as a result of the ageing process on neural and vascular structures of the labyrinth. Patients with degenerative ageing processes affecting the vestibular nerve usually also have sensorineural hearing loss as a result of degeneration of the auditory nerve.

Trauma

Although transverse fractures of the temporal bone usually involve the vestibular labyrinth and the internal auditory canal when vestibular symptoms are present, occasionally the fracture line will skirt the vestibular labyrinth and sense organs and extend into the bony channels through which the vestibular nerve branches reach the sense organs. Fractures which injure vestibular nerve fibres in this way produce a self-limiting form of vertigo, because of the adjustment to partial vestibular ablation that is made by the host. Auditory function will be preserved provided that the fracture has spared the cochlea. No treatment is required for such an injury which is identified clinically by demonstration of a decrease in vestibular function, but the presence of normal auditory function.

Compression

Compression of the seventh and eighth cranial nerves may occur in the internal auditory canal from vascular, neoplastic and osseous disorders.

Vascular

Although it is possible that a large vessel such as the anterior inferior cerebellar artery or a tortuous basilar artery may significantly compress the seventh or eighth nerves in or near the internal auditory canal, this condition probably exists less frequently than it has been clinically reported. A loop of the anterior inferior cerebellar artery resting against the facial and vestibular nerves within the internal auditory canal is a common finding in normal temporal bone specimens, yet dysfunction of these nerves was not a clinical finding in the patients from whom the temporal bones were acquired. Nevertheless, a number of clinical reports (Janetta, 1980) have indicated that a loop of vessel resting on the vestibular or seventh
nerves in the internal auditory canal is responsible for various vestibular and facial nerve symptoms. Relief of these symptoms is purported to follow when the vessel has been dissected away from the nerve structures and cushioned with an intervening sponge implant. Pressure against the nerves in the internal auditory canal by a pulsating vessel which may become more tortuous with age is a possible mechanism by which vestibular symptoms may occur at the neuronal level. Since neural-vascular arrangement is often not associated with clinical symptoms, convincing documentation that such vascular compression is responsible for the clinical disorder must be made carefully with an unbiased approach.

**Neoplasm**

The seventh and eighth nerves may be compressed in the internal auditory canal or cerebellopontine angle as a result of extrinsic compression by a neoplasm from an adjacent part of the temporal bone. Benign expanding tumours arising from the petrous apex (Gacek, 1975; DeLozier, Parkins and Gacek, 1979) (epidermoid, mucocoele, abscess, cholesterol granuloma, neurofibroma, chondroma, meniingioma), or the jugular foramen (Gacek, 1983) (neurofibroma, paraganglioma, meningioma, chondroma) may compress the nerves in the internal auditory canal. The auditory deficit produced is a retrocochlear pattern of sensorineural hearing loss. The pathological correlate is degeneration of cochlear neurons with an intact organ of Corti. Vestibular symptoms vary from intermittent dysequilibrium, to episodic vertigo to positional vertigo. Although the cells of the vestibular ganglion do not degenerate as readily as those of the cochlea, atrophy will eventually occur (years) after compression of their axons.

**Osseous compression**

Compression of the nerves in the internal auditory canal may be produced by disorders of bone metabolism. Sclerosteosis is a rare inherited bone disorder where periosteal bone growth continues and obliterates the bony channels of the temporal bone which carry neural and vascular structures (Nager and Hamersma, 1986). Vestibular and auditory symptoms of eighth nerve compression are similar to those described from neoplastic compression. Decompression of venous drainage channels has been successful in prolonging life in these patients.

It is conceivable that other disorders of bone metabolism (fibrous dysplasia, osteopetrosis) may also be responsible for seventh and eighth nerve symptoms as a result of compression in the internal auditory canal.

A more common association of dysequilibrium and a disorder of the otic capsule is seen in otosclerosis. Vestibular symptoms are frequently present in patients with otosclerosis. The exact pathophysiological mechanism responsible for vestibular symptoms ranging from episodic vertigo to dysequilibrium in this condition which is primarily manifested by a conductive auditory deficit is not known. However, compression of vestibular nerve fibres by the otosclerotic focus as they pass through the otic capsule is a plausible explanation.
Neoplasia

The vestibular nerve may be affected by either benign or malignant neoplasms. The most common benign tumour to involve the nerves contained within the internal auditory canal is the eighth nerve neuroma (schwannoma) which usually arises from the myelinated segment of the vestibular division. Since the schwann cell (myelinated) portion of the eighth nerve is located lateral (distal) to the glial-schwann cell junction, these tumours arise within the internal auditory canal and extend into the cerebellopontine angle when they have filled the canal. Most vestibular neuromata (60-70%) arise from the superior division of the nerve which makes up a majority of the vestibular nerve population. Rarely the neuroma may arise from the cochlear division of the eighth nerve.

These schwann cell tumours are divided into two histological types: Antoni A and B. The Antoni A variety is formed of tightly packed flattened schwann cells the nuclei of which are frequently stacked in layers (pallisading) and with dense cytoplasm forming the substance of the tumour. Surgically these tumours are firm, relatively avascular and well encapsulated. The Antoni B form is made up of plump cells with foamy cytoplasm, loosely arranged with areas undergoing fatty and cystic degeneration. Surgically these tumours appear soft, cystic, somewhat vascular with a thin capsule.

It is not surprising that the vestibular sensitivity test (ENG) is the most frequently abnormal study in the diagnosis of eighth nerve neuroma (Erickson, Sorenson and McGavran, 1965). This is often the case even though vestibular symptoms (vertigo, ataxia, positional vertigo) are usually mild or absent. The relatively mild vestibular symptoms are probably explained by the slow destruction of vestibular neuronal units, thus allowing for compensation by the host. This relationship is emphasized by the observation of a small occult vestibular neuroma in the temporal bones from patients without balance symptoms.

The vestibular neuroma usually presents clinically as a result of effects produced on adjacent nerve structures in the bony internal auditory canal. Of the two nerves in the internal auditory canal, the cochlear nerve is more susceptible to compression. Therefore, the most common clinical deficit is hearing loss and tinnitus (Erickson, Sorenson and McGavran, 1965). The typical hearing deficit produced by nerve compression (retrocochlear lesion) with subsequent degeneration of cochlear neurons is a severe loss in speech (word) discrimination out of proportion to the pure threshold elevation. An additional common pattern is a high frequency pure tone loss which is related to compression of the neurons innervating the basal turn of the cochlea since they are located near the periphery of the cochlear nerve trunk in the internal auditory canal. However, many variations in the audiometric picture of hearing loss may be demonstrated as a result of cochlear nerve compression from the vestibular neuroma. Therefore, additional pathophysiological mechanisms of sensorineural hearing loss may be responsible. Ischaemia of various segments of the end organ secondary to vascular compression in the internal auditory canal by tumour and changes in the perilymph surrounding cochlear nerve fibres and hair cells are two additional abnormalities which may account for sensorineural hearing deficits. Although slow compression of the facial nerve in the internal auditory canal by the tumour results in flattening of the nerve trunk with an ostensible loss of axons, motor paralysis of facial muscles is not a common clinical finding even with large eighth nerve tumours. This paradox is best explained by the fact that surviving motor axon terminal sprout to re-innervate adjacent denervated facial muscle fibres.
over time and provide adequate motor function. Although the neuroma is the most common benign neoplasm to involve the seventh and eighth nerves in the internal auditory canal, other tumours which may also simulate this picture are meningioma, epidermoid, haemangioma, arachnoid cyst, lipoma, granuloma.

Malignant neoplasms may metastasize to the temporal bone in two ways: by haematogenous spread to the marrow space of the petrous apex, and to the internal auditory canal by way of the subarachnoid space. Neoplastic replacements of the marrow in the petrous apex cause deficits of the fifth and sixth cranial nerves early in development and affect the seventh and eighth nerves in the internal auditory canal when they attain large size. However, when malignant tumours spread to the subarachnoid space of the internal auditory canal, facial nerve paralysis and eighth nerve symptoms are frequent and prominent.

The clinical picture produced by involvement of the nerves in the internal auditory canal by malignant neoplasm differs greatly from the clinical presentation of a slow growing benign tumour. Vestibular symptoms are prominent and sustained because of the rapid onset of a significant asymmetry produced when neoplasm destroys significant numbers of vestibular neurons. Sensorineural hearing loss, usually of the typical retrocochlear pattern, accompanies the vestibular deficit. Infiltration and destruction of the facial nerve motor axonal coupling by the malignant tumour cells is manifested by paralysis of the facial musculature. The most common primary malignancies that metastasize to the internal auditory canal are carcinoma of the breast, lung, kidney and prostate gland (Schuknecht, Allam and Murakami, 1968). Carcinoma of the middle ear or nearby nasopharynx may extend into the labyrinth resulting in sensorineural hearing loss and vertigo from a serofibrinous labyrinthitis. Such extension from the middle ear space across the bony labyrinth capsule does not occur readily because of the resistant nature of otic capsule bone. This barrier may be crossed by tumour cells either through the oval or round windows or through a fenestration of the otic capsule.

Central vestibular system

Since a small percentage (less than 10%) of patients presenting with vertigo represent central nervous system pathology (Barber, 1984), the recognition of these disorders is dependent on a strong index of suspicion. The major portion of central vestibular pathways are located in the brainstem and cerebellum so that most central vestibular pathology is located in the posterior cranial fossa (infratentorial). As indicated in the discussion of the peripheral vestibular disorders, pathology affecting the central nervous system may also be of inflammatory, neoplastic, vascular, congenital and degenerative types.

Central vestibular disorders of neoplastic, degenerative or vascular causes usually demonstrate multiple neurological deficits in addition to vestibular symptoms and signs. These additional defects should be documented by neurological consultation. Intrinsic lesions of the posterior fossa (vascular, neoplastic) involve significant portions of the brainstem and frequently affect the nearby nuclei such as the abducens nucleus, the facial nucleus, nucleus ambiguus and the trigeminal nucleus and tracts producing neurological signs which permit a relatively obvious diagnosis. However, early neoplasms of the cerebellum, particularly the cerebellar vermis may initially produce only positional vertigo and nystagmus of the non-fatiguing (type I or type II) type (Gregorius, Crandall and Baloh, 1976). Hearing and vestibular (ENG) tests are usually normal at this early stage. Extrinsic lesions (cerebellar
tumours and cysts, the Arnold Chiari malformation) may compress the brainstem and interrupt vestibulo-ocular pathways within the brainstem or near the surface of the fourth ventricle. Interruption of these pathways may be manifested by unique signs such as downbeat nystagmus, upbeat nystagmus, positional nystagmus, or perverted induced nystagmus. An understanding of the involvement of these pathways is helpful to the diagnosis of central vestibular disorders.

**Positional nystagmus**

Positional nystagmus of central origin is usually of the non-fatiguing variety (types I and III), but occasionally the fatiguing variety (type III) may be associated with central pathology (Harrison and Ozsahinoglu, 1975; Watson et al, 1981). However, usually types I and II are central in origin whereas type III is peripheral in origin. Positional nystagmus is frequently seen in cerebellar lesions particularly when the vestibulocerebellum (flocculonodular lobe) is involved primarily or secondarily by neoplasm. This clinical sign is probably caused by a loss of the inhibitory effect of the cerebellum on the vestibular nuclei where vestibulo-ocular neurons are located.

**Downbeat spontaneous nystagmus**

This form of spontaneous nystagmus may reflect lesions which interrupt the excitatory pathways to the inferior rectus muscle (Baloh and Spooner, 1981). This excitatory pathway which relays the input from the posterior semicircular canal originates from the medial vestibular nucleus in the caudal brainstem, crosses the midline to send its fibre projection in the contralateral medial longitudinal fasciculus and terminates in the trochlear nucleus and the inferior rectus subnucleus of the oculomotor complex. Brainstem lesions, such as vascular infarcts, demyelinating disorders and the Arnold Chiari malformation, have been identified as causes for spontaneous downbeat nystagmus. The mechanism of the downbeat nystagmus is based on an interruption of the excitatory pathway to the inferior rectus muscle. The unopposed contraction of the superior rectus which receives its excitatory input from the anterior semicircular canal by way of the brachium conjunctivum is responsible for the upward drift of the globe while the fast phase in a downward direction represents the compensatory movement. Downbeat spontaneous nystagmus may also be associated with lesions of the cerebellar flocculus as a result of loss of the inhibitory input to the superior rectus at the level of the superior vestibular nucleus.

**Upbeat spontaneous nystagmus**

Upbeat spontaneous nystagmus may result from lesions of the posterior fossa which affect the brachium conjunctivum and other nearby fibre pathways (Nakada and Remler, 1981). This vestibulo-ocular reflex finding is produced by interruption of fibre pathways which carry excitatory input to the superior rectus muscle from the anterior semicircular canal through the brachium conjunctivum by way of the superior vestibular nucleus. Ablation of this input leads to unopposed action of the inferior rectus muscle resulting in a downward drift of the eyes with an upward compensatory fast phase.
Perversion of nystagmus

Perversion of nystagmus may be produced by lesions that compress the vestibulo-ocular pathways near the floor of the fourth ventricle in the caudal brainstem. The vestibulo-ocular neurons serving the medial and lateral rectus muscles, as well as interneurons in the abducens nucleus which project to the contralateral medial rectus are located superficially at this level of the brainstem. When the horizontal vestibulo-ocular pathways are interrupted at this point in the posterior brainstem, the intact excitatory vestibulo-ocular pathways in the brachium conjunctivum and the rostral medial longitudinal fasciculus produce vertical and rotatory eye displacement. Therefore vertical and rotatory nystagmus may be observed instead of horizontal nystagmus when the lateral canal is calorically stimulated.

Internuclear ophthalmoplegia

This distinctive oculomotor deficit is produced when a focal lesion (demyelinating) of the medial longitudinal fasciculus interrupts the projection of the abducens interneurons which excite the contralateral medial rectus subnucleus. This interruption of the abducens interneuron results in a dissociated eye displacement on lateral gaze. It is a frequently observed clinical sign in multiple sclerosis.

Conclusion

The preceding anatomicophysiological discussion of the pathology of vertigo is not intended to represent a comprehensive list of pathologies which affect the vestibular system. This presentation provides a description of the various mechanisms by which the normal physiology of the vestibular system may be disrupted producing dysequilibrium or vertigo. An understanding of the mechanism by which asymmetry in the vestibular system is produced not only facilitates diagnosis but allows for logical management. The examples discussed represent the more common disorders encountered in otoneurological practice. It is appreciated that a significant number of unknown pathologies are seen daily in clinical practice. Further information will be necessary in order to clarify the pathophysiology of these disorders. Such documentation may be represented by observations provided by newer clinical technologies (magnetic resonance imaging), and experimental study in the laboratory animal of vestibulopathophysiology using physiological and morphological (ultrastructural or histochemical) techniques. The emphasis in these experimental studies may be directed toward alterations in the make-up and function of the cupula, otoconia, or the ciliary structures of the hair cells in the vestibular receptors. Temporal bone post-mortem material is still a valuable source because of the insight that it provides to disorders that affect the human vestibular system. The acquisition of temporal bone material should be encouraged for study by both light and electron microscopic techniques.
Chapter 6: Diseases of the external ear

Valentine Hammond

The auricle

Development

(See Volume 1, Chapter 1.)

The auricle develops from the first and the second branchial arches commencing on the 38th day of fetal life. Three nodules of mesenchymal proliferation develop on the margins of each arch and by day 41 these nodules have reached maximum size, moved in a dorsolateral direction and begun to fuse. The auricle is anatomically complete by the 20th week (Melnick and Myrianthopoulos, 1979a). In the fully developed ear, the first arch contributes only the tragus and possibly a little of the anterior crus of the helix. The rest of the auricle is derived from the second arch. It is important to note that the auricle begins to develop at the level of the future upper neck and migrates in a dorsolateral direction as the mandible develops.

Many minor variations in the shape of the pinna occurs. Some of these are constant enough to warrant description. Darwin's tubercle is seen as a small elevation on the posterosuperior part of the helix. This tubercle is homologous with the tip of the mammalian ear. It is usually an inherited condition. Wildermuth's ear is a distinct entity with prominence of the antihelix and an underdeveloped helix and may be associated with other syndromes and with both sensorineural and conductive deafness. Mozart's ear consists of fusion of the helix and antihelix producing a thickened area in the upper part of the pinna. It affected both Mozart and his father and has a dominant inheritance. Not surprisingly at one time it was thought to indicate musical ability. The lobule may be absent, a condition normal in some races (Bushman of Africa and the Indians of Tierra del Fuego) and rarely it may be bifid. Failure of the lobule to separate from the side of the head is more common in females and may occur in all the females of a family (Potter and Craig, 1975). The upper part of the auricle is sometimes adherent to the head. In females and the young, the auricle is covered with very fine velous hairs but in older males coarse hair may appear on the upper margin of the helix.

Hypertrichosis

Excessively hairy ears occur only in males being a Y-linked inherited trait. Hypertrichosis is present in male offspring and siblings of affected families. The hairs are long and black and usually arise from the margin of the helix, first appearing in early adult life. The condition is most commonly seen in India but also occurs in Iran and Italy (Gates and Badhuri, 1961). An excessive growth of hair also occasionally occurs on the tragus, the so-called harbula hirci (Montagna and Giocometti, 1969).
Congenital anomalies of the auricle

(See Volume 6, Chapter 5.)

Apart from the minor variations already described, major anomalies may occur. Arrested development of the mesenchymal nodules may lead to anotia, the total absence of the auricle, or microtia where the pinna is rudimentary and malformed and usually placed lower and more anteriorly than normal. There is an association between these anomalies, meatal atresia and abnormalities of the middle ear; the degree of abnormality of the meatus and middle ear is usually proportional to the external deformity (Jafek et al, 1975). Minor dysplasias of the second arch development produce folding or defects in the helix and, where the antihelix is poorly formed and there is an excess of conchal cartilage, the typical bat ear appearance is produced.

Auricular appendages

Auricular appendages or accessory auricles occur as small elevations of skin containing a bar of elastic cartilage. They may be single or multiple and most commonly occur just anterior to the tragus or ascending crus of the helix, but may extend along a line from the tragus to the angle of the mouth and can be associated with macrostomia. They may also be associated with other congenital anomalies of the first arch. Auricular appendages may be excised but it must be remembered that they may contain bars of elastic cartilage which can extend deep into the underlying soft tissue.

Congenital aural sinuses and fistulae

Congenital sinuses usually occur in the preauricular region along the ascending crus of the helix. Others may open along a line extending from the lower border of the helix to the angle of the mouth. They are blind tracks lined by squamous epithelium. Collaural fistulae have an upper opening in the floor of the external auditory meatus and a lower one at the anterior border of the sternomastoid behind the angle of the jaw. There is an association between pre-auricular sinuses, branchial fistulae and deafness (Melnick et al, 1975; Fitch, Lindsay and Srolovitz, 1976). Both conductive and sensorineural deafness may occur; the former is a consequence of malformation of the ossicular chain and the latter a result of impaired development of the cochlea. Other associated abnormalities include deformities of the auricle, blockage of the lacrimal ducts and facial palsy. Anomalies of the genitourinary tract have also been described. If congenital sinuses and fistulae are causing no symptoms they do not require treatment. However, they may become infected leading to a persistent discharge and sometimes to abscess formation. When this happens they must be completely excised. The operation requires great care as the tract may extend deep into the soft tissues and at times be related to branches of the facial nerve.
Congenital syndromes associated with microtia and deformities of the pinna

(See Volume 6, Chapter 5.)

Numerous syndromes have been described associating microtia with other congenital defects. Some of the more important of these have been well documented by Melnick and Myrianthopoulos (1979b).

1. **The Treacher Collins syndrome**: mandibulofacial dysostosis associated with meatal atresia and deafness (autosomal dominant)

2. **The otomandibular syndrome of Konigsmark and Gorlin**: folding of the pinna, thin external nares, micrognathia and bilateral stapedial fixation (autosomal dominant)

3. **The brachio-otic dysplasias**: a combination of auricular malformation, cervical fistulae, conductive and sensorineural deafness (autosomal dominant)

4. **The LADD syndrome**: the lacrimo-auriculo-dental-digital syndrome of cup-shaped ears with deafness, and anomalies of the digits and the enamel of the teeth (autosomal dominant)

5. **HRA**: the hereditary renal adysplasias with ear malformation; important syndromes in this group include:

   a. **BOR**: the branchio-oto-renal syndrome, combining brachial fistula with meatal atresia and renal dysplasias (autosomal dominant)

   b. dysplastic pinna-hypospadias-renal adysplasia syndrome

   c. dysplastic pinna-polycystic kidney syndrome (autosomal dominant)

   d. the oto-renal-genital syndrome (autosomal recessive).

The most important aspect of these syndromes to the otologist is to emphasize the importance of renal investigations in children demonstrating familial branchial arch syndromes and the early audiological assessment of these children and those with known renal anomalies. Most of these syndromes have an autosomal dominant inheritance but, even so, there is a considerable variation in the manifestations of the syndromes within affected families and among individuals. Melnick and Myrianthopoulos (1979b) in an extensive study of these conditions concluded that the underlying developmental abnormality was probably a breakdown of neural crest integrity resulting in aberrant crest cell migration.

**Potter's syndrome**

This is a well-recognized congenital abnormality of the pinna which is not the direct result of genetic abnormalities affecting the development of the ear. The auricles are large and flat and this may be associated with abnormal limb positioning, pulmonary hyperplasia and compression facies. The syndrome is the result of oligohydramnios where the very small
amount of amniotic fluid present leads to flattening and compression of the pinna. By definition the oligohydramnios is the result of renal agenesis or dysplasia but it may result from loss of amniotic fluid. If the infant survives, the pinna will, in time, return to normal in the vast majority of cases.

**Congenital malformation of extrinsic origin**

The external factors which may affect the development of the fetus and result in abnormalities of the pinna are:

1. drugs
2. X-rays and radioactivity
3. viruses

A variety of drugs has been implicated in the production of congenital anomalies.

1. **Thalidomide**

Microtia may occur in the thalidomide embryopathy and this is often associated with meatal atresia. Anomalies of both the middle and internal ears may be present. Ear anomalies occur when the drug is administered during the first 30-40 days of pregnancy (Takemori, Ishii and Suzuki, 1976).

2. **Hydantoin**

The fetal hydantoin syndrome occurs as a result of the ingestion of this group of anticonvulsant drugs by epileptic mothers during pregnancy and may include dysplasia of the auricles.

3. **Folic acid antagonists**

Auricular abnormalities are also seen following the ingestion of folic acid antagonists such as methotrexate and aminopterin.

4. **Warfarin**

Warfarin may lead to microtia, although the most striking and consistent finding produced by this drug is severe hypoplasia of the nose.

5. **The fetal alcohol syndrome**

The result of high alcohol intake during pregnancy can result in microcephaly, maxillary hypoplasia and joint anomalies, but many of these infants show an abnormality of the pinna with a marked ridge running across the concha due to hypertrophy of the crus of the helix.
 Radiation

Radiation of the maternal pelvis during pregnancy may lead to a higher incidence of congenital malformation of the ear (Jafek et al, 1975).

 Viruses

Maternal viral infections in the first trimester of pregnancy may be responsible for some isolated cases of external ear deformity, but there is no conclusive evidence of this.

 Steeter bands

Steeter or amniotic bands are bands of connective tissue that stretch across the amniotic space and can result in clefts or deformities of the auricle as well as of the face, skull and limbs.

 Congenital tumours

Haemangioma and lymphangioma may be encountered involving the auricle. Dermoid cysts occasionally occur in relation to the pinna, usually just anterior to the helix.

 Trauma to the auricle

(See Chapter 8.)

Accidental trauma to the auricle may result in lacerations, or partial or complete loss. All open wounds of the auricle carry a risk of infection being introduced leading to perichondritis. Wounds should be carefully sutured and antibiotic cover given. Even when the greater part of the auricle has been detached, it has on occasion been successfully resutured into place.

The judicial removal of the auricles for theft was practised in Roman times and persisted in some parts of the world up until the 19th century. Self mutilation of the pinna is widely practised by the insertion of earrings and when this involves the cartilaginous portion of the auricle it carries a definitive risk of perichondritis. Ear piercing unless carried out with scrupulous attention to sterility also carries the risk of spreading viral diseases such as hepatitis and acquired immune deficiency syndrome (AIDS). Septicaemia may also occur (Lovejoy and Smith, 1970) and subacute bacterial endocarditis has been reported following acupuncture to the ear (Lee and McIlwain, 1985).

 Haematoma of the auricle

Haematoma of the auricle is the result of closed trauma and occurs frequently in contact sports such as boxing and rugby football. In the 19th century it was referred to as the sanguineous tumour of the insane as a result of its prevalence among inmates of the asylums and was, therefore, thought to be a stigma of insanity. The condition results from an extravasation of blood between the cartilage and the perichondrium producing a soft doughy
swelling of the pinna. If untreated the blood clot becomes organized and the ear remains permanently thickened, producing the cauliflower ear deformity.

**Treatment**

Cases seen shortly after the injury has occurred may be treated by aspiration through a wide bore needle using aseptic precautions. Cases of longer-standing will require incision and the evacuation of the clot. The incision is placed along the margin of the helix and any clot present is sucked out. Again strict asepsis is essential, for if infection is introduced, perichondritis may occur. Following either aspiration or incision, a firm dressing must be applied to the pinna to prevent recurrence of the haematoma. Should it recur, further aspiration may be necessary.

**Infections of the auricle**

**Impetigo**

This is an infection of the superficial layers of the skin by staphylococci. Vesicles filled with serum arise on a reddish-purple base. Later the vesicles burst to exude serum which dries to form semi-adherent amber crusts. The condition is most commonly seen in young children and may be secondary to the otorrhea of a middle-ear infection.

Although the impetigo may involve the whole auricle it does not extend into the external auditory meatus. Commonly the neck and face are also involved.

**Treatment**

The crusts are removed by bathing with warm sterile saline. The area is then dried and neomycin cream applied. The treatment may have to be repeated daily for several days. If there is otitis media or externa present, this must be treated to prevent re-infection of the skin.

**Erysipelas**

This is a streptococcal infection of the skin producing a raised red oedematous eruption with a characteristically well-defined edge. The auricle becomes intensely red and swollen and the infection spreads into the adjoining skin of the face. There is usually a marked systemic upset with a high temperature and rapid pulse.

**Treatment**

The infection usually responds rapidly to penicillin by injection.

Many generalized skin disorders may involve the pinna but require no separate description.
Perichondritis

Infection of the perichondrium of the auricle most commonly occurs when the cartilage is exposed either by laceration or by surgery. The cartilage may also be exposed as a result of frostbite or burns. Infection may be introduced during aspiration or incision of a haematoma auris. Sometimes superficial infections of the meatus or pinna spread deeply to involve the perichondrium.

In the early stages of the infection, the pinna becomes red and tender. This is followed by a generalized swelling of the pinna and eventually by the formation of subperichondrial abscesses. The pus collects between the perichondrium and the underlying cartilage. The cartilage, deprived of its blood supply, may die. Extensive cartilage necrosis results in a marked deformity of the pinna.

Treatment

Cases of perichondritis should be treated promptly with a broad spectrum antibiotic as the infecting organism is rarely sensitive to penicillin. Pseudomonas aeruginosa is not uncommonly found in these cases. If there is any discharge from the ear a swab should be taken for culture and the determination of sensitivities. Pending information regarding the sensitivity of the organism, treatment should be commenced.

If subperichondrial abscesses form, they should be incised and drained. Incision should be delayed until definite fluctuation can be elicited, as premature incision may result in a further spread of the infection. In relatively rare instances, pain and suppuration may continue despite these measures and gross deformity is inevitable. In such cases, the whole of the auricular cartilage (except that of the helix) must be excised, through a wide incision on the anterolateral aspect of the auricle.

Chondrodermatitis nodularis chronica helicis

This is the name given to small painful nodular lesions which occur on the upper free margin of the pinna and occasionally on the antihelix.

It is more common in men than in women and usually occurs in middle-aged or elderly subjects with outdoor occupations. The condition is thought to be due to exposure to low temperatures causing local vasoconstriction resulting in small foci of avascular chondritis.

The lesion consists of a tender nodule often covered by an adherent crust overlying a small area of exposed necrotic cartilage.

Treatment

Local excision including a small wedge of underlying cartilage results in cure.
**Tophi**

Small subperichondrial deposits of sodium biurate crystals may occur on the pinna in cases of gout. Although rarely troublesome they may occasionally become superficially ulcerated.

Treatment is that of the underlying condition.

**Tumours of the auricle**

**Benign**

Benign neoplasms of the auricle are uncommon. Papilloma, fibroma and chondroma do occur but need no special description.

**Malignant**

(See Chapter 8.)

**Squamous cell carcinoma**

The clinical diagnosis of an epithelioma does not usually present any difficulty. Typically the lesion presents as an indurated ulcer with everted margins. The diagnosis is confirmed by biopsy. The regional lymph nodes may be involved but this is not usually an early occurrence in tumours confined to the auricle.

**Treatment**

Small lesions on the upper half of the auricle can be removed by a wedge incision with a wide margin of healthy tissue and the edges of the defect sutured together. Large lesions and those involving the lower half of the auricle require total excision of the pinna. Extension beyond the pinna will require more extensive surgery and radiotherapy. Involvement of the lymph nodes is an indication for radical neck dissection. Lesions occurring on the upper half of the auricle carry a far better prognosis than those in the lower half.

**Basal cell carcinoma (rodent ulcer)**

Common sites for the discovery of these basal cell growths are the tragus, the border of the helix and the meatal entrance. There is at first the typical raised plaque with a rolled-over edge and tendency to central crusting. Bleeding takes place when the central crust is removed. In late cases, the whole auricle may be destroyed while the underlying bone and parotid may be infiltrated.

Cystic forms are sometimes encountered. They are smooth, often pigmented tumours without any crusting or ulceration, and when small may be confused with naevi.

The regional lymph nodes are not involved.
Treatment

Rodent ulcers of the pinna are best treated surgically, the lesion being excised together with a margin of healthy tissue.

Very small superficial lesions may be successfully treated with radiotherapy. Advanced stages with infiltration of the underlying bone and soft tissue require wide excision and postoperative radiotherapy. With adequate excision, small rodent ulcers carry a very good prognosis. When extensive infiltration of the deep tissues has occurred it may be impossible to eradicate the tumour. The patient will eventually succumb, although the progress of the disease is usually very slow.

Malignant melanoma

The auricle is rarely affected by this form of malignancy. When it occurs it is seen as a nodular pigmented lesion which tends to enlarge rapidly and eventually to ulcerate. Involvement of the regional lymph nodes and distant metastasis may occur when the primary lesion is still quite small.

Treatment

Radical excision of the lesion offers the only prospect of cure. This may involve complete excision of the pinna and an en bloc dissection of the regional nodes. Even with early lesions the prognosis is poor.

The ear lobe crease

This is a diagonal crease running across the lobule and is frequently present in old age. However, in Europe and North America, there does appear to be some association between the presence of the ear lobe crease in young adults and an increased incidence of coronary thrombosis (Kaukola, 1982; Overfield, 1983). A relationship between high serum cholesterol and the ear lobe crease has been demonstrated but biopsies of the crease show no abnormalities such as cholesterol deposition.

Chen et al (1982) found that, while the ear lobe crease was often seen in younger Chinese coronary thrombosis patients, their serum cholesterol levels were inversely related to the presence of the crease.

The ear lobe crease would not appear to be a reliable indicator of an increased susceptibility to coronary thrombosis.

The external auditory meatus

Development

The meatus begins to develop on the 41st day of fetal life at the dorsal end of the first branchial cleft. Ectodermal proliferation extends inwards approaching the expanding middle
ear cavity at about the 70th day and the central cells degenerate to form the meatus (Melnick and Myrianthopoulos, 1979).

**Congenital anomalies**

*(See Volume 6, Chapter 5.)*

The association between some deformities of the pinna and congenital meatal atresia or stenosis has already been noted *(see above)*. Meatal atresia and stenosis can occur in the presence of a normal pinna.

**Acquired meatal atresia and stenosis**

**The cartilaginous meatus**

**Atresia**

A true acquired atresia of the cartilaginous meatus is rare and nearly always traumatic in origin, particularly as a result of gun shot wounds (Conley, 1946). Burns and radiation may also be responsible. Chronic otitis externa often causes stenosis but is very rarely responsible for atresia. Bilateral atresia of the outer meatus following acute otitis externa has been recorded (Marlowe, 1972).

**Stenosis**

Acquired stenosis of the cartilaginous meatus is not uncommon. It can occur as a result of:

1. **Trauma**
   - accidents: lacerations, gun shot wounds
   - surgery: usually the result of mastoid surgery
   - burns: thermal, chemical radiation

2. **Infection**
   - chronic otitis externa

3. **Neoplasia**
   - both squamous cell carcinoma and adenocarcinoma may present as a progressive narrowing of the meatus.

The commonest cause of stenosis is chronic otitis externa leading to progressive fibrosis with narrowing of the canal. Stenosis may also occur at the junction of the cartilaginous and bony meatus in cases of keratosis obturans. The expansion of the bony meatus leads to exposure of the meatal cartilage at its deep attachment. Infection of the
cartilage with granulation tissue formation occurs with subsequent fibrosis and stricture formation.

Treatment

The only effective treatment is a meatoplasty. Repeated dilatation of meatal stenosis rarely produces lasting improvement.

Using a postaural incision, the fibrous tissue and thickened meatal skin are excised but where possible preserving a strip of skin along the roof and floor. The outer part of the bony meatus may be enlarged with burrs but preserving the overlying skin. The outer orifice of the meatus usually needs to be enlarged by excising an ellipse of conchal cartilage and turning back a flap of conchal skin and suturing it in place. The meatus is then packed and allowed to re-epithelialize. Split skin grafts are usually unnecessary.

The deep meatus

In the deep meatus, bony swellings, either osteomata or exostoses, represent the commonest form of stenosis. These are described separately.

Obliterative otitis externa

In this condition there is a progressive stenosis or atresia of the deep meatus. Bonding and Tos (1974) used the term postinflammatory acquired atresia to describe the condition.

There is always a preceding otitis externa and in some cases chronic middle ear infection is present as well. In the majority of cases there is a history of irritation and discharge, intermittent or continuous over a number of years with an increasing loss of hearing. Occasionally, the condition develops rapidly with deafness persisting after a single episode of otitis externa which may have been present for only a few weeks.

In the active phase of the disease the inflammatory changes are usually confined to the deep meatus. The skin is red and thickened and may bleed easily when cleaned. The tympanic membrane is usually obscured by granulation tissue. Some cases of granulating myringitis may represent a more localized form of the same condition.

As the inflammatory stage settles the deep meatus becomes re-epithelialized, but a mass of connective tissue persists between the outer surface of the tympanic membrane and the new fundus of the meatus with a resulting conductive deafness. No consistent bacteria are found on culture from these cases and histology of tissue obliterating the deep meatus reveals a non-specific vascular connective tissue with inflammatory cells.

At times, instead of atresia, a stenosis or web develops in the deep meatus a few millimetres external to the tympanic membrane. This can progress to complete atresia, in which event, epithelium may persist in the shut-off portion of the meatus and a meatal cholesteatoma may develop.
The precise cause of the condition is not fully understood. The bacterial infection of the deep meatus leads to a loss of epithelium from the tympanic membrane and adjacent meatal wall with granulation tissue formation. During healing the granulations are replaced by fibrous tissue and the surface of the mass is covered by epithelium, but why this type of response to infection should occur in some individuals is unknown.

**Treatment**

In the active granulating phase treatment is best confined to the removal of granulations and packing the meatus with ribbon-gauze soaked in a topical antibiotic/steroid preparation. There is usually a slow response to treatment and a marked tendency to recurrence. Although a few cases respond to treatment, the majority progress to stenosis or atresia. When the atresia is established surgical treatment can be considered but should be postponed until all evidence of increased vascularity has disappeared. This may take many months.

In quiescent cases with conductive deafness, surgical removal of the obstructing tissue may restore hearing. This is best undertaken via a postaural approach. The obliterator fibrous tissue is dissected away from the meatal walls and off the fibrous layer of the tympanic membrane. The deep meatus is enlarged by burring away some bone. If there is a perforation, this should be closed with a fascial graft. If the area of exposed bone is no more than a few millimetres leaving a pack in place for up to 6 weeks will often result in re-epithelialization, but more extensive bare areas are better covered with thin split-skin grafts.

**Necrotic lesions**

**Radionecrosis**

The tympanic plate appears to be unduly susceptible to radionecrosis if it is included in the radiation field during treatment of an adjoining area. Small areas of bare bone appear on the meatal floor, sometimes associated with discomfort or irritation and occasionally with a scanty discharge. These usually develop some time after the original course of radiation and may persist for many years usually healing after the separation of the tiny sequestrum. However, occasionally very extensive necrosis occurs with almost the whole tympanic plate eventually separating.

**Benign necrotizing osteitis of the meatus**

Patients may present with exposed dead bone in the meatal floor for no apparent reason. The history is usually one suggesting otitis externa and, again, healing may be delayed until a tiny sequestrum separates. These always seem to occur on the floor of the meatus and it has been suggested that the initial lesion is irritation or otitis externa and that it is the constant scratching of the ear with a matchstick, hairpin or some similar object that eventually causes erosion of the skin and periosteum and death of a small area of bone. While this is true in some patients, there are undoubtedly those who produce this change spontaneously over a relatively short period of time for no apparent reason. Quite why the tympanic plate has this susceptibility to necrosis remains obscure. It does not appear to be related to its pneumatization.
Foreign bodies

A great variety of foreign bodies may be encountered in the external auditory meatus. Insects may enter the meatus accidentally but most foreign bodies are introduced by the patient. Children and the mentally retarded account for the majority of cases. Otitis externa is often encountered in association with meatal foreign bodies. This may be secondary to the presence of the foreign body such as cotton-wool or a piece of matchstick introduced into the ear by the patient in an attempt to relieve the irritation of a pre-existing otitis externa.

Treatment

Insects should first be killed by instilling spirit into the external auditory meatus. Small objects are most easily removed by syringing but this method must not be used if the foreign body closely fits the meatus as it may become more deeply impacted. Vegetable foreign bodies may be hygroscopic and swell if syringed with saline. They should either be removed with small forceps or syringing should be performed with alcohol.

Large foreign bodies should be removed under direct vision with small forceps or a blunt hook, but forceps should never be used for smooth, rounded objects. It is essential that the patient remains completely still during the procedure. General anaesthesia is usually desirable in children and may be indicated in very nervous adults.

When a foreign body is impacted in the deep meatus it may be necessary to open the meatus via a postauricular incision and remove some bone from the posterior wall of the bony meatus in order to facilitate removal.

Cerumen

The skin lining the cartilaginous portions of the external auditory meatus contains two types of glands, sebaceous glands and modified apocrine sweat glands or ceruminous glands. Both types of gland contribute to the formation of cerumen. The quantity of wax produced varies greatly from one individual to another. In the majority, the wax dries and separates as small flakes which fall out of the meatus. However, wax may accumulate and cause deafness by blocking the meatus.

Treatment

Wax may be removed by syringing but this method should not be used if there is a past history of ear trouble. In these cases, the wax should be removed under direct vision using a ring-ended probe or a blunt hook and aural dressing forceps.

If syringing is undertaken, normal saline at 38° is used as the irrigating solution. Any marked variation from body temperature may cause vertigo due to labyrinthine stimulation. Either a metal syringe or a Higginson's syringe attached to a curved meatal cannula may be used.

Metal syringes should be kept well greased so that they have a smooth action. When in use the nozzle of the syringe should be supported by the hand holding the patient's pinna...
to prevent a sudden head movement forcing the nozzle deep into the meatus. If these precautions are taken, the metal syringe may be used with safety.

Before syringing, the pinna should be pulled upwards and backwards in adults and directly backwards in children in order to straighten the meatus. The stream of solution should be directed along the roof of the meatus. Syringing directly onto a mass of wax will only tend to impact it more deeply. When the wax is very hard, it cannot be removed by syringing until it has first been softened. The patient should be advised to instil a few drops of olive oil into the ear twice daily for a week.

**Keratosis obturans**

In this condition a cholesteatoma-like mass is found filling the deep meatus. The mass consists of desquamated squamous epithelium. Typically the mass has a pearly white surface but this may be obscured by overlying wax.

Keratosis obturans can produce bony erosion so that when the epithelial mass is removed a marked expansion of the deep meatus may be found. The tympanic membrane is usually intact but perforation may occur as a result of pressure necrosis. The cartilaginous meatus is not involved, but granulations may occur at the junction of the eroded bony and cartilaginous parts.

Keratosis obturans appears to arise as the result of abnormal desquamation of epithelium in the deep meatus. Unlike other skin, that in the deep meatus does not normally shed the superficial layer of cells from its surface. There is a constant migration of cells from the surface of the tympanic membrane along the deep meatus (Alberti, 1964). It would seem probable that migration fails to occur in keratosis obturans and so a mass of desquamated epithelium accumulates.

There is a not uncommon association between chronic sinusitis, bronchiectasis and keratosis obturans. Morrison (1956) attributed the keratosis obturans to an excessive secretion of wax which blocks the meatus and leads to an accumulation of desquamated epithelium in the deep meatus. It is postulated that in bronchiectasis there is a stimulation of the efferent vagal nerve ending in the bronchi, producing a reflex secretion of wax in the meatus.

Munro-Black (1964), while supporting the theory of excessive wax secretion, regards sinusitis as the primary lesion.

**Treatment**

Patients with keratosis obturans usually present with either pain or deafness in the affected ear. The treatment consists of removing the mass. This may be very difficult to achieve, especially if there is also some otitis externa present. Syringing is best avoided as it rarely succeeds in shifting the mass and may increase the patient's discomfort. If difficulty is experienced in separating it from the meatal wall it is advisable to complete the removal under general anaesthesia.
After the meatus has been cleared, the patient should be kept under observation, as the keratosis may re-form. Local applications do not appear to be of any value in preventing recurrence.

**Otitis externa**

Otitis externa is the generic term applied to all inflammatory conditions of the external meatal skin. It may arise primarily in the meatus or be a manifestation of a generalized skin condition. Predisposing factors (Peterkin, 1974) may be:

(1) genetic: narrow canal, excessive wax, inherited tendency to eczema  
(2) environmental: heat, humidity and swimming  
(3) traumatic: matchsticks and hairgrips  
(4) infective.

The aetiology can be divided into two broad groups:

(1) infective: bacterial; fungal; viral  
(2) reactive: eczema; seborrhoeic dermatitis; neurodermatitis.

More than one factor may be present.

Morrison and Mackay (1976) found a high incidence of excessive negative middle ear pressure in patients suffering from recurrent otitis externa. They have postulated that impaired eustachian tube function may be a factor in causing otitis externa. It is suggested that the negative pressure in the middle ear may cause discomfort inducing the sufferer to probe the ears to relieve it and thus traumatizing the meatal skin. Another possible explanation is that the negative pressure interferes with normal migration of epithelium along the external auditory meatus leading to a build up of epithelial debris in the canal. In any individual case many factors may contribute to the clinical picture. Several predisposing factors may be present and the situation may be further complicated by the development of secondary infection or eczematous reactions to the applications being used in treatment.

**Furunculosis**

A furuncle arises from a staphylococcal infection of a hair follicle. The condition occurs only in the cartilaginous meatus as hair follicles are not found in the skin of the bony meatus. The lesions may be multiple and recur over long periods.

The early symptoms of a furuncle are tenderness in the meatus and pain which is aggravated by movements of the jaw. As the condition progresses the pain becomes more severe and the meatus may become occluded by the swelling causing deafness. In severe cases the oedema may spread to the postauricular sulcus producing forward displacement of the auricle. Eventually the furuncle discharges and unless there are multiple lesions present, the condition rapidly resolves.
Diagnosis

Examination reveals a tender red swelling in the cartilaginous portion of the meatus with a normal deep meatus and tympanic membrane beyond it. Pain is produced on pressing the tragus and pulling the pinna upwards and backwards. There may be enlarged, tender lymph nodes palpable anterior to the tragus, over the mastoid process and below the lobule of the ear.

Difficulties in diagnosis arise when there is gross meatal swelling preventing an examination of the tympanic membrane. As swelling and tenderness may also occur in the postauricular region, the condition must be distinguished from an acute mastoiditis. The main points of distinction are shown in Table 6.1.

Table 6.1. Distinguishing features between furunculosis and acute mastoiditis

<table>
<thead>
<tr>
<th>Sign</th>
<th>Furunculosis</th>
<th>Acute mastoiditis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Postauricular tenderness</td>
<td>Diffuse</td>
<td>Maximal over mastoid antrum</td>
</tr>
<tr>
<td>Displacement of pinna</td>
<td>Forwards</td>
<td>Typically forwards and downwards</td>
</tr>
<tr>
<td>Enlarged lymph nodes</td>
<td>Present</td>
<td>Absent</td>
</tr>
<tr>
<td>Pressure on tragus and moving the pinna</td>
<td>Pain</td>
<td>No pain</td>
</tr>
<tr>
<td>Mastoid X-rays</td>
<td>Mastoid air cells clear</td>
<td>Mastoid air cells cloudy</td>
</tr>
</tbody>
</table>

Treatment

When a furuncle is developing, local heat is helpful in reducing the pain and accelerating the inflammatory process. Heat may be applied by means of a covered hot-water bottle, electric pad or as short-wave diathermy.

In the early stages, local dressings are painful to apply and of no therapeutic value. Incision should be avoided as there is a danger of spreading the infection, especially to the cartilage.

When a furuncle has begun to discharge, the pus should be carefully mopped away. A wick soaked in glycerine may then be inserted. This dressing should be changed daily until the lesion is dry.

Systemic antibiotics are indicated when there is marked oedema or adenitis present, or in cases with multiple furuncles. Penicillin is usually the antibiotic of choice, although an increasing number of penicillin-resistant staphylococcal infections are encountered. A swab should always be taken for culture and sensitivity tests, and penicillin started pending the results. Flucloxacillin is indicated for penicillin-resistant organisms.
Recurrent furuncles

The above methods of treatment are used in recurrent furunculosis, but steps must also be taken to eliminate the staphylococci from the external auditory meatus. The organisms are often carried in the nasal vestibules in these cases and this site also needs attention. A cream containing neomycin or gentamicin should be applied to both the meatus and the nasal vestibules twice daily. Tests should always be carried out to exclude diabetes mellitus.

Diffuse otitis externa

This condition has received a variety of names in the past, emphasizing its frequent occurrence in hot and humid climates, for example 'tropical' ear, Singapore ear. However, diffuse otitis externa is widely encountered in all climatic conditions. Although heat, humidity and bathing are aggravating factors in some cases, the most important factor is local trauma. Scratching the ears, vigorous drying of the meatus with a dirty towel and unskilled syringing are some of the ways in which minor abrasions of the meatal skin may be produced. These abrasions provide access for the causative organisms.

Some cases are secondary to an underlying chronic suppurative otitis media and this possibility should always be considered and excluded by careful examination of the tympanic membrane.

The organisms most commonly found in diffuse otitis externa are *Pseudomonas aeruginosa*, *Bacillus proteus* and *Staphylococcus aureus*.

The condition is seen in two stages - acute and chronic.

The acute stage

The symptom of the acute stage is discomfort developing into pain in and around the ear. The pain is aggravated by movements of the jaw. In severe cases, there may be swelling of the surrounding soft tissues and outward displacement of the pinna. On examination, the meatal skin is red, swollen and very tender. Pus is found in the meatus and, as the disease progresses, the meatal epithelium desquamates forming a mass of cheesy debris in the deep meatus. The tympanic membrane is often dull and injected in appearance.

Treatment

The most important part of treatment is the meticulous cleaning of the meatus. Particular attention must be paid to the deep anteroinferior meatal recess where pus and debris accumulate. A swab should be taken and cultured. After cleaning, the meatus is packed with 12 mm ribbon gauze impregnated with a broad spectrum antibiotic such as neomycin or gentamicin and changed daily or a Pope's wick can be inserted and moistened with drops containing similar antibiotic preparations.

Topical antibiotics must be used with caution as sensitization of the skin may occur and they may encourage the development of fungal infections. The patient must keep the ear dry and avoid rubbing or scratching.
The chronic stage

The chief symptoms of the chronic stage are irritation and discharge. Deafness may occur as a result of the accumulation of debris in the meatus. There is no tenderness, but there may be thickening of the meatal skin with a reduced lumen. Pus and debris are found in the meatus. There may be small granulations on the surface of the tympanic membrane denoting a loss of epithelium.

Treatment

As in the acute phase, careful cleaning of the meatus with clearance of the deep meatal recess is the essential part of treatment. This is best achieved under the microscope with the use of suction. If there is marked meatal swelling, this can be reduced by packing the meatus daily with 12 mm gauze wicks impregnated with an antibiotic such as neomycin or gentamicin or an antiseptic (clioquinol) combined with a steroid or as drops applied to a Pope’s ear wick. The addition of the steroid helps both to reduce the inflammatory swelling and to control the irritation. When there is no appreciable meatal swelling the antiseptic and hydrocortisone cream may be applied to the meatus. Ear drops of neomycin or gentamicin, and hydrocortisone, are often effective in clearing up the infection at this stage but may produce a sensitivity reaction in some individuals. This may be difficult to recognize as it may be masked by the presence of the hydrocortisone in the preparation. In cases which fail to respond to treatment the reasons may be:

(1) underlying chronic suppurative otitis media

(2) fungal infection

(3) sensitization of the skin to the topical application being used.

Otomycosis

Although much commoner in tropical climates fungal infections of the meatus are not infrequently encountered in temperate regions.

Otomycosis may develop as a primary infection or as a mixed infection with bacteria. It may result from the prolonged treatment of an initial bacterial infection with antibiotic and steroid preparation, although a recent study did not confirm this (Mugliston and O'Donoghue, 1985). The fungi most frequently isolated in otomycosis are *Aspergillus niger* and *Candida albicans*. Symptomatically, the condition may be indistinguishable from bacterial otitis externa although the irritation is usually more marked in fungal infections.

Occasionally severe pain in the ear is the presenting symptom. On examination a mass of greyish-white debris, resembling wet blotting paper, may be seen filling the meatus. In infection with *Aspergillus niger* the conidiophores may be seen as black specks in the debris. At times, a mass of fine filaments are seen projecting from the meatal wall. The typical appearances are not always present and, in any case of otitis externa that fails to respond to treatment, the possibility of a fungal infection should be considered. The diagnosis can be confirmed by microscopical examination of the debris or by culture.
Treatment

Fungi thrive in moist conditions and in the presence of epithelial debris. It is therefore essential to remove all the debris and discharge from the meatus. A specific antifungal agent can then be applied. The most widely used of these is nystatin. Nystatin is particularly effective against *Candida* species, but less active against the aspergillus group of fungi. Econazole nitrate is a broad spectrum antifungal agent which is proving more effective for aspergillus infections. It is also active against some Gram-positive bacteria (staphylococci and streptococci). Amphotericin is also used and has a similar range of activity to nystatin.

These preparations are best applied as powders but may be used in a liquid form. Treatment should be continued for at least a week after the infection has apparently resolved.

**Otitis externa haemorrhagica (bullous myringitis)**

This condition is characterized by the formation of purple blebs on the tympanic membrane and the skin of the deep meatus. The purple colour is due to the haemorrhagic effusion filling the vesicles.

Pain, often severe, is the first symptom and serosanguineous discharge may occur as a result of bursting of the blebs. The pain is not relieved by the onset of the discharge. In uncomplicated cases the middle ear is not involved and the hearing remains normal.

The aetiology of the condition is uncertain but it is thought to be the result of a viral infection. In some influenza epidemics many cases of otitis externa haemorrhagica are seen and there does appear to be an association between the two conditions. Treatment consists of prescribing analgesics for the pain and keeping the ear clean and dry.

Antibiotics have no influence on the course of the disease. The blebs should not be incised as this is of no value in relieving the symptoms and may only introduce secondary infection.

**Herpes zoster oticus**

*(See Chapter 24.)*

Herpes zoster of the geniculate ganglion may give rise to skin lesions with or without involvement of either the seventh or eighth cranial nerves. The herpes eruption occurs on the meatal skin, tympanic membrane and the auricle, particularly in the conchal region. Initially, the rash consists of small tense blisters with surrounding erythema. Lesions may also be found on the buccal mucosa and the hard palate. The blisters gradually dry up, leaving adherent crusts which usually persist for 7-10 days.

The appearance of the rash is often preceded by pain in the ear for several days. Apart from keeping the ear dry, no local treatment is indicated.
Herpes simplex

Herpes simplex occurs most commonly on the lips as the so-called 'cold sore'. Occasionally the skin of the auricle and meatus are affected. The eruption at first consists of a crop of small vesicles which dry up after a few days leaving the skin red and scaly. There is no specific treatment and, apart from keeping the ear dry, no local treatment is necessary.

Seborrhoeic dermatitis

The main feature of this disease is a scaly condition of the scalp usually referred to as dandruff or scurf. This is often associated with scaling in the external auditory meatus, postauricular sulcus and below the lobe of the auricle. The aetiology of the condition is unknown. When the ear is involved, secondary infection may be introduced by scratching, leading to a diffuse otitis externa.

Treatment

The scalp condition always requires attention. Regular washing with a cetrimide shampoo is an effective method of keeping the dandruff under control. In uncomplicated cases, there may be a tendency for debris to accumulate in the meatus. This may require regular removal. The patient should be advised to avoid getting water in the ears and to refrain from attempting to remove the waxy debris.

Eczema

The eczematous reaction occurs as the result of sensitization of the skin cells. This sensitization may be produced by an infecting organism or by contact with an allergenic material. Of the latter group, the substances which most commonly evoke this response are the antibiotics; neomycin is by far the most troublesome in this respect. The topical application of any antibiotic may result in a sensitivity reaction. Clinical the eczematous reaction is characterized by the formation of vesicles. When the vesicles burst, serous discharge exudes from the raw surface. The eruption is usually accompanied by intense irritation.

Treatment

When the eczematous dermatitis is secondary to an infective process, the condition is best treated by cleaning the meatus and applying a cream containing clioquinol and hydrocortisone.

In cases resulting from the topical application of an antibiotic, the preparation responsible must be withdrawn. The ear should be kept dry and either a cream or lotion containing a topical steroid preparation applied regularly until the condition resolves.

Neurodermatitis

In some cases of otitis externa, there is an underlying psychosomatic disturbance which not only initiates the condition but also makes it difficult to clear it up. In these
patients, the initial symptom is irritation in the ear. At this stage, the skin is normal in appearance. Constant scratching may lead to lichenification of the skin or secondary infection may be introduced, causing a diffuse otitis externa.

**Treatment**

Local treatment consists of clearing up any secondary infection and attempting to alleviate the irritation with steroid preparations. In severe cases it may be necessary to bandage the ears to prevent scratching. In management, due attention must be paid to the psychological aspect of the problem.

**Malignant otitis externa**

This term was first applied by Chandler (1968) to describe a severe progressive infection starting in the external meatus and rapidly involving the temporal bone and adjacent soft tissues. Although it usually occurs in elderly, poorly controlled diabetic patients, cases do present in the middle-aged and when the diabetes is well controlled. Zaky et al (1976) in a review of the literature recorded that over 91% of subjects were over the age of 55 years and that 93% were diabetic. The condition is also seen in patients receiving immunosuppressive drugs and cases have been reported in children suffering from malnutrition and anaemia (Joachims, 1976).

The infecting organism is *Pseudomonas aeruginosa*. The infection starts as a cellulitis of the external auditory meatus. It may develop in a pre-existing chronic otitis externa but is often insidious in onset with minimal evidence of meatal infection. Granulomata may appear in the deep meatus usually arising from the floor and overlying areas of osteitis.

There is a rapid spread of infection to the adjacent soft tissues either via the tympanomastoid suture or via the clefts of Santorini, the naturally occurring fissures in the cartilage of the meatal floor, followed by spreading cellulitis of the skull base travelling in the soft tissue planes (Kohut and Lindsay, 1979). The infection also spreads by the vascular channels in the tympanic plate and petrous bone (Nadol, 1980). The pseudomonas organism tends to spread along vascular channels (Teplitz, 1965; Riff, 1971; Zeigler and Douglas, 1979). In addition it produces a number of exotoxins and enzymes, including an elastase, which digest vessel walls, and some enzymes from pseudomonal organisms have a collagenase effect (Lucente, Parisier and Som, 1983).

After the tympanic plate, the next area of bone involvement is usually in the region of the mastoid tip and stylomastoid foramen leading to early facial palsy. This bone involvement would appear to be secondary to the soft tissue infection and there is often no continuity of affected bone between the deep meatus and the stylomastoid region. In this stage of infection, the middle ear and mastoid cells may be spared even when a subperiosteal abscess develops over the mastoid region. Tympanotomy and mastoid exploration may show no evidence of active disease.

Further spread of the infection can lead to involvement of the lateral sinus and the superior and inferior petrosal sinuses. Secondary osteomyelitis at the petrous apex can spread to the floor of the middle cranial fossa or to the basisphenoid with the development of
sphenoidal sinusitis. During the course of the spreading infection cranial nerve palsies may develop. The seventh nerve is most frequently affected followed by IX, X, XI and VI. Even when the infection is apparently well controlled, further evidence of deep extension may appear after many weeks or even months. Spread across the midline to the opposite petrous bone via the basisphenoid can occur presenting with contralateral sixth and tenth nerve palsies and a middle ear effusion due to eustachian tube involvement. Nadol (1980) in post-mortem studies has demonstrated spread of infection anterior to the foramen magnum via the basisphenoid and cavernous sinuses with involvement of the contralateral peritubal area.

Extensive spread of infection may occur with few clinical signs. The main clinical features are the initial otitis externa or meatal granulomata associated with severe pain and the subsequent development of cranial nerve palsies. Radiological assessment is often unhelpful as there may be little involvement of bone and the middle ear and mastoid air cells may remain clear. Computerized tomography (CT) scanning can be useful but may also fail to demonstrate disease until it is very extensive. Isotope bone scanning may demonstrate increased uptake in the region of the skull base in active cases (Garty, Rosen and Holdstein, 1985; Salit, McNeely and Chait, 1985). Magnetic resonance scanning may well prove to be helpful in the future.

**Treatment**

As the infection is predominantly one of soft tissue, antibiotic therapy is the first choice of treatment. Intravenous therapy with the appropriate antipseudomonal antibiotics based on sensitivity tests, should be given for up to 3 months. It has been claimed that 6 weeks’ treatment is adequate (Uri et al, 1984), but in well-established cases further activity may develop if the antibiotics are not continued for the longer period. The intravenous antibiotic therapy usually recommended is an aminoglycoside combined with azlocillin or ticarcillin (which have replaced carbenicillin, as they are more effective). Aminoglycosides are both ototoxic and nephrotoxic and the dosage should be carefully monitored by measuring plasma concentrations.

If these drugs cannot be used either because of sensitivity or toxic effects a third generation cephalosporin may be indicated.

Generally, surgery should be confined to the drainage of subperiosteal abscesses and the removal of necrotic or sequestrated bone. A radical mastoidectomy alone has little value in most cases as the disease does not usually spread via the air cells; however a subperiosteal abscess may develop deep to the mastoid process and may require drainage (Raines and Schindler, 1980). A striking feature of the disease is the rapid relief of pain following the commencement of intravenous antibiotic therapy. The severe pain usually associated with the disease rapidly diminishes and may cease completely within a few days.

When treatment has been completed, long-term follow-up is essential as late recurrences may occur between 3-6 months after the end of intravenous therapy. The most reliable indicators of renewed activity are a recurrence of pain, the development of new cranial nerve palsies and elevation of the erythrocyte sedimentation rate (ESR).
**Benign tumours of the meatus**

Fibroma, chondroma and angioma may occur in the external auditory meatus but require no special description.

**Papilloma**

Viral papillomata occur in the outer meatus, often associated with similar lesions on the fingers. These viral warts can be removed by curetting under local or general anaesthesia.

Diffuse papillomata of the meatus are occasionally encountered. These have the typical papilliferous appearance but may extend into the deep meatus and obscure the tympanic membrane. They can be removed percutaneously in most cases but may recur locally.

**Adenoma**

There are two types of gland in the skin of the external auditory meatus and both may give rise to adenomata.

1. **Sebaceous adenoma.** This tumour arises in the sebaceous glands of the meatus. It is seen as a smooth, painless, skin-covered swelling in the outer part of the meatus. It may be treated by local excision.

2. **Ceruminoma.** This is a rare tumour arising from the ceruminous glands of the meatal skin. The glands are modified apocrine sweat glands and histologically a ceruminoma closely resembles the sweat gland tumours seen elsewhere in the skin and for this reason the term hidradenoma of the meatus is now generally preferred. Clinically the tumour presents as a firm skin-covered mass in the cartilaginous meatus. Both sessile and polypoid forms have been described (O'Neill and Parker, 1957; Juby, 1957; Arora, 1964). There are no symptoms until the mass enlarges sufficiently to cause a feeling of obstruction in the ear.

**Treatment**

Ceruminomata show a marked tendency to local recurrence after removal and may become frankly malignant adenocarcinomata (see Chapter 22).

**Osteoma**

The solitary cancellous osteoma occurs as a smooth, rounded pedunculated tumour attached to the outer part of the bony meatus. It arises from the region of either the tympanosquamous or tympanomastoid suture.

These tumours can be readily removed by fracturing through their narrow attachment to the meatal wall. Very rarely an osteoma of the temporal bone may impinge at the meatus producing a diffuse swelling in the deep meatus arising from one wall. X-rays will demonstrate the true extent of the lesion. This type of osteoma may be associated with similar lesions arising from other bones. Complete removal of these tumours may prove difficult or unwise, but simple burring away of the meatal projection to create an adequate canal may be
followed by recurrence. If the condition is causing symptoms, as much of the osteoma as possible should be removed.

**Exostoses**

Exostoses produce smooth sessile hemispherical elevations in the deep part of the meatus adjacent to the tympanic membrane. The lesions are multiple usually occurring in a group of three. They consist of dense ivory bone covered by a thin layer of normal deep meatal skin. The relationship between cold-water bathing and the formation of meatal exostoses is now widely accepted. Van Gilse (1938) was the first to demonstrate a higher incidence in cold water bathers.

Fowler and Osman (1942), working with guinea-pigs, were able to demonstrate the formation of new bone on the inner surface of the tympanic bulla following irrigation of the external canal with cold water. Harrison (1962) carried out similar experiments with guinea-pigs and found histological evidence of new bone formation in the deep meatus.

Meatal exostoses do not cause any symptoms when they are small and so are usually discovered incidentally during examination of the ears. When large they may completely block the meatus or so greatly reduce the lumen that it is readily blocked by small amounts of wax or epithelial debris. When this occurs the patient will complain of deafness.

**Treatment**

When exostoses are small they require no treatment. If they are large enough to cause deafness or impede the treatment of a chronic middle-ear infection, they should be removed.

As exostoses consist of dense ivory bone, removal must be carried out under magnification using a high speed drill and both cutting and diamond burrs. The meatus is exposed through a postaural incision and the skin overlying the exostoses is elevated and preserved as far as possible. The bone is then drilled away until an adequate meatus is fashioned taking great care not to damage the underlying tympanic membrane. At the end of the operation the skin flaps are replaced and a pack inserted and left in place for 10 days.

**Malignant tumours of the meatus**

*(See Chapter 22.)*
Chapter 7: Ear trauma

A. G. Kerr and G. D. L. Smyth

Trauma to the ear is on the increase. Society is becoming more violent, urban terrorism with guns and explosives is more widespread, and there are increasing numbers of road and other accidents. In addition, the improved management of those with severe injuries is contributing to the number of patients surviving to require treatment of aural trauma.

The lesions may range from simple blunt trauma to the pinna, without loss of tissue, through simple rupture of the tympanic membrane to transverse fracture of the petrous temporal bone with complete loss of inner ear and facial nerve function.

External ear

Traumatic lesions of the outer ear are discussed in Chapter 6.

Tympanic membrane and middle ear

Traumatic perforations of the tympanic membrane

Rupture of the tympanic membrane may be caused by changes in air pressure, by fluids or by solid objects.

Pathogenesis

Air pressure changes

Although gradual changes in air pressure may result in rupture of the tympanic membrane, this most often occurs from a rapid change. Sudden forceful blows on the ear, which seal the external auditory meatus, can result in sufficient increase in the air pressure in the ear canal to rupture the tympanic membrane. The most frequent single cause is a blow on the ear, usually with the open hand. This may occur in sporting and not so sporting situations. A blow on the ear from a ball or a fall on water are not uncommon causes of trauma to the tympanic membrane.

Blast injury of the ear commonly, and barotrauma uncommonly, may cause damage to the tympanic membrane. Blast injury is considered later in this chapter and barotrauma in Volume 1, Chapter 7.

Eustachian tube inflation, either by the Valsalva manoeuvre or by the use of a catheter, rarely results in perforation of a normal, healthy tympanic membrane, but can rupture one weakened by previous disease. Similarly, pressure changes in the middle ear as a result of nitrous oxide anaesthesia may result in rupture of a weakened tympanic membrane. There have been reports of lighting, with its associated air pressure changes, resulting in perforation of the tympanic membrane.
Perforations due to air pressure changes occur most commonly in the anteroinferior quadrant of the tympanic membrane. It is unlikely that they ever cause perforation of the pars flaccida.

**Fluid**

When syringing an ear, it is important to ensure not only that the fluid is at body temperature, but also that the full force of the jet is not directed onto the tympanic membrane. By directing the jet onto the posterior meatal wall the likelihood of rupture of the tympanic membrane is considerably reduced.

Caloric tests in patients with gossamer-thin tympanic membranes must be undertaken with considerable caution.

In skin-diving, it is possible for perforation of the tympanic membrane to occur not only from air pressure differentials but also from fluid pressure in the ear canal.

**Solid objects**

Although the usual foreign bodies occurring in children rarely rupture the tympanic membrane, attempts at their removal may do so. Matchsticks and hair clips, used to remove wax or relieve itching in the ear canal sometimes cause damage to the tympanic membrane. (It is remarkable how many people stand just inside a door to scratch the ear canal!) Sparks of hot metal, especially in welders, can perforate the tympanic membrane by burning through it. The tympanic membrane may fail to heal after extrusion of a middle ear ventilation tube.

**Management**

Traumatic perforations often occur in the healthy members of the community; generally the prognosis is excellent. The two main factors leading to failure of the perforation to heal are loss of tissue and secondary infection. Welding injuries usually result in both loss of tissue and secondary infection; water sports injuries frequently result in the latter. Consequently, the prognosis for spontaneous healing is reduced in both.

Small perforations are more likely to close spontaneously than large ones. Nonetheless, in the majority of traumatic perforations, the membrane usually heals and the function of the ear returns to normal.

The most effective management is to do nothing. Because of the risk of introducing infection, the ear should not be cleaned out unless contaminating material is found in the meatus or there is evidence of active infection. Antibiotic ear drops, in the absence of infection, are of no value and may well introduce organisms. Systemic antibiotics should also not be prescribed in the absence of overt infection unless there is good reason to believe that the ear has been contaminated. The ear must be kept dry.

There are many advocates of an active approach to the tympanic membrane following trauma. They recommend examination under a microscope with eversion of the edges of the perforation. This approach is reasonable so long as it is carried out by a competent person.
under aseptic conditions and, in fact, could be regarded as the ideal. Inverted edges are certainly undesirable and if infection is not introduced, it is unlikely that any harm will result from this procedure. However, immediate surgical repair with grafting is not indicated because of the excellent prognosis for spontaneous recovery. Even subtotal perforations often heal with an excellent end result.

If the perforation fails to close spontaneously in 3-6 months, surgical closure is indicated. Special reference should be made to welding injuries. Not only is the perforation unlikely to close spontaneously but the results of surgical closure are disappointing. In addition to the loss of tissue and secondary infection, it is likely that there is also some avascularity of the tissues with dense avascular scarring secondary to the burn.

**Complications**

The most common complication of a traumatic perforation is secondary infection of the middle ear. The development of squamous epithelial cysts in the middle ear has been seen following perforations caused by blast and is due to implantation or inversion of such tissue. Depending on the force of the injury causing the perforation, there may be ossicular displacement with conductive deafness, or inner ear damage with sensorineural deafness and tinnitus.

Squamous epithelial invasion of the middle ear is a rare but recognized complication of middle ear ventilation tubes, especially when there is a persisting perforation after extrusion.

**Blast injury**

Explosive material changes suddenly from solid to gaseous form with a massive increase in volume and pressure, resulting in a blast wave spreading outwards from the seat of the explosion. There is a short-lived positive pressure phase, usually of the order of a few milliseconds and a longer and less marked negative phase, always less than atmospheric pressure and of the order of tens of milliseconds. The amount of energy in each phase of the wave is approximately equal. The front of the blast wave is irregular and damage may be caused in a capricious fashion.

The factors influencing such damage are:

1. the rise time, that is the speed with which the pressure builds up
2. the intensity of height of the peak pressure
3. the duration of the positive pressure wave
4. the site of the explosion and the presence of objects which may reflect or deflect the blast wave.

Some people close to the bomb escape ear damage while others, further away, may be severely deafened.
Exposure to blast can result in damage to both middle and inner ears. There may be hyperaemia or even subepithelial bleeding in the tympanic membrane. Perforation due to the blast occurs in the pars tensa and the ear facing the bomb tends to be more seriously damaged. However, reflection of the blast wave from a wall, with augmentation of the pressure, may reverse this situation.

Perforations are probably caused by the positive phase of the blast wave. This conclusion is reached by the demonstration of squamous epithelium in the middle ear in post-mortem specimens and by the occasional finding of epithelial pearls in the middle ear. The latter are also sometimes seen in tympanic membranes which have healed spontaneously. Although everted edges are often seen following blast injury, these are probably caused secondarily by the suction effect of the negative phase.

Most blast injuries of the tympanic membrane heal spontaneously with conservative treatment. Kerr and Byrne (1975) reported spontaneous healing of 83% of 66 perforated tympanic membranes from one explosion.

**Radiation injury**

The ear is at risk in radiotherapy of any lesion involving the ear itself or in the nasopharynx. The development of middle ear effusion is common in these patients. Osteoradionecrosis has been reported. The management of both these conditions is influenced by the success or otherwise of the radiotherapy in controlling the original malignancy.

There is some circumstantial evidence that sensorineural loss may develop. However, the authors are not aware of any controlled prospective study confirming such damage and, without this, any aetiological connection between radiotherapy and sensorineural deafness must remain speculative.

**Surgical trauma**

**The chorda tympani nerve**

In theory, disorders of taste and salivary secretion should follow every instance of surgical trauma to this structure. In practice, although the nerve is frequently stretched, manipulated, dehydrated and even cut, dysgeusia is an uncommon complaint after stapedectomy and hardly ever occurs following tympanoplasty.

Notwithstanding this, because disorders of taste do occur following ear surgery and can considerably diminish the pleasures of the table, sometimes for many months, the surgeon should always handle the chorda tympani with care.

**The jugular bulb**

This structure is occasionally dehiscent in the posteroinferior quadrant of the mesotympanum. In these cases, it is at risk when the fibrous annulus is being elevated from the sulcus tympanicus in creating a tympanomeatal flap during stapedectomy or transcanal tympanoplasty. Brisk venous bleeding at this stage can usually be controlled by promptly
replacing the tympanic membrane and its annulus and applying a small pack. If the bleeding area is then avoided, it is usually possible to complete the procedure with only limited inconvenience.

**The facial nerve**

In all middle ear surgery, especially for chronic suppurative disease, the safety of the facial nerve will depend upon knowledge of several important landmarks.

In a mesotympanum which is completely filled with granulations or cholesteatoma, it is best to find the landmark which is more resistant to disease than all others - the eustachian tube. From there, it is safe to dissect posteriorly over the promontory as far as the grooves for the tympanic plexus. These grooves can then be followed superiorly to the base of the cochleariform process which marks the junction of the labyrinthine and tympanic segments of the nerve. When the process has been destroyed, a useful alternative guide is the belly of the tensor tympani muscle, which is usually exposed in such cases.

Dissection can then proceed posteriorly following the osseous canal of the tympanic segment of the nerve. In transcanal tympanoplasty, if any doubts develop about the anatomy of the seventh nerve, it is always wise to increase exposure of the area by converting the procedure into a combined approach tympanoplasty. This permits dissection inferiorly over the medial epitympanic wall and the anterior half of the lateral semicircular canal, exposing the tympanic segment of the nerve from its superior aspect where its bony covering is least likely to be deficient. Once the characteristic pink, rounded bone overlying the nerve is compared with the ivory-white labyrinthine bone, the position of the nerve will be apparent, and dissection can proceed over it in all directions.

It should be remembered that there are several possible abnormalities of the facial nerve in this region which may give rise to confusion and possibly disaster if there are not known. The most common of these is the facial nerve which is overlying the footplate of the stapes. For this reason, it is important to identify the nerve positively in its normal horizontal canal before removing soft tissue from the surface of the footplate.

In the mastoid segment, the following landmarks are of service: the lateral semicircular canal, the fossa incudis, and the digastric ridge. The posterior semicircular canal lies on the medial aspect of the mastoid segment of the nerve. In performing a mastoidectomy or combined approach tympanoplasty, the first landmark is the mastoid antrum. Korner's septum may give rise to confusion and lead the surgeon in an inferior and anterior route into the mastoid segment of the facial nerve. This can be avoided by:

1. awareness of the risk
2. noting the level of the tympanic membrane as compared to the medial wall of the 'false antrum'.

In combined approach tympanoplasty, posterior tympanotomy is performed by cutting a groove downwards from the tip of the short process of incus towards the mastoid tip. The groove should be parallel to the expected course of the facial nerve, and the bone should be
thinned gradually with diamond burrs so that the nerve can be seen before it is uncovered. Bleeding from the nerve sheath is often an excellent warning sign. Once the facial sinus has been entered, further enlargement of the posterior tympanotomy is carried out by removing bone inferiorly and laterally. For this, the position of the chordal eminence and the chordal ridge should be known and understood. Exposure of the hypotympanum requires removal of the styloid eminence.

Abnormalities of the facial nerve rarely occur in this area but they should be known. The most common of these is the nerve that passes posteriorly, but bifid facial nerves below the genu have been reported. The digastric ridge and the position of the chorda tympani nerve can be used as guides to the nerve when required.

**Treatment**

Surgical trauma to the facial nerve in temporal bone surgery may result in loss of continuity and loss of substance. In these situations, direct anastomosis does not necessarily produce the best result and it is now agreed that grafting with a piece of the great auricular nerve is the preferred method in most instances.

Grafting should be delayed for 3 weeks after the injury by which time axoplasmal regeneration is optimal. The results are better when tension can be avoided and a grafting technique is carried out with the use of magnification. Excessive proliferation of connective tissue in an anastomotic area can be reduced by the removal of several millimetres of epineurium from the stumps. The ends of the stumps should be approximated after they have been cut in an oblique direction in order to increase the surface areas in contact. Foreign body reaction with connective tissue proliferation is reduced by the avoidance of suturing material. The natural self-adherence of the nerve tissue is often sufficient to retain the position of the nerve graft in the mastoid and tympanic segments. If there is any doubt about the stability of the graft, however, one or two 8/0 monofilament nylon sutures should be inserted.

In conclusion, avoidance of facial nerve trauma in advanced chronic middle ear disease will be enormously enhanced by the recognition of important landmarks such as the processus cochleariformis, the lateral semicircular canal and the oval window. The great importance of surgical skill, anatomical knowledge and awareness of variations in normal anatomy, were summed up by Fowler (1961) when he said: 'Although traumatic facial palsy is more likely to occur when a surgeon is inexperienced, it can and does occur with the most skilful and experienced otologic surgeon, especially when the course of the nerve is anomalous'.

There is a natural tendency to want to terminate the operation once one is aware of having damaged the facial nerve. This should be resisted. The damage has been done and the patient's interests are not furthered by dealing inadequately with the original disease. The patient has already paid a high price. It is all the more important that the original surgical objectives be attained.
Temporal bone trauma

Fractures

The clinical features of fractures of the temporal bone can only be understood by considering their anatomy and pathology. Fractures involving the temporal bone can be classified into longitudinal, transverse and mixed, depending on the relationship of the fracture line to the long axis of the petrous temporal bone. In many, the lesion is confined to the squamous temporal bone, in which case it could be regarded as an incomplete or partial longitudinal fracture. Often the diagnosis is made purely on clinical grounds as the fractures do not always show on routine skull radiographs. Rarely, the diagnosis is delayed until the appearance of discoloration of the skin over the mastoid (Battle's sign).

Pathology

Longitudinal fractures

Most (80%) temporal bone fractures are longitudinal and usually result from blows to temporal or parietal areas (Proctor, Gurdjian and Webster, 1956). The fracture begins in the squamous temporal bone and extends along the roof of the bony external auditory meatus, tearing the meatal skin and the tympanic membrane and, crossing the roof of the middle ear, reaches the petrous temporal bone. If then runs anterior to the labyrinthine capsule, through the carotid canal, to end near the foramen spinosum or foramen lacerum.

Damage to the skin of the external auditory meatus and the tympanic membrane result in bleeding from the ear. In the absence of any other obvious cause, bleeding from the ear following a head injury can be presumed to indicate a fracture of the base of the skull, usually longitudinal, despite negative X-ray findings. Displacement of the bone is very rare but a gap may be present at the fracture line.

Middle ear structures are always involved in longitudinal fractures but, in most cases, this is not serious and healing occurs spontaneously without residual conductive deafness. However, should there be persistent conductive deafness, the possibility of ossicular dislocation must be considered.

Because a longitudinal fracture usually runs anterior to the hard bone of the labyrinthine capsule, only rarely is the inner ear directly involved, but there may be concomitant inner ear concussion with high tone sensorineural hearing loss. Although the underlying damage in the sensorineural hearing loss of longitudinal fractures is probably more often to be found in the cochlea itself, experimental and clinical evidence has been presented to suggest that some of the deafness is central in origin, secondary to neural damage (Makishima, Sobel and Snow, 1976).

Facial nerve injuries are uncommon in longitudinal fractures and when they occur, are usually delayed in onset.
Transverse fractures

Transverse fractures usually result from frontal or occipital blows and account for approximately 20% of temporal bone fractures (Proctor, Gurdjian and Webster, 1956). These patients usually suffer more severe neurological injury than those with longitudinal fractures.

The fracture line extends transversely across the petrous pyramid, passing through the vestibule of the inner ear. Although the fracture can be demonstrated radiologically in about 50% of cases, the diagnosis is essentially clinical. In a pure transverse fracture there is a haemotympanum but, as the tympanic membrane is not damaged, there is no bleeding from the ear. The severe general injuries of the patient may dominate the clinical picture but, if sought, there is evidence of severe or complete sensorineural deafness on the affected side, usually accompanied by tinnitus. The deafness is permanent.

Very severe rotatory vertigo with nausea and vomiting, due to severe damage to the vestibular apparatus on the affected side, occurs initially. Nystagmus is usually present with the fast component to the opposite side. Unfortunately, the significance of the severe dizziness, vomiting and nystagmus, is often missed by those responsible for the management of the head injury. It may not become apparent that the patient has suffered vestibular damage until he is allowed out of bed a week or two after the injury. The patient is then surprised to find that he is extremely unsteady and unable to walk without support. Central compensation develops in the subsequent weeks and months.

When the fracture line involves the vestibular aqueduct, delayed secondary endolymphatic hydrops may develop (Rizvi and Gibbin, 1979).

Facial nerve injuries occur in about 50% of these patients and the onset is usually immediate.

Mixed fractures

In severe head injuries there may be a combination of longitudinal and transverse fractures.

Management

The importance of avoiding the introduction of infection into the middle ear cannot be overemphasized and, unless there are signs of active infection, it is better to leave untouched any blood clot in the external auditory meatus. A cerebrospinal fluid leak must be treated by a sulphonamide and an antibiotic. The management of the head injury usually takes precedence and indeed it may be some days before the otolaryngologist is asked to see the patient.

Cerebrospinal fluid leak

Most cerebrospinal fluid leaks close spontaneously within 7-10 days. If this does not occur, more active treatment will be necessary. The introduction of a spinal drain at this time may well be all that is required to allow the leak to close but many neurosurgeons are
unhappy about this approach. They feel that, although closure may occur at the time, some leaks will recur later or, even without a recurrence of the leak, there may be an ascending intracranial infection from a subsequent otitis media. If the leak is profuse or if it fails to close promptly, with or without spinal drainage, exploration and surgical closure are indicated. These leaks usually arise from the middle cranial fossa and the help of a neurosurgeon is desirable. The middle cranial fossa is explored, the dura elevated and, after exposure of the tear, the defect is covered with a graft of fascia lata or temporalis fascia.

Some otologists, perhaps chauvinistically, recommend a mastoid approach to this problem. Undoubtedly this is possible and the operation may be shorter and less major. However, access to the site may be impaired and the positioning of the graft is less secure.

**Meatal damage**

Tears in the meatal skin may heal with the formation of fibrous bands in the depths of the meatus, resulting in pockets which collect epithelial debris. If these cannot be cleaned adequately and effectively via the meatus, or if repeated cleaning will be necessary over many years, surgical removal of these bands, perhaps with grafting of the tympanic membrane, may be required.

A wide fracture line predisposes to invasion of the middle ear cleft by squamous epithelium and cholesteatoma development has been reported. However, the vast majority of cholesteatomata diagnosed for the first time after a head injury have not been caused by the trauma. Medico-legal problems can arise but in the absence of a wide fracture line, and especially with a sclerotic mastoid, the cholesteatoma can reasonably be presumed to have been present before the injury. The degree of pneumatization of the temporal bone is usually a guide to the pre-existence of the cholesteatoma. When a cholesteatoma occurs, secondary to a fracture, in a well pneumatized temporal bone, it can rapidly become very extensive and subsequent surgical control may be difficult.

**Deafness**

The conductive deafness which follows a longitudinal fracture is, in most instances, due to a tear in the tympanic membrane and blood in the middle ear and it usually recovers spontaneously. Failure to regain normal middle ear transmission is usually due to ossicular dislocation or the formation of adhesions. Ossicular damage can also result from a head injury in the absence of a skull fracture.

The most commonly affected ossicle is the incus, as the malleus and stapes are relatively more stable; the most frequently found defect is a dislocation of the incudostapedial joint (Hough, 1970). All other lesions are uncommon. These include fracture of the stapedial crura, dislocation of the stapes footplate, total dislocation of the incus, dislocation of the malleus, fracture of the malleus handle, fixation of the malleus head in the epitympanum by fibrous tissue or bone and total destruction of the ossicular chain. Delayed necrosis of the long process of the incus has been described.

In these cases there is usually a conductive deafness with an air-bone gap in the region of 40 dB. Exploration of the middle ear is indicated. Ossiculoplasty is carried out on the
general principles of tympanoplasty, usually with better results than in chronic suppurative otitis media.

The sensorineural deafness caused by head injuries is, unfortunately, untreatable. Although there may be some spontaneous recovery of the high tone sensorineural loss that often accompanies longitudinal fracture, there is no likelihood of recovery of any useful hearing following transverse fractures.

Labyrinthine damage can occur without any clinical or radiological evidence of temporal bone fracture. In these cases it is presumed that labyrinthine concussion is responsible for any associated auditory or vestibular symptoms, although there is the possibility of underlying damage in the brain. The deafness usually affects the high frequencies.

Generally speaking, an injury insufficiently severe to cause loss of consciousness does not damage the hearing. However, this is not always the case and difficult medico-legal problems can arise. These are usually settled on the basis of circumstantial evidence such as when the patient first noticed the deafness and the problems that he describes. For example, the damage due to trauma is usually immediate and a severe hearing loss, first noticed 6 months after the injury, cannot reasonably be attributed to that injury.

Vertigo

Vertigo is common following head injuries and, as with deafness, can occur without a skull fracture. The most common form is that associated with the post-concussional syndrome. These patients have vague unsteadiness, especially when getting up from sitting, and usually associated with frequent severe headaches. The unsteadiness generally settles in a matter of 6-12 months and when it is prolonged beyond this time, the question of a post-concussional neurosis must be considered.

Following transverse fracture of the temporal bone, there is severe incapacitating vertigo making it impossible for the patient to walk unaided for a length of time which varies from 1 to 4 weeks, depending on factors such as age, motivation and other injuries. In the immediate period after a head injury the symptoms can be relieved by labyrinthine sedative drugs. There is a slow but gradual improvement; young patients recover to fairly normal balance in a matter of weeks and elderly patients in months. However, the convalescence is often complicated by other injuries and, especially in the elderly, associated brain damage may prevent full compensation.

Benign positional vertigo may follow as a complication of head injuries, with or without fracture of the temporal bone. Schuknecht (1969) has postulated that this results from damage to the utricle with destruction of the otolithic membrane, the otoconia of which become adherent to the cupula of the posterior semicircular canal. This is then stimulated by movement of the head, especially when the affected ear is placed undermost. The dizziness is short-lived, associated with transient and fatiguable rotatory nystagmus, and always precipitated by head movement; between these induced episodes the patient is perfectly steady. This is usually a self-limiting condition, although it often takes up to 2 years before the vertigo settles.
When the vestibular aqueduct is involved, delayed secondary endolymphatic hydrops may develop. In the unlike event that there is any remaining vestibular function this can result, years later, in episodic rotatory vertigo, similar to that seen in Ménière's disease (Rizvi and Gibbin, 1979).

Perilymph fistulae may also be a cause of post-traumatic vertigo and will be discussed later.

**Facial paralysis**

Facial paralysis following fracture of the temporal bone is classified broadly into two groups - immediate and delayed. Immediate paralysis usually indicates tearing of the facial nerve, impaling of the nerve by bone, or entrapment in a fracture line. Early surgical exploration is indicated if there is to be any reasonable prospect of good functional recovery.

Delayed onset of facial paralysis confirms that, anatomically, the facial nerve is intact, and that there has not been any direct gross trauma. The management of delayed traumatic paralysis is similar to that of idiopathic facial paralysis.

**Penetrating injuries of the temporal bone**

Injuries from bullets, missiles, and explosions may result in lesions involving any part of the body. When the temporal bone is involved, almost any lesion can occur. In most cases, the other injuries predominate and it may be some time after the injury before the otolaryngologist is asked to see the patient.

The lesions of the temporal bone are difficult to classify because of their variability; the management of each patient depends on the specific circumstances. Often the other injuries necessitate compromise in the otological management.

Patients have been reported where gunshot has remained in the temporal bone for many years without any complications. In one patient, the tympanic membrane was largely destroyed, gunshot remained in the middle ear cleft and brain herniated through a damaged tegmen tympani into the attic (Kerr, 1967). The patient lived for 40 years after the injury and died from other causes. Despite such cases, if there is gunshot in the middle ear cleft, with the possibility of infection, surgical exploration and removal are indicated. If, on the other hand, the gunshot has been adequately buried for some time, without any infection or likelihood of infection, and is not causing symptoms, action is not required.

**Whiplash**

The term 'whiplash injury' used in an unpublished paper in 1928, was first recorded in 1945 and has been a source of controversy ever since. Many object to the name but all agree that it implies an acceleration-extension injury of the neck; some also include deceleration injuries and forward or lateral flexion movements in this syndrome. The diverse symptomatology and prolonged litigation that follows these injuries has led to considerable scepticism about this condition. Nonetheless, it has been shown that many patients continue to have symptoms, sometimes disabling, related to whiplash injuries, not only when other
simultaneous severe injuries have become symptom-free, but even years after litigation has ended and compensation has been paid (Gotten, 1956). While symptoms can occur following forward and lateral flexion injuries, the vast majority arise from the acceleration-extension injuries which occur in rear-end collisions. In many instances the initial injury seems trivial, with severe pain in the neck developing only some hours later.

**Clinical features**

It is not uncommon for the passengers in a car involved in a rear-end collision to be entirely symptom-free immediately after the injury. However, during the succeeding minutes or hours, an ache begins to develop in the neck which increases within a short time to severe pain. Although the most common complaint is pain in the neck, the otolaryngologist becomes involved when the symptoms include dizziness, tinnitus, deafness and dysphagia.

Typically, the onset of dizziness does not occur until some days after the injury. The symptoms tend to be diverse but the most prominent is a generalized sensation of unsteadiness which increases, and may take the form of rotatory vertigo, in association with certain head and neck movements. Routine clinical examination is frequently unremarkable, although positional nystagmus may be demonstrated. However, with the aid of electronystagmography, nystagmus may be demonstrated even when it is not present on clinical examination. Published reports on the findings in the caloric test frequently refer to abnormalities but, unfortunately, many of these do not eliminate those patients with head injuries and, furthermore, do not include controls. However, it is the authors' view that the weight of evidence is that abnormal electronystagmography and caloric tests are often seen following uncomplicated whiplash injury.

There are four theories to explain these features. First, the problem may be neuromuscular with abnormal proprioceptive impulses causing the dizziness. Second, it may be neurovascular with abnormality of the cervical sympathetic nervous system. Third, there may be a mechanical vascular problem with kinking of the vertebral artery. Fourth, brain damage may occur as a result of the whiplash injury.

The typical history is of injury followed by a short symptom-free period before the development of pain in the neck. During the next week or so dizziness develops and may persist for years. Although this settles in the vast majority, in Gotten's (1956) series it persisted in 12% for up to 2 years after litigation has ended.

Tinnitus is a frequent complaint in the early stages. It is unlikely that there is any direct damage to the ear. The tinnitus may be due to a concussive effect on the brain; alternatively, and in the authors' opinion more probably, the stress of the injury may result in unmasking of potential tinnitus due to pre-existing sensorineural deafness.

Although deafness has been reported in some publications on this subject there is little substantiating evidence. It seems likely that deafness does not occur in the absence of an associated head injury and that whiplash injuries, of themselves, do not result in hearing loss.
Treatment

In the early days of the recognition of the clinical entity of acceleration injuries of the neck, they were most commonly the result of catapult-assisted take-offs from aircraft carriers. The injury was prevented by extending the back of the seat so that the pilot's head was supported. Many modern car seats are now similarly designed and the widespread use of head restraints should reduce the incidence of this syndrome.

Whiplash injuries are best treated during the acute phase. If the nature of the injury and the patient's symptoms suggest this condition, immediate and adequate splinting of the neck is required, accompanied by bed-rest to relieve the neck of the weight of the head. Macnab (1971) has pointed out that the persistent complaints following acceleration-extension injuries do not occur in side collisions where lateral flexion is the predominant lesion. Similarly, wrists and ankles, injured in the same accident become symptom-free long before neck symptoms settle down. He has suggested that the persistence of symptoms in these patients is not because these people are by nature litigious but that the initial injury is inadequately treated. He emphasized that if the neck needs to be splinted, it needs to be done adequately and to have the weight of the head removed from it by bed-rest. Unless the patient is relatively symptom-free within 24 hours he recommended bed-rest for one week. The time for a collar is now and not 6 months later. Heat and massage may make the patient feel more comfortable but probably do nothing to speed resolution of the underlying lesion.

Treatment in the chronic phase is difficult. If the patient appears to be developing disabling symptoms due to functional overlay, do not over-treat or over-investigate. There is no evidence that prolonged immobilization is of benefit at this stage, or that heat and massage do more than imprint the symptoms on the patient's mind. Neck traction and muscle strengthening exercises may be of benefit but must not be instituted until it has been established by flexion and extension radiographs that there is no joint instability.

A frank and open discussion with the patient about the possibilities of disordered function is the best approach, once the chronic stage has been reached. The response from tranquilizers and labyrinthine sedative drugs is variable and unpredictable.

While many patients improve with time, especially after litigation has been settled, this is not always the case; do not be misled into thinking that all these patients are malingers.

Perilymph fistula

In a perilymph fistula, not to be confused with labyrinthine fistula, perilymph may leak from the inner into the middle ear. The leakage may occur either from rupture of the stapediovestibular joint, fracture of the stapes footplate or tearing of the round window membrane. Clinical reports indicate that these are more often from the oval than the round window. Typically, there is a history of a head injury, middle ear surgery or some other event associated with raised intracranial pressure, such as coughing, straining or exertion, or sudden changes in middle ear pressure.

The clinical features are variable but there are certain characteristics. The most common symptom is unsteadiness, usually with a marked positional element and often with
a disproportionate degree of ataxia. The dizziness due to direct trauma to the vestibular apparatus in a head injury usually improves dramatically over a period of weeks. On the other hand, the dizziness associated with a perilymph fistula tends to persist until the fistula is closed either by spontaneous healing or by surgery. The main differential diagnostic problem arises with benign positional vertigo.

Sensorineural deafness and tinnitus often occur in association with a fistula but are not constant features. The deafness may fluctuate.

A high index of suspicion is necessary for the diagnosis of this condition and one must look in the history for a predisposing cause.

Examination of the ear itself is usually unremarkable. The amount of perilymph leaking is usually small and one does not expect to see a fluid level in the middle ear. The fistula test is usually, but not always, negative. (This is not surprising since this test is for a third opening into the inner ear.) However, some authors have reported a positive fistula test in this condition.

Examination of the vestibular system may show positive Rombergism.

It is in positional testing that the main features are to be seen. Singleton et al (1978) have identified the following characteristics which differentiate the positional nystagmus from that in benign positional vertigo.

1. There is either a short or no latent period.
2. The nystagmus is not as violent as in benign positional vertigo.
3. The duration tends to be longer with the nystagmus fatiguing slowly or not at all.
4. The nystagmus rarely reverses direction when the patient is brought to a sitting position.
5. The nystagmus does not necessarily beat towards the involved ear.
6. The nystagmus is only occasionally rotatory.

Audiometry confirms a sensorineural hearing loss. Repeated testing, from day to day, may show minor degrees of fluctuation. Fraser and Flood (1982) have reported small improvements in the hearing after 30 minutes in the horizontal position, with the affected ear uppermost. The speech reception threshold and the speech discrimination scores may be depressed more than one would expect from the degree of sensorineural hearing loss.

**Diagnosis**

The diagnosis of this condition can only be made with certainty by surgical exploration of the ear. A perilymph fistula may be undiagnosed because it was not considered in the differential diagnosis, because the ear was not explored or because a fistula healed
spontaneously before exploration took place. On the other hand, false positive diagnoses may occur because of a failure to understand the anatomy of the round window niche at surgical exploration, because a serous middle ear exudate has been mistaken for perilymph, or because the surgeon has fulfilled his own predictions either by probing or drilling in the region of the round or oval window niches. Unfortunately, it is unlikely that there will ever be a reliable diagnosis of this condition until some foolproof method has been devised for confirming the presence of perilymph in the middle ear.

**Medical management**

If the diagnosis is made soon after the injury, bed-rest may be all that is required. The patient should be kept in bed for 5 days with the head of the bed elevated 30-40 degrees. Sedation and faecal softeners should be prescribed.

After 5 days, if the symptoms have settled, it is recommended that the patient continues to limit his activity for a further 10 days, still sleeping with elevation of the head of the bed and avoiding any exertion.

**Surgical management**

Surgical intervention is recommended if medical treatment fails or if the symptoms have persisted for over one month. After elevation of a tympanomeatal flap it is important to inspect the middle ear carefully before disturbing any of the middle ear structures. Trauma to the middle ear mucosa can, of itself, produce a serous ooze which may be mistaken for a perilymph fistula. If the procedure is performed under local anaesthesia and a fistula is not readily apparent, the Valsalva manoeuvre may help to identify a leak.

It is important to ensure that one does not create a fistula at this stage, thus establishing a self-fulfilling prophecy. Care must be taken in probing the stapes. The round window membrane can never be seen in its entirety without removal of the bone of the round window niche and, in many cases, can barely be seen at all without removing some bone. Once again, at this stage, there is a high risk of creating the fistula for which one is looking.

It is important to remember the anatomy of the round window membrane. It faces inferiorly and care must be taken that one does not confuse mucosal folds in the round window niche for the round window membrane. This is the explanation for some of the published reports which make statements such as 'the round window membrane was in tatters'.

Having identified a fistula, the area around it should be denuded of mucosa. In round window membrane fistulae it may be desirable to drill away the bony overhang. A graft, either of fascia or perichondrium, should be applied to the denuded area and packed in place with gelfoam. There is considerable doubt about the efficacy of fat (Seltzer and McCabe, 1986). In some cases of fistula in the oval window, especially with fracture of the stapes footplate, it may be desirable to carry out a total stapedectomy, seal the oval window with a fascial or perichondrial graft and place some sound conductor between the long process of the incus and the graft. This sound conductor may be the stapes itself, which is especially suitable with a thin graft, or it may simply be one of the prostheses used routinely in stapedectomy.
The results of surgery are frequently dramatic in alleviating the patient of his vertigo and ataxia. Unfortunately, the recovery of the sensorineural hearing loss is rarely so dramatic and, with regard to the hearing, the prevention of further deterioration can usually be considered to be a satisfactory outcome.

**Blast injury**

It has been said in the past that rupture of the tympanic membrane has a significant protective effect on the inner ear. This is probably not the case and, although it is difficult to prove, a survey has shown that sensorineural deafness is no less severe in those whose tympanic membranes have been ruptured (Kerr and Byrne, 1975).

There is still considerable doubt about the underlying pathology in sensorineural deafness secondary to blast. It tends to be most marked immediately after the explosion with a natural tendency to spontaneous improvement. There may be complete bilateral deafness just after the explosion but there is, in the present authors’ experience, always some recovery. Initially, the rate of recovery is rapid so that patients, unable to hear at all at the site of the explosion, are able to understand loud speech without difficulty one hour later. In some, the hearing may have returned to its former level within 48 hours, and in others, although there is permanent sensorineural deafness, this may continue to show slight improvement for up to 6 months.

In view of the tendency to rapid spontaneous recovery, it is difficult to control any trial of treatment for blast-induced sensorineural deafness. Numerous regimens have been advocated, often without much supporting evidence, including vasodilating drugs, corticosteroids, intravenous low molecular weight Dextran, anticoagulants and carbon dioxide inhalations. Other injuries may preclude some or even all of these forms of treatment. As there is doubt about the efficacy and as some of these treatments carry risks, it is preferable to leave untreated all cases of mild or moderate deafness and to reserve the multi-drug approach only for severe cases where there are no contraindications.

Tinnitus is a common complaint in those exposed to blast. The severity of the tinnitus tends to reflect the sensorineural deafness. Initially, the tinnitus may be severe and, although it persists as a big problem to some patients, it tends to decrease. When there is permanent sensorineural deafness the tinnitus may never disappear entirely but usually ceases to be a burden to the patient. In the uncomplicated case where the hearing returns to normal, one can expect complete disappearance of the tinnitus.

**Surgical trauma**

Injury to any of the structures which lie within the petrous bone is an inherent risk in every ear operation. Although it is certainly true that the introduction of microsurgical techniques in otology has been followed by a reduction in the incidence of surgical accidents such as dislocation of the stapes, opening of the labyrinth and damage to the facial nerve, nevertheless, the possibility of postoperative labyrinthine dysfunction after any operation on the ear, including myringoplasty, is still everpresent, even for the most experienced surgeon. Cochlear losses are reported more frequently than imbalance, but the two can occur together and indeed vestibular defects might be recognized more often were they routinely sought.
Although trauma to the facial nerve and major blood vessels is always possible if anatomical knowledge and surgical expertise are lacking, nowadays, the majority of surgical injuries to the ear affect the labyrinth and follow the creation of a fistula of the oval window, or hydraulic effects on the membranous inner ear. Cellular damage from infection, circulatory changes and alterations in the dynamics of the inner ear fluids are probably responsible for most of the functional damage which complicates microsurgery of the ear.

**Labyrinthine trauma in tympanoplasty**

In tympanoplasty the principal causes of cochlear loss are:

1. The removal of cholesteatoma matrix and granulations from a labyrinthine fistula, most commonly involving the lateral semicircular canal, in the presence of infection during an initial procedure. Rupture of the membranous labyrinth, or labyrinthitis, frequently result in total loss of inner ear function.

2. Incautious removal of granulations, tympanosclerosis or cholesteatoma from the oval window, with fracture of the stapes footplate or rupture of its annular ligament creating a fistula between the mesotympanum and the vestibule of the inner ear. Prolonged perilymph loss or labyrinthitis may follow.

3. Excessive movement of the stapes footplate while removing disease from the oval window or from any part of an intact ossicular chain. Similar risks also pertain during reconstruction of the transmission mechanism and the tympanic membrane.

4. Contact between a toothed rotating burr and any part of an intact ossicular chain (most commonly the body of the incus) in combined approach tympanoplasty. Extensive hair cell damage may result (Paparella, 1962).

In a series of 1680 chronic ear operations, Palva, Karja and Palva (1973) reported a 4.5% incidence of sensorineural deafness after operation, mainly limited to the frequency range 4000-8000 Hz. In 81% the ossicular chain was maintained intact throughout the operation. Smyth (1977) reported various degrees of sensorineural hearing loss in 2.5% of 3000 tympanoplasty operations.

Apart from the special risk of cochlear trauma in combined approach tympanoplasty from contact of the burr, transmitted through the intact ossicular chain, which occurred in 5.6% of such ears, labyrinthine trauma did not appear to be related to any particular surgical technique. However, it should be noted that 1.3% of all myringoplasties (transcanal tympanoplasty with an intact chain) were complicated by a depression of cochlear function of greater than 10 dB averaged through the frequencies 500-4000 Hz, or a greater than 10% loss in speech discrimination score.

Trauma arising from the removal of diseased tissue from the isolated stapes was considered to be responsible for one-third of the casualties; of these, in one-third the dissection of tympanosclerotic plaques had been noted to cause overmanipulation or fracture of the stapes footplate. In another third of the damaged inner ears in this series, the cause...
appeared to be excessive movement of the stapes footplate during attempts to reconstruct the ossicular chain.

More recently, Tos, Law and Plate (1984) analysed the incidence and characteristics of postoperative sensorineural hearing loss in chronic ear surgery performed in 2303 ears. Sensorineural hearing loss occurred in a total of 1.2% of cases; 0.5% became totally deaf and 0.7% acquired a high tone loss, most often at 4 kHz only. The incidence was highest in congenital malformations, granulating otitis and cholesteatoma, and in mastoidectomy, especially of the canal wall down type. In this series, the most common causes of anacusis were removal of cholesteatoma from the lateral semicircular canal and removal of the fistula membrane.

One of the lessons to be learnt from these reports is that extreme caution is always necessary when instrumentation in the oval window is required in tympanoplasty. Another lesson is that the considerable risks of severe iatrogenic sensorineural deafness in ears with labyrinthine fistula can only be avoided by the use of a technique in which the matrix over the fistula is meticulously preserved (Gormley, 1986).

*Labyrinthine trauma in stapedectomy*

This is considered in Chapter 14.
Chapter 8: Plastic surgery of the ear

H. Weerda

In the last 20 years, great advances have been made over earlier surgical methods of reconstructing the auricle. Otoplastic surgeons have learned to solve a number of problems inherent in a region that is extremely difficult to reconstruct surgically (Spira, 1974).

The present chapter offers a concise survey of surgical methods now in use for:

(1) auricular malformations
(2) acquired deformities
   (i) tumours
   (ii) trauma.

The body of literature covering the same ground is large, and the standardization of terminology is still awaiting agreement. The usual practice, observed here, is to classify defects, especially auricular deformities, by the surgical methods of treatment (Tanzer, 1974).

Anatomy

The anatomy of the external ear is described in Volume 1. The surfaces of the auricle will be referred to here as anterior and posterior - 'postauricular' will thus mean 'of the posterior surface of the auricle'. The term 'retroauricular region' will signify the mastoidal area.

Classification

The definitions that follow are modifications, by Rogers (1968), of those proposed by Marx (1926).

First degree dysplasia

Most structures of a normal auricle are recognizable.

Second degree dysplasia

Some structures of a normal auricle are recognizable (second degree microtia).

Third degree dysplasia

None of the structures of a normal auricle is recognizable (third degree microtia or anotia).
Description of a normal auricle

The different areas of the auricle lie in sharp relief in the normal ear. When the ear is viewed from the front, the helical rim lies slightly further out from the side of head than the antihelical fold.

An abundant supply of blood is carried to the external ear by the superficial temporal artery and branches of the posterior auricular artery. The sensory supply to the auricle is transmitted by the anterior and posterior branches of the great auricular nerve, which run parallel to the posterior auricular artery and the median anterior auricle. The auriculotemporal nerve supplies roughly the area of the anterior auricular arteries.

The normal protrusion of an ear is about 30°, or between 2 and 2.5 cm. The angle of inclination is measured from the long axis of the auricle to a line through the external auditory canal and parallel to the facial profile line. The inclination of the auricle is between 20° and 30° and is generally parallel to the profile line of the nose. The average length of the pinna is 63.5 mm in men and 59 mm in women (Table 8.1).

Table 8.1 Average length and width of the normal auricle (Farkas, 1974).

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Length (mm)</td>
<td>Width (mm)</td>
</tr>
<tr>
<td>1</td>
<td>50.0</td>
<td>31.5</td>
</tr>
<tr>
<td>6</td>
<td>55.3</td>
<td>33.4</td>
</tr>
<tr>
<td>18</td>
<td>63.5</td>
<td>35.3</td>
</tr>
</tbody>
</table>

The normal angle between the concha and scapha is approximately 90°, with deviations of as much as 15°.

Where the angle at which the auricle protrudes exceeds 40°, or that between the concha and the scapha exceeds 110°, it is known as a protruding ear. In most instances, the distance from the side of the head to the helical rim exceeds 2.5-3 cm. The main categories of prominent ear are marked by a prominent antihelix, lack of a superior antihelical crus, lack of an antihelix and hypertrophy of the concha.

Surgery for auricular malformations

First degree dysplasia

Definition

Most structures of a normal ear are recognizable. Normally reconstruction does not require the use of additional skin or cartilage.
Macrotia

Wedge-shaped excision

A simple way to reduce a macrotic ear is by excising a wedge of skin and cartilage. This method's shortcomings are that it deforms the auricle slightly and leaves conspicuous scars.

A modification of the sliding helix procedure

The reductive procedure recommended combines a sliding helix with a crescent excision of anterior skin and cartilage (Gersuny, 1903). The author's own otoplastic method is used to form the antihelix (Weerda, 1982a-d). The results are excellent. A multitude of variations on the wedge-shaped and crescent excisions have been described in the literature.

Protruding ears

The synonyms are 'prominent ears', 'bat ears', and 'lop ears'. One of the goals of otoplasty is to invent a single simple operation for correcting all the different types and degrees of protruding ears.

A child's ears grow only slightly after his or her sixth birthday, so that children with the stigma of prominent ears may be operated on about that time without any detrimental effects on the long-term growth of the auricle. Although the size of the ear does not increase significantly, the consistency of the cartilage does change, becoming less flexible as the child grows older. This may influence the method and results of surgical correction (compare Table 8.1).

The main features of protruding ears are underdevelopment or absence of the antihelix and crus superius and an overdeveloped concha. There are three widely used corrective procedures and scores of variants that are preferred by individual surgeons.

Converse procedure

This is the procedure used by most plastic surgeons (Converse et al, 1955; Converse and Wood-Smith, 1963; Converse and Tanzer, 1977). The posterior auricle is incised parallel to the helix and the cartilage underneath exposed. The superior and inferior borders of the antihelix are marked on the posterior aspect of the exposed cartilage with straight cutting needles and blue ink.

Incisions, which should not meet, are made through the exposed cartilage. If need be, the surface between the upper and lower incisions can be thinned with an electric diamond drill or rotating wire brush. This last procedure contributes to better results when the antihelix and crus superius are folded with mattress sutures. Conchal cartilage and the cauda helicis may have to be removed. An elliptical excision of postauricular skin may also have to be made (Walter, 1972). The incision in the posterior auricle is closed with interrupted or running sutures.
Modification of the Converse procedure

Whereas the Converse procedure uses the incisions illustrated, in the author's modification (Weerda, 1979, 1982a-d), the cartilage is thinned above and below a new antihelix with a diamond burr. This method can be applied in correcting other anomalies besides protruding ears, for example in dysplasia surgery, in reconstructing a missing helical rim, and in elevating a cup ear antihelix.

Mustarde's procedure

When the ear cartilage is thin, Mustarde (1963) prefers to fold the antihelix with mattress sutures without incising or weakening the auricular cartilage. Except in this one respect, Mustarde's procedure is similar to that of Converse.

Stenström procedure

The scapha, conchal rim, and crus superius are marked with straight cutting needles and blue ink after exposure of the posterior auricular cartilage (Stenström, 1963). An incision is made through the cartilage of the scapha, and the anterior cartilage of the antihelical area is freed of skin and perichondrium. The cartilage here is scored parallel to its free margin with a knife or an instrument specially designed for this purpose.

With the tension thus taken out of the cartilage, the antihelix begins to curl back, and assumes a normal curvature without any suturing.

Additional procedures

Rotation of the concha

One way to avoid an elliptical incision of cartilage from the hypertrophic concha is by rotating the concha to the mastoid (Furnas, 1968; Spira and Stal, 1983). The posterior auricular muscle is divided, and the mastoid exposed. The concha is rotated towards the mastoid and fixed with 3-0 Vicryl sutures.

Mild pressure dressings

The ear is carefully packed with a cotton-wool dressing that has been soaked in mineral oil. The dressing is applied for 7 days. From the ninth day after surgery, when the patient's sutures are removed, he/she should wear a second, elastic dressing or cap for 4 weeks.

Complications

On the rare occasions when a haematoma or perichondritis occurs, it is treated by coagulation and with antibiotics. Unsatisfactory results are corrected 6 months after surgery. Hypertrophic postauricular scars are treated with pressure and cortisone injections shortly after surgery and again by scar revision one or 2 years later if necessary.
**Cryptotia** (pocket ear)

**Definition**

The upper part of the auricle is buried beneath the temporal skin.

**Procedure**

An incision is made along the helical rim, and a flap is incised at the retroauricular hairline. After the auricle has been elevated, the flap is used to cover the postauricular defect. The wounds are closed with sutures.

**Colobomata**

A small transverse coloboma can be closed by Z-plasty. The ear illustrated is also protruding; the otoplastic procedure was used to correct the additional anomaly.

Larger defects are closed with a rib cartilage support and retro- and postauricular flaps.

A coloboma of the lobule is closed by excising and adapting skin.

**Lobule reconstruction**

This will be discussed in connection with trauma surgery.

**Cup ear deformities**

**Type I**

Synonyms are 'lop ear, 'lidding helix', 'constricted helix', 'minor (or moderate) cupping'. The otoplastic procedure for treating cup ear deformities of type I is outlined above.

**Type II**

A more severe lopping of the upper pole of the ear is corrected by a modification of Tanzer's (1974) method. The postauricular skin is incised, and the cupping cartilage is exposed on both sides. The cartilage is dissected and turned approximately 180°. The otoplastic procedure is used to elevate the scapha.

Rib cartilage is used when a short ear has to be expanded, or for additional support when the auricular cartilage is limp (Weerda and Walter, 1984).

After surgery, the auricle is supported for 14 days by mattress sutures.
**Second degree dysplasia (second degree microtia)**

**Definition**

Some structures of a normal auricle are recognizable. Reconstruction requires the use of some additional skin and cartilage.

**Type III (severe) cup ear deformities**

The severe cup ear is malformed in all its dimensions.

**First stage of reconstruction**

The auricle is incised and expanded by a method similar to that described by Davis (1974). The middle part of the auricle is reconstructed with a rib cartilage support and a retroauricular flap.

**Second stage**

The ear is raised, and a full-thickness skin graft is sutured and glued to the rough post- and retroauricular surfaces.

**The mini ear**

The mini ear is reconstructed in the same way as severe cup ear deformities.

**Third degree dysplasia (third degree microtia or anotia)**

**Definition**

None of the structures of a normal auricle is recognizable. Reconstruction requires the use of skin (from the surrounding area) and large amounts of cartilage.

**Auricle reconstruction (normal hairline)**

The procedure for treating third degree microtia is similar to the procedures described by Tanzer (1974), Converse and Brent (1977), and Brent (1980).

**First stage**

Before surgery, a template of the size of the patient's normal ear is cut out of a piece of transparent celluloid. The position of the new auricle is outlined on the mastoid region and a rib cartilage support is carved. Remnants of auricular cartilage are removed by a small incision in the vestige. The mastoidal skin is tunnelled, and the rib cartilage support inserted. With mattress sutures, which are tied over gauze, and fibrin sealant, the thin mastoid skin is snugged into the helical sulcus.
**Second stage**

The auricle is raised from the side of the head, and the postauricular defect is surfaced with a full-thickness skin graft from the buttocks. The lobule can be rotated in the same stage into a transverse position.

**Third stage**

In this stage the scapha is formed, which may require the removal of fibrous tissue and fat. The crus helicis, tragus, antitragus, and concha are formed in the third or in a fourth stage according to whether or not the helix is well defined.

**Postoperative care**

The reconstructed ear (its concavities in particular) and the auriculocephalic sulcus are packed with fluffed oiled wool. The whole area is then covered with a bulky wool and gauze dressing and bandaged in order to cushion pressure on the ear, especially at night.

Antibiotics may be administered for the first 3 or 4 days after surgery.

**Complications**

1. A small necrosis exposing cartilage is covered with an antibiotic ointment to prevent the cartilage from drying out.

2. A larger necrosis is excised. The defect created by excision is covered with flaps from the surrounding area.

3. Because fibrin glue is used, bleeding rarely occurs. In the event of a haematoma, the bleeding has to be staunched and the haematoma evacuated.

4. Infection is likewise a very rare complication. When an infection occurs, the surgical wound has to be opened and the affected cartilage removed. An antibiotic appropriate to treating the infection is administered.

**Middle ear reconstruction**

The planning of treatments is outlined. Middle ear surgery is not performed on any child with unilateral microtia and atresia when one ear is normal. Reconstruction (Weerda, 1984) of the pinna is begun once a child reaches the age of five or six (Jahrsdorfer, 1974; Bellucci, 1980; Weerda, 1985b).

A child with bilateral microtia and atresia is fitted with a bone-conduction hearing aid before his or her first birthday. The child has to be at least four before the author will consent to perform middle ear surgery. Children aged 5 or 6 years are operated on for bilateral microtia after they have undergone successful middle ear surgery.
Surgery for acquired deformities

Often it is irrelevant to one's choice of procedure whether a defect is due to tumour excision or traumatic avulsion.

Tumour surgery

A small defect in the rim from a wedge-shaped excision can be closed by a single operation (Converse and Brent, 1977). A defect in the crus hellicis is closed with a preauricular flap. The anterior part of the upper auricle is reconstructed according to a modified version of the sliding helix procedure (Gersuny, 1903; Antia, 1974). Any additional preauricular defect can be closed with a rhomboidal flap. The author prefers to reconstruct conchal defects with a full-thickness skin graft taken from either auriculocephalic sulcus. Alternatively a pedicled retroauricular graft may be used.

Subtotal resection with preserved helix

Microscopically controlled surgery allows preservation of parts of the auricle (Weerda, 1978; Weerda and Walter, 1984). A helix and lobule saved in such a fashion are showed; the other parts of the auricle were reconstructed in one stage with a bilobed flap from the neck. To prevent shrinkage, a defect-filling support of rib cartilage has to be inserted. Epithelium must be removed preparatory to affixing a folded transposition flap.

In reconstructions after ablation or petrosectomy, flaps from the surrounding area or myocutaneous pectoralis major island flaps are used.

Trauma surgery

After removal of a haematoma, seroma, or fibrous tissue (wrestler's ear, cauliflower ear), the thinned skin is readapted with fibrin glue and sutures (Weerda, 1979, 1980). A deep abrasion of skin from an auricle, or through-and-through laceration, is repaired with thin sutures if the auricle is well supplied with blood. Small defects in the rim or the anterior upper part of the auricle are closed with Burow's triangles of a sliding helix (Gersuny, 1903; Antia, 1974; Brent, 1978).

Replantation

Replantation of a freshly avulsed auricle or part of one is hazardous work. The largest avulsed parts that have been successfully replanted as composite grafts have been under 26 x 10 mm.

Baudet's method of replantation

The only methods that significantly diminish the risks incident to replantation of larger parts of the auricle are those described by Baudet, Tramond and Goumain (1972) and Arfai (after Spira, 1974). Ninety per cent (or 13 out of 14 of replantations of larger parts of the auricle by a simple procedure have resulted in loss of the replant. By contrast, 90% of the auricles replanted experimentally according to Baudet's method have taken. Replantation
should be performed within 24 hours of avulsion (Weerda, 1986). Arfai’s modified version of the Baudet operation preserves the postauricular skin of the totally avulsed auricle. The auricle is replanted as a composite graft. The fenestrated cartilage and the postauricular skin are glued and sutured to the rough surgically enlarged mastoid wound (Spira, 1974. Using Arfai’s method, the totally avulsed ear could be reconstructed in four stages - the lobule was repaired with a Gavello flap.

**Microvascular anastomosis**

This is discussed in connection with surgery for total avulsion by Buncke and Schultz (1966) and Pennington, Lai and Pelly (1980). Their advice is that auricles should be replanted within 5 hours of avulsion.

**Reconstruction of partially avulsed ears**

*The upper part of the pinna*

In tumour and trauma surgery, reconstruction of parts of the auricle is begun by incising and tunnelling the retroauricular skin and inserting a support of rib cartilage. The helix is moulded with fibrin glue and mattress sutures tied over gauze. In a second stage, the auricle is raised, and the post- and retroauricular defects are covered with full-thickness skin grafts. Later on the ear can be corrected, for a satisfactory end result, by deepening the scapha or crus helicis or other parts of the auricle.

*The middle part of the auricle*

This is reconstructed in the same manner as its upper part.

*The lower part of the ear*

This and the lobule are both reconstructed by the Gavello-flap technique.

A rib cartilage support is embedded to prevent shrinkage. The work of shaping the auricle is completed in a second stage.

**Reconstruction after the total loss of an avulsed auricle**

*Retroauricular implantation*

A rib cartilage is embedded under the retroauricular skin in the same way as in the procedure for correcting severe microtia. The helix is moulded with fibrin glue and mattress sutures. The auricle is raised and formed in either three or four stages.

*The fan-flap method*

When a low hairline makes it impossible to repair a microtic or avulsed auricle by one of the methods outlined so far, a support is embedded under the pedicled temporoparietal fascia. The fascia can be adapted to the support with fibrin glue and by suction drainage. A
full-thickness skin graft is glued to the rough surface. The auricle is raised from the side of the head in a second stage (see Brent and Byrd, 1983).
Chapter 9: Acute suppurative otitis media and acute mastoiditis*

Joselen Ransome

* This is an abbreviation of the chapter on this subject, in Volume 6.

Definition

Acute suppurative otitis media is an inflammation of the mucous membrane lining of the middle ear cleft (consisting of the eustachian tube, tympanic cavity, mastoid antrum and mastoid air cells) produced by pus-forming organism.

Acute mastoiditis, formerly a common complication of acute suppurative otitis media, is nowadays rare in countries with well-developed primary medical care. While some degree of mastoiditis inevitably occurs early in the course of acute suppurative otitis media, since the middle ear and mastoid mucosa are in continuity, the clinical entity of acute mastoiditis consists of persistence of pain in and behind the ear despite adequate antibiotic therapy or time for natural resolution, together usually with persistence of otorrhoea, fever, and tenderness over the mastoid antrum.

Anatomy

The anatomy of the middle ear cleft is detailed in Volume 1.

Acute suppurative otitis media

Aetiology

Route of infection

(1) Via the eustachian tube.
(2) Via the tympanic membrane.
(3) Blood-borne infection.

Predisposing factors

Age

Acute suppurative otitis media is a common disease of childhood.

Socio-economic factors

The incidence is highest in populations with low hygiene, overcrowding and malnutrition.
Climate

A higher incidence of acute suppurative otitis media is seen in cold climates, especially in winter. The incidence is also higher in urban than in rural areas.

Racial factors

Studies in the USA (Brodley, Brookhouser and Tucker, 1986) have shown a higher incidence of acute suppurative otitis media in white children compared with black; a particularly high incidence is seen in Eskimos and American Indians.

Nasopharyngeal tissue masses

Adenoids (see Volume 6)

Other nasopharyngeal masses

These act in a similar way to adenoids and include polyps, teratoma, angiofibroma, lymphoma and, in adults, carcinoma (see Volume 4, Chapter 18).

Respiratory disease

Chronic rhinitis and sinusitis produce a constant flow of infected mucus which may enter the eustachian tubes, while the infected sputum of bronchitis, bronchiectasis and pneumonia may also be coughed into the nasopharynx and enter the tubes.

Allergy

The importance of allergy as an aetiological factor in acute suppurative otitis media is still debatable.

Pre-existing middle ear effusion

A pre-existing middle ear effusion may act as a ready culture medium for invading pyococci.

Immunodeficiency syndromes

Immunodeficiency syndromes, including the hypogammaglobulinaemias, are rare but important causes of recurrent upper respiratory infections including acute suppurative otitis media, and should always be excluded when recurrences are frequent. Drug induced immunosuppression may also be contributory.

Chronic systemic disorders

Chronic systemic disorders undoubtedly predispose to acute suppurative otitis media, as they do to other infective disease. Examples occurring in both children and adults are diabetes mellitus, the leukaemias, the anaemias, cystic fibrosis and nephritis.
Cleft palate

Children with cleft palate have a high incidence of middle ear disease, either acute suppurative otitis media or otitis media with effusion, due to eustachian tube dysfunction secondary to the tensor palati anomaly.

Primary ciliary dyskinesia

Primary ciliary dyskinesia, although excessively rare and more usually associated with otitis media with effusion, can also contribute to recurrent acute suppurative otitis media.

Pathology

Microbiology

While acute suppurative otitis media is appropriately considered as a bacterial disease (see Table 3.2), viruses undoubtedly play a role in many cases, paving the way for pyococcal invasion.

Middle ear inflammatory process

This can proceed quite rapidly, and consists of a stage of mucosal oedema with increased secretion, followed by hyperaemia, white cell infiltration and pus formation. This process clearly cannot be limited to the tympanum since the air spaces and mucosa of the entire middle ear cleft are in continuity; hence, tubal occlusion occurs due to mucosal swelling, preventing drainage, and involvement of the mastoid air cells also occur. If pus accumulates under pressure and there is tubal occlusion, the tympanic membrane will rupture in most cases. Destruction of cilia, normally present in the anterior part of the tympanum and in the tube, contributes to the poor drainage of thick secretions through the tube.

Spread of infection

Spread of infection can occur due to retrograde thrombophlebitis, bone necrosis, congenital dehiscences and fracture lines, as follows:

(1) intracranially, giving rise to extradural or subdural abscess, meningitis, brain abscess, lateral sinus thrombosis, and otitic hydrocephalus;

(2) to the labyrinth causing suppurative labyrinthitis;

(3) to the facial nerve canal causing facial paralysis;

(4) to the neck, by breaking through the mastoid tip, producing Bezold's or Citelli's abscess;

(5) to the petrous apex.

Details of (1) and (2) can be found in Chapter 12.
Symptoms

The variation in the clinical picture in any infection is due to the differing virulence of the invading microorganism, varying host defence, and effectiveness of and compliance in treatment.

Acute suppurative otitis media can vary from a relatively minor attack of earache with tympanic membrane hyperaemia lasting a few hours, to a fulminating febrile illness perhaps with complications requiring surgery.

By far the most common presenting symptom of acute suppurative otitis media is pain in the affected ear or ears which is accurately described and well located by older children and adults, who point to the ear canal and say the pain is 'deep inside', and frequently severe and throbbing. Usually the attack will have been preceded by an upper respiratory infection, and symptoms and signs of this may be present. Deafness in the affected ear or ears will soon be noticed by older children and adults; the disease is often bilateral in children, but in unilateral cases the hearing loss may not be apparent.

At this stage the disease may not progress and will gradually resolve, with the pain subsiding and the hearing gradually recovering. In many cases, however, it proceeds to a stage of intense pain, followed by rupture of the tympanic membrane and a complaint of aural discharge. A small percentage of both children and adults also complain of giddiness.

There may be a history of one or more of the predisposing factors described under aetiology.

Signs

Ears

In the early stages, the tympanic membrane will be injected along the handle of the malleus, around the periphery, and sometimes over the pars flaccida. Later, the whole tympanic membrane becomes hyperaemic and opaque. If infection continues and pus begins to accumulate under pressure, the pars tensa starts to bulge, mainly posteriorly, and acquires yellowish colour. Finally, the tympanic membrane ruptures and discharge will be seen in the external canal, which may be serous, serosanguineous, mucopurulent or frankly purulent. It is important to note whether the discharge has the shiny, glossy appearance of mucus - if the discharge contains mucus it can only come from the middle ear. The presence or absence of an offensive odour from the discharge should also be noted - if present it suggest underlying chronic otitis media. (See also Differential diagnosis below.)

At this time the pain usually subsides. After mopping or aspirating discharge, it is usually possible to see a small central perforation, commonly in the posterior segment of the pars tensa. Sometimes, however, the perforation may be seen only with difficulty as the oedematous edges of the middle ear mucosa tend to fill it in. It may be located by aspirating through a Siegle's speculum, or under the operating microscope, when a blood of discharge may be seen passing through the perforation. The perforation may also be anterior, but is only
marginal or in the pars flaccida in acute-on-chronic middle ear disease. If the infection has followed trauma to the tympanic membrane, a jagged perforation may be seen. If a ventilation tube is in situ, pus may be seen pulsating through the lumen.

Mastoid tenderness, elicited by pressure over McEwen's triangle, is almost invariably present early in the course of acute suppurative otitis media. It assumes significance as a sign of mastoiditis if it persists or increases despite adequate treatment.

During resolution, the hyperaemia fades and the perforation heals, often leaving no trace but sometimes leaving a scar. In older children and adults, the Rinne and Weber tests will indicate conductive deafness. In younger children the hearing for a whispered voice will be impaired.

Nose and throat

As stated, the commonest cause of acute suppurative otitis media is the common cold, and examination of the nose and throat may show inflammation of the mucosa and nasal mucoid discharge.

General signs

Children are frequently febrile, but adults rarely so.

Signs of complications

Acute suppurative otitis media may be a serious illness. Complications may develop rapidly and it is necessary to be alert to the signs of these.

Tenderness and oedema over the mastoid process with protuberance of the pinna indicate mastoiditis, as do sagging of the posterosuperior canal wall, and granulation tissue pouting through the perforation, with discharge persisting for 3-4 weeks from the onset. (See also Differential diagnosis and Acute mastoiditis below.)

Sick children should always be tested for neck stiffness, and in severe cases thorough examination of the central nervous system should be carried out to exclude intracranial complications. Nystagmus must be looked for in patients complaining of vertigo, and the fistula test carried out.

Investigations

Microbiology

In all cases when otorrhea is present, an ear swab should be taken for culture and sensitivities.
Blood studies

A full blood count, including differential white cell count is mandatory in recurrent cases or very ill patients, or those in whom complications, particularly intracranial ones, are suspected.

Quantitative immunoglobulin electrophoresis to detect varying degrees and types of hypogammaglobulinaemia should also be carried out in patients with frequent attacks of acute suppurative otitis media.

Audiometry

Pure tone audiometry needs to be performed fairly early in the course of acute suppurative otitis media, but need not be done when the patient is in severe pain and febrile.

Tympanometry should not be carried out in the acute stage.

Mastoid X-rays

X-rays are only required if mastoiditis is diagnosed and is not responding to medical treatment (see Chapter 2).

Diagnosis

This is usually straightforward and is based on the history of earache, deafness, and perhaps otorrhoea, probably preceded by a respiratory infection, together with the inflammatory changes found on examination which have been described above. However, there are some pitfalls and these are discussed below.

Differential diagnosis

This is considered later under Acute mastoiditis.

Prognosis

In this antibiotic era, complete resolution is the rule, with absence of complications, healing of the tympanic membrane, and restoration of normal hearing. In a few, a sterile middle ear effusion or a perforation persist, and only a very small percentage proceed to acute mastoiditis. Life-threatening intracranial complications are very rare, and are more often associated with a pre-existing chronic otitis media.
Complications

1. Mastoiditis, which may also lead to postauricular abscess or Bezold's and Citelli's abscess.

2. Facial paralysis.

3. Intracranial complications - extradural abscess, subdural abscess, meningitis, brain abscess, lateral sinus thrombosis and otitic hydrocephalus.

4. Labyrinthitis.

5. Petrositis and Gradenigo's syndrome.

Mastoiditis and petrositis are described below. Intracranial complications and labyrinthitis are rare nowadays, but when they do occur it is more commonly in association with chronic otitis media. These conditions are described in Chapter 12.

Sequelae

(1) Persistence of a sterile middle ear effusion.

(2) High-tone sensorineural deafness.

(3) Persistent perforation of the tympanic membrane; discharge may also persist, and the disease may evolve into chronic suppurative otitis media.

(4) Extensive scarring of the tympanic membrane, middle ear adhesions and resorption of ossicles may occur in recurrent cases (adhesive otitis).

Treatment of acute suppurative otitis media

Treatment is considered under the following headings:

(1) curative
   medical
      general
      analgesics
      topical
      antibiotics
      [decongestants]
      surgical - myringotomy

(2) [prophylactic]

(3) treatment of associated conditions

(4) treatment of complications.

The square brackets indicate treatment modes not generally considered to be appropriate.
Curative

Medical treatment

General

Both children and adults are best managed in bed in the acute phase, in a warm room, with adequate humidity to maintain ciliary function.

Analgesics

These must be given in adequate dosage and with sufficient frequency to control pain.

Topical

When otorrhoea is present the discharge should be gently mopped with dry sterile cotton wool or sucked from the canal, as often as it recurs.

Antibiotics

Most otologists and primary care physicians in the UK would favour early administration of antibiotics in all but the most minor cases, despite the fact that some cases may be viral, and notwithstanding the need to avoid overprescribing.

Route of administration. Oral administration is the route of choice except in very severe cases. In these, one or more antibiotics may be given intravenously.

Duration. Antibiotics should usually be given for 5-10 days, depending on the severity of the case.

Choice of antibiotic. Administration should not be started before an ear swab is taken (or nose and throat swabs if the ear is not discharging), but after this there is no need to wait for the result. Amoxycillin is a useful first-line treatment as it is well tolerated and the common bacteria of acute suppurative otitis media are usually sensitive to it. Other useful antibiotics are erythromycin, trimethoprim, trimethoprim with sulphamethoxazole (cotrimoxazole), and cefaclor. Severe and fulminating cases can be given a combination of ampicillin, flucloxacillin and metronidazole intravenously.

The response to the chosen regimen should be monitored carefully and, if ineffective, it should be altered according to the results of the swab cultures and organism sensitivities.

Decongestants. Both systemic and topical decongestants are often prescribed in the hope that they will improve the patency of the eustachian tube and thus improve middle ear drainage. Unfortunately, however, many trials have now shown that systemic decongestants are no better than a placebo in the management of middle ear disease. Since systemic administration of pseudoephedrine and similar compounds may sometimes cause sleep disturbance, irritability and, occasionally, psychotic symptoms, especially in children, the conclusion is inescapable that their use is unwise. The use of topical decongestants in acute
suppurative otitis media is not recommended as they are unlikely to produce a useful effect on the eustachian tube.

**Surgical treatment**

While the vast majority of ears with acute suppurative otitis media will respond to the above regimen of appropriate antibiotics, bed-rest and analgesia, and while some tympanic membranes will rupture spontaneously with or without treatment, in a very small minority there is persistence of pain and temperature with a red bulging tympanic membrane despite adequate medical management. *Myringotomy* should then be undertaken with a view to releasing pus accumulating under pressure.

The operation is carried out under general anaesthesia using an operating microscope (see Volume 6), and with full aseptic procedures. The patient is placed supine on the operating table with the head turned to one side. Using an aural speculum and angled myringotome, a radial incision is made in the posteroinferior segment; the maximum bulging is posterior in acute suppurative otitis media, and the inferior incision avoids the risk of damaging the ossicular chain, chorda tympani and facial nerve. Pus then gushes out under pressure, and a swab is taken and sent for culture and sensitivities. Residual pus is gently sucked out. The incision should be about 3-4 mm in length; tiny incisions tend to heal too quickly and allow put to reaccumulate in the middle ear cleft. Ventilation tubes should not be inserted in acute suppurative otitis media.

Postoperatively, on recovering from anaesthesia the patient will usually say that the earache has disappeared, and usually the temperature quickly returns to normal. Antibiotic treatment is continued until resolution is virtually complete, but the regimen is changed if necessary as soon as the results of the swab taken at operation are known.

**Prophylactic treatment**

Long-term prophylaxis with oral antibiotics is not generally recommended.

**Treatment of associated conditions**

The treatment of acute suppurative otitis media, especially when recurrent, should include a search for and management of treatable associated disease. *Rhinitis and sinusitis* should also be looked for and treated vigorously. The presence of *lower respiratory infection* requires treatment with the help of a respiratory physician. *Other conditions* referred to under aetiology must receive the appropriate management.

**Treatment of complications and sequelae**

**Persistence of middle ear effusion**

This is a common sequel to an attack of acute suppurative otitis media and therefore there must be careful follow-up of each case by otoscopy and tympanometry. The treatment is described in Volume 6, Chapter 12.
Persistent perforation of the tympanic membrane

See Chapter 11 on reconstructive surgery of the ear.

Labyrinthitis and intracranial complications

These are described in Chapter 12.

Facial paralysis

The treatment of facial paralysis occurring in the course of middle ear cleft infection is the vigorous treatment of the primary condition - when the infection is controlled the facial nerve recovers.

Mastoiditis and petrositis

These are described below.

Acute mastoiditis

Aetiology and pathology

Acute mastoiditis is a complication of acute suppurative otitis media. In developed countries with effective primary and secondary health care, it is nowadays rare, largely due to the widespread use of antibiotics for acute suppurative otitis media. However, if the preceding attack is untreated, or fails to respond, the inflammatory process will persist and increase in the mastoid air cells. The accumulation of pus in the air cells leads to necrosis of the bony walls of the cells producing the so-called 'coalescent mastoiditis'. For a time the disease may remain walled off within the mastoid bone, but eventually it will spread:

(1) laterally through the lateral outer table of the mastoid bone to give:
   (i) a subperiosteal abscess and, if pus ruptures through the periosteum
   (ii) subcutaneous abscess
(2) superiorly and posteriorly, giving rise to:
   (i) extradural abscess
   (ii) subdural abscess
   (iii) meningitis
   (iv) brain abscess
      (a) the temporal lobe
      (b) the cerebellum
   (v) lateral sinus thrombosis
   (vi) otitic hydrocephalus
(3) medially causing
   (i) labyrinthitis
   (ii) petrositis and Gradenigo's syndrome (due to direct spread through a pneumatized petrous bone
(4) *inferiorly* through the mastoid process tip or medial wall causing:
   (i) Bezold's abscess (tracking along the sternomastoid muscle)
   (ii) Citelli's abscess (tracking along the posterior belly of the digastric muscle)
(5) *anteriorly* to the facial nerve canal causing facial paralysis, and also to the posterosuperior external auditory canal wall, causing the appearance of sagging.

**Predisposing factors**

These are the same as described above for acute suppurative otitis media. The disease can occur at any age.

**History**

The patient will have had an attack of acute suppurative otitis media, with the characteristic symptoms and signs described above, anything from a few days up to 3 or 4 weeks previously.

**Symptoms**

**General**

Mastoiditis is frequently a serious illness with pyrexia and general malaise.

**Local**

Commonly there is persistence of earache, otorrhoea and increasing hearing impairment, from the time of onset of the preceding acute suppurative otitis media. The presence of unilateral headache is a danger sign suggesting the onset of intracranial complications. Similarly a complaint of giddiness is a warning that purulent labyrinthitis is imminent, or developing.

**Signs**

**General**

The patient will frequently appear pale, ill and restless. There may be pyrexia of 40°C or more in children, although in adults pyrexia may be low or absent.

**Local**

*External auditory canal*

On examination of the external auditory canal, there may be:

(1) discharge

(2) sagging of the postero-superior canal wall.
**Tympanic membrane**

(1) Perforation is almost invariably present, and is nearly always posterocentral.

(2) Granulations or a polyp, bright red in colour, are sometimes seen pouting through the perforation.

**Signs of complications**

Severe headache, drowsiness, vomiting, and neck stiffness are serious signs of intracranial complications and must prompt an immediate and thorough examination of the central nervous system. Vertigo with nystagmus suggests purulent labyrinthitis.

**Postauricular area**

(1) Mastoid tenderness, elicited by pressure over McEwen's triangle, will invariably be present.

(2) Swelling over the mastoid bone may be present, and if so either the postauricular groove is accentuated indicating that the pus is still subperiosteal, or the postauricular groove is absent, because either the periosteum has given way and the pus is subcutaneous, or there is simple inflammatory oedema over the mastoid. The presence of fluctuation will distinguish the later abscess formation from the earlier simple inflammatory oedema.

(3) Protuberance of the pinna can occur either due to simple inflammatory oedema over the mastoid, or of subcutaneous abscess; subperiosteal abscess with retention of the postauricular groove does not push the pinna forwards unless the abscess is very large.

**Investigations**

These are the same as for acute suppurative otitis media.

**Mastoid X-rays**

While seldom required in simple acute suppurative otitis media, where mastoiditis is present and not responding to treatment, X-rays (see Chapter 2) may show not only clouding of cells (always present in acute suppurative otitis media), but also breaking down of bony air cell walls, indicating progressive disease. The films are also a useful guide if surgery is required, as to the extent of pneumatization which varies greatly.

**Diagnosis**

Diagnosis is made on the history, symptoms and signs, sometimes supported by X-rays, as already described. The principal features can be summarized as follows: an attack of acute suppurative otitis media fails to resolve and is followed by persistent or recurrent earache, pyrexia and otorrhoea, increasing deafness, with mastoid tenderness and sometimes a protuberant pinna.
Differential diagnosis of acute suppurative otitis media and acute mastoiditis from other conditions

Acute suppurative otitis media

Acute suppurative otitis media may sometimes have to be distinguished from the following conditions:

Otitis externa

Otitis externa may also give earache and otorrhoea, and the tympanic membrane may appear red as the outer layer is in continuity with the canal epithelium and is frequently involved in the inflammatory process (myringitis). The discharge is frequently watery, but if purulent it never has the shiny, glossy appearance of middle ear discharge due to the presence of mucus. The hearing in otitis externa is normal or only slightly impaired. Itching is a very common feature of otitis externa.

Very severe otitis externa may mimic acute mastoiditis (see below).

Tympanic membrane hyperaemia

The whole tympanic membrane can become quite diffusely red in a child who is crying. Since he may be crying because he has earache, time must be allowed for him to settle down and then the examination is repeated.

Otitis media with effusion

The tympanic membrane may sometimes look pinkish and opaque, but is never as intensely red as in acute suppurative otitis media.

Myringitis haemorrhagica bullosa

This condition frequently occurs during epidemics of respiratory viruses such as influenza, and is characterized by excruciating earache followed by a small quantity of serosanguineous discharge. Inspection of the tympanic membrane shows either the presence of haemorrhagic blebs, or the outlines of ruptured blebs. When uncomplicated the hearing is usually normal. Secondary bacterial invasion of the middle ear may occur, so the two conditions may coexist.

Other conditions

There are conditions which stem from other causes of otalgia (see Chapter 13). In referred pain the tympanic membrane and hearing are not affected.

Acute mastoiditis

This may have to be distinguished from:
Acute severe otitis externa

This is usually localized in the form of a furuncle and may lead to really marked postauricular oedema and protuberance of the pinna; this, together with severe earache and some purulent otorrhoea, produces the resemblance to acute mastoiditis. However, in furunculosis, there is severe pain on pushing the tragus gently in and on pulling gently on the pinna. There will be no history of a preceding attack of acute suppurative otitis media. The hearing is usually normal or only slightly impaired. If the postauricular groove is accentuated, this is a sign of subperiosteal pus which has spread from the mastoid. (Note that absence of this sign is not a differentiating factor.) X-rays of the mastoids will show apparent cloudiness of the air cells in either condition (due in external otitis to the overlying oedema), but if breaking down of the bony mastoid air cell walls is shown, this indicates that mastoiditis is present.

Postauricular lymphadenitis

Very rarely, suppuration in a postauricular lymph node, due to infection in the skin or scalp, may cause confusion. However the tympanic membrane, external auditory canal and hearing will be found to be normal.

Erysipelas

Erysipelas may occasionally affect the skin of the postauricular area, and resemble mastoiditis because of pain, fever and red oedematous skin. However, careful examination will reveal a raised, red spreading edge of the lesion, contrasting sharply with the normal pale adjacent skin. The external canal skin, tympanic membrane, and the hearing, will all be normal.

Complications of acute mastoiditis

These have been referred to under pathology for both acute suppurative otitis media and acute mastoiditis and will not be described here, except petrositis. The reader is reminded that labyrinthitis and the intracranial complications are discussed in the chapter on complications of otitis media (Chapter 12).

Acute petrositis

The degree of pneumatization of the temporal bone is extremely variable, but may extend right through the petrous bone to its apex. If so, when there is mastoiditis, there is nothing except host defence and timely treatment to prevent infection spreading right to the petrous apex. However, acute petrositis is now excessively rare, and even in the preantibiotic era, it was not common.

Clinical picture

The clinical picture is that of the preceding acute suppurative otitis media and acute mastoiditis which fails to respond to treatment, sometimes even if this included cortical mastoidectomy. There is persistence of earache and temperature, then pain is felt in the
distribution of the ipsilateral trigeminal (fifth cranial) nerve. Finally, involvement of the ipsilateral abducent (sixth cranial) nerve gives rise to diplopia, and examination of the eye movements will show paralysis of the external rectus muscle of the eyeball on the affected side (sixth nerve paralysis).

**Gradenigo's syndrome**

The features of this are acute infection of the middle ear cleft associated with pain in the distribution of the trigeminal nerve and sixth nerve paralysis. The syndrome is due to the close anatomical relationship of the fifth and sixth nerves with the petrous apex. Besides acute petrositis it may also be due to an extradural abscess or a patch of meningitis overlying the petrous apex.

**Diagnosis**

Diagnosis depends on the foregoing clinical picture, assisted by polytomography and/or computerized tomographic (CT) scanning of the temporal bone.

**Treatment**

Intensive antibiotic treatment (*see above under* Treatment of acute suppurative otitis media and *below*) is begun immediately and in a previously untreated case with a short history, this may well be all that is required. However, if the patient fails to respond in 24-48 hours, or if cortical mastoidectomy has already been performed but the disease nevertheless progresses to petrositis, further surgical exploration will be required. This is considered below following surgical treatment of acute mastoiditis.

**Treatment of acute mastoiditis**

**Medical**

Even when a child or adult presents with an advanced case of acute mastoiditis with postauricular oedema and protuberant pinna, the treatment is initially medical in hospital, and even the majority of these cases will resolve completely. The exceptions are those cases with postauricular fluctuation, previous adequate medical management, or suspected intracranial complications.

**Surgical**

**Cortical mastoidectomy**

Cortical mastoidectomy is indicated:

(1) if subperiosteal fluctuation, suspected intracranial complications, or a neck abscess are present when the case presents
(2) if there is persistence of pain, temperature, and otorrhoea, or even just profuse otorrhoea on its own, after 2-4 weeks of adequate medical management including use of the correct antibiotic based on culture results, and known compliance in the antibiotic regimen.

The aim of the operation is to exenterate the mastoid air-cell system as completely as possible.

**Preoperative investigation**

Besides those investigations previously mentioned, the patient's fitness for general anaesthesia should be assessed, when possible an immediate preoperative audiogram should be carried out, the facial movements examined to exclude preoperative facial paralysis, the eye movements examined to exclude nystagmus, and the central nervous system examined to exclude or assess intracranial complications. Mastoid X-rays not only help to confirm the indications for surgery, but also give guidance to the surgeon on the extent of pneumatization and the positions of the dura of the middle and posterior cranial fossae.

**Preparation**

A postauricular incision is used and, as it is fairly close to the hair-line, the hair should be taped out of the way with Sellotape or other adhesive tape. It is not usually necessary to shave the hair in children.

**The operation**

This is performed under general anaesthesia. A curved incision is made through the skin of the postauricular region a few millimetres behind and parallel to the postauricular groove (see Volume 6).

Care must be taken in the lower half of the incision in infants, in whom the mastoid process is undeveloped, and the facial nerve, as it leaves the stylo mastoid foramen, is therefore superficial. The periosteum is elevated forwards as far as the lateral end of the posterior bony meatal wall, backwards for a few millimetres, and upwards (pushing up the temporalis muscle at the same time) to the level of the upper attachment of the pinna.

In exenterating part of the mastoid bone to uncover the antrum it must be remembered that: (a) the antrum is at a depth of 15 mm in the adult, but only a few millimetres in the infant; (b) the surface marking of the antrum is McEwen's triangle; and (c) the position of the middle and posterior fossa dura can be judged by examining the lateral oblique X-ray of the mastoid.

Bearing these landmarks in mind, bone is gradually removed with the drill until the antrum is exposed.

If pus is encountered a further swab is taken and sent for culture. To confirm that the antrum - rather than merely a large cell - has been entered - a small Dundas Grant probe is passed into the aditus. This should be done gently to avoid dislodging the short process of the incus. At the same time the size of the aditus can be judged; if it is very small it may be
enlarged slightly with a fine bone curette to ensure adequate drainage of the middle ear. (Note that the bony posterior meatal wall must be preserved, and the skin not dissected from it.)

The air cells are now followed and removed in every direction. It is particularly important to clear all the cells from the sinodural angle. The smooth bone covering the middle fossa dura above and the lateral sinus posteriorly is usually recognized.

There is frequently a group of cells in relation to the vertical part of the facial nerve which are best removed under the operating microscope. In a well-pneumatized skull, cells may extend anteriorly into the root of the zygoma and posteriorly into the occipital bone; these too must be followed as far as is practicable.

It is not necessary to remove the whole tip of the mastoid; all cells up to the tip should be removed.

The bony cavity thus created has the antrum as its deepest point, and is bounded above by the dural plate, posteriorly by the sinus plate and anteriorly by the bony meatal wall and aditus. In patients with intracranial complications, a small area of both middle fossa dura and lateral sinus should be exposed; if this reveals granulations or an extradural abscess, exposure of dura is continued until healthy dura is found.

A small drain is inserted into the antrum and led out near the mastoid tip. The skin is closed with interrupted sutures, and a dressing pad and bandage should be applied firmly to prevent a subcutaneous haematoma.

**Postoperative care**

As soon as the patient is conscious, the facial movements are examined to exclude operative damage to the facial nerve. Antibiotic therapy is continued.

The patient's temperature should be taken every 4 hours. It usually falls dramatically within the first 24 hours, when the patient can be allowed up.

The drain should be removed when there is no further discharge either through the wound or through the external meatus. In practice this is usually after 2-3 days, but the drain should be left longer if necessary.

**Complications**

Complications of the operation are few and due mainly to errors of technique.

*Persistent deafness.* This may be due to the following:

1. incus dislocation or removal
2. persistent infection due to residual cells.
Complete facial nerve paralysis. If present immediately postoperatively, but not preoperatively, the facial nerve has been damaged at operation, and the mastoid must be reopened and the facial nerve explored.

Meatal stenosis. This may occur if the bony meatal wall is taken down and the skin dissected off the bony wall. It requires excision of the stenosed area and firm packing of the canal until re-epithelialization occurs.

Incision and drainage of a postauricular abscess

As described, this condition occurs when pus spreads beyond the confines of the middle ear cleft and ruptures through the lateral surface of the mastoid process into the subperiosteal space. This then would normally be an indication for cortical mastoidectomy, since incision and drainage alone may not be sufficient to enable the mastoiditis to resolve. However, in two circumstances simple incision of the abscess is indicated:

1) In infants, who may occasionally develop a postauricular abscess from a middle ear infection, but in whom the mastoid is not pneumatized nor the mastoid process developed; particular care must be taken with the incision because of the superficial placing of the facial nerve.

2) In a patient, of any age, judged too ill to sustain even the not very long procedure of cortical mastoidectomy, in whom time is of the essence and rapid evacuation of at least some pus is thought to be adequate for the time being - for such cases an even simpler alternative is needle aspiration.

The procedure consists of a simple postauricular incision over the point of maximum fluctuation. When the pus is found a swab is taken, then as much pus as possible is sucked out. A small drainage tube is stitched in and the incision closed.

Myringotomy

Myringotomy alone is obviously not a sufficient form of surgery for acute mastoiditis, but in those few patients who require surgery, but in whom there has been no spontaneous perforation of the tympanic membrane, a myringotomy should be performed as well as other appropriate procedures.

Surgical treatment of acute petrositis

The indication is the presence of acute petrositis, perhaps with Gradenigo's syndrome, and failure to respond rapidly to medical treatment.

The following account of the various approaches to the petrous cells used in the past, has been given by Mawson (1979). It is emphasized that such surgery would be exceptionally rare nowadays; it is difficult and hazardous, and should only be performed by those with very considerable familiarity with the field.
Extrapetrosal drainage

A cortical mastoidectomy operation is performed or reopened. Any fistulous tracks found must be followed. If necessary surgery must proceed to radical mastoidectomy. Tracks may then be found which lead towards the apex from the hypotympanum or attic.

Various routes for a deep exploration are as follows:

Eagleton's operation

A wide exposure of the dura of the middle fossa is made by removal of the tegmen, the base of the zygoma and part of the squamous temporal bone. The dura of the middle fossa is gently elevated towards the petrous apex.

Almoor's operation

The petrous apex is approached through a triangle bounded by the tegmen tympani above, the carotid artery anteriorly and the cochlea posteriorly.

Ramadier's operation

Here the petrous apex is approached more widely. The tympanic plate of the external auditory canal, posterior to the base of the glenoid fossa suture line, is removed. The carotid artery is lifted forward by a gauze sling. The petrous apex may then be explored through the posterior wall of the bony carotid canal.

Frenckner's operation

Sometimes a group of cells runs under the arch of the superior semicircular canal. This is a good approach to the petrous apex, but it would have to be combined with an approach to the hypotympanum.
Chapter 10: Management of chronic suppurative otitis media

P. M. Shenoi

Chronic suppurative otitis media is typically a persistent disease, insidious in onset, often capable of causing severe destruction and irreversible sequelae, and clinically manifests with deafness and discharge. The existence of chronic suppurative otitis media in prehistoric times has been clearly documented (McKenzie and Brothwell, 1967). These authors also referred to the discovery of cholesteatoma in a skull found in Norfolk, UK, and thought to be of Anglo-Saxon date. Radiological changes in the mastoid as evidence of previous infection have been the subject of enquiry in 417 temporal bones from South Dakota Indian burials (Gregg, Steele and Holzhueter, 1965) and in 15 prehistoric Iranian temporal bones (Rathbun and Mallin, 1977); both of these studies demonstrated changes compatible with previous infection in approximately 40% of specimens.

The incidence of chronic suppurative otitis media appears to depend on race and socioeconomic factors. A significantly higher incidence of the disease was reported in Inuit (Eskimos) and American Indians (Fairbanks, 1981), in the Alaskan indigenous population (Tschopp, 1977), in Australian aboriginal children (McCafferty et al, 1977), and among black South Africans (Meyrick, 1951). Socio-economic factors such as poor living conditions and overcrowding, poor hygiene and nutrition have been suggested as a basis for the widespread prevalence of chronic suppurative otitis media in the Third World and similar factors were observed among the poor whites with chronic ear disease in Appalachia (Kentucky), the incidence of which closely resembled that seen in the American Indians (Fairbanks, 1981). In systematic investigation of middle ear disease in samples of the general population in Goteborg, Ruding et al (1983) observed the incidence of perforated tympanic membrane to be 2.1% and 2.3% among the 60- and 50-year-old cohorts respectively, compared with only 0.8% in the 20-year-old cohort. The incidence of active disease was 1.05% in the 60-year and 1.15% in the 50-year cohorts. These findings of increased prevalence of perforated tympanic membranes in the older compared with the younger age group concur with the results of Hinchcliffe (1961) who, in an earlier study involving and adult rural population in the UK, found the overall incidence of active chronic suppurative otitis media to be 1.1%. An incidence of active chronic suppurative otitis media of 0.6% among the adult population of the UK was reported by Browning et al (1983b).

The management of chronic suppurative otitis media has witnessed a profound change over the last 100 years, from the early attempts at surgical exposure of the middle ear in 1889 to the present day techniques of tympanoplasty in persistent but inactive disease and the 'canal-up' or the 'canal-wall-down' techniques in cholesteatoma surgery (Milstein, 1980). Earlier methods of radical surgery were necessary to control, even at the expense of hearing loss, an undoubtedly destructive disease associated with serious complications at a time when antibiotics were unavailable. The introduction, over the last four decades, of antimicrobial therapy in the treatment of infection has virtually eliminated the risk of chronic ear disease following acute necrotizing otitis media during acute exanthemata. Developments in microbiology, together with the emphasis on preserving hearing in chronic suppurative otitis media, has further modified the approach to its management.
The modern concept of management of chronic suppurative otitis media therefore demands careful assessment of the clinical presentation of the disease, the extent of the destructive pathological process and sequelae, if any, the nature of microbial flora within the ear, and the functional loss. No assessment of the ear with active chronic suppurative otitis media is complete without a search for both possible complications and the presence of a distant nidus of infection in the upper respiratory tract.

**Clinical assessment**

Clinical assessment of the presenting ear in chronic suppurative otitis media requires a careful evaluation of the history and examination, both of which are essential in determining the type, state and extent of the disease process prior to management strategy.

**History**

The classical symptoms in uncomplicated disease are of a long-standing history of unilateral or bilateral, painless otorrhoea associated with deafness. The type and duration of discharge frequently, though not necessarily, relate to the histopathological changes within the middle ear cleft and mastoid and serve as a useful guide to the clinician in assessing the activity of the disease. In the 'tubotympanic-type' of the disease, the discharge is intermittent and mainly mucoid or mucopurulent and is often precipitated by an upper respiratory tract infection, or may follow entry of water through the perforation after swimming; typically the discharge is non-odorous. In contrast, in the 'atticoantral-type' the discharge is frequently scanty, but may be profuse in the presence of active mixed infection and, in addition to being malodorous, the ear is seldom dry.

The presence of bloody discharge, facial palsy or a history of pain, vertigo, or severe headache are evidence of complications. While conductive deafness is usually the rule rather than the exception in tubotympanic disease, in the atticoantral type, patients may sometimes deny a hearing loss if the cholesteatoma is confirmed to the attic only in the early stages or when the cholesteatoma sac acts as a bridge between the necrosed long process of the incus and the head of the stapes. A history of any previous ear surgery must also be sought.

**Examination**

Clinical examination forms the main basis of assessing the activity, type and extent of the disease in chronic suppurative otitis media and includes naked eye inspection of the ear, otoscopy and examination of the ear under the microscope. It is imperative to assess the state of the upper respiratory tract in tubotympanic disease by examination of the nose, pharynx and postnasal space. Inspection of the affected ear with a head mirror helps to evaluate the type of discharge in respect of its colour, consistency and odour. Occasionally, a fleshy polyp may be seen in the external auditory meatus or opening; secondary otitis externa may be present; the postaural region may reveal a scar from previous surgery. In the presence of a history of vertigo, evidence of spontaneous nystagmus is sought and the ear tested for the fistula sign. A swab is obtained for aerobic and anaerobic culture and sensitivity.
Otoscopic inspection with an auriscope is particularly useful in the evaluation of tubotympanic disease in its quiescent phase when the site and size of the perforation, the state of the remainder of the tympanic membrane, and the nature of the middle ear mucosa are noted. In atticoantral disease, otoscopic examination may reveal the presence of a crust, polyp or granulations obscuring cholesteatoma in the attic. A posterior retraction pocket may be associated with keratin debris and a necrosed lenticular process of the incus with granulations over the deep meatal margin.

Microscopical evaluation of every ear with active chronic suppurative otitis media at initial presentation is essential to formulate a policy of management. Debris and/or discharge, which is frequently pulsatile, is cleared from the ear by aspiration as an outpatient or ‘office’ procedure; however, in children, general anaesthesia may be desirable. Microscopic inspection of the ear allows the examiner to obtain a bacteriological swab from the exudate in the middle ear, from a site at which the disease is in its active state. The following observations are then made and recorded:

1. the size and site of the defect in the tympanic membrane
2. the state of the remainder of the drum around the defect - the presence of any tympanosclerosis, and the lack of middle fibrous layer around the central perforation
3. the appearance of the middle ear mucosa through a perforation - oedematous and slightly injected, red and velvety, the presence of tympanosclerotic plaques
4. the presence of a polyp and granulations and its site - in the attic or deep posterior meatal margin, in the posterior retraction pocket, in a modified radical cavity
5. the extent of the cholesteatoma sac
6. the integrity of the ossicular chain - disruption of incudostapedial joint, necrosis of the long process of the incus, medial retraction and shortening of the handle of malleus.

It is advisable to make a schematic representation of the findings under the microscope in the patients' case notes since repeated examination may be required as part of medical management of the disease and changes observed in the initial active stage could well resolve under treatment.

Classification of chronic suppurative otitis media

Chronic suppurative otitis media is traditionally classified into two main groups - tubotympanic and atticoantral disease. Tubotympanic disease was considered 'safe' from complications while the atticoantral type was considered to be a 'dangerous' form of the disease in view of the risk of intracranial suppuration. Such a view has recently been seriously challenged by Browning (1984a) who, in a retrospective study of 26 cases of consecutive otogenic brain abscess admitted to the West of Scotland Institute of Neurological Sciences between 1973 and 1980, observed that 46% had cholesteatoma, 38% had mucosal disease, and 15% had previously undergone a modified-radical mastoidectomy. It would appear from the above study that persistent active infection whether associated with cholesteatoma, persistent
mucosal disease in the middle ear or in a modified-radical mastoidectomy cavity predisposes the patient to the risk of intracranial infection.

**Tubotympanic disease**

Tubotympanic disease is characterized by the presence of a central perforation and the clinical presentation varies depending on the extent and severity of the disease. Thus, several factors influence the condition in any particular ear and at any given time, for example the patency of the eustachian tube, the presence of a nidus of infection in the upper respiratory tract, the natural mucosal barrier to infection which is impaired in immune compromised patients, the presence of mixed aerobic and anaerobic microbes, the extent and degree of mucosal changes, and the secondary migration of squamous epithelium. For details of histopathological changes, the reader is referred to Chapter 3. However, clinically tubotympanic disease presents as:

1. **active disease:** when the patient reports to the clinician with a discharging ear and/or deafness

2. **inactive disease:** if bilateral the only presenting feature is deafness, while in unilateral disease the patient may not seek medical advice.

**Active tubotympanic chronic suppurrative otitis media**

Active disease is usually preceded by either an extension of infection through the eustachian tube from the upper respiratory tract, for example after a common cold, or by way of the external auditory meatus following swimming. The anterior pulsatile discharge varies from mucoid to mucopurulent. Occasionally, there is a long interval free from discharge and the patient may have overlooked a previous episode(s) of ear disease, perhaps made apparent by syringing. The size of the perforation may vary from a pinhole to a large subtotal defect confined to the pars tensa. It is not unusual to find a large polyp in the external auditory meatus. Extension of the infection into the mastoid air cells resulting in widespread and persistent mucosal disease should be suspected if conservative measures fail to control the infection, or if there are granulations in the mesotympanum with or without secondary migration of skin, in which event there is frequently a pulsatile discharge over the posterosuperior quadrant.

**Inactive tubotympanic disease**

This stage of the disease represents a balance between the various pathophysiological factors outlined above and infection. It is remarkably symptom free apart from mild conductive deafness. The ear at examination presents a dry central perforation with a pale thin middle ear mucosa. In a few, one ear may be the seat of active tubotympanic disease while the opposite ear demonstrates an inactive disease; in others an unsuspected dry perforation is discovered on routine examination.
**Atticoantral disease**

The typical feature of atticoantral disease is the presence of a cholesteatoma. The terminology has attracted a good deal of criticism and the alternative terms of keratoma, epidermoid tumour, epidermosis and many more have been suggested to describe what is basically the same pathological entity, that is the presence of keratinizing squamous epithelium in the middle ear cleft. It is not within the scope of this chapter to discuss the merits or otherwise of the various terminologies and the author prefers to adhere to the term 'cholesteatoma'. For a detailed description of aetiology, pathogenesis, and spread of cholesteatoma within the temporal bone together with its complications, the reader is advised to refer to appropriate sections.

The cholesteatoma may vary in size from a small sac confined to the attic or to the posterosuperior quadrant of mesotympanum, to widespread disease involving the entire mastoid bowl and the posterior half of the mesotympanum. Occasionally the cholesteatoma may extend medially into the petrous apex or into the entire middle ear cavity including the eustachian tube opening inferiorly. Extensive disease may lead to complications.

**Bacteriological assessment**

The wide range of microbes, both aerobic and anaerobic, present in chronic suppurative otitis media has been the subject of exhaustive investigation. However, the exact role of these organisms in the disease process is uncertain. Earlier studies reported the predominance of Gram-positive bacteria. Friedmann (1952) isolated *Staphylococcus aureus* in 32.7% of 318 cases, of which 41% were penicillin resistant and 59% sensitive; among the Gram-negative organisms, *Proteus* was isolated in 27%, *Pseudomonas aeruginosa* in 16%, and *Escherichia coli* in 10.7%. Subsequent studies have stressed the widespread presence of mixed Gram-positive and negative organisms in varying proportions, with Gram-negative aerobes predominating.

The widespread prevalence of Gram-negative aerobes in chronic suppurative otitis media, in particular in tubotympanic disease, has cast serious doubt on the role of the nasopharynx as the source of infection. An alternative theory of a 'faecal-aural' route has been suggested (Fairbanks, 1981). In a carefully documented study of different types of *Proteus* organisms associated with active chronic suppurative otitis media, Senior and Sweeney (1984) demonstrated the presence of no less than 57 strains in 38 patients. Furthermore, nine patients were tested for *Proteus* in the ear during, pre- and post-treatment, and seven were discovered to be reinfected with a different strain which led the authors to believe that *P. mirabilis* and *P. vulgaris* were particularly virulent in relation to chronic suppurative otitis media. These authors concluded that the 'faecal-aural' route does not play a significant role in the microbial colonization in active chronic suppurative otitis media.

Examination of various reports on the nature of aerobic bacterial flora in active chronic suppurative otitis media, either in tubotympanic or in cholesteatoma has failed to demonstrate any significant difference in the type of aerobic Gram-negative organisms. However, there is a greater predominance of *Staph aureus* among the Gram-positive organisms in tubotympanic disease (Harker and Koontz, 1977; Sweeney, Picozzi and
Browning, 1982; Brook, 1985). The presence of multiple strains of both Gram-negative and positive aerobes is the rule rather than an exception. In a quantitative study of both aerobic and anaerobic microbes in active chronic suppurative otitis media, Sweeney, Picozzi and Browning (1982) showed rather exceptionally high counts of *Pseudomonas* of $10^{11}$ bacilli per millilitre compared with the counts of other main aerobic and anaerobic species. The presence of beta-lactamase-producing microbes of both aerobic and anaerobic types in 69% of 33 patients was reported by Brook (1985) and has considerable implications for the chemotherapeutic management.

Perhaps the most exciting development in the field of microbial flora in chronic suppurative otitis media, in recent years, is the discovery of the presence of non-sporing anaerobes. Recent improvements in culture techniques of anaerobic organisms have further contributed to their successful isolation ever since their association in otogenic brain abscess and meningitis was first described (Smith, McCall and Blake, 1944; Heineman, Braude and Osterholm, 1971; Ingham, Selkon and Weiser, 1975; Yoshikawa, Chow and Guze, 1975; Chattopadahay, 1977; de Louvois, Gortvai and Hurley, 1977). The main species of anaerobes isolated from exudate in chronic suppurative otitis media were *Bacteroides melaninogenicus* and *B. fragilis*. Non-sporing anaerobes were invariably isolated together with aerobic organisms; however, in a few patients, mainly anaerobes were isolated.

Jokipii et al (1977) reported an average ratio of 3.8 bacteria, 1.9 anaerobes and 1.9 facultative species, in the exudate. In a quantitative study of aerobic and anaerobic microbes in chronic suppurrative otitis media, Sweeney, Picozzi and Browning (1982) demonstrated an average count of $10^9$ anaerobic organisms per millilitre. The widespread distribution of *Bacteroides* species in the oral cavity, the oropharynx, nasopharynx and the nasal cavity in health has been described by Finegold (1981). The commonest species isolated from these sites is *B. melaninogenicus*, the most common non-sporing Gram-negative pathogen associated with infections in the oral cavity and otitis media (Collee, 1982). Recently, however, Hudac (1980), Sweeney, Picozzi and Browning (1982) and Browning et al (1983a) have demonstrated the prevalence of *B. fragilis* in chronic suppurative otitis media, although *B. melaninogenicus* is still the commonest Gram-negative non-sporing anaerobe. The route of entry of these organisms in chronic suppurative ear disease is still uncertain; like Gram-negative aerobes they are not usually discovered in a normal domestic environment (Whitby and Rampling, 1972). The alternative route through the ear is a possibility.

The role of anaerobic organisms in active chronic suppurative otitis media, has been the subject of intense investigation and speculation. The metabolism of facultative species in mixed infections, by lowering the local concentration of oxygen and reduction in oxidation-reduction potential, provides a suitable environment for the anaerobic pathogens (Onderdonk et al, 1976). The reduction of the partial pressure of oxygen due to obstruction of air around cholesteatoma or granulations causes an inverse increase in carbon dioxide pressure and, as a direct result of this, the anaerobes multiply (Sugita et al, 1981). Further evidence of synergy between the Gram-negative bacilli, particularly coliforms and *Proteus*, and *Bacteroides* species was elaborated by Ingham et al (1977), who reported inhibition of phagocytosis, by human leucocytes, of these Gram-negative bacilli in the presence of *Bacteroides* species in studies *in vitro*. Evidently, the frequent isolation of *B. fragilis* in chronic suppurative otitis media may reflect an even greater pathogenic potential and has important implications in the clinical
management of the disease (Sweeney, Picozzi and Browning, 1982). The production of certain
growth factors by one organism that permits survival of another pathogen at the infected site
was demonstrated by MacDonald, Socransky and Gibbons (1963).

In a review of the role of anaerobes in mixed infections Gorbach (1982) elaborated
the following five reasons for the success of *B. fragilis*:

(1) virulence factor
(2) growth factors
(3) cascade effect
(4) protective environment of an abscess
(5) immunological factors.

Among the growth factors essential for the growth of *B. melaninogenicus* is the
molecule naphthoquinone which is closely related to vitamin K and produced by non-
pathogenic diphtheroids. Many strains of *B. melaninogenicus* require vitamin K for their
growth *in vitro* and for their pathogenicity *in vivo*. One of the immunological factors is the
resistance to phagocytosis by the polysaccharide in the capsule of *B. fragilis*. Furthermore,
anaerobes are known to interfere with the phagocytosis of aerobes. Kelly (1978) showed that
when a mixture of *E. coli* 9 x 10⁴ and *B. fragilis* 9.3 x 10⁴ was inoculated into a freshly
inflicted wound in guinea pigs, the wound demonstrated profound inflammation and copious
pus, while inoculation of the same quantity of organisms separately into different wounds
failed to show such infection. Furthermore, a threshold of 10³ *E. coli* and 10⁴ *B. fragilis* was
required to produce pus. The results of the above experiment were extrapolated to the clinical
context by Sweeney, Picozzi and Browning (1982), when they observed, in a quantitative
study of both aerobic and anaerobic microbes in active chronic suppurrative otitis media,
bacterial counts of greater than 10⁴. The latter authors, therefore postulated that the
characteristic malodorous pus associated with tissue destruction may represent an example of
such a 'pathological synergy' in the clinical situation.

Further examples of the presence of fetid pus in anaerobic infections may be seen in
acute maxillary sinusitis secondary to dental sepsis and in periodontal abscess. The
demonstration of beta-lactamase-producing organisms in more than two-thirds of patients with
active chronic suppurrative otitis media, most of whom received multiple courses of
antimicrobial drugs including penicillin, erythromycin, co-trimoxazole (Brook, 1985) is a
disturbing clinical development. The same author in an earlier study *in vitro* (Brook et al,
1983) demonstrated the ability of beta-lactamase-producing strains of both *B. fragilis* and *B.
melaninogenicus* to protect group A beta-haemolytic streptococci from penicillin.

The bacteriological assessment in active chronic suppurrative otitis media should,
therefore, include a culture and sensitivity test from an ear swab for both Gram-positive and
Gram-negative aerobes and a separate swab for anaerobic culture which should be transported
in a special container to the microbiology laboratory.
Audiological assessment

Until recently, it was widely accepted that pathological changes in uncomplicated chronic suppurative otitis media resulted in a conductive hearing loss. Prasansuk and Hinchcliffe (1982) described four basic dysfunctions in chronic suppurative otitis media which correlate hearing levels with the otoscopic appearance of the perforated tympanic membranes - impairment of the tympano-ossicular impedance matching mechanism; reduction of the ‘baffle’ effect on the round window; underlying middle ear pathology such as mucosal oedema, fluid, granulations, cholesteatoma, osteitis and ossicular necrosis which impairs the tympano-ossicular mechanism; and underlying cochlear dysfunction. Audiometric study of hearing loss in perforated tympanic membranes was reported by Anthony and Harrison (1972). However, it was not possible to draw a significant quantitative correlation between the size and site of the perforation and the hearing loss. In their pilot study on 15 consecutive young patients with active bilateral chronic suppurative otitis media, Prasansuk and Hinchcliffe (1982) were able to identify quantifiable clinical descriptions of perforated tympanic membranes that correlated with air conduction hearing threshold levels. Furthermore, these authors were able to predict, by a mathematical formula, the threshold of hearing from the duration of the aural discharge.

The evidence of sensorineural hearing loss in chronic suppurative otitis media is much more recent. Paparella, Brady and Hoel (1970) reporting on the decade-audiograms in 279 ears out of more than 500 studied from patients with chronic suppurative otitis media, observed significant sensorineural hearing loss particularly at higher frequencies both in unilateral and bilateral disease. Such a loss was attributed to diffusion of toxic products from inflammation into the scala tympani via the round window membrane causing temporary or permanent threshold shifts of bone conduction, confined initially to the basal turn but capable of spreading to the apical turns. The presence of serofibrinous exudate within the scala tympani in juxtaposition to the round window membrane in experimentally-induced otitis media in cats, was observed to substantiate the above hypothesis (Goycoolea et al, 1980). It must be stressed, however, that the scala tympani in such animals was remarkably devoid of any cellular deposits. Of the 13 temporal bones of mostly adult patients with chronic suppurative otitis media examined histologically, Paparella, Hiraide and Brady (1972) reported the presence of serofibrinous and inflammatory cells in the cochlea of four cases, although definite hair cell loss due to the chronic ear disease could not be confirmed.

It is well known that accurate assessment of bone conduction thresholds in the presence of conductive hearing loss is fraught with difficulties. Walby, Barrera, and Schuknecht (1983), in a retrospective study of 37 patients with uncomplicated and unilateral chronic suppurative otitis media, confirmed the evidence of increased bone conduction thresholds at 0.5, 1, 2, and 4 kHz on the diseased side when compared with normal, opposite ears. Furthermore, there was a greater loss in bone conduction with a longer duration of the disease. The above authors, in the same study, examined histological sections from 12 temporal bones with unilateral chronic suppurative otitis media and found no evidence of abnormality in the hair cells and the supporting structures within the cochlea when compared to the normal opposite ear. They postulated, based on their findings, that the abnormally raised bone conduction thresholds in chronic suppurative otitis media may well be due to changes in the mechanics of sound conduction.
Paparella et al (1984) in a multicentric epidemiological survey of sensorineural hearing loss in chronic suppurative otitis media, involving six medical centres in five countries, reported highly significant differences between the bone conduction thresholds in the control and diseased side and between those with bilateral disease and the controls from four of the medical centres. They stressed the importance of repeating the bone conduction measurements at frequent intervals, particularly when the disease is in both its active and inactive stages. Conversely, Dumich and Harner (1983) observed no significant evidence of sensorineural hearing loss in 200 patients with chronic suppurative otitis media.

The audiological assessment in chronic suppurative otitis media must commence by assessing the hearing with a tuning fork (512 or 1024 frequency) and a Barany noise box. The use and limitations of the tuning fork in the diagnosis of conductive hearing loss has been discussed by Doyle, Anderson and Pijl (1984). An accurate pure tone audiogram with appropriate masking for air and bone conduction is carried out at the first visit and at intervals to determine, in particular, the level of cochlear reserve. If surgical treatment is planned, it is essential, in bilateral disease, to choose the worse hearing ear. A 'dead' ear with healed disease on the one side, and active disease on the other, is sometimes seen and such a finding has important implications in management. A speech audiogram with masking is advisable. Preoperative assessment of eustachian tube function is unhelpful (Smyth, 1980(i); Sheehy, 1983).

**Radiological assessment**

It is not the intention of the author to describe in detail the various projections of plain radiographs of the mastoid to evaluate the destructive process associated with chronic suppurative otitis media, as this subject has been extensively dealt with elsewhere (Phelps and Lloyd, 1983, see also Chapter 2).

Computerized tomographic coronal scans define the scutum, Prussak's space, the tegmen tympani, the ossicular heads, and the horizontal portion of the facial nerve, while axial scans reveal sinus tympani, facial recess, lateral semicircular canal, stapes and the vertical portion of the facial nerve (Jackler, Dillon and Schindler, 1984). It does seem, however, that the contribution of computerized tomographic (CT) scanning in the management of chronic suppurative otitis media is outstanding when applied to the diagnosis of intracranial complications, especially extradural, subdural and intracerebral abscesses.

The radiological assessment of chronic suppurative otitis media, where possible, should include a lateral view of the affected mastoid and a general lateral view of the skull. The radiologist's report, not uncommonly, concentrates on the appearances of the mastoid air-cell system and perhaps to the presence or absence of bone erosion on such plain films. However, to the clinician the lateral view offers important information about the anatomical dimensions within the mastoid segment, information that is relevant to the surgical management.

**Medical management of active chronic suppurative otitis media**

The medical management of active chronic suppurative otitis media is a complex clinical problem, occupying as it does a major proportion of the clinical work load of an average otolaryngology outpatient department in the UK. A great deal of expense is incurred
in both general and hospital practice by the use of either topical or systemic antimicrobial agents and, all too often, the results of controlling the infection are disappointing to both patient and clinician alike. However, antimicrobial drugs have a proven role in the management of acute suppurative otitis media and the prevention of its complications. The following factors can be identified to account for the disappointing results of antimicrobial therapy in chronic suppurative otitis media, particularly in diffuse mucosal disease involving the mastoid bowl and the middle ear cavity.

(1) Poor drainage of inflammatory exudate: the morphology of the middle ear cleft, with its inherent narrow channels of communication between the mesotympanum and the attic, the attic and the mastoid antrum, is such that all of these may be the site of obstruction in active diffuse mucosal disease. Similarly, pinhole central perforation is an impediment to proper drainage to the exterior and for the entry of antibiotic drops into the middle ear.

(2) The presence of destructive disease associated with osteitis and granulations/polyps further promotes retention of inflammatory exudate.

(3) The lack of information on the efficacy of antimicrobial therapy in chronic ear disease based on large scale controlled trials.

(4) The presence of keratinizing squamous epithelium and keratin debris, both of which provide a natural have for organisms.

(5) The presence of mixed aerobic and anaerobic bacterial flora: except for chloramphenicol ear drops, none of the commonly used antibiotic/hydrocortisone ear drops have any therapeutic effect on the anaerobes.

(6) Failure of antibiotics to penetrate the inflammatory exudate (Senior and Sweeney, 1984).

(7) The possibility of reinfection with a different strain of the same species, for example Proteus species.

(8) The possibility that certain strains may have particular virulence in relation to a chronically diseased ear.

(9) The presence of debris and inflammatory exudate in the middle ear prevents topical antibiotic drops from acting on the organisms.

(10) Mucosal changes in active chronic suppurative otitis media particularly in patients with a long history of the disease, are characterized by subepithelial scarring and devascularization, both of which predispose to poor mucosal concentration of antimicrobial agents (Browning et al, 1983a; Jahn and Abramson, 1984).

(11) Pathological synergy between aerobes and anaerobes, particularly the Bacteroides species, which promotes inhibition of phagocytosis of aerobes in conditions such as chronic suppurative otitis media (Sweeney, Picozzi and Browning, 1982).
(12) Consistently high bacterial counts of both aerobes and anaerobes in the pus.

(13) Bacterial presence in chronic suppurative otitis media is a result of secondary invasion of inflamed mucosa caused by an as yet unidentified process (Browning et al, 1983b).

(14) Emergence of beta-lactamase-producing Bacteroides species in chronic suppurative otitis media (Brook, 1985).

(15) Other associated generalized disorder, for example immune deficiency, Wegener's granulomatosis, histiocytosis X, etc.

The aim of medical treatment in uncomplicated chronic suppurative otitis media is to control the infection and thereby eliminate aural discharge.

Correction of the hearing loss is usually by surgical means.

_Tubotympanic disease_

**Anterior central perforation**

Exacerbation of active infection in an ear with a small anterior central perforation is frequently fuelled by an episode of upper respiratory infection and is characterized by the presence of pulsatile mucoid or occasionally mucopurulent aural discharge. Isolation of the same type(s) of organism in the aural discharge as that present in the nose, oropharynx or nasopharynx, for example, Streptococcus pneumoniae, Staphylococcus aureus, Haemophilus influenzae (Palva and Holopainen, 1978), has governed the use of systemic broad-spectrum antimicrobial agents resulting in control of the disease in the majority of patients. Indeed, it is not unusual to see such an outcome in children by the time they are seen in the outpatient clinic, the child having completed a course of chemotherapy from the general practitioner. An attempt must be made to identify and eliminate the nidus of infection in the upper respiratory tract. Similar exacerbation of the disease is observed if water, from swimming or following syringing, gains access to the middle ear and treatment along the above lines often results in control of infection.

**Central or marginal perforation**

The size of the central perforation may vary from a small defect of 2 mm to a total defect in the pars tensa. Similarly, the size of the marginal perforation may also vary. Medical management is described below under the diffuse mucosal variety. It is not always possible to make a distinction on clinical grounds between disease confined to the mucosa of the middle ear and that which is widespread in the mastoid bowl, although the presence of osteitis with granulations and a malodorous discharge should raise suspicions.

.Diffuse mucosal disease_

Widespread involvement of mucosa within both the mastoid bowl and the middle ear is characterized by the presence of destructive osteitis and granulations and can be seen in
both tubotympanic and atticoantral types. In the tubotympanic type, it exists usually with a large subtotal or posterior marginal defect. In the atticoantral type, an attic defect is observed and keratinous debris may be present. It is also evident in a few radical/modified radical mastoidectomy ears postoperatively, either in the cavity, in the middle ear, or in both. It would be appropriate to deal with the medical management of diffuse mucosal disease as a 'common entity' since the pathological changes, and notoriously poor results of treatment, appear to be common to all three forms of the above disease, in relation to the anatomical sites.

Reference has already been made to the several factors which consistently influence the high rate of failure to control infection in such a complex disease by medical means. A swab for aerobic and anaerobic culture and sensitivity along the lines already suggested should be carried out. Several modalities of treatment have been suggested to achieve the primary aim in management - eradication of infection. The lack of large scale controlled trials makes critical appraisal of different modalities difficult.

**Aural toilet**

(a) **Cotton-buds**: mopping the discharge with cotton-buds, either self-made or prepacked sterile ones, is a convenient method for dealing with aural discharge. Patients are taught to mop the discharging ear with self-made fine cotton-buds several times a day, the procedure being repeated on each occasion until the ear appears dry. Prepacked cotton-buds, although a little more bulky, are convenient to use in a discharging mastoid cavity. The patient's relatives can also be taught how to do this. Browning (1984b) reported cessation of discharge in 85% of patients treated by dry mopping with cotton-buds once the ear has been cleaned out thoroughly by the clinician.

(b) **Syringing**: clearing the debris and inflammatory exudate by syringing the ear has been practised in some centres. Physiological saline solution at body temperature is recommended by Chui (1982) and Jahn and Abramson (1984), and a solution containing white vinegar, to provide an acid medium and counteract alkaline pus, diluted 1:2 with water at body temperature and repeated twice daily is suggested by Jahn and Abramson (1984. Syringing of an infected ear is not widely practised in the UK.

(c) **Suction aspiration debridement**: aspiration of inflammatory exudate, under the operating microscope is probably the most popular method. The magnification offered by the microscope allows accurate assessment of the site and size of the tympanic membrane defect, the extent and type of pathological changes, the evidence of destructive disease in the ossicular chain where possible, the presence of sequelae of chronic ear disease, such as tympanosclerosis in the middle ear and atrophic changes in the drum. Furthermore, small polyps can be removed to allow better drainage of inflammatory products. Suction aspiration is attempted as an 'office procedure' without a general anaesthetic in adults. Aspiration debridement during active disease forms an important part of medical management and is carried out either at weekly intervals in the outpatient department (Cronin, Dogra and Khan, 1974), or daily as a preoperative regimen (Karma et al, 1978). Preoperative conservative treatment has been shown to decrease significantly the amount of 'culture-positive' ears prior to surgery (Palva, Karaja and Palva, 1971). Young children will require general anaesthesia for suction aspiration and initial assessment.
Antimicrobial agents

These are used either topically or systemically or by both routes.

(a) Topical antiseptic agents: several antiseptic agents have been in use and their therapeutic effects have been attributed to the acid medium they provide, since most microbes prefer an alkaline medium (Fairbanks, 1984). Antiseptic ear drops include aluminium acetate, spirit, and phenol, while boric acid and iodine as a powder insufflation is a popular choice.

(b) Topical antibiotic preparations, chiefly in a liquid base, have enjoyed wide popularity in the treatment of active chronic ear disease. The antibiotic component in the ear drops varies but falls into two main categories - aminoglycosides and beta-lactams - in combination with or without steroid. The following aminoglycoside ear drop preparations are available in the British National Formulary (1986): framycetin sulphate (neomycin B); gentamicin; neomycin sulphate. Compound preparations include neomycin undecenoate (to discourage secondary fungal infestation), neomycin and polymyxin B sulphate, bacitracin and polymyxin B sulphate, framycetin sulphate and gramicidin. The beta-lactam antibiotic group includes penicillin and chloramphenicol, of which penicillin has largely been discontinued as a topical antibiotic because of the development of hypersensitivity.

Topical antibiotic therapy has been extensively used in the treatment of active chronic suppurative otitis media in combination with aural debridement, in both children and adults (Fox, 1964; Federspil, 1969; Mendonca, 1969; Kilcoyne, 1973; Gyde, 1976; Palva and Holopainen, 1978; Fairbanks, 1981; Chui, 1982; Browning et al, 1983b; Supance and Bluestone, 1983; Bluestone and Kenna, 1984; Fairbanks, 1984; Jahn and Abramson, 1984). Neomycin is a particularly valuable agent against *Proteus* and *Staphylococcus aureus* but is inactive against Gram-negative anaerobes and has limited action against *Pseudomonas aeruginosa* because of an increasing degree of resistance. Polymyxin is effective against *Ps. aeruginosa* and a few other Gram-negative organisms but is ineffective against Gram-positive organisms (Fairbanks, 1984). Like other aminoglycosides, gentamicin and framycetin sulphate are active against Gram-negative bacilli and gentamicin is moderately active against streptococci. None of the aminoglycoside antibiotics are effective against anaerobes.

Aminoglycosides are more active in an alkaline medium (Phillips, 1982). Chloramphenicol ear drops are available in an acid carrier and may produce pain on local application in the ear, although using an ophthalmic preparation can overcome this drawback. Chloramphenicol is active against a wide spectrum of Gram-positive and Gram-negative bacilli except *Ps. aeruginosa*, but it has a great advantage over aminoglycosides in being effective against anaerobes, particularly *B. fragilis* (Fairbanks, 1984). However, when chloramphenicol has been applied into the ear some patients have shown skin hypersensitivity. The total duration of topical application of antibiotic ear drops required to eradicate infection in active chronic ear disease, without any adverse effects on cochlear function, is not quite clear nor is the therapeutic value. A lack of large scale controlled trials is mainly responsible for the wide gap in our knowledge of the use of topical antibiotics in active chronic suppurative otitis media. It is not unusual to see recommendations of therapy from a few weeks to a few months (Turner et al, 1966; Mendonca, 1969; Gyde, 1976, 1981; Tambic and Tambic, 1976; Picozzi, Browning and Calder, 1983).
Long-term use of aminoglycoside ear drops, particularly where the round window is exposed, must raise the question of ototoxicity in such patients. Cochlear damage from intratympanic application of aminoglycoside drops has been demonstrated in experimental animals (Kohonen and Tarkanen, 1969; Wright and Meyerhoff, 1984). A case of profound sensorineural hearing loss following 11 months of treatment with framycetin ear drops in chronic suppurative otitis media was reported by Tommerup and Moller (1984). Until more is known about the actual incidence of ototoxicity of aminoglycoside ear drops, caution must be exercised in their use.

One of the earliest controlled trials with 0.3% gentamicin drops in active chronic suppurative otitis media, was reported by Turner et al (1966) who demonstrated dry ears in 85% of patients at the end of 6 weeks' treatment compared to no improvement in the control group. In a randomized double-blind trial of trimethoprim-polymyxin (TP) against trimethoprim-sulphacetamide-polymyxin (TSP) ear drops in active ear disease, Gyde (1981) showed a statistically significant result in patients receiving TSP ear drops. Picozzi, Browning and Calder (1983) in a controlled trial with gentamicin-hydrocortisone drops in active chronic suppurative otitis media reported a statistically significant benefit in the active group (65%) compared to the placebo group (21%). Browning et al (1983b), in what is perhaps the only controlled trial comparing three modalities of medical treatment in active chronic suppurative otitis media, demonstrated that there was no significant difference between aural toilet and systemic or topical antibiotics. The benefits of supplementing hydrocortisone into various antibiotic drops have not been conclusively proven.

Despite several uncontrolled and a few controlled trials of the therapeutic effects of antibiotic ear drops in active chronic ear disease, there is no clear-cut information on the most effective method of applying such drops into the ear, the frequency of application, the optimum number of drops to be used and the ideal contact time between the active chemotherapeutic agent and the inflamed surface area in the middle ear cavity.

(c) Systemic antimicrobial agents: it could be said that almost all available antibiotics have been tried systemically in the treatment of active chronic ear disease as a result of the wide variety of Gram-positive and Gram-negative microbes isolated from such ears. However, their efficacy in controlling the disease has been disappointing, particularly in the diffuse mucosal variety and the results are further clouded by the lack of large scale controlled trials. Thus, Bluestone and Kenna (1984) recommended a full schedule of different types of antibiotics and their dosage in children with active chronic suppurative otitis media, and included penicillin G, broad-spectrum penicillins, anti-pseudomonal penicillins, cephalosporins, clindamycin, vancomycin, and chloramphenicol. Fairbanks (1981) suggested that the antibiotic choice should be related to the organisms isolated:

Pseudomonas - aminoglycoside ± carbenicillin
Proteus mirabilis - ampicillin
P. morgagni - aminoglycoside ± carbenicillin
P. vulgaris - aminoglycoside ± carbenicillin
E. coli - ampicillin or cephalosporin
Klebsiella - cephalosporin or aminoglycoside
Enterobacter - aminoglycoside
Staphylococcus aureus - anti-staphylococcal penicillin, cephalosporin, erythromycin, aminoglycoside
Streptococci - penicillin, cephalosporin, erythromycin, aminoglycoside
B. fragilis - clindamycin.

Haverkos et al (1982) reported the use of latamoxef sodium intravenously. Brook (1985) has documented the presence of twice as many beta-lactamase-producing organisms in patients with active chronic suppurative otitis media who have previously received penicillin. Browning et al (1983b), in a controlled trial of medical treatment in active chronic ear disease, demonstrated no significant difference in results between those receiving topical antibiotics, systemic antibiotics (cephalexin, flucloxacillin, or amoxycillin) and simple aural toilet.

Isolation of anaerobes from 33% of 70 cases (Jokipii et al, 1977) and 44% of 130 patients (Sweeney, Picozzi and Browning, 1982) with active chronic ear disease has attracted the use of antimicrobial agents against these organisms in recent years. Three different therapeutic agents have been identified - clindamycin, an antibiotic, metronidazole, an antimicrobial drug which was used against protozoal infestation but now employed increasingly in anaerobic infections, and compound amoxycillin trihydrate and potassium clavulanate (Augmentin), an antibiotic with broad-spectrum activity against Gram-positive and Gram-negative organisms, except Ps. aeruginosa, and active against anaerobes. To date there does not appear to be any reported trial of Augmentin in active chronic ear disease.

Clindamycin is well concentrated in bone and besides being active against anaerobes is also active against Gram-positive cocci including penicillin-resistant Staph. aureus. Its serious toxic effect is pseudomembranous colitis. In an uncontrolled study of clindamycin in active chronic suppurative otitis media, Khambata (1972) reported a success rate of 74%. However, the results in infected mastoid cavities were disappointing. Cooke and Raghuvaran (1974) in an equally uncontrolled trial demonstrated that 70% of patients not receiving the drug required a drainage procedure, compared with only 35% who had received clindamycin.

Metronidazole has been shown to exert a bactericidal effect on most anaerobic bacteria tested by studies in vitro (Prince et al, 1969). Jokipii, Karma and Jokipii (1978), while investigating the tissue concentration of metronidazole in active chronic supplicative otitis media, reported the presence of the drug in the inflammatory exudate within 2 hours or less, of ingestion and it continued to be present in the middle ear mucosa even 12 hours later. High serum levels of the drug were obtained in all patients. A further advantage of the drug is the lack of demonstrable microbial resistance at the present time. Browning et al (1983a), in a controlled trial of metronidazole with and without antibiotics (cephalexin and cotrimoxazole) in active chronic suppurative otitis media, observed that metronidazole 400 mg 8-hourly for 2 weeks, or 200 mg 8-hourly for 2-4 weeks, eliminated the anaerobes in 22% of patients, while a 2.4 g stat dose, or repeated once, successfully eliminated anaerobes in 86% of patients. In combination with an antibiotic, metronidazole eliminated anaerobes in all patients. However, aerobes were unaffected by the treatment and continued to be present in all but one patient.
Suggested line of medical management of active uncomplicated chronic suppurative otitis media

Active tubotympanic disease with an anterior central perforation

(1) The disease is probably inactive by the time the patient has arrived at the clinic; if not
(2) assess the ear under the microscope while, at the same time, obtain a specimen of pus for culture and sensitivity as outlined above. The ear is cleaned by suction aspiration
(3) commence a systemic broad-spectrum antibiotic, that is oral amoxycillin or cephalosporin. If the patient is allergic to penicillin, erythromycin is a suitable alternative
(4) eliminate any nidus of infection in the upper respiratory tract
(5) prevent water from gaining access into the ear. Cotton wool smeared in vaseline is a suitable ear plug; swimming is discouraged
(6) if the ear becomes inactive, myringoplasty is considered.

Active chronic suppurative otitis media with a central or posterior marginal perforation

(1) Assessment of the ear is carried out by examination under the microscope. A swab for both aerobic and anaerobic culture and sensitivity is obtained from the most active area of the disease.

(2) The active ear is carefully debrided with a tube aspirator, removing any small polyp at the same time. The changes observed under the microscope are schematically documented in the case notes.

(3) The patient is instructed in cleaning the ear by self-made small cotton-buds and advised to carry out aural toilet four or five times a day. On each occasion, the ear is mopped dry until the cotton buds are free of inflammatory exudate. A further appointment is made for the following week when the results of culture and sensitivity should be available. The ear is protected from water, as previously described.

(4) If the ear is inactive when seen at the next visit, the patient's name is placed on the waiting list for appropriate surgical treatment following discussion of management with the patient. If however, the ear is still active a course of suitable topical and systemic antimicrobial therapy is commenced depending upon the culture and sensitivity report. If Gram-negative microbes are isolated and are sensitive to aminoglycosides, topical gentamicin and hydrocortisone ear drops are used. The patient is instructed in their usage by instilling four or five drops into the ear, after gently warming the container under warm running tap water, with the patient in the lateral position and the diseased ear uppermost. The tragus is gently pressed inwards several times to promote displacement of the drops into the diseased middle ear and the patient is allowed to remain in the treatment position for several minutes. The topical therapy is repeated three or four times a day with the final application at night in bed and the patient is advised to sleep on the 'good' ear. The topical therapy is continued for 7-14 days depending on the response. Systemic antimicrobial therapy includes oral metronidazole 400 mg 8-hourly for 2 weeks if anaerobes are isolated, together with a broad-spectrum antibiotic against Gram-positive organisms if these organisms are isolated. A course
of cephalosporins or co-trimoxazole is prescribed for 7 days if there is a history of penicillin hypersensitivity. Care must be exercised in prescribing co-trimoxazole to patients over the age of 65.

(5) In the event that the ear becomes inactive when seen during the subsequent visit, the patient's name is placed on the waiting list for closure of the perforation as a 'cold' procedure. Conversely, if the ear continues to manifest activity, diffuse mucosal disease is suspected and immediate surgery is contemplated. Those who refuse surgery are advised to self-mop the ear as above and a suitable hearing aid, to be worn on the dry side, is offered in bilateral disease associated with a significant conductive hearing loss.

**Active chronic suppurative otitis media in a previously modified radical mastoidectomy cavity**

The presence of active mucosal disease in the mastoidectomy cavity, in the middle ear mucosa, or in both, appears to be resistant to medical management and will require a revision procedure.

**Cholesteatoma**

It is generally accepted that medical management has no place in the treatment of uncomplicated cholesteatoma. However, there are a few exceptions in which surgical ablation of the disease may not be advisable.

The following clinical presentations would qualify for such exemption and continued medical management by aspiration debridement at suitable intervals, aimed at controlling infection, appears to be the best alternative:

(1) an elderly patient, over the age of 65 years, who is unfit for a general anaesthetic on account of poor cardiopulmonary function

(2) a small cholesteatoma sac confined to the attic with normal hearing; the keratinous debris can successfully be cleared by aspiration debridement. However, a careful watch is required in case the disease does spread with the onset of infection, although a few ears tend to remain stable for a number of years

(3) those patients who refuse surgery.

**Surgical management**

In this section, emphasis is placed on the general principles of surgical management of uncomplicated chronic suppurative otitis media and the reader is referred to the following Chapter for the details of surgical reconstructive techniques.

The basic principles of surgical management in chronic suppurative otitis media are:

(1) to eradicate active disease and thus promote drainage or healing in an ear with diffuse mucosal disease and cholesteatoma
(2) to prevent recurrence of infection in an ear that has remained inactive, by restoring an air-filled middle ear cavity lined by mucosa

(3) to prevent complications occurring in an active ear

(4) to restore function.

It appears that the overall success rate of myringoplasty, as reported by an experienced otologist, is about 95% (Smyth, 1980(ii)), with failure rates much more frequently observed in larger perforations treated by transcanal and combined approach procedures. The rate of successful outcome following myringoplasty in an active ear is no different to that in an inactive ear (Smyth, 1980(ii)); Sheehy, 1983), although the failure rate is significantly higher in the transcanal approach in infected ears with a small perforation - a defect which involved 50% or less of pars tensa (Smyth, 1980(ii)).

A good deal of controversy still exists in relation to tympanoplasty in children. Lee and Schuknecht (1971), Booth (1974), Smyth, 1980(iii); and Sade et al (1981) claimed that age does not influence the successful outcome in myringoplasty. Smyth (1980(iii)) observed that the overall objective of the treatment of chronic suppurative otitis media in children is to ensure functional restoration, by surgery, with minimum delay after treatment of any upper respiratory problems, so that normal development of speech continues, especially in bilateral disease. Conversely, Plester (1982) defined a minimum age of 5 years, and Dawes (1972) of 10 years, for repair of tympanic membrane defects. Raine and Singh (1983) in a retrospective analysis of 114 tympanoplasties in children between the ages of 7 and 16 years demonstrated a significantly higher rate of failure in children aged between 8 and 12 years. In view of the increased risk of upper respiratory tract infection in younger children, it would appear that repair of the drum head is best deferred until the child is about 10-12 years of age.

It is generally accepted that the biological graft materials act as a scaffold of tissue matrix when applied to seal the perforation and this is subsequently revascularized in readiness for migration of fibroblasts and epithelium. A variety of connective tissue graft materials have been used to close the perforation depending on the choice of individual surgeons. Homologous graft materials include temporalis fascia, dura mater, and homograft tympanic membrane with or without ossicles while autologous temporalis fascia also enjoys popular support. Smyth (1980(ii)) demonstrated no significant difference in success rate between autologous temporalis fascia and homologous dura when the results of the postoperative air-bone gap were compared after 6 months in patients with an intact ossicular chain. Heterologous graft materials have also been used (Jansen, 1973; Siedentop, 1975). The exact choice of material used therefore rests on factors such as ease of handling the graft material at operation, access to the graft tissue, availability of stored material, whether or not a separate incision is required to obtain the graft material and so forth. In some centres, the autologous temporalis fascia is dehydrated to facilitate easy handling during application while others prefer to use fresh fascia. Shenoi (1982) has drawn attention to the gross alterations in biological characteristics of the protein matrix within the fascia when dehydrated by unphysiological heating. Walby et al (1982) observed the effects of surgical preparation of autologous temporalis fascia in tissue culture. Scraping loose connective tissue from the fascia or allowing it to dehydrate caused significant reduction in fibroblast growth in tissue culture, while both procedures completely abolished it. Until recently, the middle ear has been
regarded as a 'privileged site' for transplantation of allografts. However, Frootko (1985) has demonstrated the rejection phenomenon in humans when heterologous dura was used in myringoplasty despite alteration in its antigenic properties as a result of different methods of storage. Kuipers, Veldman and van den Broek (1985) described the possibility of immunotolerance within the middle ear in experimental animals to account for the success following allograft tympanoplasty.

The exact position of the graft in relation to the perforation - onlay or underlay - has attracted much discussion. Each method appears to have advantages and disadvantages. Thus the onlay technique has to its credit the advantage of using a transcanal approach and avoiding an external incision in smaller defects, is less time consuming, with both easier preparation of the graft bed and subsequent application of the graft. Included among the disadvantages of this technique are the risk of trapping squamous epithelium and consequent cholesteatoma pearl formation, lateralization of the graft, anterior blunting and dermoid inclusion when repairing an anterior perforation involving the fibrous annulus.

The advantages of the underlay technique include an opportunity to inspect and test the mobility of the ossicular chain, the squamous epithelium of the meatal skin and drum remnant remain lateral to the graft, any intratympanic adhesions preventing re-aeration of the reconstructed tympanic cavity can be divided, and the procedure can be used in those whose previous onlay operation has failed. Among the disadvantages are the risk of medial prolapse of the graft, and retraction of the anterior edge.

The surgical approach in uncomplicated chronic suppurative otitis media depends on the extent and the nature of the disease - the presence of active diffuse mucosal disease of cholesteatoma or a small central perforation in an inactive ear, anatomical variations in the mastoid segment and external ear. The following approaches have been widely used:

1. transcanal
2. endaural with or without mastoidectomy
3. postaural with or without mastoidectomy; combined approach tympanoplasty (intact canal wall tympanoplasty) with posterior tympanotomy
4. circumferential tympanomastoid access.

Suggested line of surgical management in uncomplicated chronic suppurative otitis media

Tubotympanic disease with an anterior central or marginal perforation

A small anterior central perforation

A transcanal approach with an onlay technique may suffice. In the presence of an exaggerated anterior canal hump, an endaural approach together with reduction of the hump may be advisable or, alternatively, a postaural approach with an underlay technique.
Anterior marginal perforation would require an underlay technique with the anterior edge of the graft buried deep to the meatal skin to avoid dermoid formation (either endaural or postaural approach).

**Central or posterior marginal perforation**

A small central perforation may be treated by the transcanal route using an onlay technique, while large central and posterior marginal perforations are best dealt with by an underlay technique through either an endaural or postaural route. Sade et al (1981) have demonstrated damage to the ossicular chain in about 40% of patients with a posterior-superior perforation while only 3% with anterior perforation had damaged ossicles. Furthermore, the above authors recorded that the presence of active disease at surgery predisposed to a greater incidence of ossicular chain necrosis (45%) compared with those with dry ears (10.6%). The ossicular chain must be inspected in larger central and posterior marginal perforations.

**Diffuse mucosal disease**

Eradication of the disease from the mastoid and the middle ear is essential and involves mastoidectomy with tympanoplasty, either through an endaural or postaural approach.

**Active disease in a modified radical mastoidectomy**

It is estimated that up to 30% of the mastoid cavities following modified radical mastoidectomy continue to discharge despite aggressive local treatment (Janzen, 1981). Sade, Berco and Brown (1981) estimated cavity problems in about 20% of marsupialized mastoids. Furthermore, Sade et al (1982) have identified four factors which determine a dry cavity postoperatively:

1. small and medium-sized cavities are much more likely to be dry
2. height of facial ridge: a low or no ridge is associated with a greater incidence of a dry cavity
3. external auditory meatus: a larger meatal opening has a greater incidence of a dry cavity
4. the presence of air in the middle ear cavity, thereby excluding the eustachian tube opening from the cavity produced a drier cavity.

Rambo (1979) concluded that retained infected mucosa in the mastoid bowl predisposes to a discharging cavity.

The surgical management of a draining mastoid cavity therefore includes revision mastoidectomy with particular attention directed towards exenteration of all infected cells in the mastoid tip, Trautman's triangle, perifacial cells, retrosinus cells, cells in the root of zygoma, and perilabyrinthine cells followed by creating a low facial ridge, closing the perforation in the drum head and creating a meatoplasty. Obliteration of the mastoid cavity,
following the above procedure by a suitable soft tissue flap, helps to achieve a dry cavity (Palva, 1979; Smyth, 1980(iv); Bennett, 1981; Janzen, 1981).

**Cholesteatoma**

Surgery is the only mode of treatment for aural cholesteatoma except in those already identified as suitable, for differing reasons, for medical management. The principle is the same as that for a chronic discharging ear, that is eradication of the disease and converting a potentially dangerous to a relatively safe ear. The surgery of cholesteatoma has witnessed a profound change during the lifetime of some of our most eminent otologists. Earlier pioneers in the late 19th and early 20th century successfully achieved the principle of treatment by radical and modified radical mastoidectomy. With the introduction of the operating microscope the era of 'canal-up' (combined approach tympanoplasty with posterior tympanotomy) emerged. The rationale behind such a procedure was:

1. to avoid an open cavity with its inherent problems of retention of epithelial debris and infection
2. to facilitate functional reconstruction
3. a hearing aid could be provided in a dry ear in those in whom it might still be needed.

However, as the long-term results of canal-up procedures began to emerge, it became evident that failure to eradicate the disease occurred in 13.43-36% of cases (residual disease) and with 5-13% showing recurrent disease (retraction pockets). Such results challenged the validity of this operation as a routine procedure in every ear with cholesteatoma (Wright, 1977; Charachon, 1978; Smyth, 1980(v); Sade, Berco and Brown, 1981; Sheehy and Robinson, 1982; Cody and McDonald, 1984; Sanna et al, 1984). Residual disease and recurrent disease are defined by Sheehy (1978a) as squamous epithelium left behind, either inadvertently or on purpose by the surgeon, and cholesteatoma developing in a retraction pocket in the epi- or mesotympanum, the facial recess, or from a graft failure respectively. Failure to eradicate the disease has led to the concept of staging the surgical procedure. During the first stage, an attempt is made to obtain a dry ear by removing the cholesteatoma followed by tympanoplasty. At the second stage, between 1 and 2 years later, the ear is re-explored and reconstruction of the sound transformation mechanism is attempted which, in effect, provides an opportunity to identify any residual disease. The canal-up approach requires an experienced operator who is well versed with the anatomy of the temporal bone and also patients who would be prepared to attend for long-term follow-up. The danger of atrophy of the posterior bony canal wall in the canal-up approach resulting ultimately in a retraction pocket has been highlighted by Sade, Berco and Brown (1981). Contraindications for the canal-up procedure have been summarized by Sheehy (1983) and include the only hearing ear, the presence of a labyrinthine fistula, extension of the cholesteatoma into an inaccessible area, and when the cholesteatoma has destroyed one-third or more of the posterior bony wall.
A further modification of the canal-up procedure has been described by Tos (1982) and consists of an extended atticotomy with reconstruction, for attic disease, and removal of the deep posterior meatal wall for access to the sinus tympani.

Due to the disappointing incidence rate of both residual and recurrent disease, there has been a shift of opinion in recent years towards the 'canal-down' procedure (modified radical mastoidectomy) combined with obliteration of the cavity and tympanoplasty (Smyth, 1980(vi); Smyth and Hassard, 1981; Sade, Berco and Brown, 1981; Ojala and Palva, 1982; Parisier et al, 1982; Sade et al. 1982; Hough, 1983; Palva, 1985). The incidence of failure to eradicate the disease varies from 4.7% to 13% (Sheehy and Patterson, 1967; Turner, 1970; Austin, 1976; Ojala and Palva, 1982). Smyth and Hassard (1981) reported no significant difference for residual disease in either of the procedures, although when the hearing gain is compared in canal up and down procedures, the results are superior in the canal-down procedure in the presence of a functional ossicular chain.

In summary, the choice of operative procedure in uncomplicated aural cholesteatoma depends to a large extent on the experience of the operator, the extent of the disease, the size of the mastoid bowl, the preoperative hearing, and whether or not the patient can be followed-up postoperatively.

**Retraction pockets**

Shallow posterior retraction pockets are best managed by periodic suction aspiration under the microscope in the outpatient department or office, as they are usually self-cleansing (Sade, Avraham and Brown, 1981; Sade, 1982). If they should become infected and fail to respond to medical management then surgical excision of the pocket followed by myringoplasty is indicated.

Deeper retraction pockets, particularly if they are persistently infected, call for surgery which usually involves excision of the deep pocket together with eradication of the squamous lining from the sinus tympani. Often there is associated osteitis of the deep posterior meatal margin, signalled by the presence of granulations, which requires removal of the deep posterior meatal margin (marginectomy). Reconstruction of the defect in the drum head and deep posterior meatal margin follows and a ventilation tube is inserted in the anterior quadrant of the tympanic membrane. At a second stage, a suitable ossiculoplasty is considered (Sade, Avraham and Brown, 1981; Sade, 1982).

The author has found the above approach both practical and satisfactory.

**Total obliteration of the mastoid and external auditory canal**

Total obliteration of mastoid, middle ear and the external auditory meatus has been employed as an effective alternative surgical procedure in the treatment of chronic discharging ear with or without cholesteatoma in highly selected patients (Rambo, 1958; Gacek, 1979; Schuknecht and Chandler, 1984). The indications for the procedure include an ear with absent auditory function; severe mental retardation preventing postoperative care of the cavity; and dural herniation with or without cerebrospinal fluid leakage (Schuknecht and Chandler, 1984). Contraindications include the possibility of residual cholesteatoma developing within the
cavity; the presence of osteonecrosis; and metabolic disorder such as diabetes mellitus (Gacek, 1979). Pedicled grafts and free abdominal fat grafts are used to obliterate the cavity. The results of the procedure in six patients showed no evidence of recurrence when seen between 5 and 10 years later (Gacek, 1979) and in a total of 44 cases spread over a period of 20 years, there was recurrence of cholesteatoma in 6% (Schuknecht and Chandler, 1984).

Management of cholesteatoma in children

Aural cholesteatoma in children is characterized by a rapidly growing disease which is much more extensive within a well pneumatized mastoid bowl when compared to adults (Jansen, 1978; Jahnke, 1982; Tos, 1983). There is some evidence to suggest that such a difference in behaviour may be related to the correlation between the bony growth and the formation of air-filled spaces (Wullstein, 1978). The incidence of aural cholesteatoma in children is much lower compared with adults; the ratio of adults to children is 5.6:1 (Sheehy, 1978b) and 4:1 (Tos, 1983).

The principles of surgical treatment are exactly the same as those in adults. However, based on the extensive nature of the disease in children, at least in some centres, a natural reluctance has emerged in performing a canal-up procedure. The advocates of the canal-up procedure claim that a canal-down approach would succeed in creating a large mastoid cavity with associated difficulties in postoperative management. A study of the results of the canal-up approach demonstrates a 51% incidence of residual disease, twice as high as that in the adult, in 82 children aged between 4 and 15 years, although the location of the residual disease and the hearing results were identical in the two groups (Sheehy, 1978b). The overall incidence of residual and recurrent disease (9% and 8%) and improvement in hearing was the same in both children and adults (Smyth, 1980(iii)), although in children who were included in a planned second stage of canal-up procedure, there was a significantly greater incidence of residual disease in the mesotympanum. Jansen (1978) reported an incidence of 7.5% recurrence with the canal-up approach. It is claimed that even if residual and recurrent disease should develop, no serious complication has been witnessed so far and that the recurrent disease would declare itself either by destroying the posterior canal wall or by forming a subperiosteal abscess. It is, however, widely accepted that if a canal-up approach is contemplated, it should be carried out as a two-stage planned procedure. Tos (1983) reporting on a long-term study of the modified canal-up procedure demonstrated a recurrence rate of 5% in his personal series, while 23% recurrence was observed if the procedure was carried out by his trainees.

Palva, Karja and Karaja (1977) using a canal-down approach and obliteration of the mastoid reported residual disease in 5%, and cavity problems in 8% of 65 children. Gristwood and Venables (1982) adopted a limited canal-down technique of atticotomy and attico-antrostomy in 202 children and reported an incidence of 19% of residual disease at 10-year follow-up.

In summarizing the overall results of the two different approaches, it would therefore seem that the selection of any particular surgical procedure in children with aural cholesteatoma depends primarily on the training and experience of the operator and a need for long-term follow-up of patients. It is evident that if a canal-up approach is planned, it
should be staged. Eustachian tube function does not appear to influence the outcome of surgery (Sheehy, 1978b; Smyth, 1980(iii)).

**Cholesteatoma in the mesotympanum with an intact drum**

There is a good deal of speculation on the exact aetiology of this entity, although the congenital theory appears to have gained wide acceptance. The incidence of the disease is low; 3.7% was reported by House and Sheehy (1980) from a total of 1024 operative procedures for aural cholesteatoma. The disease is commonly observed in younger children and is characterized by the absence of symptoms except in a few in whom persistent conductive hearing loss is the presenting feature. Frequently, the only finding on examination of the ear is the presence of a whitish mass medial to the tympanic membrane. Tympanometry may suggest the presence of ossicular chain discontinuity. Diagnosis is confirmed at surgery and the type of surgical procedure depends on the extent of the disease varying from tympanotomy and enucleation of the cyst to both canal-up or down approaches (Derlacki, 1973; House and Sheehy, 1980; Cross, 1981; Sanna and Zini, 1984; Wang et al, 1984). An incidence of 19% residual disease following canal-up procedure was reported by House and Sheehy (1980).

**Functional reconstruction**

This is attempted to restore a conductive hearing loss caused both by perforation in the tympanic membrane and ossicular chain discontinuity. The former would have been corrected by successful closure of the drum head defect. There is an overwhelming view in favour of reconstructing the ossicular chain as a second-stage procedure, although a few surgeons favour primary reconstruction during closure of drum head defect, particularly if a composite homograft tympanic membrane with ossicles is used. A wide range of both natural and synthetic materials have been employed in the reconstructive techniques of the ossicular chain and varies from auto- and homograft ossicles, bone chips, and cartilage to synthetic biomedical plastics and ceramics with varying degrees of success depending on the nature of the ossicular chain defect. The reader is advised to consult the next chapter for details of reconstructive techniques.

**Complications of surgical management**

For a full list of complications following surgical management of chronic suppurative otitis media with or without cholesteatoma, the reader is advised to consult Chapter 12.

**Tuberculous otitis media**

The true incidence of tuberculous otitis media is unknown in view of the highly selected material in various reports. Lucente et al (1978) reported that tuberculosis still remains one of the most common lethal infectious disease in the USA. Tuberculosis of the middle ear and mastoid is estimated to be present in fewer than 1% of ears.

Tuberculosis is a rare disease among the indigenous population of the UK, although within the ethnic minority of Asian immigrants the incidence of non-respiratory tuberculosis is more than 50% higher than in the indigenous white population (National Survey of
Tuberculosis Notifications in England and Wales, 1978-79). It would appear from the literature that the clinical presentation of tuberculosis of the middle ear has altered over the last three to four decades and multiple perforations of the drum head which were thought to be the characteristic feature are no longer seen (Wallner, 1953; Lucente et al, 1978; Plester, Pusalkar and Steinbach, 1980; Windle-Taylor and Bailey, 1980; Glover, Tranter and Innes, 1981). The typical feature of the disease at presentation is profuse otorrhoea, most commonly painless (Wallner, 1953; Lucente et al, 1978; Windle-Taylor and Bailey, 1980; Glover, Tranter and Innes, 1981) but painful in a few (Plester, Pusalkar and Steinbach, 1980), which fails to respond to both topical and systemic antimicrobial therapy in combination with suction aspiration. In all patients there was a disproportionate hearing loss compared with the clinical findings and the majority had pale exuberant granulations. Complications were significantly higher (facial palsy, sensorineural hearing loss, labyrinthitis) when compared with non-cholesteatomatous suppurative otitis media.

The spread of the disease into the middle ear is thought to be either through the eustachian tube or haematogenous. In the majority of the above reports, the tympanic membrane demonstrated a single perforation and only one patient had two perforations.

Diagnosis is based upon a high index of suspicion and, in particular, a history of previous exposure to the disease or a past history of active disease. The presence of a discharging ear in a patient from the Asian ethnic minority should alert the clinician to the possibility of tuberculosis. Bacteriological culture is usually time consuming and Ziehl-Neelsen staining is unreliable. Final diagnosis is established by histology of the granulation tissue, which may need to be repeated.

The treatment is by modern antituberculous chemotherapy and usually involves a course of multiple chemotherapeutic agents to prevent development of resistance to the organisms. However, surgery may also be required, not only to remove sequestra but also to allow adequate drainage.

**Chronic suppurative otitis media: some unusual presentations**

**Immune deficiency**

Immune deficiency may be idiopathic or secondary to various immune depressant drugs when the host immune defence is deliberately compromised to prevent rejection of transplanted organs or as planned treatment in leukaemia.

The idiopathic group, of which hypogammaglobulinaemia is the best example, is characterized by a deficiency in the IgG fraction of serum globulin which often presents with recurrent upper respiratory tract infections and otitis media at an early age. In some of these patients, a chronic discharging ear could well be the sequela of such recurrent middle ear infections, a clinical dilemma also observed in IgA deficiency. If the condition is not recognized, all attempts of combined medical and surgical treatment will result in repeated failure. Recognition of such immune deficiencies is of paramount importance. Sasaki et al (1981) reported the management of chronic discharging ears in such patients and included:
(1) canal-up approach to minimize wound contamination

(2) if canal-down procedure is preferred, stabilization of the cavity is achieved by skin grafting

(3) appropriate correction of IgG and IgA fractions by pre- and postoperative replacement therapy guided by repeated plasma estimations of the above fractions

(4) bactericidal antimicrobial therapy during, pre- and postoperatively.

In the drug-induced immune deficient patient associated with chronic suppurative otitis media, where the patients are quite ill, the author has successfully carried out myringoplasty with an onlay technique under a local anaesthetic. Pre- and postoperative antibiotic cover was found to be essential.

Chronic ear disease is sometimes observed in Job's syndrome (also referred to in some centres as lazy leucocyte syndrome) and is associated with recurrent 'cold' staphylococcal abscesses, purulent nasal discharge and sinusitis, pulmonary infection and elevated IgE in peripheral blood. A defect in neutrophil granulocyte chemotaxis is thought to be the cause of recurrent infection (Davis, Schaller and Wedgwood, 1966).

**Wegener's granulomatosis**

Wegener's granulomatosis is characterized by the presence of granulomatous deposits in the upper and lower respiratory tracts together with multi-system involvement, particularly the kidneys. Histologically, it presents as a vasculitis with granulomatous changes and is thought to be a hypersensitivity disorder.

Middle ear infection, either as a primary or secondary involvement of the disease, has been described (Karmody, 1978). Secondary involvement is much more common and results from infection in the nasal fossa or the sinuses and commonly presents as middle ear effusion. Kornblut, Wolff and Fauci (1982) reported that 45% of 60 patients with Wegener's granulomatosis had either active or resolved infective aural pathology and a few had chronic suppurative otitis media with *Staphylococcus aureus* and *Pseudomonas aeruginosa* predominantly in the exudate. In one patient with chronic suppurative otitis media, surgery failed to control the disease until the underlying disorder was treated. In another, granulomata were discovered over the tympanic membrane; biopsy proved the diagnosis. Fauci et al (1983) described the largest series of prospective clinical and therapeutic trial in 85 patients with Wegener's granulomatosis followed-up for 21 years and nearly 30% had middle ear infections.

Diagnosis is established by being aware of the possibility of Wegener's granulomatosis in patients with recurrent middle ear infection/discharge associated with persistent mucopurulent rhinorrhoea and an elevated erythrocyte sedimentation rate (ESR). Final diagnosis is by histology on suspected lesions within the nose.

Treatment is by combination therapy with cyclophosphamide and prednisolone and details of the regimen have been fully described by Fauci et al (1983). Middle ear infection improves parallel with the response to systemic treatment.
Histiocytosis X (Langerhans cell histiocytosis)

Coutte et al (1984) reported 65 patients with histiocytosis X and recurrent otitis media was the presenting symptom in 10 children. Five children had aural polyps and nine had cholesteatoma on otoscopy. An elevated ESR was of particular significance in suspecting the disease; the diagnosis was made on biopsy. Treatment is by a combination of steroids and chemotherapy (vinblastine sulphate).
Chapter 11: Reconstruction of the ear

Nicholas J. Frootko

In this chapter the evolution of surgical techniques of tympanoplasty with and without mastoidectomy in chronic suppurative otitis media is outlined, the terminology defined and the biological and synthetic materials used to reconstruct the middle ear transformer mechanism are described.

Definitions of operative terms currently used in middle ear and mastoid surgery

Skin incisions

These are named according to the anatomical site in which they are made, that is meatal, endaural and postaural and can be combined and fashioned in a variety of ways to provide the access, exposure and other requirements (for example meatal skin flaps and meatoplasty) of the operation to be performed.

Myringoplasty

An operation performed to repair or reconstruct the tympanic membrane, often incorrectly referred to as type I tympanoplasty (because myringoplasty does not imply removal of disease from the middle ear).

Tympanoplasty

An operation performed to 'eradicate disease in the middle ear and to reconstruct the hearing mechanism, without mastoid surgery, with or without tympanic membrane grafting' (Committee on Conservation of Hearing, of the American Academy of Ophthalmology and Otolaryngology, 1965).

Ossiculoplasty

An operation performed to repair or reconstruct the ossicular chain.

Mastoidectomy

Open or canal wall-down procedures

Atticotomy

An operation performed to remove all or part of the outer attic wall (scutum) and adjacent deep posterior meatal wall, to expose the attic (epitympanum) and when necessary the aditus ad antrum in order to gain access to these sites and their contents and/or remove disease limited to these sites.
**Radical mastoidectomy**

An operation performed to eradicate all middle ear and mastoid disease in which the mastoid antrum and air cell system (when present), aditus ad antrum, attic and middle ear (mesotympanum and hypotympanum) are converted into a common cavity exteriorized to the external auditory meatus. During the course of removal of all diseased tissues the tympanic membrane, malleus and incus are removed, leaving only the stapes in situ (footplate only plus/minus superstructure, if intact and healthy).

**Modified radical mastoidectomy**

This operation differs from the radical mastoidectomy in that the tympanic membrane or remnants thereof and ossicular remnants (usually the malleus handle and stapes) are retained (synonym: attico-antrostomy if the operation is performed by the anterior-posterior technique, that is by exposing the attic first and then proceeding backwards into the aditus ad antrum and mastoid antrum).

**Closed or canal wall-up procedures**

**Cortical mastoidectomy**

This is an operation performed to remove disease from the mastoid antrum and air cell system (when present) and the aditus ad antrum, with preservation of an intact posterior bony external auditory canal wall, without disturbing the existing middle ear contents.

**Combined approach tympanoplasty**

(Synonym: intact canal wall tympanoplasty with mastoidectomy.) This is an operation performed to remove disease from the middle ear and mastoid by way of (a) the mastoid, (b) a posterior tympanotomy, and (c) the transcanal route, followed by reconstruction of the middle ear transformer mechanism.

**Tympanoplasty with mastoidectomy**

This is an operation performed to eradicate disease in the middle ear and mastoid and to reconstruct the hearing mechanism with or without tympanic membrane grafting; for example, combined approach tympanoplasty or cortical mastoidectomy with tympanoplasty (closed or canal wall-up techniques); muscle or other obliteration of an open mastoid cavity with tympanoplasty (obliteration techniques); reconstruction of the outer attic and posterior canal wall of an open mastoid cavity with tympanoplasty (canal wall reconstruction techniques); open or canal wall-down mastoidectomy with tympanoplasty (cavity techniques).

Cavity obliteration and canal wall reconstruction techniques convert an open cavity into a closed cavity.
The evolution of surgical techniques of tympanoplasty with and without mastoidectomy

The fundamental techniques and concepts of modern reconstructive middle ear surgery in chronic suppurative otitis media with and without cholesteatoma, came into being when Moritz (1952), Zöllner (1953, 1955) and Wullstein (1953, 1956) in Germany, introduced the tympanoplasty operations. These operations were designed to restore or conserve hearing and promote healing, after the excision of disease from the middle ear and mastoid. Skin grafts were used to repair the tympanic membrane and close the tympanum and were positioned as free 'onlay' grafts over the tympanic membrane remnant and whatever elements of the ossicular chain remained after the surgical excision of disease. If only a mobile stapes footplate remained, this was left exteriorized and the skin graft was positioned so as to create a round window baffle (an air containing tunnel, in continuity with the eustachian tube and incorporating the round window). If the stapes was fixed by tympanosclerosis or otosclerosis, a fenestration operation was performed.

Prior to this pioneering work, the surgery of chronic suppurative otitis media had been wholly orientated to the eradication of chronic infection and cholesteatoma and the prevention of intracranial infection. The radical mastoid operation (Stacke, 1893), the modified radical mastoid operation (Bondy, 1910) and the more conservative modifications of the Bondy operation, such as the atticotomy (Tumarkin, 1948) were all operations designed to expose, excise and exteriorize disease to the external auditory meatus. Although attempts had been made by a few surgeons to obliterate open mastoid cavities with muscle, and thus promote healing (Kisch, 1928; Meurman and Ojala, 1949), no attempt had been made by these surgeons to close the tympanum and repair the ossicular chain after the excision of disease.

The concepts and final execution of the classical tympanoplasty operations by Moritz, Zöllner and Wullstein had not come about by chance, but were influenced by other events. Berthold (1876) in Germany had successfully repaired the tympanic membrane with full thickness skin and called the operation 'myringoplastik'. In 1921, Nylen working in the Stockholm University Ear Clinic introduced a monocular operating microscope and a year later Holmgren, Nylen's teacher, was first to introduce the binocular operating microscope and magnifying ocular loop. There had also been a re-orientation of otological surgery from operations for infection towards reconstruction, when Lempert (1938) in America, successfully carried out the one-stage fenestration operation. Rosen (1953) revived the stapes mobilization procedure for otosclerosis and Juers (1953) had noted that in some patients with cholesteatoma and erosion of the long process of the incus, pathological approximation of the pars tensa with an intact mobile stapes, produced excellent hearing. He created a similar conduction mechanism surgically, using a meatal skin flap and called the operation 'myringodermostapediopexy'. The dental drill rapidly replaced the hammer and gouge previously used for mastoid exenteration, sulphonamides and antibiotics in the form of penicillin were now available and there had been significant improvements in general and local anaesthetic techniques. Leading otologists such as Simson Hall in Edinburgh, Cawthorne in London and Shambaugh in America had operating microscopes which incorporated light sources and were developing new otological techniques, but were largely ignorant of developments in Germany at that time. In 1948, Wullstein had his own binocular microscope built by Leitz and from 1948 to 1953 performed over 1000 ear operations (Wullstein, 1981).
In 1953, the Zeiss operating microscope became available commercially and, in the same year, Wullstein and Zöllner launched their tympanoplasty methods at the Fifth International Congress of Otorhinolaryngology in Amsterdam.

These methods were soon adopted vigorously by otologists all over the world, but many experienced difficulty and disappointment with skin grafts used to repair the tympanic membrane and line open mastoid cavities and with the hearing results obtained from the classic tympanoplasties. Full thickness skin fared badly in the ear. The grafts were bulky, continued to secrete sebum and became infected and necrotic (Wright, 1960). Eleven per cent of the grafts perforated; epithelial cysts and graft cholesteatomata complicated 3% of cases (Guilford, 1962; Wright, 1963) and the formation of fibrous adhesions between the undersurface of the graft and the promontory resulted in obliteration of the middle ear space (Thorburn, 1960; Palva, 1963). Similar problems were encountered with split skin grafts, 30% of which perforated, and surgeons were encouraged to find alternative grafting materials for tympanic membrane repair.

In 1956, Zöllner (Zöllner, 1963) successfully used autologous fascia lata. Hall (1956) introduced autologous cheek mucosa and Claros-Domenech (1959) introduced autologous periosteum. Shea (1960a) accidentally tore the tympanic membrane during a stapedectomy procedure and repaired the tear successfully with a free autologous vein graft placed medial to the tympanic membrane, thus introducing the ‘underlay’ technique of myringoplasty. Heermann (1960) reported successful myringoplasty results using autologous temporalis fascia ‘onlay’ grafts and successful results were also reporting using tragal perichondrium (Goodhill, Harris and Brockman, 1964) and free autologous fat grafts (Ringenberg, 1962). These grafts were stable and easy to handle, only a small percentage perforated and they could be positioned lateral to the tympanic membrane remnant (onlay) or medial to it (underlay). Chalat (1964) was the first to use tympanic membrane allografts and 2 years later Albrite and Leigh (1966) published their preliminary report on allograft dura mater myringoplasty.

The surgery of otosclerosis was yet again to have a profound effect on tympanoplasty techniques. In 1956, Shea performed the first stapedectomy, covered the oval window with subcutaneous connective tissue and replaced the stapes with a Teflon replica (Shea, 1956). He later introduced the vein graft-polyethylene tube method of stapes replacement. Soon other implant materials including tantalum, platinum and stainless steel wire were used as stapes replacement prostheses and, as such, were well tolerated in the middle ear. These materials were, therefore, applied to ossicular chain reconstruction in tympanoplasty but early enthusiasm for these techniques soon waned when it became apparent that many prosthetic assemblies were unstable and became displaced in the middle ear. If the prosthesis came into contact with the undersurface of the tympanic membrane, extrusion was common, despite the ingenuity of design, such as that shown by the polyethylene-tube umbrella (Oppenheimer and Harrison, 1963), the polyethylene tube-wire mesh ‘sunflower’ columella (House and Sheehy, 1963) and the Teflon ‘umbrella’ (Austin, 1963), and these prostheses were, therefore, abandoned.

From this catalogue of disasters, enormous experience was gained with microsurgical techniques, together with a more comprehensive understanding of the reparative processes in the middle ear and mastoid and the realization that successful ossicular chain reconstruction could only be achieved in a closed, air-containing ear cavity (Rambo, 1961; Tabb, 1963). To
promote growth of new, healthy middle ear mucosa, to maintain a middle ear free of adhesions and to support the neotympanic membrane, absorbable and non-absorbable materials were placed in the middle ear. Wullstein (1960a) advocated the use of absorbable gelatin sponge known today as Gel-foam or Gel-film. Non-absorbable plastic sheeting made of polyethylene (House, 1960), Teflon, Silastic (see Shea, 1981) and paraffin wax (Rambo, 1961; Tabb, 1963) were introduced for use in ears where the excision of disease included removal of most of the middle ear mucoperiosteum. These materials needed to be removed from the ear 3-6 months postoperatively and the concept of 'staged tympanoplasty' was born, that is in these 'severely damaged' ears, no attempt was made to reconstruct the sound conducting mechanism until a healthy, ventilated middle ear cavity and an intact, healthy tympanic membrane existed (Tabb, 1963; Farrior, 1966; Austin, 1969; Sheehy and Crabtree, 1973).

Leading otologists had also come to realize that no single operation was pertinent to the surgical treatment of chronic suppurative otitis media. The two opposing demands of tympanoplasty, namely radical and complete removal of disease and reconstruction of the sound conducting mechanism posed a major problem. Every case needed to be evaluated on the basis of whether disease excision required a purely transcanal operation, or whether, in addition, some form of mastoidectomy was needed together with a tympanoplasty.

When a mastoidectomy is necessary, two basic surgical techniques have evolved, namely, the canal wall-down and the canal wall-up procedures.

In the canal wall-down procedures, the posterior bony meatal wall and the outer attic wall are removed and the attic, aditus ad antrum together with the mastoid antrum and air cell system are exteriorized to the external auditory meatus. Small 'open cavities' thus created usually epithelialize rapidly and are healthy and stable postoperatively. Large cavities, however, are often prone to recurrent infection due to incomplete epithelialization (despite complete excision of disease, a low facial ridge and the presence of a wide meatus) and this, in turn, prejudices the reconstruction of the middle ear sound conducting mechanism. To avoid this, cavity obliteration techniques and posterior canal wall reconstruction techniques were introduced.

Obliteration techniques to reduce the size of the mastoid cavity, or obliterate it completely, have been successfully achieved using autologous cancellous iliac crest bone grafts (Schiller and Singer, 1960) and allogeneic femoral cortical bone chips (Shea, Gardner and Simpson, 1972). More popular, however, are the muscle obliteration techniques using pedicled muscle-periosteal transposition and rotation flaps of sternomastoid muscle (Meurman and Ojala, 1949), temporalis muscle (Rambo, 1958), postauricular muscle-periosteal flaps based on the sternomastoid muscle (Hilger and Hohmann, 1963) and the anteriorly based postauricular muscle-periosteal transposition flap (Palva, 1963, 1982).

Posterior canal wall and outer attic wall reconstruction techniques using autologous or allogeneic cartilage grafts (Jansen, 1972; Smyth, 1972a; Wehrs, 1972, 1982a), allogeneic external auditory meatus bone (Smith, 1970) or autologous mastoid bone (Marquet, 1976a) and mastoid bone paté (Pulec, 1976) have been introduced as an alternative to cavity obliteration.
The canal wall-up techniques of tympanoplasty with mastoidectomy preserve the posterior bony external auditory canal wall and the tympanic sulcus, avoid a postoperative mastoid cavity and allow for reconstruction of the tympanic membrane in its normal anatomical position.

With the passage of time, increasing evidence has accumulated indicating that many surgeons fail to eradicate cholesteatoma (residual disease) in about 25% of all 'closed' operations at primary surgery (Smyth and Hassard, 1981) and in all forms of combined approach tympanoplasty there is a high incidence of retraction pocket formation (recurrent disease) (Austin, 1977; Smyth, 1982a). Of necessity therefore, all 'closed' operations must be staged and 'second look' revision procedures need to be continued until the surgeon is confident that the tubotympanic cleft is free of cholesteatoma. Alternatively, the ear with recurrent or residual disease must be converted into an 'open cavity'.

Enormous controversy surrounds the merits and demerits of 'open cavity' and 'closed cavity' (cavity obliteration, posterior canal wall reconstruction and intact canal wall techniques) (Kohut, 1980; Sheehy, 1980; Smyth, 1982a). Despite this, these operations produce two distinctly different types of middle ear space, namely, 'shallow' and 'deep', depending on whether the tympanic membrane is reconstructed in its normal anatomical position or at the level of the facial ridge. Consequent upon this different techniques of ossicular reconstruction needed to be found.

Grafts used in tympanoplasty and mastoidectomy

Otolologists using tissue transplants to reconstruct the middle ear have, like other transplant surgeons, needed to add a number of new words to their vocabulary in order to describe the types of graft they use. This jargon has been called 'transplantese' and there has been much debate over the terminology that will prove to be most appropriate, informative and etymologically accurate. Nonetheless, a new terminology has evolved and this can and should be applied to tympanoplasty and mastoidectomy (Frootko, 1985a).

Four types of graft can be defined according to the genetic relationship between donor and host (Table 11.1).

Reconstruction of the ossicular chain

Ossicular bone autografts

Reticent to use metal and plastic prostheses in the middle ear, Hall and Rytzner (1957) performed the first ossicular chain reconstruction using autologous ossicular bone. Having accidently fractured the stapes superstructure performing a stapes mobilization for otosclerosis, they successfully interposed the patient's own sculptured incus between the tympanic membrane and the mobilized stapes footplate. The immediate postoperative air-bone gap closure was short-lived because the incus slipped off the footplate. To prevent this complication in subsequent cases of otosclerosis, a small fenestration was made in the footplate or the stapes was removed, and the short process of the autologous incus placed directly into the oval window. In cases of chronic suppurative otitis media with erosion of the long process of incus, Hall and Rytzner removed the incus, malleus and stapes superstructure.
The autologous malleus was then sculptured and interposed between the neotympanic membrane and stapes footplate. They reported no serious cochlear damage but, in some cases, the interposed ossicle became displaced, or bony fixation occurred in the oval window niche. Three interposed ossicles removed at revision surgery showed histological evidence of vascularization of marrow spaces, some viable osteocytes in the lacunae, but no obvious new bone formation or bone resorption apart from minor reduction of calcified matrix on the surface (Hall and Rytzner, 1960, 1961). This work led directly to the application of ossicular bone grafting for reconstruction of the ossicular chain in tympanoplasty.

Table 11.1 Terminology

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<th>Old terminology</th>
<th>New Terminology</th>
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<tr>
<td>Noun</td>
<td>Adjective</td>
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<tr>
<td>Autograft</td>
<td>Autogenous</td>
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<td></td>
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<tr>
<td>Isograft</td>
<td>Isologous or isogenic</td>
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<tr>
<td>Homograft</td>
<td>Homologous</td>
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<tr>
<td>Heterograft</td>
<td>Heterologous</td>
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Autologous ossicles were also repositioned using transposition techniques. In these operations the incus remnant and/or malleus were partially mobilized from their normal anatomical positions and transposed onto the stapes head or footplate. When the long process of the incus was missing Bell (1958) removed the incus and transposed the malleus attached to the tympanic membrane by its umbo, onto the stapes head (tymanomalleostapediopexy). Similar malleus transpositions were described by Hall and Rytzner (1957), Farrior (1960) and Portmann (1963). Other transposition techniques used when the long process of the incus was missing involved mobilizing the incus out of the fossa incudis, dislocating the incudomalleolar joint and transposing the necrosed long process onto the stapes head. In such cases
Farrior (1960) mobilized the incus/malleus complex leaving the incudomalleal joint intact and transposed either the short process of the incus or its eroded long process onto the stapes head. Long-term hearing results achieved with these transposition procedures were not published, but Farrior (1969) reported that many transpositions had failed because of ankylosis of the transposed ossicles to the bony walls of the tympanum.

Throughout the 1960s, therefore, most surgeons focused their attentions on the more successful interposition techniques using a sculptured autologous incus or malleus (Farrior, 1960, 1966; Portmann, 1963; Chandler, 1965; Guilford, 1965; Sheehy, 1965; Szpunar, 1967; Wright, 1967).

The usefulness of autologous ossicular bone grafts in tympanoplasty was challenged by Jongkees (1957) when he stressed that failure to control infection in chronic suppurative otitis media might be due to occult osteitis in the ossicles retained in the middle ear after the surgical removal of mucosal disease and/or cholesteatoma. These suspicions were confirmed when Grippaudo (1958) reported histological evidence of infection in 92% of incudes and mallei removed from 42 cases of chronic suppurative otitis media. Grippaudo emphasized that the use of these diseased autologous ossicles in tympanoplasty may prejudice the results of reconstruction. Similar evidence of osteitis in ossicles removed from cases of chronic suppurative otitis media was reported by Bellucci and Wolff (1966), and Steinbach and Hildmann (1972). Austin (1971) warned about the use of autologous ossicles that showed any evidence of erosion macroscopically and advised that any such ossicles with adherent squamous epithelium or cholesteatoma should never be used in reconstruction.

**Ossicular bone allografts**

Realizing the need to find a new material to reconstruct the ossicular chain in patients without a malleus, and/or incus, and/or stapes superstructure, or with severe infection or cholesteatoma involving the ossicles, House, Patterson and Linthicum (1966) introduced the incus allograft. These incus allografts, acquired from the healthy middle ears of patients undergoing surgery for the removal of an acoustic neuroma were preserved in 70% ethyl alcohol prior to use. Twenty-eight ossiculoplasties were performed using an alcohol-preserved allograft incus interposition technique, but only 10 were followed up. Of five tympanic membrane-to-stapes head interpositions, only two achieved a postoperative air-bone gap of less than 20 dB and, in five tympanic membrane-to-footplate interpositions, only one was successful. One incus extruded 9 months postoperatively and was examined histologically. No inflammatory response was found in or around the graft, the marrow spaces were vascularized but there was no new bone formation. House's (1969) impression was that these grafts remain in the middle ear as dead bone and he recommended that ossicles could be acquired post-mortem provided the donor did not have malignant disease, hepatitis, syphilis or chronic suppurative otitis media. Pulec (1966) found no evidence of resorption or change in shape of three alcohol-preserved incus allografts removed at revision surgery 3-21 months postoperatively.

Histologically, these grafts were found to be covered by mucous membrane and there were no signs of an inflammatory response. In the bony matrix 'no evidence of any living cell was discerned'. Linthicum (1966) compared the histological findings in nine autograft incudes and two alcohol-preserved allograft incudes used in tympanic membrane-to-stapes
interpositions removed 9-12 months after surgery, because of lateral displacement of the graft off the stapes head. He found no evidence of inflammation in the middle ears of these cases at the time of revision surgery. In all specimens, host vascularization and connective tissue infiltration of marrow spaces was seen. New endosteal bone formation was found at a single site in only one specimen; in all the others, no new bone formation was found and most lacuane were empty. There was no difference in the macroscopic or histological appearance between the autografts and allografts. Austin (1971) found histological evidence of limited osteoblastic activity with new bone formation in one alcohol-preserved incus removed one year postoperatively; in another, 'massive absorptive erosion' was seen and Austin question whether or not this represented a rejection phenomenon. Kerr and Smyth (1971a) examined 19 incudes (nine autografts and 10 alcohol-preserved allografts) and four mallei (one autograft and three alcohol-preserved allografts) removed at revision surgery 3-39 months postoperatively; no macroscopic evidence of erosion was found. Histologically, bot the allografts and autografts were similar, with vascularization and plasma cell infiltration of marrow spaces together with small areas of new bone formation. It was noted that most new bone was formed in those grafts which had been longest in the middle ear. The authors concluded that there was no evidence of allograft ossicular bone rejection in the middle ear and that in time the grafts would be incorporated into the ossicular chain as vital structures. In a later report, however, Smyth, Kerr and Hassard (1977) concluded that new bone formation in alcohol-preserved ossicular bone allografts was not directly proportional to the time in the middle ear and that complete replacement of these grafts by new bone would be rare.

Preservation of cadaver acquired ossicular bone by autoclaving was introduced by Hildyard (1967). Having observed no adverse reactions and no morphological changes in autoclaved allogeneic incudes placed in the hypotympanum of six patients with central tympanic membrane perforations, Hildyard used an autoclaved incus allograft as a tympanic membrane-to-footplate interposition in one case. Ten months postoperatively, the incus was removed because of poor hearing gain; histologically the graft was found to be acellular with no evidence of revascularization, new bone formation or inflammatory response.

Encouraged by the apparent lack of immune or inflammatory response and the ability of these ossicular bone allografts to remain in the middle ear without resorption many surgeons started using allograft ossicular bone preserved in alcohol (Pulec, 1966; Wehrs, 1967; Smyth and Kerr, 1967) or by autoclaving (Hildyard, 1967; English et al, 1971) for ossiculoplasty when healthy ossicular autografts were not available.

Otolists now began to concentrate on designing stable ossicular interpositions. The popular 'loose' interposition techniques, that is tympanic membrane-to-stapes head interposition or tympanic membrane-to-footplate interposition did not produce consistently good results (Guilford, 1966; Hildyard, 1967; Armstrong, 1969; Szpunar, 1969; Hough, 1970). The problems encountered included displacement of the graft, lateral retraction of the stapes head or footplate, consequent on lateral retraction of the neotympanic membrane during healing, and fibrous and bony ankylosis between graft and posterior bony annulus, facial canal or promontory (Hough, 1970; Austin, 1971). The grafts were also often too bulky (Goodhill, Westerberg and Davis, 1974) and filled the space between the facial canal and the annulus blocking the epitympanic isthmus and therefore obstructing air flow into the aditus ad antrum with resulting mucus accumulation and continued inflammation (Austin, 1971).
By surgical trial and error, coupled with careful postoperative observation Guilford (1966) found that interpositions between the malleus handle and stapes head, that is malleus-stapes interposition or malleus-footplate interposition were more stable and produced better postoperative hearing gains than tympanic membrane-to-stapes head or tympanic membrane-to-footplate interposition. These sentiments were strongly supported by the experiences of Hildyard (1967), Armstrong (1969), Szpunar (1969), Hough (1970) and confirmed by Elbrond and Elpern (1965) in an experimental study of the stability and acoustic properties of various incus interposition techniques in cadaver temporal bone models.

In 1971, Austin presented his classification of the anatomical defects found in the ossicular chain in 1151 consecutive ears with chronic suppurative otitis media at the Abraham Lincoln School of Medicine in Chicago. Isolated loss of the malleus handle (2% of ossicular defects) and isolated loss of the stapes superstructure (1.7% of ossicular defects) were not classified because of their rarity. In all other cases, the incus was deficient either wholly or in part and four types of ossicular defect were therefore described depending on the presence or absence of the malleus handle and the presence or absence of the stapes superstructure (Austin, 1971).

When the malleus handle and stapes superstructure were present, Austin sculptured an autologous or allogeneic malleus head or incus body to fit between the malleus handle and stapes head. A cup-shaped depression was drilled into the graft to receive the stapes head and a concave depression carved to fit snugly against the malleus handle. This interposition technique was called the 'malleus/stapes assembly' and was more stable, less bulky, and less affected by lateral movement of the tympanic membrane during healing than was tympanic membrane-to-stapes head interposition.

When the malleus handle was present/stapes superstructure absent, Austin sculptured an autologous or allogeneic incus and interposed the graft precisely between the malleus handle and a small connective tissue pad placed on the stapes footplate. As with malleus/stapes assembly, the malleus handle was used as an energy coupler and lateral fixing point, and the small connective tissue pad on the stapes footplate helped centre the graft in the oval window niche and prevent slipping. This interposition technique was called the 'malleus/footplate assembly' and was more stable than tympanic membrane-to-footplate interposition and produced better hearing results. Similar techniques were described by Hildyard (1967) and Hough (1970).

Pennington (1973) improved the design of the Austin malleus/stapes assembly to deal with the two basic anatomical malleus/stapes relationships encountered in tympanoplasty. He designated the vertical malleus/stapes head relationship 'type 1a' and 'type 1b' and the horizontal malleus/stapes head relationship 'type 2'. In type 1a and 1b the incudomalleal joint surface of the incus was grooved to a deep yoke or 'mortice' to receive the malleus neck or handle, the incus short process was amputated and the long process dowelled or cupped to fit over the stapes head. In the type 2 case, the double dowel technique over the stapes head. Using these malleus/stapes assembly techniques, Pennington reported closure of the air-bone gap to less than 16 dB in 69% of 216 ears followed up for 2-5 years.

Wehrs (19740 introduced the notched incus autograft or allograft technique. For malleus/stapes assembly, the incus long process was amputated, a notch was drilled into the
short process to accommodate the malleus neck or handle and the incus body was dowelled to fit the stapes head (‘notched incus with short process’). For malleus/footplate assembly, the incus short process was drilled in a similar fashion and the long process placed directly onto the stapes footplate (‘notched incus with long process’). To deal with the varying spatial relationships between the malleus handle and the stapes head or footplate, appropriate sculpturing of the notch and dowel was found to be applicable to most anatomical situations encountered.

These basic sculpturing techniques for malleus/stapes and malleus/footplate assemblies using allograft or autograft *incudes or mallei* with minor modifications are used by most surgeons today (Smyth, 1972b; Goodhill, Westerbergh and Davis, 1974; Marquet, 1976a; Ironside, 1979; Smith, 1980a, b; Hough, 1982; Smith and McElveen, 1982).

The least common of the ossicular defects encountered, namely the absent malleus handle but with stapes superstructure present and the absent malleus handle with absent stapes superstructure, pose the most difficult reconstructive problems. The number of solutions proposed testify to this fact, but fundamentally the problem has been tackled in two ways.

The first was to establish a link between the neotympanic membrane and the stapes using a sculptured allograft malleus or incus, that is tympanic membrane-to-stapes head or tympanic membrane-to-footplate interposition (Austin, 1971, 1982; McGee, 1979; Smyth, 1980). In a shallow middle ear space, myringostapediopexy has been recommended by Lee and Schuknecht (1971), Goodman (1980) and Smyth (1980) if the stapes superstructure is absent, Smith and Dobie (1976) and Marquet (1976a), recommended myringostapediopexy using an allograft stapes positioned onto the footplate. Gotay-Rodrigues and Schuknecht (1977) were able to achieve a 30-dB postoperative air-bone gap in 59% of 72 ears treated by open mastoidectomy and the use of autologous temporalis fascia to create a round window baffle and small split-skin grafts to cover the exteriorized mobile footplate (type IV tympanomastoidectomy).

The second method was to reconstruct a neomalleus in the neotympanic membrane to form the main building block upon which a link could be established with the stapes head or footplate. Early attempts by Guilford (1966) to suture a rod-shaped autologous cortical bone graft to the undersurface of the neotympanic membrane were unsuccessful. Schiller (1979) was able to achieve a postoperative air-bone gap of less than 15 dB in only 30% of 33 cases using his two-stage malleomyringoplasty procedure. Hough (1982) has reported successful results using autologous cortical bone, shaped like the malleus handle or an allogeneic malleus placed on the undersurface of the neotympanic membrane and held in place by a sculptured allograft ossicle interposed between the neomalleus and the stapes head or footplate. Using a two-ossicle (allograft stapes - incus) assembly in ears without a tympanic membrane, malleus, incus and stapes superstructure, Tos (1978) has reported early postoperative closure of the air-bone gap to 18 dB or less in 67% of 23 cases.

**Tympanomeatal and tympano-ossicular allografts**

A major contribution to the problem of reconstruction of the malleus handle in the neotympanic membrane, developed as an evolution of the pioneering work with orthotopic
cadaver acquired allograft tympanic membrane transplantation by Chalat, Betow and Marquet in the early 1960s.

Chalat (1964) used fresh, unpreserved tympanic membrane allografts to repair central perforations in three patients; two of these grafts perforated early and the procedure was abandoned. In 1959, Betow (1982) used an unpreserved tympanic membrane allograft to repair a perforation and noted graft resorption and necrosis on the twenty-eighth day postoperatively. In the same year, Brandow (1973) had observed similar necrosis and perforation of unpreserved tympanic membrane allografts in 11 patients. Both Betow and Brandow recognized that this graft necrosis was probably an immunological rejection phenomenon. Betow (1982) subsequently preserved tympanic allografts preoperatively in an antibiotic solution at -24°C, but the majority of these grafts perforated. Smyth and Kerr (1969) using tympanic membrane allografts which included a 6-mm cuff of meatal skin (tympanomeatal grafts), preserved in 5% chlorhexidine and 10% framycetin solution at -20°C preoperatively, reported necrosis and perforation in 65% of cases and Glasscock and colleagues (Glasscock and House, 1968; Glasscock, House and Graham, 1972) reported a similar high incidence of necrosis in tympanic membrane grafts preserved preoperatively in propriolactone or benzalkonium chloride or by freeze-drying techniques. Preservation in 70% ethyl alcohol, however, increased the graft take rate to 70%. House, Glasscock and Sheehy (1969) then conceived the idea of alcohol preserved composite allografts, consisting of en-bloc tympanic membrane with ossicles attached (tympano-ossicular monoblock grafts) for use in ears without a tympanic membrane, malleus and incus, with or without a stapes superstructure. Sixteen tympano-ossicular transplants were performed but hearing results were poor.

Working independently in Antwerp, Marquet had noted that bone and tendon allografts preserved in the organomercuric compound Cialit (sodium 2-ethyl mercurithiobenzoxazole-5-carboxylate, Hoechst Pharmaceuticals) had been used successfully in orthopaedic procedures. Inspired by the reported lack of an immune response to these grafts, Marquet used Cialit to preserve cadaver acquired de-epithelialized tympanic membranes to repair perforations and reported successful myringoplasties using this technique in 15 out of 17 cases (Marquet, 1966). Other surgeons (Brandow, 1969; Morrison, 1970; Smyth, Kerr and Goodey, 1971; Smyth, 1976) were less successful with Cialit-preserved tympanic membrane grafts. Marquet's excellent results coupled with the experiences of House, Glasscock and Sheehy (1969) with tympano-ossicular grafts offered a potentially reliable method for reconstruction of the middle ear transformer, in those ears where radical excision of disease was necessary. With the recent introduction of combined approach tympanoplasty (Jansen, 1963), Marquet was not able to transplant and accurately position tympanomeatal allografts with attached ossicles via a posterior tympanotomy (Marquet, 1968, 1969, 1976a).

Perkins (1970a, b) reported successful myringoplasty in 23 out of 24 subtotal perforations repaired with allogeneic tympanic membranes preserved preoperatively in buffered formaldehyde solutions. Glasscock, House and Graham (1972) reported a 90% graft take rate and Lesinski (1982) has reported an 85% graft take rate in 100 consecutive tympanomeatal allografts with and without attached ossicles using the formaldehyde preservation technique.
Marquet then combined his method of preservation with that of Perkins by fixing tympano-ossicular grafts in 4% buffered formaldehyde for 2-3 weeks and then preserving the grafts in aqueous Cialit 1/2000 at 2°C prior to use. His immediate postoperative graft take rate in 1912 ears improved progressively from 73% in 1964 to 97% in 1976 (Marquet, 1977). This improvement has been attributed to refinements in surgical technique (Marquet, 1976a) and to the introduction of the Marquet/Perkins method of preservation (Marquet, 1977; Plester and Steinbach, 1977).

Wehrs froze cadaver temporal bone cores prior to preservation of the 'dissected out' tympanic membranes and tympano-ossicular grafts in 70% ethyl alcohol. Using 'de-epithelialized' tympanic membranes preserved in this manner (with or without an attached malleus) as onlay grafts, covered by autologous temporalis fascia or pedicled meatal skin, Wehrs (1982b) has reported successful closure of perforations in over 90% of 920 cases operated on between 1968 and 1980.

In 1976, Smith introduced the technique of freeze-drying and ethylene oxide gas sterilization for the preoperative preservation of otologic allografts (Smith, 1980a, b). Tympanomeatal, tympano-ossicular and ossicular bone allografts prepared by this technique appear to be successful in the short term, but long-term results have not been published (Smith, 1982; Smith and McElveen, 1982).

In those ears without a tympanic membrane, malleus or incus, with or without an intact stapes superstructure, composite tympano-ossicular allografts have been used by some surgeons as the main building block for middle ear reconstruction. In combined approach tympanoplasty procedures, tympano-ossicular allografts (comprising tympanic membrane and meatal skin cuff, malleus and incus) have been transplanted successfully into ears where only an intact mobile stapes remains (Marquet, 1977). Tympano-ossicular allografts (comprising tympanic membrane and meatal skin cuff, malleus, incus and stapes crura) have been less successful in those ears where only a mobile stapes footplate remains. This is primarily because of problems inherent in making adequate and lasting contact between the donor stapes crura and the recipient stapes footplate (Marquet, 1982, personal communication). Another major problem encountered with these types of reconstruction is fibrous and bony ankylosis of the short process of the transplanted incus to the lateral semicircular canal (Ironside, 1979) or to the bony margins of the posterior tympanotomy.

In order to adapt these tympano-ossicular grafts to both the shallow and deep middle ear and to try to avoid postoperative discontinuity and fixation of the reconstructed ossicular chain, a two-stage tympanoplasty method has been advocated by Ironside (1979), Lesinski (1982), Smith (1982) and Wehrs (1982b). In stage I, a composite tympanic membrane and meatal skin cuff with incorporated malleus is transplanted to act as the main building block for the middle ear reconstruction. At the second stage, 6 months later, a sculptured preserved ossicular bone allograft can be used as a malleus-to-stapes assembly or malleus-to-footplate assembly according to whether or not the stapes superstructure is intact.

**Autologous and allogeneic cortical bone grafts**

Sculptured columellae and autologous cortical bone from the outer mastoid cortex, bony external auditory meatus and spine of Henle have been used in tympanic membrane-to-
stapes head and tympanic membrane-to-footplate interpositions, malleus-to-stapes and malleus-to-footplate assemblies by Hough (1958), Zöllner (1960, 1969), Farrior (1960, 1966), Kley and Draf (1965), Bauer (1966), Guilford (1966), Wright (1967) and Tos (1974), but long-term hearing results have not been reported by these authors. Pulec and Sheehy (1973) reported resorption of autologous cortical bone columellae in the middle ear but Robin, Bennett and Gregory (1976) were unable to comment on surface resorption of cortical bone grafts removed at revision surgery 12-48 months postoperatively, because such features were masked by preoperative sculpturing of the grafts. Berkovits et al (1978) have performed 200 ossiculoplasties using autologous cortical bone, precisely modelled on a Micro-fraize machine for malleus-to-stapes and malleus-to-footplate assemblies. Eight grafts removed because of recurrent cholesteatoma, showed histological evidence of vascularization of marrow spaces with some viable osteocytes in the lacunae, but there was ‘rounding off’ of the edges of these grafts due to surface resorption of bone. Graft resorption was also seen in those ears in which chronic infection persisted postoperatively (Berkovits, 1982, personal communication).

Ojala et al (1983) compared the hearing results in 51 ears in which autologous mastoid bone struts were used, and 113 ears in which autologous or preserved allogeneic ossicular bone had been used to reconstruct the ossicular chain. He concluded that the early (one year postoperative) and late (5-12 years postoperative) hearing results were the same for ossicular and cortical bone grafts in tympanic membrane-to-stapes head interposition and malleus-to-stapes assembly.

In animal experiments, Beck and Franz (1961) have demonstrated resorption of fresh allogeneic cortical bone grafts in the middle ear of guinea-pigs and Müsebeck and Falck (1963) reported similar results in rabbits. Fresh cortical bone allografts used to reconstruct the ossicular chain in dogs (Guilford, Shortreed and Halpert, 1966) and in cats (Benitez, Behar and McIntire, 1971) showed new bone formation, good vascularization of marrow spaces and no histological evidence of resorption. Cialit-preserved cortical bone allografts induced an inflammatory response associated with osteoclastic resorption of the grafts in the middle ear of non-inbred rabbits (Hildmann, Steinbach and Koburg, 1974; Steinbach, 1982, personal communication). As a result of these experiments preserved cortical bone allografts have not been used extensively in tympanoplasty.

**Autologous and allogeneic cartilage grafts**

Utech (1960) introduced sculptured auricular cartilage autografts for tympanic membrane-to-stapes head and tympanic membrane-to-footplate interpositions and Jansen (1963) found autologous tragal cartilage and autologous or preserved allogeneic nasal septal cartilage suitable for tympanic membrane-to-stapes head interposition (short columella) and tympanic membrane-to-footplate interposition (long columella) reconstructions in combined approach tympanoplasty procedures. Jansen (1972) soon found the long cartilage columellae too flimsy and reinforced them with stainless steel wire, a procedure also adopted by Smyth (1969) in his ‘boomerang’ strut. To increase the stability of tympanic membrane-to-footplate interposition, Brockman (1965) designed a composite autologous tragal cartilage-perichondrial columella. Using this technique, he reported postoperative closure of the air-bone gap to less than 16 dB in 30 cases. Encouraging hearing results were also achieved by Portmann (1963) and Shea and Glasscock (1967) using similar techniques with autologous cartilage perichondrial grafts.
Altenau and Sheehy (1978) found that the most common cause of failure of autologous and alcohol-preserved allogeneic cartilage struts assessed at revision surgery was that they were 'too short' and became displaced. No obvious resorption of cartilage was found in these grafts or in the cartilage grafts removed from the middle ear and studied histologically by Don and Linthicum (1975). Goodhill et al (1979) noted postoperative softening of autologous tragal cartilage used in tympanic membrane-to-footplate interpositions and Smyth (1980) reported displacement of 'boomerang' struts in 22 revision operations, with erosion of the medial limb of the strut in three cases. Notching of the medial limb of the strut was also noted in some ears where the strut had come into contact with Silastic sheeting placed over the promontory and oval window niche.

Seventy-six alcohol-preserved nasal septal cartilage allografts that had been in the middle ear for up to 9 years were studied histologically by Kerr, Byrne and Smith (1973). In most cases the morphology of the grafts was retained. Variable amounts of fibrous tissue replacement of cartilage together with erosion and thinning of the medial limb were seen particularly in those grafts longest in the middle ear. Kuijpers and van den Broek (1975) have also reported resorption of alcohol-preserved cartilage columellae and Smyth (1980) found resorption of the medial limb of 3% of 'boomerang' struts removed at revision surgery. Other causes of failure were lateral displacement of the columella off the stapes footplate and immobilization of the columella by middle ear adhesions.

A most significant histological study of the fate of cartilage in ossicular reconstruction was undertaken by Steinbach and Pusalkar (1981). Fifty-two cartilage struts (39 tragal cartilage autografts and 13 Cialit-preserved nasal septal cartilage allografts) were removed 1-15 years postoperatively. Forty-four of these grafts were removed because of failure of hearing improvement and eight because of recurrent disease. In the vast majority of cases, deterioration in hearing occurred between the third and seventh year postoperatively. There were no obvious differences in the macroscopic or histological appearance in the removed allografts and autografts. Thirty-eight grafts had become soft and spongy, 25 grafts had decreased in size and, in seven, the medial limb had been resorbed completely. In three ears revised because of recurrent cholesteatoma, the grafts had disappeared.

Total or partial resorption of alcohol-preserved cartilage columellae with or without stainless steel reinforcement has been a common finding at revision surgery by the author (unpublished data) and Austin (1982) has used the term 'creeping resorption' to describe the behaviour of cartilage columellae in the middle ear.

Glues and adhesives

To aid in stabilizing ossicular bone assemblies and tympano-ossicular allografts, stainless steel microscrews and wire have been employed by Marquet (1969) and Jako (1972) and the properties of different glues have also been evaluated. Mecrylate (COAPT-1), Bucrylate (COAPT) and Eubucrylate (Histo-Acryl) cause inflammatory responses including foreign body reactions and osteitis in the middle ear (Kerr and Smyth, 1971b; Heumann and Steinbach, 1980) and have therefore been abandoned by most otologists. The two component fibrin-sealant, Tissucol/Tisseel (Seelich, 1982), forms a stable adhesive by combining concentrated human fibrinogen and factor XIII with a thrombin calcium chloride/aprotinin solution. The resulting adhesive retains its properties in a moist field and does not induce an
inflammatory response (Katzke, Pusalkar and Steinbach, 1983). Marquet (1982) and Portmann (1982) have used this adhesive successfully in tympanoplasty over the last few years and there are indications that its use will become widespread.

**Otological tissue banks**

Many surgeons using allografts in tympanoplasty secure their own cadaver donor material from the hospitals in which they work and the ‘dissecting out’ and preservation of these allografts is performed by themselves or their staff. In the USA, the passing of the Universal Donor Act in 1969, made it possible to obtain donor material easily and, in 1970, Perkins created the first ear bank under the sponsorship of Project Hear (Palo Alto, California). Other ear banks have subsequently been established in the USA and elsewhere. Most function as non-profit-making organizations to provide high quality, preserved, sterile otological allografts. These banks are currently preserving otological allografts in chemical agents, that is formaldehyde, glutaraldehyde, Cialit, alcohol or by freeze-drying and ethylene oxide sterilization (*Table 11.2*). Grafts are distributed on demand, nationally and internationally, to surgeons who do not have the time or facilities to acquire their own donor tissues or cannot do so because of the medicolegal or religious restrictions of the countries in which they work (Chiossone, 1977; Lesinski, 1977, 1982; Smith, 1980b).

Acquired immunodeficiency syndrome (AIDS): the virus is inactivated by tissue preservation in glutaraldehyde, formaldehyde or alcohol, but not by freeze-drying alone.

**Table 11.2 Preservation techniques for otological allografts**

1. 70% ethyl alcohol
2. 0.02% aqueous Cialit, (sodium 2-ethylmercurithiobenzoxazole-5-carboxylate)
3. 4% buffered formaldehyde fixation and 0.5% buffered formaldehyde preservation
4. 4% buffered formaldehyde fixation and 0.05% aqueous Cialit preservation
5. 0.5% buffered glutaraldehyde fixaton and 0.02% aqueous Cialit preservation

**Biomaterials**

In recent years, collaborative efforts between biomaterial scientists and surgeons have led to the manufacture of new materials specifically designed for implantation. As a result of these efforts, three porous plastic materials, namely Proplast, Plastipore and Polycel, together with a vast range of ceramic materials have been developed for use in tympanoplasty and mastoidectomy (*Table 11.3*).

Proplast 1 prepared by the combination of two polymer families, namely polytetrafluoroethylene and vitreous carbon was first used by Janeke and Shea (1975) as a total ossicular replacement prosthesis in 23 cases in whom the malleus, incus and stapes superstructure were missing. Proplast prostheses subsequently became available for tympanic membrane-to-stapes head and tympanic membrane-to-footplate interpositions, and malleus-to-stapes, and malleus-to-footplate assemblies, but foreign body reactions to the prosthesis and extrusion of these prostheses through the tympanic membrane have occurred (Kerr, 1981; Palva and Makinen, 1983).
The second plastic implant material, Plastipore (porous polyethylene) reported to have non-reactive properties and sufficient porosity to encourage host tissue ingrowth to stabilize the implant in the middle ear, was first used successfully by Shea (1976) for tympanic membrane-to-footplate interposition and malleus-to-footplate assembly and was called the total ossicular replacement prosthesis (TORP). For tympanic membrane-to-stapes head interposition and malleus-to-stapes assembly, a Plastipore partial ossicular replacement prosthesis (PORP) was introduced (Richards Technical Publication, 1980).

Shea, Emmett and Smyth (1977) and Hicks, Wright and Wright (1978) reported encouraging short-term hearing results and only a small percentage of extrusions using partial and total ossicular replacement prostheses. Smyth (1982b), however, has reported a 5-year follow-up of 28 ears in which partial ossicular replacement prostheses were used and 116 ears in which total ossicular replacement prostheses were used. Fifty-seven per cent of the partial and 78% of the total prostheses failed to maintain closure of the air-bone gap (preoperative bone conduction and postoperative air conduction) to 10 dB or less at 0.5-2 kHz. Using the same criteria, Frootko (1983) reported a 3-5 year follow-up of 78 ears in which partial ossicular replacement prostheses and 41 ears in which total ossicular replacement prostheses were used; the failure rates were 72% and 83% respectively. Extrusion of the prosthesis through the tympanic membrane was the major cause of failure (40% partial, 32% total). This was not prevented by the interposition of connective tissue between the prosthesis head and the undersurface of the tympanic membrane, nor was extrusion prevented by placing the prosthesis under the malleus handle or chorda tympani nerve, when present. At the present time, it appears that cartilage interposed between the prosthesis head and the tympanic membrane is the best method of protection against extrusion, reducing this complication to less than 5% of cases (Brackmann, 1986). Other causes of failure include postoperative migration and displacement of prosthesis. With partial ossicular replacement prostheses, necrosis and fracture of the stapes superstructure has been observed (Belal and Odnert, 1982; Frootko, 1983) and with total ossicular replacement prostheses single cases of foreign body granuloma on the stapes footplate (Palva and Makinen, 1983) and perforation of the stapes footplate with resultant perilymph fistula (Myer and Cotton, 1982) have occurred. There is also conclusive light and electron microscopic evidence that biodegradation of Plastipore occurs in the middle ear, albeit at microscopic level (Kerr, 1981; Belal and Odnert, 1982) and the prostheses evoked a local but sustained foreign body reaction (Kerr, 1981; Frootko, 1983; Palva and Makinen, 1983).

The third plastic implant material, Polycel (thermofusion formed ultra-high-molecular-weight porous polyethylene; Treace Medical Inc) offers design advantages over other porous plastic implants. The prostheses for both tympanic membrane-to-stapes head and tympanic membrane-to-footplate interpositions offer a centred and offset peg-top platform onto which the cartilage interposition can be secured. In addition, the tympanic membrane-to-footplate interposition prostheses have a stainless steel core and slim shaft, enabling the shaft and head to be bent to the desired configuration and the stainless steel core acts as a 'tack' fixing the prosthesis to the stapes footplate. Using these prostheses, Chüden (1985), Brackmann (1986) and Moretz et al (1986) have reported encouraging hearing results, low extrusion rates and minimal foreign body reaction in the middle ear, but longer-term follow-up results of cases in which these prostheses have been used are awaited.
The most recent materials available for ossiculoplasty, posterior canal wall and outer attic wall reconstruction and mastoid obliteration, are the ceramics (Grote, 1984) (see Table 11.3). The almost totally bio-inert and very hard aluminium hydroxide ceramic (Frialit) has been used successfully in ossiculoplasty by Jahnke and Plester (1981). The prostheses become encapsulated in the middle ear and produce no interface reactions. The bioactive calcium silicate glass ceramics undergo chemical changes at their surface, resulting in interface bonding with adjacent structures, that is the adjacent ossicle or undersurface of the tympanic membrane, and very encouraging ossiculoplasty results using the bioactive calcium silicate glass ceramic 'Ceravital' have been reported by Reck (1980, 1985). Biodegradable hydroxyapatite-tricalcium phosphate ceramics of the porous variety have been used in posterior canal wall reconstruction and mastoid obliteration and have been shown to be replaced in part by host connective tissue elements and osteogenic cells (see Grote, 1984).

Table 11.3 Implants used in middle ear and mastoid reconstructive surgery

1. Metallic
   Stainless steel
   Tantalum
   Platinum
   Titanium

2. Non-metallic

2.a. Plastics

2.a.1. Solid
   Polyethylene
   Polytetrafluoroethylene (Teflon)
   Polydimethylsiloxane (Silastic)

2.a.2. Porous
   Polytetrafluoroethylene-carbon fibre composite (Proplast 1)
   Polytetrafluoroethylene-aluminium oxide composite (Proplast 2)
   High density polyethylene (Plastipore)
   Ultra-high molecular weight polyethylene (Polycel)

2.b. Ceramics

2.b.1. Bio-inert
   Aluminium oxide ceramics (Frialit)

2.b.2. Bioactive
   Calcium silicate glass ceramics (Ceravital, Bioglass)

2.b.3. Biodegradable or bioresorbable
   Hydroxyapatite - tricalcium phosphate ceramics (dense and porous varieties).
Conclusions

The ear surgeons of today, have at their disposal, a wide range of surgical procedures for the treatment of chronic suppurative otitis media, both with and without cholesteatoma. The fundamental prerequisite for this type of surgery is the meticulous and complete removal of disease from the middle ear and/or mastoid.

Ideally, every ear surgeon should be accomplished and competent enough to perform all of the surgical procedures that have evolved and should have a thorough knowledge of temporal bone anatomy and physiology, but this ideal has and probably never will be achieved. The surgery of chronic suppurative otitis media must, therefore, not only be tailored to the patient's presenting pathology and requirements, but also to the level of competence of the surgeon and the surgical and follow-up facilities available. It is, to take the extreme example, quite wrong for an unaccomplished ear surgeon to perform a combined approach tympanoplasty on a patient who will be lost to follow-up postoperatively.

The debate as to whether the open techniques of mastoidectomy with tympanoplasty are better or worse than the closed techniques will continue. There is no short cut to successful excision of disease and the operation of choice must be that in which all the disease can be excised. Once this is achieved, the surgeon can decide on the type of middle ear and/or mastoid reconstruction procedure to be used, whether this should be staged or not and what the reconstruction should ultimately achieve.

There is one situation that permits special mention in this chapter: the patient who has lost all useful hearing in one ear, and requires surgical removal of cholesteatoma in the other ear. In this situation, the surgeon must be aware that any surgical technique or manoeuvre that may endanger the cochlea must be avoided. The best method of management is by open mastoidectomy. No attempt should be made to reconstruct the ossicular chain. The stapes superstructure and/or footplate must not be manipulated and cholesteatoma or diseased mucosa on these structures should not be removed. Tympanic membrane reconstruction should only be considered if ossicular discontinuity already exists, thus protecting the stapes, and the middle ear must be free of disease.

Many graft and implant materials are available for middle ear reconstruction. Most ear surgeons prefer to use healthy, fresh, autologous tissues whenever possible and, in the main, these have proved most successful. Their second choice has been preserved allogeneic tissues and their use has only been possible, because the deep external auditory meatus and middle ear are sites where immune rejection responses to a tissue allograft across major histocompatibility barriers are somewhat muted (Frootko, 1985b). These sites may therefore be regarded as sites favourable to graft acceptance, that is immunologically privileged sites (van den Broek, 1968; Frootko, 1984). Current preoperative otological allograft preservation techniques (see Table 11.2) also appear to make these tissues less susceptible to rejection after grafting across major histocompatibility barriers, by alternating, to a greater or lesser extent, the molecular configuration of antigenic determinants of transplantation antigens. This appears to diminish the graft's ability to immunize the recipient, but does not alter their specificity (Frootko, 1985b). It is presumably for similar reasons that successful tympanic membrane reconstruction has been achieved using preserved bovine connective tissue xenografts.
The solid and porous plastic implants have not gained universal acceptance by the otological fraternity for reasons outlined in this chapter, and the ceramics have yet to prove their superiority over autografts and preserved allografts in middle ear reconstruction.
Chapter 12: Complications of suppurative otitis media

Harold Ludman

Complications of suppurative otitis media arise when infection spreads from the middle ear cleft to structures from which it is normally separated by bone. Before antibiotics were regularly used, these complications arose more frequently from acute middle ear suppuration than from chronic middle ear disease. Nowadays, most otological experience indicates that chronic middle ear infection is the greater hazard, although some writers (Gower and McGuirt, 1983) have still found a higher incidence of intracranial complications from acute infections. This probably reflects the high proportion of young patients in their series, and illustrates the fact that complications of acute otitis media are commoner in the young. Although the overall incidence of complications has fallen greatly with antibiotic treatment, it cannot be overstressed that the mortality from intracranial complications is as high now as it was 20 years ago (Editorial, 1982).

Whether the preceding disease has been acute or chronic, spread of infection can follow a number of possible routes.

1. By extension through bone that has been demineralized during acute infection, or suffered resorption by cholesteatoma or osteitis in chronic destructive disease.

2. By the spreading of infected clot within small veins through bone and dura to venous sinuses - the lateral and the superior petrosal - and so to intracranial structures. Apparently intact bone may be transgressed by thrombophlebitis within its Haversian vascular system. Thrombophlebitic spread from the lateral sinus to the cerebellum and from the superior petrosal sinus to the temporal lobe explains the frequent association between these complications.

3. Through normal anatomical pathways - the oval or round windows into the internal auditory meatus, the cochlear and vestibular aqueducts, dehiscence of the thin bony covering of the jugular bulb, dehiscence of the tegmen tympani, and dehiscent suture lines of the temporal bone.

4. Through non-anatomical bony defects caused by trauma - accidental or surgical - or by neoplastic erosion.

5. Through other surgical defects; in particular, the vestibular opening deliberately created at a stapedectomy operation, and possibly through the fenestration opening into the lateral semicircular canal.

6. Into brain tissue along the periarperiolar spaces of Virchow-Robin. This spread does not affect the cortical arterioles themselves and explains abscess development in the white matter with no apparent continuity of infection to the brain surface.

Chronic middle ear disease extends slowly and many of its complications are caused by the progressive and relentless erosion of bone, thus exposing the structures at risk to
damage - the facial nerve, the labyrinth, the dura. Acute infections cause complications earlier, through the thrombophlebitic mechanisms and the anatomically available pathways.

Despite the apparent 'skipping' of a brain abscess into the white matter, the general pattern of infective spread, through the mechanisms described, is progressive from one structure and tissue plane to the next. Progress is from the middle ear cleft to extradural spaces and venous sinuses; through dura to the cerebrospinal fluid spaces; and into brain tissue. It should not then be surprising that multiple complications are common, arising in one-third of cases, and that certain associations, such as those between lateral sinus thrombosis and cerebellar abscess, are frequent.

The propensity for spread of infection, and the development of complications depends on:

1) patient attributes - age, immune state, intercurrent chronic disease such as diabetes mellitus or leukaemia

2) bacterial attributes - virulence, susceptibility to chemotherapeutic elimination. For example in acute suppurative infection, Streptococcus pneumoniae type III and Haemophilus influenzae type B have sinister reputations

3) efficacy of treatment of the underlying middle ear disease.

Infecting bacteria predominantly responsible for infections have varied in accounts over the years, and still do from one report to another. One explanation is the difference in the nature of bacteria associated with acute and with chronic, cholesteatomatous, disease. Some variations may represent genuine differences in the pattern of microbial infections in different parts of the world, while others indicate changes that have taken place in patterns of infection over the years. Lastly, previously unidentified bacteria such as anaerobes (Ingham, Selkon and Roxby, 1977) have been recognized by new bacteriological techniques. These explanations for apparent inconsistencies should be remembered when reading the sections below on the individual complications.

Although cholesteatoma, with posterior marginal or attic disease, is considered to be the hallmark of an ear with a poor prognosis, Browning (1984), in a study of patients in the West of Scotland, has shown that a brain abscess may arise from ears with mucosal disease, and from ears previously treated by modified radical mastoidectomy. He has also indicated that the risk of any patient with chronic otitis media developing a brain abscess is as low as 1 in 3500.

The complications to be discussed fall into two main categories:

1) those within the cranial cavity:
   - extradural abscess
   - subdural abscess (empyema)
   - sigmoid sinus thrombophlebitis
   - meningitis
   - brain abscess
   - otitic hydrocephalus
(2) those within the temporal bone:
   facial paralysis
   labyrinthine infections.

Rarer complications, for example subclavian vein thrombosis, and internal carotid aneurysm (Kimmelman and Grossman, 1983), have also been reported.

Petrositis, which may be considered an unusual extension of mastoiditis, is described in Chapter 9.

**Intracranial infections**

**General principles**

Certain aspects of the presentation, diagnosis and management of intracranial complications are common to all; so it is pertinent to make some general comments concerned with principle here, before considering individual features under separate heading below. This plan may help to avoid unnecessary repetition, and should emphasize that these complications have to be considered as a group, since they are multiple in about one-third of instances.

The symptoms of intracranial spread of infection are those of infection, and compression of brain tissue. Headache, malaise, fever, drowsiness are all suspicious symptoms. Otalgia is not a feature of uncomplicated cholesteatoma. Any of these should alert the otologist to the possibility of a complication, and provoke initiation of appropriate investigation and treatment. More specific features of individual complications will be discussed under the appropriate headings. At any time one complication may be clinically dominant with others emerging from the investigative findings. Investigation and treatment must run concurrently. To delay treatment until investigation is complete may allow disease to proceed beyond the chance of recovery. The principles of treatment, common to all intracranial complications include:

(1) systemic antibiotic therapy
(2) local neurosurgical attention to the complication(s) identified
(3) treatment of the ear lesion.

Antibiotics have radically reduced the incidence of complications, but have had much less effect on the mortality of established complications. Of equal importance, they have altered the clinical pattern of presentation, introducing an element of 'masking'. Specific examples will be discussed under individual complication headings, but it is indicative of the problem that Pfaltz and Griesemer (1984) found normal otoscopic appearances in 10% of children with mastoiditis.

It is unwise to offer rigid recommendations for antibiotic therapy, for several reasons. First, the armamentarium of available drugs is changing rapidly, so suggestions at the time of writing could be obsolete within a short period. Second, the pattern of infecting organisms changes, as has been discussed above. Lastly, bacterial resistance varies with time, and from one place to another. Microbiologists are usually familiar with the drugs locally available, and often have developed policies for treating particular types of infection. Advice from the
Certain general principles can however be addressed. Antibiotics must be used in large doses, and preferably should be administered intravenously. Drugs should be chosen on probabilities, without waiting for culture and sensitivity reports. Changes should be based on clinical responses and determined by bacteriological reports. When the ear infection is acute, a drug competent to kill *Haemophilus influenzae* must be used. Since this organism is becoming increasingly resistant to ampicillin, chloramphenicol is usually the drug of choice. The recommended dose is generally 100 mg/kg per day (Brand, Caparosa and Lubic, 1984). The risks of agranulocytosis and aplastic anaemia demand that its administration be repeatedly monitored by blood counts (every 2 days). It is usual to combine chloramphenicol with a penicillin. Since many staphylococci produce beta-lactamase, methicillin or flucloxacillin may be chosen. The possibility of Gram-negative infections, and particularly with *Pseudomonas aeruginosa*, in chronic ear disease requires consideration of antibiotics such as azlocillin, ticarcillin - these have replaced carbenicillin, since they are more effective. Aminoglycosides, of which gentamicin is at the moment the typical example, are effective against Gram-negative aerobes. Gentamicin is generally given in a dose of 4.5 mg/kg per day, after a loading dose of about 1.5 mg/kg - the precise quantity depending on serum creatinine, and lean body mass. The risks of otoxicity and nephrotoxicity must be minimized by measuring peak (20 minutes after intravenous administration) and trough (predose) serum levels. The cephalosporins also offer members that are bactericidal for beta-lactamase-producing cocci, and for Gram-negative rods. Metronidazole, in a dose of 400-600 mg 8 hourly remains the drug of choice for Gram-negative anaerobic organisms such as *Bacteroides fragilis*. This drug has been shown to penetrate well into the pus within brain abscesses (Ingham, Selkon and Roxby, 1977). At one time sulphadiazine, in combination with a penicillin, was favoured because of its ability to pass the blood-brain barrier. It is well recognized now that penicillin, and many other drugs enter the cerebrospinal fluid readily in high doses when the meninges are inflamed. Chloramphenicol, penicillin and metronidazole all penetrate abscess capsules in effective doses (Maurice-Williams, 1983). The numerous different combinations described in ’case report’ literature should be considered against this background of principles.

**Treatment of the ear**

Acute otitis media will usually be cured by the antibiotic selected for the treatment of its complications, but occasionally, a myringotomy will be needed. If cortical mastoidectomy becomes necessary, it is customary to advise removal of the bony covering of the sigmoid sinus, and also of the middle fossa dura, since extradural pus or granulation tissue can exist deep to intact bone.

Chronic middle ear diseases poses the eventual need for some form of radical or modified radical mastoidectomy. Timing is important. Generally, with exceptions that will be described, it is advisable to wait until the intracranial complications have been controlled before operating on the ear. Deterioration of the state of a complication, despite appropriate treatment could, however, impose the need for earlier intervention.
Investigations

The advent of computerized tomographic (CT) scanning and, in particular, the introduction of the latest generation of high resolution scanners with the ability to reconstruct images in different planes, has revolutionized the investigation of intracranial complications to the same dramatic extent that antibiotics have affected the incidence and prognosis. By the use of CT scanning, intracranial masses - extradural abscesses - can be identified, localized and monitored during treatment. Before the advent of these techniques, masses could be recognized by straight X-rays, which might show shift of a calcified pineal gland, by EEG, by arteriography, which offered the best way to demonstrate supratentorial masses, by distortion of the vascular pattern, or by air encephalography and ventriculography, with certain attendant risks. In the near future magnetic resonance (MR) imaging may prove to be better than CT scanning. Evaluations are at present in progress.

Lumbar puncture, to provide cerebrospinal fluid for examination, still has an essential role in diagnosing meningitis, but its risks in the presence of raised intracranial pressure must be recognized. Its contribution to the diagnosis of lateral sinus thrombosis is discussed under that heading. Specialized forms of angiography for example digital subtraction venography, are also mentioned below.

Extradural abscess

Involvement of the dura mater by spreading disease constitutes pachymeningitis. Most often such spread is preceded by bone loss, through demineralization in acute infection, or erosion by cholesteatoma in chronic disease. Non-infected cholesteatoma may expose and coat the dura with matrix, without inflammatory reaction, but more often an inflammatory response produces granulation tissue on the surface of the dura. Fortunately, the dura is tough and resistant to invasion and destruction. Commonly, the result of infection reaching its outer surface is the development of a collection of pus between it and the more superficial bone. This constitutes an extradural abscess, and this is the commonest of all intracranial complications arising from middle ear infections.

A middle fossa extradural abscess may strip dura from bone extensively on the inner surface of the squamous temporal bone, even to the extent of producing a sizeable intracranial mass, which, by raising intracranial pressure can, albeit rarely, cause focal neurological signs and papilloedema. Erosion through the skull to the exterior from there would produce a subperiosteal abscess, the classical but rare 'Pott's puffy tumour'. Most middle fossa extradural abscesses are confined to the upper surface of the tegmen tympani, with much less dramatic results, since firm attachment of the dura to the arcuate eminence prevents separation of a large area from the bone, and impedes the development of a large volume of pus. More rarely, an extradural abscess may develop medially to the arcuate eminence, over the petrous apex. Irritative involvement there of the Gasserian ganglion of the trigeminal nerve, and of the sixth cranial nerve, produces the characteristic features of Gradenigo's syndrome - facial pain, diplopia, and aural discharge. Posterior fossa extradural abscesses are limited anatomically by the attachments of the dura laterally to the groove for the sigmoid sinus, and medially to the region of the internal auditory meatus and the subarcuate fossa. Posterior extension around the sigmoid sinus produces a sigmoid sinus-perisinus abscess. This may contribute to the development of, and may be associated with, thrombophlebitis developing...
within the sigmoid and transverse sinuses. Very rarely such a perisinus abscess may extend through the jugular foramen into the neck.

**Clinical features**

The clinical pattern depends on the site of the abscess, its size, duration and the rate of its development. The discussion above touched on some of the features associated with the more unusual patterns of extradural pus but, in most instances, the features are vague and rather non-specific. Indeed, many times an extradural abscess is an incidental finding uncovered during mastoid surgery. With chronic ear disease, a complaint of headache, broadly spread on the side of the affected ear, especially when accompanied by malaise, is a suspicious symptom. If the abscess communicates freely with the middle ear, there is, characteristically, intermittent relief from pain during episodes of aural discharge.

**Diagnosis**

Ultimately, diagnosis depends on operative findings. Suspicion may be confirmed by the appearances of a CT scan, and this investigation is essential to exclude a possible brain abscess in those unusual patients presenting with raised intracranial pressure.

**Management**

Suspicion of dural inflammation or an extradural abscess is an indication for surgical exploration. Released pus is evacuated, and enough bone should be removed for an area of healthy dura to be exposed all the way round the diseased portion. Granulation tissue attached to the dura should not be disturbed, for fear of breaching the dura and infecting the subdural spaces. The possibility of other coexisting complications must be considered and excluded or treated. Appropriate antibiotic treatment will be needed, especially when the extradural abscess complicates acute otitis media. In the absence of other complications, recovery should be as rapid and as complete as after uncomplicated mastoid surgery.

**Subdural abscess (empyema)**

Spread of infection through the dura exposes the subdural space to the hazards of infection, which become manifest as widespread leptomenigitis or, if the accumulating fluid is contained, as subdural effusion or abscesses (subdural empyemas). The rate of spread probably determines the clinical and pathological pattern, and the type of organisms may also be important. Dawes (1979) described the predominance of non-haemolytic streptococci in subdural abscess. As is the case with other intracranial complications, the condition is frequently, if not usually, associated with other complications, and that should be expected from an understanding of the way in which it develops.

As has been noted, the dura is very resistant to destruction, and granulation tissue developing on its inner surface as an inflammatory reaction tends to obliterate the adjacent space. This granulation tissue may eventually be converted to fibrous tissue. Eventual necrosis of the dura may lead to infection of the subdural compartment. At first, a seropurulent effusion collects. Gower and McGuirt (1983) identified sterile effusions in the subdural space in a small proportion of patients with subdural fluid collections, and observed that none had
been recorded before the advent of CT scanning. Eventually, a seropurulent effusion becomes
frankly purulent, and extends over the surface of the cerebral hemisphere to an extent limited
by the granulation tissue obliteration of the space. Continuing granulation tissue invasion
loculates the developing abscess.

The abscess may remain small near the site of dural penetration, or it may extend
widely with the production of a volume of pus large enough to act as a space-occupying
lesion. Adjacent cortical veins may become involved with thrombophlebitis, which is
responsible for some of the clinical features. This process may produce multiple small
abscesses within the brain adjacent to the preceding subdural infection. The subdural pus
tends to accumulate near the falx cerebri, and particularly where that structure joins the
tentorium cerebelli. Healing may be associated with fibrosis in the limiting granulation tissue,
with obliteration of the subdural space. The established pathological pattern is commonly one
of numerous multiloculated abscesses over the convex surface of the cerebral hemisphere, and
between the hemispheres along the falx. Although non-haemolytic streptococci are often the
infecting organisms, Gower and McGuirt (1983) reported the finding of *Haemophilus
influenzae* in all of eight non-sterile effusions, although only one of these was of the sinister
type B.

**Clinical features**

The development of a subdural empyema is heralded by the development of severe
headache and drowsiness, which is followed by the onset of focal neurological symptoms,
both irritative as fits, and paralytic.

Drowsiness may develop over a few hours and proceed quickly to coma. Paralysis of
one upper or lower limb may rapidly extend to hemiplegia. Hemianopia and hemianaesthesia
occur, and if the lesion is on the dominant side, aphasia develops. Epileptic fits of Jacksonian
type, starting locally and spreading to affect one side of the body, may precede the weakness.
These fits sometimes become increasingly frequent, and are probably the result of the cortical
thrombophlebitis. Papilloedema is not common, nor are cranial nerve palsies, although they
have been described in the fully developed picture. The site of the fits, and the pattern of
weakness should suggest the position of the empyema.

**Diagnosis**

Meningism may accompany the headache. Despite meningism, the clinical picture can
be distinguished from that of meningitis by virtue of the characteristic neurological localizing
features. The rate of development, over hours rather than days, is much faster than would be
expected from a typical brain abscess. In children suspected of having meningitis, subdural
empyema should be seriously considered if there is no response to treatment, or if motor
seizures occur (Gower and McGuirt, 1983). Nowadays, a definitive diagnosis depends on CT
scanning. Lumbar puncture is helpful. The cerebrospinal fluid pressure is raised, but the sugar
content is normal, and cultures are sterile. The fluid may occasionally be turbid if there is
marked pleocytosis. If CT scanning is not available, angiography and exploratory burr holes
may be needed to clinch the diagnosis.
Management

This complication must be managed in close cooperation with a neurosurgeon. Treatment comprises the administration of massive doses of systemic antibiotics, drainage of the subdural fluid with irrigation of the subdural space if the collection is purulent, and treatment of the ear disease. The choice of antibiotic will probably now include intravenous penicillin and chloramphenicol, because of the increasing presence of *Haemophilus influenzae* in acute infections. The possibility of Gram-negative organisms from chronic ear disease may impose the need to use aminoglycosides. Acute ear infection will almost always require myringotomy and sometimes cortical mastoidectomy, while appropriate surgical treatment to the mastoid will be demanded by chronic infection, usually after the patient's general state has been stabilized by neurosurgical treatment. The neurosurgical management involves at least one burr hole to sample the fluid, and several may be made in order to establish an irrigation system. Previously, when disease was often more advanced before diagnosis, it was common practice to advise burr holes on both sides of the skull, since the abscess can track under the falx to the opposite hemisphere.

Antiepileptic medication must be prescribed to suppress fits, and may have to be continued for many months after recovery.

Lateral sinus thrombophlebitis

Thrombophlebitis may develop in any of the veins adjacent to the middle ear cleft. Of these, the lateral sinus, comprising the sigmoid and transverse sinuses, is the largest, threatening the greatest risks when it is filled with suppurating blood clot. The process is usually, but not invariably, preceded by the development of an extradural perisinus abscess. Mural thrombus then partly fills the sinus. Progressive expansion of this clot eventually occludes its lumen. The clot may become partly organized, and may be partly broken down and softened by suppuration. From this stage on, the release of infecting organisms and infected material into the systemic venous circulation causes bacteraemia, septicaemia, and septic embolization. Extension or propagation of the thrombus upwards may extend to the confluence of the sinuses - the torcular Herophili - and beyond there to the superior sagittal sinus. Invasion of the superior or inferior petrosal sinuses may extend the disease to the cavernous sinus. Venous thrombophlebitis extending into brain substance accounts for the very high association of this complication with brain abscesses. Downward propagation of thrombus into and through the internal jugular vein can reach the subclavian vein (Surkin et al, 1983; Albert and Williams, 1986).

The harmful effects then derive from the release of infective emboli into the circulation, and from the haemodynamic disturbances caused to venous drainage from inside the cranial cavity.

The use of antibiotics has greatly reduced the incidence of lateral sinus thrombosis. Formerly, most instances were associated with acute otitis media in childhood; now the incidence is much higher in chronic ear disease (Teichgraber, Per-Lee and Turner, 1982), although one series, reported by Gower and McGuirt (1983), was dominated by acute infections. The mortality from lateral sinus thrombosis before the days of operative treatment was 100%. This fell to 50% in the early 1900s (Gower and McGuirt, 1983), while reports
since the advent of antibiotic treatment still describe death rates over 20% (Seid and Sellars, 1973).

Before the use of antibiotics, the commonest infecting organism was the beta-haemolytic streptococcus, and this could reliably be cultured from the blood. Its propensity for red cell destruction caused progressive anaemia, which was a characteristic feature of the disease in the pre-antibiotic era. Nowadays, a large variety of mixed flora may be found. Aural cultures by Venezio, Naidich and Shulman (1982) grew *Proteus mirabilis*, *staphylococci*, *Streptococcus pneumoniae*, and *Bacteroides oralis*, and in only one of 14 cases were blood cultures positive. Similar floral diversity, with cultures producing *Bacteroides*, *streptococci*, *enterobacteriaceae* and other Gram-negative rods was reported by Teichgraeber, Per-Lee and Turner (1982). The latter account describes many negative cultures.

**Clinical features**

The classical pattern, before antibiotic modification, was of a severe pyrexial wasting illness in a patient with middle ear infection. Usually this would develop over several weeks, but occasionally a fulminating infection by virulent organisms would arise soon after the onset of an acute otitis media. Fever was high and swinging, following a so-called 'picket fence' pattern. Rigors, with profuse sweating, occurred as the temperature rose rapidly to 39-40°C and then fell. The shivering during these rigors has been described as so violent as to shake the bed, but few otologists practising today will have seen this phenomenon. Headache and neck pain were the rule. Emaciation was accompanied by progressive anaemia.

Many clinical features depended on the gradual extension of thrombus, effectively limiting the systemic dissemination of infection. As clot extended down the internal jugular vein, it would be accompanied by perivenous inflammation, with tenderness along its course. This tenderness descended the neck with the clot, and might be accompanied by perivenous oedema, or even suppuration in jugular lymph nodes. Perivenous inflammation around the jugular foramen occasionally caused paralysis of the lower three cranial nerves. Raised intracranial pressure produced papilloedema and visual loss. Hydrocephalus could develop if the larger or only lateral sinus was occluded, or if the clot reached the superior sagittal sinus. Extension to the cavernous sinus, along the superior petrosal sinus, presented with chemosis and proptosis of one eye. This could spread to the other eye if the circular sinus became involved.

Embolic propagation of infected clot and organisms produced infiltrates in the lung fields and septic spread to large joints and subcutaneous tissues. Other viscera and the pleuroperitoneal cavity were also targets for embolization. Although these distant effects usually developed late in the course of the disease, they could be presenting features if the insidious nature of the sinus disease had prevented its earlier recognition. Even today there are reports of chest disease caused by septic pulmonary emboli, from a completely inapparent lateral sinus thrombosis (Hawkins, 1985). This is even more likely to occur now, perhaps because of the 'masking' effects of antibiotics on the primary ear disease.

This masking by antibiotic treatment has muted the more dramatic and often diagnostic clinical character of the disease (Teichgraeber, Per-Lee and Turner, 1982). The clinical picture
has so far been described in the past tense, to indicate that the disease has changed, but it is important to remember these dramatic features as they may still be encountered occasionally. What follows is an attempt to describe the clinical pattern more likely to be met today, in those patients who have been treated with antibiotics before coming to the attention of the otologist.

Patients always feel ill and persisting fever is still usual, but often without the violent swings and rigors of earlier times. Earache and neck pain with mastoid tenderness and stiffness along the sternomastoid muscle are universal features. These, together with fever, should be recognized nowadays as the most consistent clinical features of lateral sinus thrombosis. Anaemia is now rare. Cases have even been described with no evidence of ear infection (Hawkins, 1985). Papilloedema is still a common finding - described in 50% of instances by Wolfowitz (1972). The state of mental awareness may be impaired, with drowsiness, lethargy and coma. Other intracranial complications should be expected in nearly 50% of patients with lateral sinus thrombosis. Of these, meningitis and brain abscess are the most frequent, and their symptoms can so dominate the illness that the lateral sinus thrombosis may be inadvertently overlooked.

Extension of infected clot down the internal jugular vein is always accompanied by tenderness extending along its course down the neck, and localized oedema over the thrombosing internal jugular vein may still be seen.

Very rarely, thrombosis may extend to the subclavian vein (Surkin et al, 1983; Albert and Williams, 1986). In the latter report, engorged collateral veins developed over the shoulder, and intravascular clotting was so extensive that it mopped up platelets and caused thrombocytopenia.

The clinical examination will usually, but not always, indicate middle ear infection. Tenderness over the mastoid process and along the sternomastoid muscle is almost always apparent, and must be regarded seriously as an important sign exciting suspicion of this complication. Examination of the fundi may show papilloedema. A rare finding is pitting oedema over the occipital region, well behind the mastoid process, caused by clotting within a large mastoid emissary vein; this constitutes Griesinger's sign. Physical signs of other associated complications are often present.

There is no single pathognomonic sign of lateral sinus thrombophlebitis. Vigilance, a high level of suspicion, and investigation along the lines suggested below should secure recognition of this dangerous complication.

**Investigation**

A full blood count may show anaemia with a raised white cell count and raised erythrocyte sedimentation rate, but none of these possible abnormalities is sufficiently specific to be helpful in making or excluding the diagnosis.

Blood cultures, with specimens taken as the temperature rose to its swinging peak, used to be considered a most important diagnostic step, but their value nowadays has become
greatly diminished, since bacteraemia, with rigors, is so much less common, and because of the development of more reliable diagnostic tests.

A lumbar puncture should be performed, if papilloedema does not suggest that raised intracranial pressure might precipitate coning. Examination of the cerebrospinal fluid is the most important way of identifying meningitis. In uncomplicated lateral sinus thrombosis, the white blood count in the cerebrospinal fluid will be low when the cause is chronic middle ear disease, and somewhat raised in acute otitis media (Gagnon, Sierra-Dupont and Huot, 1976). The cerebrospinal fluid pressure is usually normal. Variations in protein and sugar levels in the cerebrospinal fluid are not sufficiently consistent to be useful.

The Queckenstedt, or Tobey-Ayer test is traditionally recommended whenever a lumbar puncture for possible intracranial infection is indicated. Queckenstedt (1916) had described the manoeuvre as a means of recognizing spinal cerebrospinal fluid obstruction, but Tobey and Ayer (1925) declared the test diagnostic of lateral sinus thrombosis. The test involves measurement of the cerebrospinal fluid pressure and observing its changes on compression of one or both internal jugular veins by fingers on the neck. In the normal subject, compression of each internal jugular vein in turn is followed by a rapid rise of cerebrospinal fluid pressure of 50-100 mmHg, above the normal level. There is an equally rapid fall on release of pressure. It is normal for there to be a difference in rise on the two sides, but unusual for it to exceed 50 mmHg. In a typical case of lateral sinus thrombosis, pressure over the vein draining the occluded sinus causes either no rise, or a very slow one of 10-20 mmHg. Compression of the normal internal jugular vein, on the other hand, produces a rapid pressure rise to two or three times the normal level. Unfortunately, there are instances in which the Tobey-Ayer test may suggest lateral sinus thrombosis, when there is none and also false negative results, with a normal finding in the presence of lateral sinus thrombosis. As Albert and Williams (1986) have fully discussed, the false negative results stem from collateral channels draining the dural venous sinuses. False positive results appear if a normal lateral sinus is very small or absent, creating an erroneous impression of occlusion by disease.

Before the advent of CT scanning and angiography, the Tobey-Ayer test, combined with blood cultures was considered of high diagnostic importance. Now the emphasis has changed.

**CT scanning**

A CT scan is an essential investigation for any patient with suspected intracranial complications. It may show the increased density of fresh clot (Venezio, Naidich and Shulman, 1982). Filling defects within the sinus can often be shown with iothalamate (Conray) enhancement, and failure of opacification may be evident. Septic thrombosis shows as intense inflammatory enhancement of the sinus walls and of the adjacent dura. Other findings, which are non-specific, include cerebral oedema, reduced ventricular size because of oedema, parasagittal haemorrhages, and tentorial enhancement from collateral venous flow. Computerized tomographic scanning is essential also to identify or exclude accompanying complications, for example brain abscess and subdural empyema.
Angiography

Despite the help available from CT scanning, and its literally vital role in exposing other complications, the definitive investigations for lateral sinus thrombosis (before operative exposure) involve angiography, to demonstrate the obstruction and its site and extent, and the anatomical arrangement of the individual's venous drainage. There is a possible risk of displacing loose infected thrombus, but the consensus view is that vascular studies must be undertaken whenever a lateral sinus thrombophlebitis is suspected.

Arteriography, with radiopaque dye in the carotid artery can show the venous outflow during the venous phase. The demonstration is made clearer by subtraction angiography. This technique involves precisely registered superimposition of a negative arteriogram on a positive film of the bone structures. The effective cancellation of the skeletal image leaves the vascular pattern clearly exposed.

Digital subtraction venography is the preferred vascular imaging technique available at present. The contrast material is administered intravenously, and so without anaesthesia, and without any of the risks of arteriography. The imaging is produced by digital computer techniques. These allow the much diluted agent to be traced even after passing through the heart and onwards into the systemic circulation for a second systemic venous transit.

For completeness, radioisotope scanning with gallium should be mentioned. This is a technique that can show the 'hot spots' of sepsis.

Treatment

Treatment consists of the administration of antibiotics together with exposure of the lateral sinus and incision and removal of its contents.

The principles involved in the choice of an antibiotic for treating any intracranial infection have been discussed in the introductory comments to this chapter, and those guiding rules should govern the selection of the most appropriate agents for managing a patient with lateral sinus thrombophlebitis. Intravenous administration will generally be recommended. As Teichgraeber, Per-Lee and Turner (1982) advise, most patients should receive a combination of two or more of the following: ampicillin, chloramphenicol, a cephalosporin and an aminoglycoside.

In the past, anticoagulants were recommended. Most writers now agree that there is no regular place for their use except in those very rare instances where spreading thrombus has reached the cavernous sinus (Hawkins, 1985).

Surgical

Of all intracranial complications, lateral sinus thrombophlebitis is the most important for which operation should be undertaken early, in order to expose and treat the infected lesion. The same could be said for extradural abscess, but this is a much less serious condition, and often discovered incidentally at the time of operative exploration. This early intervention contrasts with the principles governing the otological surgical management of
other intracranial complications, where it is almost always advisable for the complication to be treated, medically or with neurosurgical attention, first and for the infecting ear to receive operative attention later, when the patient's condition has greatly improved. Exceptions to this principle, when treating the other complications, usually arise if the ear continues to infect the intracranial contents, preventing the expected improvement in the brain abscess or meningitis. Lateral sinus thrombophlebitis, however, like an extradural abscess, is a localized, often purulent lesion to which easy access is available only through the mastoid region. Drainage of the infected site then requires a mastoidectomy operation.

Before operation intensive medical treatment must be started, and the timing of mastoidectomy should depend to some extent on the response. During this early period, under otological care, the temperature chart should be watched every 4 hours, and the central nervous system should be examined once or preferably twice daily. Unless there is very rapid improvement, and certainly if these is deterioration, mastoid exploration should be carried out within the first 2 days.

If the lateral sinus thrombophlebitis follows acute otitis media and coalescent mastoiditis, cortical mastoidectomy is needed. In chronic otitis media, a radical mastoidectomy is undertaken through a postaural incision. With the temporal bone drill, the mastoid is opened and the region of the sinus plate approached. A perisinus abscess may declare itself with an outflow of pus through a tract in necrotic bone over the sinus. That necrotic plate can be separated from the underlying sinus with probes and curettes.

Often, there is no bone necrosis and the sinus plate is firm, healthy and intact. The sinus must then be deliberately uncovered, by drilling the plate, at first with a fast cutting burr, and later as the soft tissue becomes visible through the thinning bone with a diamond paste burr. When the bone is tissue paper thin, it can be lifted off the underlying sinus with flat blunt dissectors. At this stage, the sinus should be fairly widely exposed upwards towards the jugular bulb. Its appearance determines further action.

The normal healthy sinus is soft, bluish in colour and compressible with a blunt probe. If this is the case a small needle should be inserted through the wall to seek a free flow of venous blood. Such a flow would indicate that the diagnosis of lateral sinus thrombophlebitis was incorrect and, apart from stopping the bleeding by placing a small piece of free muscle tissue on the puncture, no further action is needed. The sinus might feel firm, and appear white and opaque. This would suggest that its lumen was occluded with fibrosing clot or fibrous tissue. In these circumstances it should be opened with a sharp instrument, and the absence of blood or necrotic debris confirmed by inspection. Lund (1978) pointed out that an obliterated cord of scar tissue is sometimes found as testimony to a 'silent' lateral sinus thrombophlebitis. If the sinus wall is covered with granulation tissue or if it is necrotic, the sinus must also be opened and the abscess and necrotic tissue within it removed.

This evacuation must extend in both directions - upwards towards the confluence of the sinuses, and downwards if necessary as far as the jugular bulb. Pus and any unorganized thrombus should be removed. In the past, it was advised that clot removal should be extended in each direction until blood flowed freely from either end of the opened sinus. It is now generally agreed (Teichgraeber, Per-Lee and Turner, 1982; Hawkins, 1985) that it is unnecessary to remove organized thrombus, and that it is no longer desirable to follow clot
centrally until free blood flow is established. If profuse venous bleeding is encountered, the lumen of the sinus should be obliterated with a ribbon gauze pack, impregnated with an antibacterial agent, inserted between the bone and sinus wall; bismuth iodoform paraffin paste (BIPP) should be avoided since it is radiopaque.

Whenever cortical mastoidectomy is performed for coalescent mastoiditis, even if intracranial complications are not suspected, the sigmoid sinus should be exposed and needled. This is a routine measure to avoid missing an unsuspected lateral sinus thrombophlebitis. The same investigation of the sinus is not recommended during radical mastoidectomy for chronic ear disease, unless the operation is being conducted during the management of an intracranial complication.

Internal jugular vein ligation used to be considered important to prevent dissemination of infected clot. The current consensus view, as summarized by Teichgraeber, Per-Lee and Turner (1982) is that ligation should be reserved for the very rare cases in which septicaemia does not respond to initial antibiotic treatment and surgery and that it should be considered for children showing signs of embolization.

**Meningitis (leptomeningitis)**

This is a major and serious complication of middle ear infection, and probably still the commonest intracranial complication (Gower and McGuirt, 1983). Before the days of antibiotics most sufferers died. Nowadays, recovery is usual provided that recognition is prompt and treatment expeditious. The patients at greatest risk are those with multiple complications, which may be overlooked because of the severe symptom of the meningitis. As with all other otogenic complications, the incidence, particularly that from acute otitis media, has fallen greatly with the use of antibiotics. Although most reports indicate that it is more frequently now a complication of chronic ear disease, childhood otogenic meningitis is seen most often as a complication of acute middle ear infection (Gower and McGuirt, 1983). It is probably fair to say that, in adults, it is now more commonly a complication of chronic disease.

Although spread may be through any of the channels previously described, such as preformed pathways, otogenic meningitis usually arises by direct spread through necrosing bone from the middle ear cleft. The rate of development depends on factors discussed in the introduction to this chapter, and particularly on the virulence of the organism, the resistance of the host, and the development of preformed access by bone erosion. Suppurative labyrinthitis, described later in this chapter, offers access to the cerebrospinal spaces through the internal auditory meatus and through the vestibular and cochlear aqueducts. Rarely, rupture of an established brain abscess into the subarachnoid space may lead to meningitis. Under the least favourable circumstances meningitis can develop within hours of onset of acute suppurative otitis media.

The organisms usually responsible for acute infection are *Haemophilus influenzae*, especially type B, and *Streptococcus pneumoniae*, of which type III has a sinister reputation for causing rapid complications. Infection from chronic ear disease may be caused by any of the organisms normally found in these conditions (Lampe and Edwards, 1984). Gram-negative
enteric organisms, *Proteus*, and *Pseudomonas*. Anaerobes such as *Bacteroides* species have also been reported (Siegler, Faiers and Willis, 1982).

The initial inflammatory response of the pia-arachnoid to infection is an outpouring of fluid into the subarachnoid space, with a rise in cerebrospinal fluid pressure. This fluid soon becomes permeated with white blood cells, and then with rapidly multiplying bacteria. The organisms feed on glucose, and thereby reduce its level in the cerebrospinal fluid, producing the characteristic biochemical feature of pyogenic meningitis. Once purulent, a sticky exudate is formed. This accumulates at first in the basal cisterns, and more rarely at the vertex. Free flow of cerebrospinal fluid is impeded by exudate obstructing the ventricular foramina to cause a non-communicating hydrocephalus. Obstruction to cerebrospinal fluid flow in the subarachnoid spaces may produce communicating hydrocephalus. Irritation of upper cervical nerve roots by inflammatory exudate is the basis for the classical features of this condition - neck pain and neck stiffness. Exudate collecting around exit foramina of cranial nerves can cause palsies in the late stages of the disease. Spread of infection along the Virchow-Robin spaces into the brain substance sometimes leads to brain abscess, while accumulations of the exudate in loculated masses on the cerebral surface are no different from those found in subdural empyema, which has been discussed under that heading.

**Clinical features**

The two most constant and reliable early clinical features are headache and neck stiffness. At first, the headache is often localized to the side of the head of the infected ear, but soon becomes generalized and 'bursting'. There is malaise and pyrexia, often to 39°C. Initial neck stiffness shows as resistance to flexion; later, rigidity or retraction develop. Mental hyperactivity usually colours this early stage, with restlessness and fretfulness in children. Anxiety, punctuated by periods of drowsiness is usual in adults. At this stage, the tendon reflexes may be exaggerated. Photophobia is a constant characteristic symptom and, before neck stiffness is marked, the patient may lie curled up away from the light. Vomiting, caused by raised intracranial pressure is also a feature.

As the condition progresses, all these symptoms become more severe. The headache may be excruciating, and neck rigidity is marked, with a positive Kernig's sign, retraction and later on opisthotonus. The temperature remains uniformly raised, with none of the swinging pattern, which used to characterize lateral sinus thrombosis. Gradually, the tendon reflexes become less marked, and the abdominal reflexes may be lost.

Deterioration is marked by alternating delirium and stupor, passing finally into coma. The tendon reflexes disappear, and cranial nerve palsies develop. Eventually Cheyne-Stokes respiration follows, with fixed dilated pupils, then coma and death.

Any focal neurological signs, especially in the early stages, should arouse suspicion of a subdural or cerebral abscess. Similarly epileptic fits do not occur with otherwise uncomplicated meningitis. The neck stiffness, which is so typical of the disease may be delayed for several days from the onset, especially if the first accumulation of exudate is vertical, rather than in the basal cisterns.
Diagnosis

The diagnosis is made by examination of cerebrospinal fluid. Any patient with middle ear infection, headache, and neck stiffness must undergo a lumbar puncture. At the same time, suspicion of other complications must always be entertained, and possible brain abscesses and subdural empyemas need to be excluded, preferably by CT scanning. In the earliest stages of otogenic meningitis the only abnormality on lumbar puncture is a rise in fluid pressure above the normal 100-150 mmHg. As the infection proceeds white cells accumulate in the cerebrospinal fluid, and the fluid becomes cloudy and then turbid in appearance. On histological inspection, most of these cells will be found to be polymorphonuclear leucocytes, which are not present in normal cerebrospinal fluid. They increase in number to reach the range of 0.1-10 x 10^9/L (100-1000.000/mm³), although with Staphylococcus epidermidis, counts below 0.1 x 10^9/L may be met. As the inflamed blood-brain barrier allows free passage into the cerebrospinal fluid, its constitution approximates more closely to that of serum, and this can be demonstrated by biochemical tests. Thus the protein content may rise from a normal 150-400 mg/L to a raised level of 2-3 g/L. The chloride content may fall from the normal 120 mmol/L to 80 mmol/L. The appearance of bacteria in the cerebrospinal fluid is accompanied by a fall of cerebrospinal fluid glucose levels from the normal value of 1.7-3.0 mmol/L to zero. Bacteriological examination of cerebrospinal fluid is first undertaken by direct examination after Gram staining, and then by culture of the fluid. Despite positive diagnostic findings on cellular and biochemical testing, positive bacteriological diagnosis is by no means the rule, and so treatment cannot wait for, nor depend upon, it. The lumbar puncture findings are decisive, when no mass shows on CT scanning, even without bacteriological recognition. There is no other complication in which the cerebrospinal fluid sugar level is lowered, and few in which the white cell count is so high. A brain abscess, if leaking into the subarachnoid space may cause a huge rise of cerebrospinal fluid white cell count even to more than 50 x 10^9/L (50.000/mm³), and a subdural abscess to counts over 0.1 x 10^9/L. In both of these the cerebrospinal fluid pressure may be raised, but in neither is the cerebrospinal fluid sugar level reduced. In the presence of cerebrospinal fluid pleocytosis, CT scanning should exclude either form of abscess, leaving a diagnosis of meningitis unchallenged.

Treatment

Surgical

As with most other complications, treatment of the intracranial sepsis should take precedence over management of the otitis media. Medical treatment of the meningitis is of paramount importance, and any operation for the ear condition should, if possible, be deferred for several days until the patient’s general condition has improved. Years ago, before antibiotics offered hope for cure, appropriate ear surgery was undertaken as soon as the diagnosis had been made. Nowadays, urgent surgical intervention should be advised only if the expected response to treatment does not appear. Certainly deterioration or failure of response over 48 hours implies loculated infection in the mastoid, needing surgical drainage. In acute otitis media, Gower and McGuirt (1983) would advise early middle ear drainage, with myringotomy, either repeated, or possibly assisted in drainage by insertion of a ventilation tube. Coalescent mastoiditis is an indication for cortical mastoidectomy but, in many, if not most instances, cure of the meningitis by antibiotics cures the preceding acute
infection. As with other complications, chronic middle ear disease needs eradication by some form of radical mastoidectomy, but again that should be deferred if possible until the dangerous meningitis is under control.

Medical

The lumbar puncture used for diagnosis may be repeated several times to reduce intracranial pressure, possibly a second time in the first 24 hours, and then daily until improvement is assured. Subsequent punctures are needed to check the state of the patient, and discharge from hospital must not be considered until the cerebrospinal fluid characteristics have returned to normal. Differential white cell counts are needed, since improvement may be indicated by a change from polymorphs to macrophages, even though the total count persists at, say, the $0.2 \times 10^9/L$ level. In earlier days, the initial and subsequent lumbar punctures were used to instil intrathecal antibiotics, and in particular pure crystalline penicillin in a dose not exceeding 5000-10,000 units in 5 mL of normal saline. Intrathecal antibiotics pose a risk of epilepsy, and their use now has largely been abandoned.

The mainstay of medical treatment rests with large doses of systemic antibiotics. A few years ago a standard choice was intramuscular penicillin, intrathecal penicillin, and sulphadiazine (which, of all sulphonamides, most readily crosses the blood-brain barrier). Streptomycin might have been recommended as an occasional adjunct because of its efficacy against *Haemophilus influenzae*. Today, as has been discussed in the introduction to this chapter, it is more difficult to be dogmatic. Because of its frequent role as a causative agent, *Haemophilus influenzae* must be a target of any regimen, and since more and more strains are becoming resistant to ampicillin, chloramphenicol is considered the first choice, combined with ampicillin or penicillin. The risk of toxic effects from chloramphenicol must be minimized by regular blood cell counts.

Rifampicin has recently been shown to be an effective agent against *Haemophilus influenzae* type B that has previously not responded to chloramphenicol (Lewis and Priestley, 1986). This drug has the unique ability to penetrate pus and kill phagocytosed organisms - even after oral administration.

Agents likely to be effective against Gram-negative organisms must also be considered when the infection is secondary to chronic middle ear disease. In these categories are azlocillin, ticarcillin, and some newer cephalosporins such as ceftazidime. All are less toxic than aminoglycosides like gentamicin. Whichever combination is selected, the preferred route is intravenous. Systemic therapy must be continued for at least 10 days after apparent clinical recovery. If *Bacteroides* are found on anaerobic culture, metronidazole should be administered in a dose of 400 mg 8-hourly (Siegler, Faiers and Willis, 1982).

Failure of an adequate response may be the result of:

1. organisms resistant to the chosen antibiotics: a change should be planned, guided as far as possible by bacteriological data

2. persisting leakage of infected material into the cerebrospinal fluid; urgent surgical treatment of the ear must then be considered
(3) presence of a previously unidentified other complication; CT scanning will be needed urgently for its recognition

(4) leakage into the cerebrospinal fluid from an unrecognized brain abscess.

**Brain abscess**

Otogenic brain abscesses almost always develop in the temporal lobe or the cerebellum of the same side as the infected ear from which they emanate. They are found in the temporal lobe approximately twice as frequently as in the cerebellum. In children, 25% of all brain abscesses are otogenic, while in the adult, with a greater predominance of chronic ear disease, the proportion of brain abscesses caused by ear infection is nearer 50%. Of the various routes of spread previously described, the commonest responsible for brain abscess is by direct extension of infection through an osteitic tegmen tympani, with formation of a middle fossa extradural abscess. Although the dura is very resistant to infective invasion, a local pachymeningitis may be followed by thrombophlebitis penetrating the cerebral cortex of the temporal lobe, or by extension of infection along periarteriolar Virchow-Robin spaces into the cerebral white matter. Cerebellar abscesses are frequently preceded by lateral sinus thrombophlebitis. They usually lie within the lateral lobe of the cerebellum, which may be adherent to the lateral sinus or to a patch of dura underneath Trautmann's triangle. The frequently repeated observation that intracranial complications are often multiple can be understood by this pattern of progressive involvement.

Formation of an abscess starts with an area of cerebral oedema and encephalitis. Rarely, this oedema is poorly contained and proceeds to massive cerebral oedema with spreading encephalitis. More often, the development and extension of the abscess is contained by the formation of a capsule. This fibrous tissue restriction depends on a microglial and blood vessel mesodermal response to the inflammatory process, and is variable in its rate of development. In general, capsular formation takes 2-3 weeks, and while it proceeds, the central part of the affected brain liquefies. After these stages of initial encephalitis and abscess localization, there may be a period of abscess enlargement, as renewed or continuing infection increases the volume of contained pus. Now, the features of a space-occupying lesion dominate, with rising intracranial pressure and focal neurological damage. Abscesses in the posterior fossa - in the cerebellum - cause raised intracranial pressure earlier than those above the tentorium, and rapidly rising intracranial pressure may cause 'coning' or impaction of the flocculus and brainstem into the foramen magnum, followed by fatal disruption of vital centres in the brainstem. If capsular development is slow, softening of brain around the developing abscess may allow further spread of infection into the relatively avascular white matter, with the formation of secondary abscesses, separate from the original or connected by a narrow stalk. In this way a multilocular abscess is formed. Eventually, an abscess may rupture into the ventricular system or subarachnoid space, with overwhelming meningitis and death.

Like other complications the incidence of otogenic brain abscess has fallen, but the mortality rate, even in the past decade was still 40% (Editorial, 1977). A report by Fischer, McLennan and Suzuki (1981) of their experiences during the 1970s described a mortality of 14%, so this is still a life-threatening complication, although there has been an improvement.
in outlook as a result of earlier recognition by CT scanning, better understanding of bacteriology, and the addition of steroids to the treatment regimen to control cerebral oedema.

**Bacteriology**

The bacterial flora is usually a complex mixture of aerobes and obligate anaerobes. Anaerobic streptococci are the commonest organisms (Maurice-Williams, 1983). Pyogenic staphylococci are also common, especially in children, and *Streptococcus pneumoniae* and *Strep haemolyticus* are often found. Gram-negative bacilli - *Proteus mirabilis*, *Escherichia coli*, and *Pseudomonas aeruginosa* - are cultured with increasing frequency. This may reflect the higher incidence of otogenic abscesses from chronic ear disease, or the fact that the Gram-positive organisms are so often sensitive to, and therefore eradicated by, the most commonly prescribed system antibiotics. The recognition of obligate anaerobes, first suggested as infecting agents by McFarlan (1943) has shown that many supposedly sterile abscesses are infected by organisms of the *Bacteroides* genus, especially *B. fragilis*, and organism that produces a highly active beta-lactamase (Editorial, 1977; Ingham, Selkon and Roxby, 1977).

**Clinical features**

The earliest stage of 'encephalitis', when brain tissue is invaded, causes headache, fever, malaise and vomiting, followed by drowsiness. The symptoms may be slight, and are easily masked by those of an acute otitis media, but drowsiness should always arouse suspicion. These early features may be hidden completely by a dramatic complication such as meningitis, or even by lateral sinus thrombophlebitis. The cerebral disturbance is sometimes so slight as to be ignored, and in chronic otitis media, headache must be considered the most important symptom. Persistent headache with chronic middle ear infection is always suggestive of intracranial spread and, although it may be caused by a much less sinister cause such as an extradural abscess, the possibility of local encephalitis cannot be excluded.

If this early phase of localized encephalitis progresses rapidly to a generalized form before containment by encapsulation, drowsiness may progress to stupor and then coma and death from tentorial herniation. More often, the period of local encephalitis is followed by a 'latent period' during which the pus becomes contained within the developing fibrous capsule. Throughout this stage, which may last from 10 days to several weeks, there are no symptoms, and the preceding encephalitis illness may be forgotten, if indeed it ever attracted the patient's attention.

The next stage of an enlarging abscess causes first some clinical features, as a result of the alteration in cerebrospinal fluid dynamics, which are common to abscesses in any part of the brain, and second site-specific features caused by focal neurological impairment. Naturally, the neurological effects of damage in the temporal lobe differ from those in the cerebellum.

Abscesses are surrounded by an area of cerebral oedema and low grade encephalitis, which fluctuates in size causing variation in the severity of the symptoms. There is malaise and anorexia, weakness and lethargy. With rising intracranial pressure the pulse rate slows, and the temperature may fall to subnormal levels. Constant headache is usual, and vomiting
of cerebral type occurs in many patients. The drowsiness varies and may alternate with irritability. Thought processes may become slow. Papilloedema is often found, but only if cerebrospinal fluid pressure has remained raised for 2 or 3 weeks. As explained before, papilloedema appears earlier with an abscess in the cerebellum than in the temporal lobe. A long-standing abscess may be associated with emaciation. If intracranial pressure continues to rise, the patient eventually lapses into coma, the ipsilateral pupil dilates and finally both become fixed and dilated. Death eventually supervenes, either from the effects of raised intracranial pressure, or from overwhelming meningitis following intraventricular rupture of the abscess contents.

These are features common to all abscesses, and during their development specific neurological signs must be sought to try to localize the site of the space-occupying lesion.

**Cerebral-temporosphenoidal abscesses**

A cerebral abscess in the dominant (usually left) hemisphere often causes so-called nominal aphasia. The patient cannot name a common everyday object such as a key, a pen or a screwdriver, but he or she is able to demonstrate its use correctly. Visual field defects arise from involvement of the optic radiations. Most commonly there is a quadrantic homonymous hemianopia, affecting the upper part of the temporal visual fields, or much more rarely the lower quadrants. The fields lost are on the side opposite to that of the lesion, because of damage to fibres arising in the two retinae of the same side. Although best examined by formal perimetry, the patient's state of consciousness may prevent adequate cooperation. Simple clinical testing by confrontation can then be useful. Motor paralysis develops as the abscess enlarges. Upward development affects facial movement on the opposite side, and then, progressively, paralysis of the upper and lower limb. Inward expansion affects first the leg, then the arm, and finally the face.

**Cerebellar abscesses**

The focal features of cerebellar involvement include weakness and muscle incoordination on the same side as the lesion. Ataxia causes a tendency to fall to the side of the lesion. Clinical tests for cerebellar faults, show that the ipsilateral side is ataxic on specific testing, with a tendency to past-pointing when attempting to touch a target with a finger. The finger-nose test exposes intention tremor and past pointing, and dysdiadochokinesis is demonstrated by attempts at rapid alternating supination and pronation of the forearm, and by difficulty in rapidly touching each finger to the thumb tip. Spontaneous nystagmus may be present; this is coarse and irregular, but very variable in its appearance. Generally, it beats to the side of the lesion, and this contrasts with the paralytic jerk nystagmus of suppurative labyrinthitis. As mentioned previously, intracranial pressure rises early and rapidly with a cerebellar abscess, and the effects of this rising pressure may dominate the clinical pattern before focal signs can be recognized clinically.

**Investigations**

The investigation and management of brain abscess require a team approach, and at the earliest stage of clinical suspicion, advice should be sought from neurosurgical colleagues.
in order to plan the most expedient way of investigating the possible complication, and treating it, and the underlying ear disease.

**Radiological**

Computerized tomographic scanning with and without intravenous iothalamate (Conray) enhancement is without question the most important investigation in the diagnosis of brain abscess. Not only can the position and size of the abscess be identified, but the appearance of localized encephalitis can be distinguished from those of an encapsulated abscess. The CT scan will also help to identify associated complications such as subdural abscesses, and lateral sinus thrombophlebitis. Scanning is also the most valuable method for observing the progress of an abscess during treatment. In the absence of CT scanning, and before this technique became available, supratentorial masses were best demonstrated by carotid arteriography. Upward and medial displacement of the middle cerebral artery would indicate a temporal lobe mass. Plain X-rays of the skull are of limited value, they may show displacement of a calcified pineal gland. Ventriculography used to have a role for demonstrating posterior fossa masses.

Nowadays, there is no useful place for electroencephalography. Before the availability of CT scanning, it was useful for showing abnormal delta-wave activity, which was said to allow accurate localization in about 50% of abscesses.

**Lumbar puncture**

Great care is needed when cerebrospinal fluid is removed in the presence of raised intracranial pressure, because of the risk of coning. If the patient is stuporose, has violent headache, or papilloedema, sampling should be performed only in a neurosurgical unit with immediate availability for intervention. Earlier in the development of brain abscess, lumbar puncture is particularly valuable, especially to exclude meningitis, for which it is the definitive investigation. Usually with brain abscess, a lumbar puncture will show some rise of cerebrospinal fluid pressure, with raised protein content. Any rise in white cell count is much less than that encountered in meningitis. If an abscess is leaking into the cerebrospinal fluid, very high cell counts may be found. The glucose content of the cerebrospinal fluid remains unaffected - at a normal level.

**Burr hole needling**

The definitive diagnosis was formerly established by needling the brain through a burr hole to seek pus. This is a neurosurgical manoeuvre, to be conducted by neurosurgical colleagues. With the advent of modern CT scanning, it should no longer be necessary.

**Differential diagnosis**

A brain abscess should be suspected during the course of any intracranial complication. The conditions to be differentiated include meningitis, subdural abscess, lateral sinus thrombophlebitis, otitic hydrocephalus, and brain tumour.
In meningitis, there is high sustained fever and neck stiffness, and the cerebrospinal fluid findings are abnormal, and diagnostically typical. A subdural abscess is suggested by much more rapid evolution of focal neurological signs. Lateral sinus thrombophlebitis is often a precursor of cerebellar abscess, and an abscess should be suspected if any features not typical of a thrombosed sinus develop. Otitis hydrocephalus should easily be distinguished by the absence of focal neurological signs, the CT scan findings, and the cerebrospinal fluid findings on lumbar puncture. Finally, if evidence of a space-occupying lesion is found in a patient with middle ear disease, even though a brain abscess must be presumed, a brain tumour, of coincidental origin, requires exclusion. The CT scan appearance, especially with reconstruction in different planes, which is available on the most advanced scanners, usually makes the distinction. If not, neurosurgical exploration could be necessary.

**Treatment**

Historically several phases have been recognized in the management of otogenic brain abscesses (Brand, Caparosa and Lubic, 1984). Until this century, most patients died when all that was available was craniotomy. During the next phase, in the early part of the century, intracranial pus was evacuated at the time of mastoidectomy, by opening the dura and needling the brain along the tract established by the inward extension of the infection. There must now rarely, if ever, be a place for that form of management. Today, the treatment of the abscess involves the use of large doses of systemic antibiotics, combined with a surgical approach through a clean field. Treatment of the ear disease must take second place, in accordance with the principles discussed previously. Ideally the abscess should be completely controlled neurosurgically and with antibiotics, and predisposing chronic ear disease dealt with by radical mastoidectomy 10-14 days later. As is the case with most of the other intracranial complications discussed, acute ear infections may well resolve with the antibiotics used for the abscess treatment, and only rarely will myringotomy or cortical mastoidectomy be needed.

The first step must be urgent consultation with neurosurgical colleagues. If raised intracranial pressure has caused coma or rapid deterioration, it may be lowered temporarily by the administration of dexamethasone, 4 mg intravenously every 6 hours, or intravenous 20% mannitol, in a dose of 0.5 g/kg. This may be a life-saving measure until neurosurgical help can be obtained. Corticosteroids may also be needed after surgical treatment of an abscess if cerebral oedema persists.

Antibiotics must be started in large doses and administered intravenously. For reasons already discussed, the initial choice should include chloramphenicol, which is effective against *Haemophilus* and many enterococci, and which passes readily into the cerebrospinal fluid in high doses (Brand, Caparosa and Lubic, 1984). This should be combined with a penicillin, often chosen from those active against beta-lactamase-producing organisms. Both chloramphenicol and penicillin penetrate the capsule in effective concentrations. If *Pseudomonas* or *Proteus* species are suspected, because of the primary source in a chronically infected mastoid, an aminoglycoside may also be added. Metronidazole should also be given from the start, in view of the strong likelihood of *Bacteroides* infections (Editorial, 1977). This drug also penetrates the capsule and high concentrations have been found in the pus within abscesses after administration in doses of 400-600 mg 8 hourly (Ingham, Selkon and Roxby, 1977). Antibiotics should be administered for at least 3 or 4 weeks, with careful regard to their potential toxic effects.
Surgical

The commonest current neurosurgical options are to drain the abscess repeatedly through burr holes, or to excise it completely with its capsule. Opinion is divided on the choice of technique (Maurice-Williams, 1983). Repeated needle aspiration involves a smaller operation than excision and, since it can be performed under local anaesthetic, it is safer for very ill patients. There are, however, several disadvantages. It may do little to reduce the mass effects of the abscess, especially if the pus is thick. Forty per cent of abscesses are multilocular (Stephanor, 1978), and total removal of pus is sometimes impossible by aspiration. At best, aspiration involves repeated procedures, and as the capsule collapses, it thickens so that there is a risk of the cannula glancing off and damaging adjacent white matter. If the abscess does not collapse, excision may eventually be necessary after all. Furthermore, there is a risk of late recurrence, which may be as high as 8%.

Aspiration offers access to the pus for bacteriological examination. In order to identify obligatory anaerobes, such as *Bacteroides fragilis*, which has increasingly been shown to cause apparently 'sterile' abscesses, cultures must be set up rapidly (within an hour) in a low oxygen tension medium, and preferably one containing nalidixic acid to inhibit the growth of Gram-negative organisms. With each aspiration antibiotics can be instilled into the cavity of the abscess. Before the advent of CT scanning it was also usual to put 2 mL of thorotrast into the abscess on the first aspiration. This radiopaque agent is taken up by the fibrous wall of the abscess capsule, and allows subsequent changes in the lesion to be watched by straight X-ray examinations.

Primary excision is favoured by some neurosurgeons as the treatment of choice. It offers a means to decompress the brain immediately. Its main disadvantages is that the operation can cause extensive damage to cerebral tissue, especially if the abscess is multiloculated with tentacular extensions. Excision is then possibly associated with a higher incidence of residual neurological deficit. It is a more major operation than repeated aspiration, and one demanding a higher level of neurosurgical skill to minimize brain damage, and to avoid rupture into the ventricle.

Recently, open operation to remove pus from the abscess cavity under direct inspection has been advocated (Maurice-Williams, 1983). The abscess is incised widely, and all the pus removed from it and its daughter loculi. This removes the mass effect and the sepsis at one operation, as does excision, but with much less risk of further neurological damage.

Although the otologist will be interested in the possible techniques available, the choice of the procedure is a neurosurgical decision, which will be determined by the facilities and preferences of the neurosurgical colleague cooperating in the patient's care.

After successful treatment of a temporal lobe abscess, there is a high risk of epileptic seizures. If followed-up for long enough, 70% of patients will have a fit, so anticonvulsant medication is needed, and should be continued indefinitely.
Otitic hydrocephalus (benign intracranial hypertension)

This is one of the least common complications of middle ear infection. First described by Symonds (1931), this is a misnomer; it is a syndrome of raised intracranial pressure during or following middle ear infection. The most frequent victims are children and adolescents. In a review of 60 patients with benign intracranial hypertension, Foley (1955) uncovered a history or preceding acute otitis media in 13. 'Pseudotumor cerebri' occasionally appears in the literature as an unhelpful synonym for the condition.

Pathogenesis

The aetiology is unknown, but most accounts recognize a relationship with lateral sinus venous outflow. The inference is either that obstruction of the lateral sinus affects cerebral venous outflow, or that extension of thrombus to the superior sagittal sinus, impedes cerebrospinal fluid resorption by Pacchionian bodies (Pfaltz and Griesemer, 1984). However, it has been argued that superior sagittal sinus thrombosis should be associated with more neurological deficits than are found in otitic hydrocephalus, and with ventricular dilatation, which is lacking in this syndrome. Lateral sinus thrombosis usually occurs without subsequent hydrocephalus. Seid and Sellars (1973) found only one case among 13 with sinus thrombosis and, indeed, ligation of the internal jugular vein in the neck does not cause hydrocephalus; so that mechanism must also be suspect. Gower and McGuirt (1983) considered that otitic hydrocephalus should be accepted as an idiopathic benign intracranial hypertension associated with ear disease, and argued that raised intracranial pressure following lateral sinus thrombosis is a different entity. Any attempt to make this distinction is probably not helpful since most writers accept that the syndrome to which the name of otitic hydrocephalus is properly attached most often follows lateral sinus thrombosis. Thus, Foley (1955), with a large series of 44 cases, described lateral sinus disease in 27 out of 34 cases surgically explored, and Wright and Grimaldi (1973) described three cases all with lateral sinus thrombosis. Lenz and McDonald (1984) reviewed the literature to disclose 10 patients of whom only one, with bilateral ear disease, had normal sinuses. Some of the problems in explaining pathophysiology may depend on variations in venous arrangement in the skull. Clemis and Jerva (1976) described the venous patterns, showing that there is a right predominance in 35% of subjects and a left predominance in 13%; 24% showed disproportion, while there is poor cross circulation at the confluence of the sinuses in just over 10%, and an absent sinus in 4%. Foley’s (1955) series indicated more cases with right-sides ear disease, and a higher incidence of sinus thrombosis in the right-sided than in the left-sided cases. These lateralizing relationships were also evident in Lenz and McDonald's (1984) rather smaller review.

Clinical features

The leading symptoms are headache, drowsiness, blurred vision, nausea and vomiting, and sometimes diplopia. The onset may be many weeks after an acute otitis media, or many years after the start of chronic middle ear disease. Clinical examination reveals papilloedema and drowsiness. Lateral rectus palsy due to sixth nerve stretching (a false localizing sign in raised intracranial pressure) may be found on one or both sides. These signs are associated with evidence of acute or chronic middle ear infection, or with a history of a recent acute middle ear infection since recovered.
The differential diagnosis includes any other cause for raised intracranial pressure, and in particular a brain abscess. Investigations to exclude that possibility should include CT scanning. The scan will show normal ventricles.

**Treatment**

The ear disease, if acute, may have recovered. Any persisting middle ear infection has to be treated on its own merits. Management of the complication requires measures to reduce the raised intracranial pressure, in order to prevent visual impairment by papilloedema. Treatment includes the use of steroids, diuretics, and hyperosmolar dehydrating agents. Repeated lumbar puncture has been advocated, but this is not free from risk in the presence of raised intracranial pressure. Long-term thecoperitoneal shunting may occasionally be needed.

**Prognosis**

The outlook for survival is good, but treatment may be needed over many weeks or even months. Permanent deficits such as visual impairment are not common (Pennybacker, 1961), but recurrences have been reported, albeit rarely (Johnston and Paterson, 1974).

**Facial paralysis**

The management of the paralysed facial nerve is discussed fully in Chapter 24. Here, mention will be made of aspects of facial palsy as a complication of middle ear infection.

**Acute otitis media**

Facial palsy occurs in acute otitis media only in that small proportion of patients (less than 10%) with a congenital dehiscence of the thin bony wall normally separating the horizontal part of the facial nerve canal from the middle ear mucosa. Infection of the mucosa may cause an inflammatory reaction in the subjacent epineurium and perineural spaces. The diagnosis is usually straightforward, but the Ramsey Hunt syndrome (see Chapter 24) can cause confusion, since the pain and facial palsy of that condition is associated with blistering of the surface of the tympanic membrane, which may be mistaken for evidence of acute otitis media.

**Treatment**

The affection of the nerve is invariably a neuropraxia, and full recovery of facial muscle function is to be expected after cure of the preceding infection. Although this can usually be achieved by appropriate systemic antibiotic treatment, occasionally myringotomy or, more rarely, cortical mastoidectomy may be needed. Operative decompression of the facial nerve is unnecessary (Alford and Cohn, 1980).

**Chronic otitis media**

In chronic destructive middle ear disease, the facial nerve trunk may be exposed if its bony covering is eroded by cholesteatoma, with a subsequent inflammatory reaction to the
expanding surface of the cholesteatoma sac. Pressure of that sac may also be a factor since uninfection congenital cholesteatoma of the petrous apex invariably present with a slowly progressive facial paralysis.

Diagnosis

Facial paralysis of slow onset, which is insidiously progressive, should arouse suspicion of erosive disease in the temporal bone. The association with aural discharge will point attention to chronic middle ear infection, although a similar clinical pattern may be caused by neoplasms, such as carcinoma of the middle ear. In that dread disease, pain is usually a feature, and this is not a symptom of otherwise uncomplicated cholesteatoma. The absence of discharge does not exclude the possibility of cholesteatoma; meticulous examination of the tympanic membrane, preferably under the binocular operating microscope, is essential in all patients with a lower motor neuron facial palsy. If there is no suspicion of attic or posterior marginal disease, radiological examination with high resolution CT scanning may provide an explanation for the progressive facial nerve lesion. On occasion it may not be possible to examine the tympanic membrane fully without general anaesthesia. If any doubt about the state of the middle ear remains, surgical exposure of the nerve in the middle ear and mastoid region must be advised.

Treatment

Urgent operative exploration of the middle ear, to treat the chronic middle ear disease is needed, proceeding if necessary to a radical mastoidectomy. The facial nerve should be exposed carefully throughout its horizontal course in the middle ear and in its vertical mastoid segment, by following cholesteatoma, granulation tissue and osteitic bone. Cholesteatoma matrix may be gently removed from the surface of the 'soft' nerve, but any attached granulation tissue should be left untouched to avoid further neural injury. Healthy bony should be removed from the nerve on either side of the diseased segment, to allow space for oedema of the nerve without further compression. Naturally any packing in the cavity at the end of the operation must be inserted gently and carefully to avoid pressure on the nerve. The management of the problems caused by the facial paralysis are discussed in Chapter 24. Good recovery can be expected if no axonal degeneration had occurred before treatment.

Labyrinthine complications

Pathogenesis

Acute middle ear suppuration

Acute middle ear suppuration may extend to the labyrinth through the round window. The round window membrane is thinner in acute than in chronic otitis media, and its permeability may be increased. Pus cells may pass into the scala tympani perilymph by diapedesis from adjacent inflamed labyrinthine blood vessels. A fibrillary precipitate then accumulates in both perilymphatic and endolymphatic spaces, and developing endolymphatic hydrops is followed by destruction of the membranous labyrinth. Preformed fistulae into the labyrinth from the middle ear, as for example, after a stapedectomy operation offer another route for infective spread. The process may stop at any stage and, if the inflammatory changes
induced in the labyrinth by the transgression are reversible, the clinical condition is called serous labyrinthitis. Should the intralabyrinthine suppuration destroy cochlear and vestibular function in the affected ear, the complication is labelled suppurative labyrinthitis.

**Chronic destructive ear disease**

Chronic destructive ear disease can erode the bony labyrinth by cholesteatoma or osteitis, leading to similar inner ear destruction, but fully developed intralabyrinthine inflammation is preceded by thinning of the bony labyrinthine wall to produce a fistula of the labyrinth. Labyrinthine damage from slowly eroding cholesteatoma may be followed by new bone deposition. This allows destruction of one part of the labyrinth with preservation of the rest. Furthermore, bony fistulae are often closed by new bone deposition after the eroding disease has been eliminated.

Vestibular irritation caused by inflammatory disease very near to the endosteum of the bony labyrinthine lumen is sometimes termed ‘paralabyrinthitis’. Very rarely, chronic osteitis around the bony labyrinth may cause necrosis of the whole otic capsule, a condition described as sequestration of the labyrinth. The term perilabyrinthitis is also encountered in writings on this topic, and its correct usage will be discussed later.

Suppurative labyrinthitis is now a rare complication of acute otitis media, because of the use of antibiotics, but the development of labyrinthine fistula remains as common, at 10% of all cases of chronic otitis media, as it was in the pre-antibiotic days (McCabe, 1984). Because of this high incidence, labyrinthine fistula should perhaps be considered the most important of the labyrinthine complications.

**Suppurative labyrinthitis and serous labyrinthitis**

As has been indicated, the distinction between the two depends on the retrospective recognition of recovery of cochlear and vestibular function; so the term serous labyrinthitis has little clinical value. The method of spread of infection has been described, but should be amplified by the observation that, on rare occasions, infection can extend from meningitis to the labyrinth through the internal auditory meatus, or through the cochlear or vestibular aqueducts. Even more rarely, the infection may be blood borne.

**Clinical features**

The patient suffering from acute or chronic middle ear infection presents with violent prostrating vertigo and vomiting. Severe hearing loss of a sensorineural type is to be expected, but will be adumbrated as a complaint by the severe disabling vertigo, especially if there has been a preceding conductive impairment from the acute or chronic middle ear disease. The patient lies still, avoiding any head movement, on the side with the infected labyrinth upwards. Examination demonstrates evidence of the preceding ear disease. The complication itself causes little systemic infective disturbance. Pyrexia or leucocytosis appear only as features of accompanying acute suppurative otitis media. At first there may be a spontaneous 'irritative' jerk nystagmus beating towards the infected ear; but this is soon replaced by a 'paralytic' jerk nystagmus, beating towards the healthy side. The direction of this nystagmus probably dictates the preference for lying on the unaffected ear; in that position, the patient's
efforts to look at a bedside visitor involve turning the eyes towards the damaged labyrinth, and in this direction gaze, the violence of the nystagmus is least. In the earliest, irritative, phase, when subsequent progress may happily confirm that serous labyrinthitis was the appropriate label, tests of cochlear function by masked bone conduction should indicate retained hearing. Loss of cochlear function as the condition is watched indicates transition to the irreversible suppurative state. The paralytic jerk nystagmus is initially third degree in its severity. Provided no additional problems develop, recovery takes place by the mechanisms common to recovery from any cause of vestibular failure, with gradual subsidence of the nystagmus through a second to a first degree state, and then to absence of spontaneous nystagmus with fixation. At this stage, after perhaps 2-3 weeks, the recovering patient will have gained fairly good balance, but will still be unsteady when trying to walk in the dark, or with the eyes closed, and will still be unhappy to make sudden head movements. Since this improvement in equilibrium depends on central compensatory changes, it may be upset later in life, long after the original infection, by other general illnesses, impaired central nervous system function, drugs or psychiatric illness. The hearing loss in the damaged ear will be total and permanent.

**Diagnosis**

The clinical pattern described above is that of sudden vestibular failure from any cause, and suspicion of suppurative labyrinthitis primarily rests with precise recognition of the underlying middle ear infection. Examination of the ears with the binocular microscope is necessary, and occasionally examination under general anaesthesia will be needed to inspect the attic fully, and to remove obscuring crusts, secretions or debris. Haemorrhagic, or bullous, myringitis can produce sudden vestibular failure with acute pain and inflammatory changes on otoscopic examination. Mastoid X-rays confirming a clear air cell system would help to support that diagnosis, but if in doubt the safest course must be to treat the illness as suppurative labyrinthitis. Once a middle ear infection has been recognized the diagnosis poses little difficulty, although traditionally a cerebellar abscess has always been considered to offer a source of confusion. In the latter complication, the patient may appear far more ill, show cerebellar signs on neurological examination, and demonstrate nystagmus persisting longer after the time of the severest vertigo. Nowadays, a CT scan should provide a definitive distinction.

**Sequelae**

During the course of the acute illness there is a continuing danger of intracranial spread of infection with the development of meningitis. In the long term, the labyrinth may remain filled with sequestered pus, and traditional teaching suggested the occasional need to drain such a labyrinth surgically. The long-term effects on balance and hearing have been mentioned above.

**Management**

As with all complications, separate attention must be given to the management of the complication itself, and to the antecedent ear disease.
Treatment of suppurative labyrinthitis requires complete bed-rest. Head movements should be avoided as much as possible. Any hearing tests must be carried out at the bedside, and not in a chair in the audiometric department. Tests of vestibular function, which inevitably excite endolymphatic movement must be eschewed. (In any case they add nothing useful to the clinical examination.) Vertigo and vomiting may be controlled by parenteral prochlorperazine or cinnarizine. If vomiting prevents hydration, intravenous fluids must be infused. It is usual to advise the administration of parenteral antibiotics, and certainly these will be needed to treat acute otitis media as the cause, but it is doubtful whether penetration into the labyrinth itself can affect the course of the labyrinthitis. The development of meningitis, however, may possibly be prevented by antibiotics. The choice of antibiotic may be decided by bacteriological examination of any available secretions. Broad-spectrum drugs such as ampicillin should be used, and if there is any anxiety about infection with *Haemophilus influenzae* type B, then intravenous chloramphenicol should be chosen. Immobility must be secured throughout treatment, and observations are planned to recognize the earliest signs of meningitis.

Treatment of an acute ear infection may demand myringotomy, and more rarely cortical mastoidectomy but, in most instances, the otitis media will recover with antibiotic therapy alone. In chronic middle ear infections, formal exploration of the mastoid will be needed to make the ear safe. Premature surgical trauma to temporal bone can promote dissemination of infection, and so mastoid exploration should be deferred until the acute symptoms of the suppurative labyrinthitis have subsided. This policy involves conservative medical treatment with continuing observation for 7-10 days before mastoid exploration is performed. Nowadays, it is not considered necessary, or indeed advisable, to drain a 'dead' labyrinth during that mastoidectomy operation.

After full recovery from the acute infective illness, vestibular head exercises (Cawthorne-Cooksey, see Appendix) may accelerate central compensation for the vestibular deficit.

**Labyrinthine fistula**

As has been explained, this is a complication of chronic otitis media. An ear, in which the endosteum of the labyrinth has been exposed by bony erosion, continuously threatens the development of suppurative labyrinthitis, and so urgent treatment is essential. The incidence of 10% of all cases of chronic mastoid disease with mastoidectomy has remained unchanged over 20 years (Sheehy, Brackmann and Graham, 1977). Fistulae occur most commonly in the dome of the lateral semicircular canal, but other parts of the bony labyrinth may be eroded, including the promontory.

A labyrinthine fistula may be silent, with no symptoms, and with its discovery at operation unexpected. Suspicion should be attached to any patient with chronic middle ear disease complaining of brief episodes of vertigo or unsteadiness. Even if longer attacks of vertigo are a complaint, and if they seem to fit the pattern of another disorder (such as Ménière's disease), an infected middle ear and possible labyrinthine fistula should remain under suspicion until operative exploration proves otherwise. It is safer to explore an ear with an intact otic capsule than to miss exploration of one with a fistula.
Assessment of the dizzy patient with chronic middle ear disease must include a careful examination of auditory function. The state of hearing in the apparently healthy ear bears heavily on treatment decisions. Although cold air caloric stimulation may be used as an indication of vestibular function, water must never be used for caloric testing in the presence of chronic ear disease and a suspected fistula.

The fistula sign

This is an important physical sign, which depends on transmission of air pressure changes from the external ear canal to a fistula in the labyrinth, causing endolymph movement. Raised air pressure may be produced by pressure with a finger on the tragus, but more reliably by the use of a pneumatic otoscope fitted with a speculum large enough to fit securely into the meatus, and produce an air-tight seal. Recognizable and precise effects of pressure changes arise when the fistula test is positive. The nature of these positive findings has often been incorrectly described in textbooks. The sign is not simply one of nystagmus induced by the increased pressure. As McCabe (1984) has fully explained, increased pressure causes conjugate deviation of the eyes away from the examined side. If the pressure is maintained, a jerk nystagmus develops beating towards the examined, and affected ear. As the pressure is released, the eyes return to the midline. Pulsation of pressure in the meatus causes repeated deviation of the eyes to the unaffected side with each pressure rise, and return to the primary position of gaze when the pressure falls. The patient feels dizzy during these events, and accompanying head movements away from the examiner may make continuous inspection of the eyes difficult. McCabe (1984) has also shown that the direction of deviation of the eyes on raised pressure depends on the site of the fistula. The above description of deviation towards the normal ear is the commonest finding, associated with a fistula in the most usual site in the dome of the lateral semicircular canal. A lateral canal fistula anterior to the ampulla causes deviation towards the side of the fistula. An erosion into the vestibule is indicated by rotatory horizontal deviation towards the diseased ear. Raised pressure on a fistula in the superior canal causes rotatory movement towards the normal ear. Finally, vertical deviation of the eyes suggests a fistula into the posterior canal.

It is always important to seek a positive fistula sign in any vertiginous patient, and in any patient with chronic middle ear disease. There are however both false positive and false negative results. The fistula sign may sometimes be positive after a labyrinthine membrane rupture, when there is a perilymph leak into the middle ear. In the presence of an intact tympanic membrane, a positive fistula sign has traditionally been considered to indicate syphilitic otic capsule disease (Hennebert's sign) but this has also been demonstrated in Ménière's disease. A false negative fistula sign may come about from inadequate sealing of the speculum in the meatus, or because a mass of cholesteatomatous debris protects the inner ear from the transmission of the raised pressure, or yet again if the vestibular labyrinth has previously succumbed to the disease and is unresponsive.

Treatment of labyrinthine fistula

Whenever chronic middle ear disease is recognized in a vertiginous patient, labyrinthine erosion must be presumed. This is so, no matter how characteristic of another disorder the pattern of vertigo may seem to be, and no matter how slender the evidence for middle ear disease available. The patient's safety demands surgical exploration of the middle
ear. Only if inspection during operation fails to reveal erosion of the labyrinth, should other possible explanations be followed.

During surgical exploration of the middle ear cleft, a labyrinthine fistula should be suspected whenever cholesteatoma is encountered, since asymptomatic fistulæ are not rare. Preoperative demonstration of a positive fistula sign will alert the surgeon to the risk, and its characteristics will indicate where the fistula may be found. Great care is needed while peeling cholesteatoma matrix off the dome of the lateral semicircular canal, and away from areas where fistula is suspected. Matrix should be removed from other sites first, and then dissection carried out slowly under high power magnification. A slight change in colour at the junction of the matrix and subjacent bone suggests a possible fistula. Eventually a small sheet of cholesteatoma matrix over the possible fistula will have been isolated. Its management requires careful consideration, for if the endosteum of the bony labyrinth is breached, a 'dead ear' with total deafness can be expected. Clearly then the state of hearing in the other ear is a factor of great importance. The options are to remove the matrix, or to leave it in place.

If an open cavity operation, such as a radical mastoidectomy, is in hand the matrix can safely be left undisturbed unless there is any suspicion of vascular infected granulation tissue deep to it. That dangerous state is unlikely if the fistula is clearly demarcated as a blush area through the matrix, but McCabe (1984) recommended biopsy and frozen section examination in all instances of doubt. If cholesteatoma and granulation tissue do extend beyond the fistulous opening, then the labyrinth must be explored as far as the limits of invasive disease. A bony fistula left under cholesteatoma matrix will close by new bone growth if the surface inflammatory condition is controlled. Whenever matrix is completely removed from a fistula, closure of the defect with connective tissue material such as temporalis fascia or perichondrium may avert the problems of perilabrynthitis discussed later. During intact canal wall tympanoplasty, as opposed to open cavity operation, any fistula revealed will remain protected from the exterior, so vertigo caused by perilabrynthitis will not become a problem. However, any remaining cholesteatoma matrix over a fistula, whether left deliberately or accidentally, presses the need for a second exploration after an interval of 6-12 months. By that time, the abandoned matrix will have formed a small epithelial pearl, which can easily be removed. Many surgeons would contemplate intact canal wall procedures only when the other ear has good hearing and is free from disease, and only when the patient will accept a second operation, and may be relied upon to honour that obligation.

Whatever procedure is undertaken, accurate documentation about the state of hearing and vestibular function before operation, about the findings and events during the procedure, and about any postoperative vertigo that may have been caused by vestibular damage during operation, is of paramount importance. Investigation of subsequent vestibular symptoms after mastoid surgery is very difficult when such records are not available.

Perilabrynthitis

This term should be reserved for the particular condition for which it was appropriated by Cawthorne (1957). It denotes the problems caused by a fistula into the labyrinth after mastoid surgery, in the presence of retained vestibular function. The fistula may have preceded the mastoidectomy, or have been caused by it. The vertigo arises through the Tullio
phenomenon, since the stapes footplate in the affected ear is mobile. Giddiness may be provoked by pressure changes near the fistula, and cold air blown into the ear at windy street corners may cause imbalance. Sometimes the symptoms can be prevented by occluding the external meatus. Operative help consists of exploration, removal of skin from the fistula and protection by a connective tissue graft. Occasionally, deliberate labyrinthine destruction, or vestibular nerve section may be needed to procure relief.

**Vertigo after mastoid surgery**

Vertigo and imbalance may develop for many reasons after mastoid surgery (Ludman, 1984, 1986). Analysis of an individual problem is greatly helped by access to reliable information about the state of the ear before operation, the findings at operation, and subsequent progress. The causes include:

1. unrelated vestibular disease
2. persisting middle ear disease with further bone erosion
3. perilabyrinthitis (Cawthorne, 1957)
4. delayed endolymphatic hydrops (Nadol, Weiss and Parker, 1975; Schuknecht, 1978; Ludman, 1986)
5. breakdown of central compensation, after loss of labyrinthine function (Ludman, 1984)
6. cerebellar abscess

**Cochlear complications**

When discussing labyrinthine complications of middle ear infections emphasis has usually been placed on vestibular symptoms. It is probable, however, as Paparella et al (1973) have explained, that sensorineural hearing loss can follow middle ear infection, without overt balance disturbance. The transmission of toxic substances through the dependent round window membrane, into the basal turn of the cochlea has been well documented. Serous labyrinthitis induced in this way may be confined to that region, causing first a temporary, and later a permanent, high frequency threshold shift. High frequency sensorineural hearing losses have been shown in chronic otitis media (for example Walby, Barrera and Schuknecht, 1983). The risk to hearing may be greater in acute than in chronic infection, because the round window membrane is demonstrably thicker in the latter condition, and pus may accumulate under pressure when the tympanic membrane is intact.
Appendix 12.1. The Cawthorne/Cookseye regime of head exercises
(From Dix (1984), with permission.)

The Cawthorne/Cookseye system of exercises is designed to restore balance and to train the eyes and muscles and joint sense by performing many exercises with the eyes closed. The movements are carried out in the following graduated stages:

**Stage 1: head kept still - in bed or sitting**

Eye movements only are practised looking up and down and from side to side and then focussing. The patient focusses on the instructor's finger held three feet away and follows the finger to one foot from the eyes.

**Stage 2: head and eye movements while sitting**

Head movements bending forwards and backwards and then from side to side are at first slow, then quick. The movements are then repeated with the eyes closed.

**Stage 3: head and body movements while still sitting**

Movements of shoulder shrugging and circling are first practised. The patient then picks up an object from the ground and looks right up with it. Bending forwards, he then passes an object (such as a ball) from hand to hand under the knees. It is important that he should relax between the various movements.

**Stage 4: standing exercises**

The following manoeuvres are carried out in turn:

1. The patient gets up and stands without support first with the eyes open and later closed;
2. the above exercise is repeated turning round while standing;
3. a large ball is thrown from hand to hand while standing.

**Stage 5: moving about**

1. Walking across the room and around a chair with the eyes open. The exercise is repeated with the eyes closed;
2. circling around a centre person who throws a large ball and to whom it will be returned;
3. standing back to back with an instructor who passes a large ball to the patient between the legs, receiving the ball back from him above the head. This manoeuvre is performed as quickly as possible;
4. walking up and down a slope with the eyes open and later closed;
5. walking up and down steps with the eyes open and later closed;
6. games involving stooping, stretching, and aiming, such as skittles, bowls or basketball.
The principles of the Cawthorne/Cookseye exercises
instructions for patients

The balance parts of the two ears complement each other, sending equal impulses to the brain which are essential for the maintenance of equilibrium of the head and body.

If either or both balance centres are damaged, equilibrium is upset. The result of this is vertigo or giddiness which may be accompanied by nausea and vomiting. Although this condition may be very frightening it is not serious in that it does not, in itself, threaten life. It can, furthermore, be overcome by carrying out special exercises.

The purpose of the exercises is to build up a tolerance mechanism in the brain which compensates for the unequal balance of the two ears. The exercises stimulate the development of this tolerance mechanism and the more diligently and regularly they are performed, the sooner will vertigo disappear.

The exercises should be carried out persistently for at least 5 minutes three times daily and for as long as vertigo persists. This may be for 1-3 months. A conscious effort should be made to seek out the head positions and movements that cause vertigo insofar as one can be tolerated, because the more frequently vertigo is induced the more quickly is the brain compensation mechanism built up.

Certain medications help to control the vertigo while brain compensation is being achieved and any such tablets should be taken regularly during the course of exercises.

As normal a life as possible is, meanwhile, to be recommended. Early return to work and sports are helpful in rehabilitation.

Diligence and perseverance will be required but the earlier and more regularly the balance exercise regime is carried out the faster and more complete will be recovery to normal activity.
Chapter 13: Otalgia

Carol Wengraf

Most episodes of earache are caused by pathology in the ear. The diagnosis should be easy to make after an accurate history has been taken and a careful examination of the ears, nose and throat carried out.

Previous chapters in this volume have dealt, in detail, with the symptoms, appearances and treatment of ear diseases, including those in which pain is a feature. To recapitulate, Table 13.1 lists those conditions of the outer, middle and inner ear which are associated with pain.

This chapter describes the causes of pain which are apparently in the ear but are either referred from other structures which share the same innervation or those in which the nerves are inflamed or irritated.

Innervation of the ear

The ear is served not only by the fifth, seventh, ninth and tenth cranial nerves, but also by the second and third branches of the cervical plexus. The richness of its innervation presumably explains why pain referred to the ear is so common.

The exact distribution of the nerves is subject to variation and some overlap occurs (Last, 1984). Briefly, however, most of the cranial surface of the pinna, its lateral surface below the meatus and the lobule are supplied by C2 and C3 via the great auricular nerve. The lesser occipital nerve, C2, overlaps the great auricular nerve to supply the upper part and rim of the cranial surface of the pinna. The auriculotemporal nerve, a branch of the mandibular division of nerve V supplies the auricle above the meatus, the superior wall of the meatus, the skin of the tragus and the majority of the outer surface of the tympanic membrane. The auricular branch of the vagus supplies the posteroinferior quadrant of the tympanic membrane, posterior wall and floor of the meatus and a small area of the skin on the cranial surface of the pinna near the mastoid process. The facial nerve, via the tympanic plexus, probably supplies a small part of the outer surface of the drum and a small area of skin on the concha, but the details remain undetermined in man (Gray, 1973).

The mucosa of the inner aspect of the drum and that of the middle ear is supplied by the glossopharyngeal nerve through its branch to the tympanic plexus, probably assisted by the facial nerve. The eustachian tube is supplied by the pharyngeal branch of the pterygopalatine ganglion and its ostium, as well as the mastoid air cells, by a meningeal branch of the fifth cranial nerve.

In summary, therefore, the pinna is supplied by C2 and C3; the meatus by cranial nerves V, VII and X; the drum by nerves VII and X; and the middle ear by nerves V, VII and IX.
Table 13.1 Conditions of the outer, middle and inner ear associated with pain

**Pinna**
- (1) Trauma - tears, lacerations, bites
- (2) Haematoma, which may lead to perichondritis
- (3) Infected eczema
- (4) Infected preauricular sinus
- (5) Erysipelas
- (6) Frostbite
- (7) Sunburn
- (8) Chondrodermatitis nodularis chronica hellicis
- (9) Infected basal or squamous cell carcinoma

**Meatus**
- (1) Impacted wax. Attempts at removal with blunt instruments, wax solvents. Failed syringing
- (2) Keratosis obturans
- (3) Impacted foreign bodies
- (4) Boils
- (5) Otitis externa. Pain suggestive of fungal infection
- (6) Hypersensitivity to antibiotics
- (7) Malignant otitis externa. Pain indicates activity and means that antibiotics must continue
- (8) Necrotizing osteitis
- (9) Bullous myringitis
- (10) Herpes zoster oticus
- (11) Exostoses when wax and debris are impacted medially
- (12) Tumours, mainly carcinoma. Pain should alert suspicion

**Middle ear**
- (1) Traumatic perforations
- (2) Water through perforations
- (3) Haemotympanum
- (4) Otitic barotrauma
- (5) Serous otitis media
- (6) Acute otitis media
- (7) Carcinoma

**Mastoid**
- (1) Acute mastoiditis. Continuing pain is an indication for drainage
- (2) Bezold abscess - torticollis
- (3) Zygomatic mastoiditis
- (4) Exacerbations of chronic granulomatous mastoiditis
- (5) Complications of cholesteatomata. Pain is usually an indication for surgery
- (6) Cholesterol granuloma. Persistent pain is again an indication for surgery
- (7) Wegener's granuloma
- (8) Eosinophilic granuloma (Fradis et al, 1985)

**Inner ear**
- (1) Noise. In noise-sensitive people, this may cause pain
- (2) Tinnitus may be described as a throbbing pain
- (3) Ménière's disease. Attacks may be preceded by pain and fullness in and behind the ear.
The auriculotemporal nerve also sends branches to the temporomandibular joint, the skin over the parotid and the fascia around the gland - C2 and C3. The temporomandibular joint is also supplied by the masseteric nerve, a branch of the anterior division of the mandibular nerve.

**Referred pain**

Pain is one of the most common and disturbing human experiences and it must be remembered that individuals vary widely in their appreciation of, and reaction to it, and the same individual may react in a different way to a similar pain at different times. Pain is a warning and is always real to the patient, even if the cause for each type or bout is not necessarily found. If there is no obvious local cause, then pain referred from another site should be considered.

The physiological explanation for referred pain is uncertain (Walton, 1985), but the phenomenon can probably be explained by a central summation mechanism in relation to the gate theory (Melzack and Wall, 1965). There is a widespread diffuse monosynaptic input to the cells of the substantia gelatinosa of the spinal cord, often from relatively distant afferents.

A good example of referred pain is that in which there is irritation of the diaphragm - innervated by the phrenic nerve cervical branches 3 and 4 - and this is then appreciated as a pain in the tip of the shoulder the cutaneous innervation of which is C3 and C4.

**Tonsillitis**

Tonsillitis must be one of the commonest causes of pain referred to the ear. Children find localization difficult and there is, of course, often an associated eustachian tube dysfunction secondary to the tonsillitis, which will add to the ear discomfort, and in many cases an otitis media will also be present.

Post-tonsillectomy pain varies considerably and seems to be less severe in children than adults. The average length of time for which pain was experienced in a group of 95 children was 4.9 days (Paradise et al, 1984). It is, of course, important not to assume that pain in the ear postoperatively is referred pain, and to examine the ears to exclude a concomitant ear infection.

Peritonsillar, retropharyngeal and parapharyngeal abscesses, will all cause earache, too, but should be easy to distinguish from simple tonsillitis. If trismus makes examination impossible, 12 hours of intravenous broad-spectrum antibiotics plus fluid, should reduce this sufficiently to enable adequate visualization. These abscesses need to be drained promptly to prevent the development of respiratory obstruction.

**Nasal polyps**

Antrochoanal and nasal polyps which are large enough to fill the posterior choanae or even the nasopharynx will obstruct the medial end of the eustachian tube and give rise to a feeling of discomfort in the ear.
Sinusitis may also produce a feeling of blockage in the ear when purulent secretions flow past the orifice of the eustachian tube and cause inflammation and oedema. A secondary serous otitis may develop in both conditions adding to the discomfort.

**Mumps**

Mumps is one of several infectious diseases caused by a virus and usually contracted in childhood. Pain in the ear is a common symptom and if only one parotid gland is affected and the swelling inconsiderable, the diagnosis may be missed. (Antibiotics do not, of course, affect the pain or the condition.) The incubation period is 12-28 days but most cases develop 7-18 days after exposure. When the infection is complicated by mumps labyrinthitis with vomiting, vertigo and deafness, it is most important to exclude an associated ear infection.

**Parotitis**

Parotitis in adults with pain in front of, and in, the ear used to be relatively common postoperatively, but with better hydration, dental hygiene, antibiotics and after care, it is now usually confined to debilitated, elderly and immunocompromised patients. The causative organism was commonly *Staphylococcus aureus* (Lundgren, Kylen and Odkvist, 1976), but more recently *Pseudomonas aeruginosa* (Pruett and Simmons, 1984), and anaerobic bacilli (Anthes, Blaser and Reller, 1981) have been cultured from Stenson's duct in these cases.

The apparently separate disease entity of recurrent parotitis in childhood, which usually subsides after the child is about 10 years old, may be mistaken for mumps initially. There is some evidence that this infection is related to the Epstein-Barr virus (Akaboshi et al, 1983). In severe cases, parotidectomy may have to be considered, if sialography shows definite evidence of sialectasis.

**Thyroid**

Painful lesions of the thyroid will frequently produce pain referred to one or both ears. The cause is usually obvious, but occasionally cases of subacute (de Quervain's) thyroiditis may be diagnosed as pharyngitis and referred to otolaryngologists when symptoms do not respond to antibiotics. There is usually a small firm diffusely tender goitre and a greatly increased erythrocyte sedimentation rate. The pain will usually respond to aspirin but severe cases may require steroids (The Lancet, 1986). These do not, however, alter the natural history of the disease and 10% of patients will eventually become hypothyroid. Occasionally, Hashimoto's thyroiditis is painful but this does not usually respond to steroids, although thyroxine will alleviate the pain in most cases if the dose is high enough to suppress thyrotropin secretion (Zimmerman et al, 1986). Differentiation from subacute thyroiditis may be necessary by fine needle aspiration biopsy, as both have a tendency to recur.

Haemorrhage into a cyst or nodule will cause pain which usually only lasts a few days, but fibrosis (Riedel's struma) must be differentiated from invasive malignancy. This may be difficult and operation to split the isthmus and relieve the pressure symptoms may be necessary; histology of the specimen will confirm the diagnosis (De Groot et al, 1984).
**Tuberculosis of the larynx**

Pain in the ear is sometimes found in tuberculous ulceration of the larynx (Tilley, 1919). The condition is uncommon nowadays in the UK (Bailey and Windle-Taylor, 1981), but in developing countries it is still a considerable problem. In Tanzania, for example, in 1983, Manni found that just over one-quarter of the 341 cases of untreated pulmonary tuberculosis presenting to one clinic in a single year had laryngeal involvement. Tilley (1919) recommended injection of alcohol around the superior laryngeal nerve to control the severe pain in the throat and ear, but nowadays the pain usually settles quickly once antituberculous chemotherapy has been started.

**Styloid process**

'The styloid process has been blamed for pain within the ear but we have never been satisfied that this is true' (Edwards, 1973).

In 1937, Eagle described two patients with elongated styloid processes who complained of an ache in the pharynx referred to the ear, and a sensation of a foreign body in the throat. Later he suggested that in those cases which follow tonsillectomy, scar tissue in the fossa binds the mucosa down on to the tip of an elongated process restricting movement and thus causing symptoms (Eagle, 1958). Russell (1977) advised palpation of the tonsillar fossa in these cases and if a bony protuberance is felt and touching it causes the pain, the area should be infiltrated with local anaesthetic. If this produces temporary relief of the symptoms, operative removal of the styloid process should provide permanent relief.

Eagle (1958) advocated removal of the elongated process at the same time as tonsillectomy, to prevent the pain developing, but as it only occurs in an occasional case this would appear excessive. Lindeman (1985) and Strauss, Zohar and Laurian (1985) felt that an external approach is safer as the great vessels can be viewed directly, and have found this most effective in selected cases. Elongation of the styloid process is common and in most cases must be entirely asymptomatic. However, there does seem to be the occasional patient who has suffered pain in the throat and ear for many years and may indeed have had many other operations to attempt to relieve this symptom, who will be cured by shortening of the styloid process (Baddour, McAnear and Tilson, 1978).

**Teeth**

Pain caused by diseased teeth is commonly referred to adjacent structures; the lower molars are most frequently those implicated in pain referred to the ear. Erupting teeth, caries causing exposure of the dentine, periodontal and dental abscesses may all cause ‘earache’ as well as pain in the tooth itself. Episodic pain arising in the teeth is rare and if there is doubt, infiltration with local anaesthetic will abolish the pain if it does come from the tooth and confirm the diagnosis. This should prevent the unnecessary extraction of otherwise healthy teeth for pain of uncertain origin.
Oral ulceration

Oral ulceration is painful locally but when the posterior third of the tongue, tonsillar region or the pharynx is involved, pain will be referred to the ear. Primary herpetic stomatitis usually occurs in children over the age of 6 months but is rare in adults. It is caused by infection with herpes simplex virus, lasts about one week and rarely recurs. Recurrent aphthous stomatitis can be classified as minor, major when scarring follows, and herpetiform. Behçet's syndrome is thought to be the multisystem equivalent of the unifocal ulceration and is characterized by orogenital ulceration, often with involvement of other systems, and is probably an autoimmune disease (Wray, 1984). There is evidence that recurrent aphthous stomatitis is related to autoimmunity (Lehner, 1968), trauma (Wray, Graykowski and Notkins, 1981), nutritional deficiencies (Wray et al, 1978), and alteration in hormone levels.

Local steroids, carbenoxolone (Poswillo and Partridge, 1984), antiseptic mouthwashes and topical analgesics are the mainstay of management. Systemic steroids and thalidomide (Bowers and Powell, 1983) should be reserved for exceptional cases.

Temporomandibular joint

The temporomandibular joint, like any other joint within the body, is subject to trauma, infection and arthritis. Not only is the joint the immediate anterior relation of the external auditory meatus, but, in addition, it is supplied by an articular branch of the auriculotemporal nerve which also supplies cutaneous sensation to a large portion of the pinna. It is not surprising, therefore, that disorders of this joint are frequently misinterpreted by the patient as earache. Rheumatoid arthritis affects the temporomandibular joint in both children and adults, occurring in up to 70% of the latter, and related to the severity of the disease generally (Chalmers and Blair, 1973). Osteoarthritis also affects the joint and is said to develop relatively frequently following significant trauma to the jaw (Norman, 1982). Sixty per cent of these people will have otalgia and condylectomy usually relieves this pain. Gout will occasionally occur, but rarely is this joint affected in the absence of others. Ten per cent of those with ankylosing spondylitis have pain in the joint and trismus (Scully and Cawson, 1982).

The vexed question of temporomandibular arthrosis is an extremely complicated subject; there is much research and large numbers of studies have been published (for example Griffiths, 1983). It is certainly a common condition affecting 15-20% of the population (Howe, 1983), commonest in the young female adult, but also occurring in children (Blake, Thorburn and Stewart, 1982) and in the older members of the population who have lost many of their teeth. The condition is associated with pain in the joint which radiates to the ear, temple, jaw and upper neck. It is made worse by eating, yawning and periods of stress. Some patients who grind their teeth (bruxism) or have violent dreams will wake with pain (Every, 1960) and a significant number will develop the condition after a course of dental treatment, when the joint has been stressed and the bite altered. Many different treatments have been based on widely different concepts of the cause, and include an explanation of the origin of the pain, simple analgesics, local heat, physiotherapy (Hargreaves and Wardle, 1983), acrylic splints, restorative dentistry to alter the bite (Thomson, 1959) and muscular exercises (Howe, 1983). A large proportion will become pain free, either because of or in spite of treatment, but there remain a few cases with persistent symptoms who may
be offered condylectomy. It is most important that these are differentiated from those patients with an allied disorder - atypical facial pain. This latter condition is related to emotional stress and adverse life events and should be treated with long-term antidepressants or dothiepin hydrochloride; operative intervention is specifically contraindicated (Feinmann and Harris, 1984).

Costen's syndrome still appears in many textbooks (Costen, 1934). He described a syndrome of pain and fullness in the ear associated with hearing loss, tinnitus and vertigo, which he attributed to wearing of the glenoid fossa causing pressure on the auriculotemporal nerve by the displaced condyle, and which in turn erodes the tympanic plate and compresses the chorda tympani. The eustachian tube is compressed by the pterygoid muscles causing vertigo by alteration in the middle ear pressures. These views were accepted by some authors, especially in the USA, and Pinto (1962) has even described a fibroelastic ligament which passes from the temporomandibular joint capsule to the head of the malleus whose movement causes deafness. This syndrome is not usually accepted now and Brookes, Maw and Coleman (1980) were unable to find one case out of 45 which satisfied the criteria.

**Myocardial ischaemia**

Pain in the ear related to episodes of exercise and stress, with angiographic evidence of coronary artery disease and brought on by an exercise treadmill, has been described (Bryhn and Hindfelt, 1984), although this presentation in isolation must be very rare.

**Malignant disease**

The most important cause of referred pain to the ear which must be excluded in all cases is a malignant tumour. The commonest 'silent' neoplasm causing earache is one in the pyriform fossa, but those in the glottis, supraglottis, postcricoid region, posterior pharyngeal wall, tonsil, posterior third of the tongue, parotid and nasopharynx may do so. All these sites must be inspected and palpated, if necessary under anaesthesia, and biopsies taken of any suspicious areas, so that treatment can be started as early as possible to relieve the patient of his pain and, if possible, cure his disease.

Unfortunately, one of the most difficult types of earache to treat is that caused by a mass of malignant glands in the neck. A radical neck dissection should be performed, if possible, to include the parotid gland in continuity, when indicated. If an area of skin is involved this should be excised and cover provided if necessary by a deltopectoral flap. It may be justified to excise a length of the carotid artery and replace it with a Teflon or saphenous vein graft (Lore and Boulos, 1981) to clear the disease, because it is usually impossible to control the pain in these cases adequately with drugs and it may take the patient weeks, or even months, to die.

**Pain of nervous origin**

**Herpes zoster oticus**

Ramsay Hunt was the first to describe this disease in 1907 and he suggested that the geniculate ganglion was the site of the inflammation. This has been queried by Dawes (1963),
who suggested that the syndrome is a zoster lesion of more than one cranial nerve. At post-mortem, however, in a typical case, the geniculate ganglion showed unequivocal pathological changes consistent with previous herpetic inflammation (Aleksic, Budzilovich and Liebermann, 1973). Hunt described preherpetic pains as sharp, stabbing pains in and around the ear for 3-4 days before the eruption appeared, although they have been reported as lasting up to 3 weeks before the vesicles develop (Juel-Jensen et al, 1970). The pinna may be hyperaesthetic and pain may be severe enough to be called preherpetic neuralgia (Harrison, 1954). The diagnosis at this stage may be very difficult, but if careful and repeated examination fail to reveal any other cause for earache, this in itself should suggest the diagnosis, which will become obvious when the vesicles appear. In some cases, the pain subsides when the eruption develops, but in most it will persist for days, weeks or even months after wards, when it is then called postherpetic neuralgia.

**Glossopharyngeal zoster**

This has been described (Clark, 1979) in a patient who had been exposed to varicella and became ill. He developed vesicles on the posterior third of the tongue only, with associated severe pain in the ears and rising varicella virus titres.

**Postherpetic neuralgia**

The inflammatory process associated with infection of the first sensory neuron by the varicella zoster virus is followed by a certain amount of destruction which leads inevitably to disordered sensations in the affected area. The characteristic cutaneous scars will map out the area involved and that which follows geniculate zoster or the Ramsay Hunt syndrome usually covers the concha, helix, tragus, antitragus, plus a small area of the cranial surface of the pinna behind the lower portion of the concha (Aleksic, Budzilovich and Liebermann, 1973). In many cases, the disordered sensation following varicella zoster virus infection will be mild and acceptable to the patient. In a proportion, however, which rises with increasing age, the combination of stabbing burning pains plus anaesthesia becomes a serious problem and this is then called postherpetic neuralgia. In mild cases, a detailed explanation of the mechanism helped by a mild antidepressant will suffice. Some patients, however, are driven to the verge of suicide by this pain especially if they are unfortunate enough to have an added ipsilateral facial palsy and a sensorineural hearing loss.

Many different treatments have been tried over the years with varying degrees of success. Taverner (1960) found local ethyl chloride spray very effective in resistant cases and Nathan and Wall (1974) used prolonged electrical stimulation to good effect. The local application of a solution of idoxuridine 40% in dimethyl sulphoxide to the vesiculated area is said to shorten the length of time pain is suffered (Juel-Jensen et al, 1970). The use of intravenous acyclovir certainly reduces the pain of varicella zoster virus infection initially, as well as preventing new lesions and promoting healing, but was said not to influence the proportion of patients developing postherpetic neuralgia (Peterslund et al, 1981; Bean, Brain and Balfour, 1982). If, however, it is given orally within 24 hours of appearance of the vesicles (Finn and Smith, 1984) it seems to be effective in stopping its development.
**Trigeminal neuralgia**

Trigeminal neuralgia is characterized by frequent paroxysms of pain lasting 10-30 seconds, triggered by moving or touching the face, more lower than upper, more right than left, in women more than men and in the elderly more than the Young (The Lancer, 1984). Carbamazepine will frequently control the attacks but, if it does not, or if the pain recurs, surgery is indicated. The choice is wide - from local block to section of the sensory root affected - all of which unfortunately inevitably produce anaesthesia which may be nearly as distressing as the original pain, the so-called anaesthesia dolorosa (Walton, 1985). There is increasing evidence that at least some cases are caused by compression of the nerve by vascular loops and abnormalities, and operations to relieve these compressions, first described by Gardner and Miklos (1959), are becoming increasingly common and apparently effective (Richards, Shawdon and Illingworth, 1983).

**Glossopharyngeal neuralgia**

This is much less common than trigeminal neuralgia, seen mainly in those over the age of 50, occurring twice as often in women as men and affecting the right side twice as often as the left (Edwards, 1973). It is virtually always unilateral, with paroxysms of pain of a stabbing or lancinating nature. These usually originate in the back of the tongue, radiating to the external meatus, angle of the jaw and even deeply into the ear and strike every few minutes. The spasms rarely last more than one minute each but may be repeated for as long as several hours without a break (Chawla and Falconer, 1967). Attacks may be precipitated by swallowing, coughing, sneezing or turning the head and occasionally the tragus is a trigger zone; the ear may be sensitive between attacks (Walton, 1985). Unusually attacks are associated with syncope (St John, 1982) when it is suggested that there is vagal involvement as well. The diagnosis has to be made entirely on the history as there are no abnormal physical signs and no specific pathology in the nerve has been found. The diagnosis may be confirmed by spraying the throat with topical anaesthetic which will relieve the pain, briefly (Bonica, 1984).

Carbamazepine 100 mg three times daily increasing, if necessary, to as much as 200 mg four times daily will control the paroxysms of pain in many cases, but, if the attacks recur subsequently, control is much less likely. The glossopharyngeal nerve may then be sectioned and avulsed in the neck as first described by Sicard and Robineau (1920), but recurrence often occurs following this operation (Chawla and Falconer, 1967). Jennett and Galbraith (1983) recommended sectioning of the ninth nerve in the posterior fossa or its tract in the medulla as the first and definitive procedure. They also suggested sectioning the upper two rootlets of the vagus, as described by Dandy (1945) and advocated by Chawla and Falconer (1967), because these carry sensory fibres to the ear. Recently, it has been suggested (Morales et al, 1977) that some of these cases are caused by vascular compression of the ninth nerve. Interposition of a prosthesis between the nerve and the vessels is then said to relieve the symptoms.

**Idiopathic geniculate neuralgia**

This rare condition presents as severe, brief, episodic pain deep in the auditory meatus. It may be relieved by dividing the nervus intermedius (Hannington-Kiff, 1974). Attacks may
be triggered by touching the external meatus and a dull background pain may persist between
attacks (Dubuisson, 1984).

Cervical spine

In degenerative or neoplastic disease of the upper cervical spine, when C1, C2 and C3
roots are compressed or distorted, pain may be felt in the neck, occiput or mastoid area
(Dubuisson, 1984). The pinna, but not the meatus, and the lower border of the jaw are
commonly affected on one or both sides, depending on the site and severity of the disease.

Upper cervical or occipital neuralgia is usually associated with upper cervical root
damage and causes either paroxysms of pain lasting from minutes to hours, or constant pain.
Tenderness or hyperaesthesia in the occiput or over the mastoid region is sometimes present.

Migraine

Classical migraine with its aura, followed by a throbbing unilateral headache,
associated with vomiting, is easy to diagnose from the history. Less clear cut are those cases
where the temporal or postauricular area are involved (Delession, 1980), and which may be
preceeded by tinnitus or rarely by auditory hallucinations. Again, the episodic nature with
complete freedom from pain and lack of signs in between attacks should confirm the
diagnosis.

Periodic migrainous neuralgia

This is another condition which relies particularly on taking an accurate history for its
diagnosis, and was fist clearly defined by Harris (1936). The patient may well have been
referred as a case of sinusitis or ear infection which has persisted or recurred despite
treatment. The attacks are, however, quite classical and show a remarkable similarity on with
another and, indeed, from one patient to another (Edwards, 1973). The time of onset, length
of time to achieve maximum severity, length of attack, the severity of the pain and area
involved are almost identical. These attacks occur in bouts or clusters, lasting 30 minutes to
3 hours, once or twice per day, more commonly at night than during the day and the bouts
may be separated by periods of up to several months which are free from attacks.

The pain is severe and constant, unlike the throbbing pain of true migraine. It is
usually centred on or near the eye but radiating to the cheek, ear or temple, and may be
associated with an ipsilateral red eye and nasal obstruction. Hence the confusion with
sinusitis. The pain can usually be prevented by taking ergotamine tartrate half an hour before
the expected onset. It is not possible to take this every day, however, because it causes
peripheral ischaemia. Recently prophylaxis with pizotifen 1.5 mg daily appears to be even
more effective.

Acoustic neuroma

Headache is common in patients with acoustic neuromata, occurring in 73% of late
cases (Ellis and Wright, 1974) and 20% of those less advanced (Hard and Davenport, 1981).
Pain localized to the ear is only occasionally seen but it is sometimes described as fullness and so great care must be taken to differentiate these cases from those of Ménière's disease.

**Thalamic syndrome**

The thalamic syndrome is usually caused by an infarct or tumour in the posterolateral thalamus, which produces a diminution in sensation on one side of the body. During recovery some patients will develop a particularly disagreeable gnawing, crushing, pain which is constant, on the contralateral side (Levin, Ramirez and Katz, 1983). This is pain where there is no peripheral stimulus and is most often felt in the side of the face (Walton, 1985).

**School avoidance**

Occasionally, an older child will be brought to the clinic with a history of recurrent attacks of earache, severe enough to cause several days absence from school. The tympanic membranes and hearing are normal at presentation, but there is usually well documented evidence of ear infection and significant hearing loss in the past. The child's general practitioner may, unfortunately, have allowed the situation to continue by simply issuing another prescription for antibiotics, assuming there to be yet another ear infection present. It is most important that, rather than for example arranging to insert ventilation tubes as a next step, the parents should be asked to bring this child to the clinic next time he or she has an earache. This in itself may be curative as the child realizes that examination will reveal normal ear drums and no others cause for the pain. If the child does re-attend, and it is pointed out to the family that the ears are normal, the excuse for staying away from school is lost and the problem usually resolves itself.
Chapter 14: Otosclerosis

Philip H. Beales

The bone of the otic or labyrinthine capsule may be affected by many conditions of diverse aetiology and the majority of these are generalized diseases affecting the skeletal system as well as the temporal bone. Otosclerosis is confined to the otic capsule and, together with a few other conditions, gives rise to deafness and vestibular symptoms.

Definition

Otosclerosis is a hereditary localized disease of the bone derived from the otic capsule. Mature lamellar bone is removed by osteoclasts and replaced by woven bone of greater thickness, cellularity and vascularity.

The otosclerotic focus may be asymptomatic or, if in the area of the stapes footplate, may give rise to ankylosis and conductive deafness. Other parts of the labyrinthine capsule may be involved resulting in sensorineural deafness and vestibular abnormalities. The focus produces an enzyme which may give rise to sensorineural deafness and vertigo, whether or not the stapes footplate is affected. A combination of effects may thus be produced by the otosclerotic lesion sometimes referred to as 'histological', 'stapedial', 'cochlear' and 'combined otosclerosis'. The commonest manifestation seen clinically is of the combined variety where there is both a conductive and sensorineural hearing loss.

Many European otologists use the term 'otospongiosis' when referring to the active vascular focus, but in North America and in the UK the term 'otosclerosis' is used and this refers to the final inactive stage of the lesion where the bone is sclerotic or hardened; neither of these terms is strictly accurate.

History

The first description of ankylosis of the stapes is attributed to Antonio Valsalva who, in 1741, carried out a post-mortem examination on the body of a patient who was believed to be deaf. In 1861, Joseph Toynbee, noted ankylosis of the stapes footplate in 39 out of a total of 1959 temporal bone dissections.

In 1894, Adam Politzer introduced the term 'otosclerosis' and gave the first final account of the histopathology of this condition. In this disease, fixation of the stapes footplate by bony deposits occurs, leading to progressive ankylosis of the footplate in the oval window niche and a progressive conductive deafness. The term 'otosclerosis' refers to the final inactive stage of the process, while the essential pathological lesion is, in fact, a replacement of lamellar bone.

Siebenmann introduced the term 'otospongiosis' in 1912, which referred to the active and vascular stage of the process and this term is widely used in Europe. It is more accurate as it indicates that an active lesion may be present. The belief that the process is inactive, or soon becomes so, has delayed understanding that sensorineural deafness if often an integral part of the disease. Politzer's work was of fundamental importance as he demonstrated, for
the first time, that the stapedial ankylosis was not secondary to 'chronic middle ear catarrh', which was previously believed to be an inflammatory condition, but was the result of a primary disease of the labyrinthine capsule. It was not until nearly 50 years later, when the fenestration operation allowed direct inspection of the oval window in the living patient, that the concept of a chronic catarrhal condition causing secondary fixation of the stapes footplate, was finally abandoned.

Aetiology

Otosclerosis is a disorder affecting the growth of collagen and it is only seen in the human species. Despite intensive research, the cause of the development of the disease process remains obscure. The characteristic lesion is a deposit of new bone with a different fibrillar and cellular pattern which is laid down at certain sites in the temporal bone. Known sites of predilection are the oval and round windows, and in these areas cartilaginous rests are found. Otosclerotic foci have been observed in other areas, remove from these special regions and, in these cases, symptoms of conductive deafness do not occur. This condition has been termed 'non-clinical', or 'histological', otosclerosis and is more common than clinical otosclerosis (Guild, 1944).

Many theories of the aetiology of otosclerosis have been proposed and these include metabolic disorders, vascular disease, infection, trauma, and anatomical and histological anomalies of the temporal bone. Although histological studies of focal changes in otosclerosis have shown features in common with bone dystrophies, such as Paget's disease and osteogenesis imperfect, studies of the mineral content of the temporal bone and ossicles have shown variable results. Jense, Neilsen and Elbrond (1979) reported a study of the mineral content of skeletal bone in patients with and without otosclerosis and showed no difference between the two groups. This work supports the assumption that otosclerosis is a localized disease of the labyrinthine capsule.

In 1944, Guild examined 1161 unselected autopsy specimens. Microscopic sites of otosclerotic bone were found in 6.1% of white males, 10.3% of white females, 1.0% of Negro males and 0.5% of Negro females. Bony ankylosis of the stapes was seen in six white and two Negro subjects. There is thus a very marked difference between clinical and non-clinical otosclerosis.

Incidence

Guild (1944) first pointed out the importance of making a distinction between clinical and non-clinical, or histological otosclerosis; the latter is about 10 times more common than the former. The results of other workers (Weber, 1935; Engstrom, 1940; Soifer, Weaver and Holdsworth, 1970) supported those of Guild giving an incidence of histological otosclerosis of up to 10% in white adults but much less in the African races. Friedmann (1974) has estimated that 2% of all white persons suffer from deafness caused by otosclerosis. Morrison (1967) studied the incidence of otosclerosis in a population of nearly one-quarter of a million persons in Outer London and showed the incidence to be approximately 2% in patients between the ages of 30 and 59 years of age (Table 14.1). Shambaugh (1949) in North America estimated the frequency of otosclerosis to be at least 0.5%.
Table 14.1 Incidence of otosclerosis 30 years of age and above

<table>
<thead>
<tr>
<th>Age group</th>
<th>Incidence per 1000 population</th>
<th>Age group</th>
<th>Incidence per 1000 population</th>
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<tbody>
<tr>
<td>30-34</td>
<td>2.15</td>
<td>60-64</td>
<td>1.38</td>
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<td>1.94</td>
<td>65-69</td>
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<tr>
<td>40-44</td>
<td>1.85</td>
<td>70-74</td>
<td>0.57</td>
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<tr>
<td>45-49</td>
<td>1.85</td>
<td>75-79</td>
<td>0.77</td>
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<tr>
<td>50-54</td>
<td>1.80</td>
<td>80 and over</td>
<td>0.53</td>
</tr>
<tr>
<td>55-59</td>
<td>1.29</td>
<td>30 and over</td>
<td>1.54</td>
</tr>
</tbody>
</table>

The variation in the figures produced by different authorities makes it obvious that the true incidence of the disease is not known. In recent years, it has become quite clear that the number of patients seen in clinics and operated on by stapedectomy has fallen dramatically and this is unlikely to be the result of patients failing to attend for treatment as the results of surgery are good and widely known to be highly successful. The most likely explanation is that the original pool of patients has been reduced by energetic otologists, keen to operate on those patients who came to them with a conductive deafness caused by otosclerosis. Hammond (1976) has shown the decline in the number of patients treated by operation at St Thomas’ Hospital, London, between the years 1962 and 1971. Beales (1979) conducted a survey of the number of stapedectomy operations performed in 10 major centres in the UK between 1957 and 1977, in a sample of over four million.

Racial incidence

Otosclerosis is most frequently encountered in the Caucasian races and is a common cause of deafness in Europe, the Balkans, the Middle East, and the subcontinent of India, together with the Caucasian peoples of North and South America, Australia, New Zealand, South Africa and elsewhere. It is rarely found in Mongoloid or Negroid man, although it is encountered in the Negro population of America and the West Indies, presumably as a consequence of hybridization. In the latter group, the disease is about 10 times less frequent than among Caucasians (Morrison, 1967).

The disease also occurs, less frequently, in the Negrito populations of Malaya, New Guinea and the Philippines, and in the Japanese, a mixed race of Mongul, Ainu and Negrito blood (Joseph and Fraser, 1964).

Sex incidence

In clinical practice, otosclerosis is seen more often in women than men, and a sex ratio of 2:1 has been noted by many authorities. However, the incidence is likely to be the same in both sexes, although hormonal influences may cause the disease to advance more rapidly in the female; it also seems that they are more likely to seek medical advice. Asymmetrical deafness caused by otosclerosis is more common in the male and those working in a noisy environment are less likely to be aware of this because of the phenomenon of paracusis.
Genetic factors

Although Toynbee (1861) noticed the familial pattern of deafness and ear disease, it was not until nearly a century later that a comprehensive investigation into the genetic of otosclerosis was conducted by Larsson (1960, 1962). Larsson carried out a field investigation into 357 otosclerotic families between 1956 and 1958. His analysis pointed to a simple autosomal dominant inheritance with incomplete 'penetrance' or manifestation.

Morrison conducted a most detailed and comprehensive survey between 1961 and 1964. In this, the clinical diagnosis was based on a conductive deafness confirmed by audiometry, in the presence of a normal tympanic membrane. In 19 patients, otosclerosis was diagnosed on clinical grounds alone, and in the other 131 it was confirmed by stapedectomy, with histological proof in 109 operations (the specimens being inadequate in the remainder). He confirmed Larsson's result that the disease has an autosomal dominant inheritance. He also found that it occurred in about 40% of individuals carrying abnormal genes; 30% of cases were isolated and this was though to result from failure of manifestations in other family members; some sporadic cases were the consequence of new mutations. Chromosome studies and analyses in otosclerosis and in osteogenesis imperfecta demonstrated normal caryotypes. Morrison concluded that otosclerosis, like osteogenesis imperfecta, belonged to a group of hereditary disorders of collagen, with a similar mode of inheritance, incomplete manifestation, varying degrees of expressivity, and possibly an abnormal enzyme system.

Age of onset of hearing impairment

The disease generally starts in the 'teens and is uncommon before the age of 5 years. The rate of progression varies and in the majority of patients clinical evidence of stapes fixation is not seen. Soifer, Weaver and Holdsworth (1970) showed histological evidence of otosclerosis in 8.3% of 601 temporal bones, but the incidence of stapedial fixation amounted to only 0.09%.

The rate of progression is variable and there are periods of extension alternating with quiescent phases in some patients, while in others the progress of the disease continues relentlessly and, in a small proportion, may be rapid. During periods of endocrine activity, such as puberty, pregnancy and the menopause, the disease may progress; in the majority of patients, signs of hearing loss are complained of between the ages of 20 and 30 years, but sometimes not until 50 years or even later.

The effect of prolonged exposure to industrial noise on patients with otosclerosis

Alberti, Hyde and Symons (1980) reported on the results of an investigation of 135 cases of otosclerosis among men referred for compensation for industrial deafness, all of whom had been exposed to high level industrial noise for a prolonged period of time. When compared to cases without otosclerosis, following similar exposure, both groups showed the typical audiogram of high frequency sensorineural hearing loss associated with acoustic trauma. Most otologists who are experienced in examining patients with industrial deafness will have noticed that the bone conduction audiograms of patients with a marked conductive loss probably caused by otosclerosis, show a high frequency sensorineural deafness which is
typical of noise-induced hearing loss. The explanation of this phenomenon is that it is likely that the person was exposed to damaging levels and gave rise to the sensorineural deafness before the conductive loss developed. The conductive loss developed later and so the audiometric pattern is the combined result of the otosclerosis and the noise deafness present when the person was younger. As otosclerosis may also give rise to sensorineural deafness it can be difficult to arrive at a definite conclusion from the medicolegal point of view.

It is conceivable that a marked conductive deafness does not protect the individual from the damaging effects of a high level of industrial noise, although it is also possible that otosclerosis may make the cochlea of the affected person more sensitive to the damaging effects of noise in the early stages of the disease with minimal hearing loss.

Otosclerosis and pregnancy

In 1967, Shambaugh studied 475 mothers who had received surgical treatment by the fenestration operation. He found that 50% had not observed any noticeable effect on their hearing from any of the pregnancies but, in 42%, there was an associated increase in hearing loss. He estimated that the risk of increased hearing loss from any one pregnancy in a woman with stapedial otosclerosis to be about one in 24. Elbrond and Jensen (1979) studied the influence of pregnancy on the hearing threshold, before and after stapedectomy and found that the operation afforded some protection from further hearing loss.

Gristwood and Venables (1975) studied 479 women who were deaf from otosclerosis. They found that in bilateral cases, pregnancy aggravated the deafness and this incidence ranged from 33% after one, to 63% after six, pregnancies. In unilateral cases, it was found that the pregnancy-related deterioration of hearing was much less common.

Site of otosclerosis in the temporal bone

Although any part of the bony labyrinth may be affected by otosclerosis, the most common site is between the anterior part of the stapedial footplate, the cochleariform process and the bulge of the promontory.

The focus extends, infiltrates and fixes the footplate in the oval window niche and eventually firm bony ankylosis results. It is more common for the new bone to affect the anterior part of the footplate leaving the centre free. About 85% of lesions are situated in the oval window area.

The second most common site for the focus is in the region of the round window, and here, evidence of otosclerosis has been found in up to 50% of cases. In the majority of cases (70-80%) both temporal bones are affected, and a characteristic feature of the disease is the striking similarity of the localization and extent of the lesion in each ear and the similar development of the process.

Other areas of predilection are the round window, the anterior wall of the internal auditory meatus, and within the stapedial footplate.
Unilateral otosclerosis

Although both temporal bones are usually affected, unilateral otosclerosis has been described by various authorities as occurring in 10-15% of patients with this disease (Nager, 1939; Cawthorne, 1955).

Histopathology of otosclerosis

In the otosclerotic focus in the temporal bone, there are two types of bone - woven and lamellar - and two types of cell - osteoblasts and osteoclasts. The first bone to appear during the course of embryonic development, and all early membrane bone, is called 'woven bone' because it contains an interlaced tangle of calcifiable fibres. Lamellar bone, on the other hand, consists of fibres in bundles which lie parallel to one another in the intercellular substance and it is formed, like woven bone, by osteoblasts. The mode of action of osteoclasts is not understood; they produce proteolytic enzymes in tissue culture, may actively phagocytose particles of bone and are constantly seen where bone resorption is taking place (Friedmann, 1974).

Stages of the otosclerotic lesion

Although it is usual, on light microscopy, to describe several stages seen, there is no orderly progression from one to another and it is a feature of the otosclerotic lesion that one focus may contain areas at different stages of activity. The stages may be described as active, intermediate, and inactive (final stage). The term otosclerosis refers to the final stage consisting of highly mineralized bone with a mosaic appearance. The osteoclasts have disappeared but osteocytes and/or osteoblasts may still be seen. The vascular spaces are narrowed, or obliterated, by new bone formation and the lamellar bone which is formed is thicker and more cellular when compared to normal bone.

The term 'otospongiosis' refers to the active phase of the disease and the characteristic feature is the presence of vascular spaces containing some fibrous tissue, and osteoclasts and osteoblasts, forming loosely knit bone. The new bone is called 'woven' because the collagen fibres run in an irregular criss-cross pattern through the otosclerotic focus. A clearly defined boundary between the normal and abnormal bone is a feature, or there may be finger-like processes, which are resorption spaces produced by osteoclasts dissolving some of the perivascular bone. The spaces become filled with osteoclastic bone which stains with haemotoxylin and these areas are sometimes referred to as 'blue mantles'. These are also seen in chronic mastoiditis and other bone diseases (Friedmann, 1974), but Weber (1935 believed that the 'blue bone' was abnormal and otosclerotic foci might be formed through their fusion.

As has been stated previously, there is no orderly development from the active to the inactive stage and all stages may be seen together in one focus which may become quiescent or reactivated at any time.
Clinical features

Deafness

The typical features of otosclerotic deafness are a bilateral, gradually increasing hearing loss, most frequently occurring between the third and fifth decade, the presence of paracusis and tinnitus.

The deafness is often unnoticed by the patient, until the loss reaches 25-30 dB, when difficulty in understanding speech becomes apparent. The patient may remark that the hearing is better in the presence of background noise. The phenomenon of paracusis Willissi is frequently present if there is a predominantly conductive deafness without a sensorineural loss. One explanation of this is that, in general, people with normal hearing raise their voices above the noise level, so that they can remove the masking effects of the noise, and this level of speech sound is above the threshold of the patient with conductive deafness. Although paracusis is seen in other forms of conductive deafness it is most often seen in stapedial fixation caused by otosclerosis.

The patient with otosclerotic deafness has a characteristically quiet voice, which is of good tone, and the change in the speech pattern may be detected by close relatives who often notice the hearing loss before the patient becomes aware of it. The deafness is generally progressive, occurring in a direct linear form; alternatively there may be a plateau-like period, or both features may occur together.

The hearing loss may be almost equal in each ear but often one ear shows a greater loss, and this ratio is usually maintained. Unilateral otosclerosis occurs in approximately 15% of patients. The deafness can remain confined to one ear, or the second ear may become affected later. Many patients with a pure conductive loss will, in later years, develop a sensorineural deafness that is greater than that to be expected as the result of ageing.

Tinnitus

Tinnitus is a common symptom and occasionally the presenting feature. It is sometimes seen in patients without cochlear degeneration when it is the result of an abnormal degree of vascularity of the otosclerotic bone; more often, tinnitus is an indication of sensorineural degeneration.

The tinnitus may be unilateral or bilateral, and of a roaring, hissing or pulsatile character. Fluctuation of the tinnitus is not uncommon and this can be related to metabolic and endocrine disturbances, pregnancy or menstruation. It is more common in the early stages of the disease and it may disappear as the lesion matures and the spongy vascular bone is replaced by the hard sclerotic bone.

Vertigo

Attacks of vertigo, usually of a transient nature, are not uncommon, and they are probably the result of the action of toxic enzymes, which are liberated by the lesion, on the vestibular labyrinth (Causse et al, 1977). A variety of vestibular lesions have been described
in otosclerosis and the most common is true benign positional nystagmus (Colman, 1979). If vertigo is a prominent symptom, the coexistence of Ménière's disease must be considered, as both disorders are common and will be seen from time to time in the same patient.

When taking a history, former episodes of ear disease, head injury, exposure to noise, administration of ototoxic drugs, bone or joint disease must be enquired into, as these factors may be of importance in diagnosis and management.

Morrison (1979) has called attention to the importance of a detailed family history in the assessment of the prognosis when other members of the family are affected.

**Diagnosis**

**Examination**

The examination of the tympanic membranes will include inspection at rest, testing with a Siegle's speculum for mobility and examination after inflation of the eustachian tubes by a Valsalva manoeuvre. The tympanic membranes in otosclerotic patients are sometimes described as being in 'mint condition' but they may be atrophic, thickened, rigid or mobile, and the response to tubal inflation may vary. The 'flamingo blush', or Schwartz sign, is uncommon. It is a result of vascular bone on the promontory, or prominent blood vessels in the submucosal layer of the mucous membrane of the promontory. When seen, it indicates active disease which can progress rapidly.

In every case, examination of the nose, nasopharynx and nasal accessory sinuses is necessary to exclude infection, which may need treatment.

**Clinical assessment of hearing loss**

A rapid estimation of the hearing loss is made in the clinic by simple speech tests, using conversational and whispered voice, the effect of a hearing aid and tuning fork tests. Patients with otosclerosis do not usually show recruitment and are able to hear amplified sounds clearly, unless there is a marked sensorineural deafness.

The tuning fork tests, which will include the Rinne, Weber and Schwabach tests, must be carried out before the more complex tests of auditory function are performed. They are of particular value in two instances:

(1) When there is a predominantly unilateral otosclerosis, with poor bone conduction simulating sensorineural deafness. Here the Weber test will show lateralization to the deaf side.

(2) When there is a severe combined (stapedial and cochlear) otosclerosis where the bone conduction cannot be recorded as there is more than 60 dB hearing loss (which is beyond the limit for the majority of clinical audiometers). If the Rinne test is negative with 256 fork and the patient's voice has reasonable quality, good results can still nevertheless be obtained from operation (Morrison, 1979).
Audiometry

Bone

Audiometric tests are the most important of the testing methods used in otosclerosis. While the air conduction curve gives an indication of the hearing threshold, and its configuration may give a clue to the diagnosis of otosclerosis in the early stage (Carhart, 1964), bone conduction audiometry is of special value in diagnosis and in the selection of patients for surgical treatment. There are certain difficulties in pure tone audiometry and it is important to realize these problems or false information may result.

Carhart, in 1950, pointed out that bone conduction audiometry revealed distinctive curves in patients with stapes fixation caused by any lesion, congenital or acquired, that interferes with the mobility of the stapes. Anything which reduces the inertia of the movement of the stapes footplate, for example an ossicular discontinuity, can also produce this effect. This in turn depends on the fact that one element of bone conduction is the inertia caused by the weight of the ossicular chain, whereby the stapes footplate vibrates out of phase with the skull as a whole, as the latter is set into vibration by the tuning fork or bone conductor. Thus when the footplate is fixed, it is no longer free to vibrate and so the inertial component of bone conduction is lost. If the main mass of the ossicular chain, the malleus and incus, is disconnected from the stapes it also loses most of the inertial component of bone conduction (it can also occur in chronic otitis media).

This effect is most noticeable in otosclerosis, and reductions in sensitivity described by Carhart are: 5-10 dB at 500 Hz, 10-20 dB at 1 kHz, 15-30 dB at 2 kHz and 5-20 dB at 4 kHz. The maximum reduction in sensitivity is most commonly at 2 kHz, although this is not always so. This shift in sensitivity is known as the 'Carhart's notch'.

The Carhart notch effect may disappear after stapedectomy and this phenomenon is sometimes called 'over-closure of the air-bone gap'. It means that after surgery, only the air conduction thresholds have been measured and then compared with the preoperative bone conduction thresholds; it is important therefore to re-test the bone conduction after surgery.

The otologist can, by correcting the bone conduction audiogram for the Carhart effect, determine with accuracy the degree of sensorineural reserve that a patient with otosclerosis possesses. There is, however, a variation in the mechanical shift in bone conduction response which differs from one patient to another. The use of average figures for correction may be inaccurate and so it is important to have some knowledge of the possible variations.

Variability of the Carhart notch

There are two ways in which an estimate can be made as to whether the notching in the bone conduction audiogram is unusual:

(1) if the bone conduction curve shows an irregularity, or peculiarity, which the air conduction curve duplicates, this should be attributed to sensorineural impairment
(2) if the air conduction curve does not show the peculiarity, and the audiogram shows an unusual modification of the bone conduction response.

Gibb and Mal (1973) carried out an investigation to see if the Carhart notch is abolished after successful stapedectomy surgery; they found that in the majority of cases bone conduction thresholds were improved after operation, especially at 2 and 4 kHz. Their paper made it clear that a correction figure for the Carhart notch was important and failure to make an adjustment might result in borderline cases, suitable for operation, being excluded. They also found that the bone conduction shift, in their series, was much less than Carhart's original estimate.

**Limitations of bone conduction audiometry**

Even when bone conduction audiometry is carefully performed it possesses three defects which can cause serious error in threshold measurement: false lateralization; hyperdistractibility; and shadow response.

*False lateralization*

This error is common when bone conduction audiometry is performed without masking; a 'Weber-type' effect is produced and the bone conduction threshold on the worse side appears to be the better ear (the patient is hearing the sound in the other ear).

*Hyperdistractibility*

In some cases, the masking noise interferes with the response of the ear under test; such patients are hard to test accurately.

*Shadow response*

In some patients, the hearing losses are so great that efforts to mask the contralateral ear are ineffective. This situation arises because effective masking is reduced by the amount of the air conduction loss in the masked ear at that frequency. In the majority of cases good bone conduction audiometry is valid, but incorrect results will be obtained in some patients unless the difficulties which have been outlined are appreciated.

**Objective audiometry**

The application of the concepts of acoustic impedance to clinical audiology dates from 1946, when Metz published his monograph.

The investigations carried out are: tympanometry, acoustic impedance and the measurement of the acoustic reflex threshold.

**Tympanometry in otosclerosis**

If the compliance is greater than 0.6 cm$^3$, it is probable that the footplate of the stapes will be relatively thin and, if the compliance is less than 0.2 cm$^3$, there is a likelihood that
the footplate may be thick or obliterated; if the loss is symmetrical, the information may be helpful in selecting the more suitable ear for surgery (Morrison, 1979).

Browning, Swan and Gatehouse (1985) doubted the value of tympanometry in the diagnosis of otosclerosis and found that measuring compliance is of little help because the results overlap those of the normal range. They believed that testing for the absence of the acoustic reflex is helpful in confirming the presence of a conductive defect when the results of pure tone audiometry are equivocal.

In general, it is true to state that impedance audiometry is valuable in differential diagnosis, when taken in conjunction with other tests.

**Speech audiometry**

As pure tone audiometry does not predict the ability of the deaf person to hear speech sounds clearly, such tests must be included among the other tests of auditory function.

These tests are described in detail in Volume 2. The investigations usually ordered by the clinician are: the speech reception test, the speech discrimination test, and the speech audiogram.

**Radiological examination** *(see Chapter 2)*

**Plain X-ray examination**

Although otosclerotic involvement of the temporal bone cannot be demonstrated on plain X-ray films, standard views of the mastoid and Stenvers' view of the internal auditory meatus should be carried out for the purpose of differential diagnosis.

Plain X-rays may reveal a sclerotic mastoid, indicating the possibility of past infection, cholesteatoma, an unsuspected acoustic neuroma, or a skull lesion such as Paget's disease. A meningioma may also be detected. These conditions can give rise to a conductive hearing loss, which is not caused by otosclerosis and without X-ray examination they may not be diagnosed.

**Linear tomography**

Linear tomography is available in most radiological departments and is adequate for many purposes, but it does not show sufficient detail of the otic capsule.

**Polytomography**

Polytomography can show details of the auditory ossicles, the oval window and the capsule.

Three variations of capsular otosclerosis can be recognized:

(1) limited changes in the basal coil
(2) diffuse involvement of the cochlear capsule
(3) widespread labyrinthine otosclerosis.

Areas of radiolucency, indicating demineralization of the otosclerotic bone, may be seen side by side with sclerotic changes. Naunton and Valvassori (1969) have been able to correlate the bone conduction levels and the evidence of capsular otosclerosis in 74.3% of patients with combined stapedial and cochlear otosclerosis; Gungovich and Rosenfeld (1974) have confirmed their work.

Recalcification of a focus may result in a normal radiographic appearance (Shambaugh, 1971) and this explains the not uncommon finding of normal X-rays in patients with combined stapedial and cochlear otosclerosis. Positive evidence of radiological changes is helpful, but their absence does not exclude otosclerosis.

**Differential diagnosis**

The diagnosis of otosclerosis is usually straightforward and is made on the history of a bilateral hearing loss, an intact mobile tympanic membrane and evidence of conductive deafness. Unilateral otosclerosis is seen in about 15% of patients and when it does occur, the possibility that the conductive hearing loss is the result of another cause must be considered. Otosclerosis can give rise to sensorineural deafness and this must be considered in the differential diagnosis.

**Middle ear lesions**

**Secretory otitis media**

This is a common condition giving rise to a conductive hearing loss that may persist for many years. Tinnitus and vertigo are absent and careful examination of the tympanic membrane shows loss of translucency, and fluid may, or may not, be seen. The tympanogram is usually typical in this condition and a plain X-ray of the mastoids will show haziness or increased density. In adults secretory otitis media is often unilateral and may be associated with a lesion in the postnasal space.

**Middle ear fibrosis (chronic adhesive process)**

In this condition the tympanic membrane may appear normal, but it is usually retracted, or thickened, and shows lack of mobility. A tympanogram and mastoid X-rays will establish the diagnosis.

**Tympanosclerosis**

Although tympanosclerosis can occur in the middle ear, with minor changes in the tympanic membrane, this is not usual and the drum is generally opaque with white patches. The condition is common and it may result in a severe conductive deafness if the deposits immobilize the stapes, or the malleus and incus. Tympanometry will show reduction of mobility of the tympanic membrane and an X-ray may show lack of translucency of the mastoid air cells.
Fibro-osseous footplate fixation

In this condition, the history of previous otitis media is helpful and the tympanic membrane will usually show evidence of past inflammation, but as otosclerosis is not uncommon in conjunction with past otitis media, it is not always possible to diagnose this condition without tympanotomy.

Mobilization, or stapedectomy, may give good results provided there is no associated fixation of the malleus and incus.

Congenital footplate fixation

It is important to recognize this condition as stapedectomy carries a risk of perilymph flooding and a sensorineural hearing loss. The deafness is not progressive but the audiogram with a Carhart notch may be identical. If the condition is bilateral, the speech will be affected, but the unilateral cases are usually diagnosed in late childhood or early adult life.

Congenital fixation of the malleus and incus occurs, generally associated with a developmental aplasia of the ear with meatal atresia, but it is occasionally seen without meatal atresia. The condition is rare.

Ossicular discontinuity

Traumatic dislocation of the incus is seen after injuries. It is not uncommon as a result of road traffic accidents where the injuries are severe with loss of consciousness, and bleeding from the ear and not infrequently facial palsy. Less commonly, traumatic dislocation of the incus also occurs after minor head injuries. A blow on the ear, or an unskillful attempt to remove a foreign body when it is pushed through the tympanic membrane, may also lead to dislocation (see also Chapter 7).

Tympanometry is of importance in the diagnosis of these lesions and it will show an absent stapedial reflex, an abnormal compliance and low impedance system.

Polytomography may demonstrate ossicular chain abnormalities, but radiography cannot be relied upon if there is only a very small gap, even though the hearing loss may be profound.

Tympanotomy will often be required to make the exact diagnosis, but it is essential for the otologist to recognize the presence of these lesions, as in most cases stapedectomy is not indicated and the deafness will be treated by some form of ossiculoplasty, or occasionally the use of tissue glue. It should also be remembered that injury can also produce ossicular fixation.
Malleus and incus lesions

The fixed malleus - incus syndrome

This lesion was described by Goodhill in 1960, and Morrison (1979) found it in 2% of tympanotomies.

In this condition, there is stiffness, or fixation, of the malleus, incus, or both, but the stapes is not immediately involved. This lesion may be missed if the surgeon who has made a diagnosis of otosclerosis proceeds to remove the stapes without a preliminary testing of the mobility of the malleus and incus. Following the stapedectomy operation, there will be no improvement in hearing and this is attributed to a failure of the stapedectomy.

Impedance audiometry will help to distinguish this lesion and if the mobility of the ossicular chain is tested at every operation, a wrong surgical procedure will be avoided.

Osteoarthritis of the ossicular chain

The entire ossicular chain may be involved by an osteoarthritic condition and when this occurs it may be difficult to distinguish from otosclerosis. It is more commonly unilateral and tympanometry will show a negative stapedial reflex with high total impedance.

Congenital cholesteatoma

A primary cholesteatoma may occur behind an intact tympanic membrane, producing a conductive deafness. Careful examination of the drum with magnification will usually reveal this condition before operation. Tympanotomy and removal of the cholesteatoma with, if necessary, ossicular chain reconstruction will be required.

Fluid in the middle ear: cerebrospinal fluid or perilymph

The most common cause of fluid in the middle ear is secretory otitis media and this has already been described.

A patient at operation for otosclerosis may show the presence of clear fluid in the middle ear and this fills up again after aspiration. The fluid may be cerebrospinal fluid, the result of a fracture of the tegmen tympani caused by a previous head injury, or it could be perilymph which is leaking from the scala vestibuli when there has been a fracture or dislocation of the stapes. Rupture of the round window membrane usually heals spontaneously but this does not always occur and perilymph can leak from an unsuspected fistula.

Degenerative footplate arthritis: crural atrophy

In this condition, which was described by Goodhill in 1979, there is a circumferential ossification of the annular ligament of the stapes, or crural atrophy resulting from latent chronic otitis media. Crural atrophy may be distinguished before operation by tympanometry, which will show the presence of a stapedial reflex and abnormal tympanic membrane.
compliance. Degenerative footplate arthritis cannot be distinguished before operation, but treatment by stapedectomy will give good results.

**Persistent stapedial artery**

A persistent stapedial artery is occasionally seen at operation and stapedectomy may be possible if the whole footplate is not covered. Rarely, a large artery may cover the footplate and fix the stapes, giving rise to a conductive deafness without footplate fixation. Operation is contraindicated in the presence of this condition.

**Paget's disease (osteitis deformans)**

Woodhouse (1973) estimated that about 750,000 people have this disease in the UK and that the temporal bone is involved in about 50% of those with clinical evidence of the disease. Paget's disease rarely gives rise to conductive deafness but, if it occurs, it usually starts after the age of 45 years. In the early stages, there is a conductive type of loss associated with a high tone sensorineural loss (see Chapter 15).

The cause of the conductive deafness is ossicular fixation, mainly of the malleus head. As there is no histological evidence of stapedial fixation, the operation of stapedectomy is not logical, although ossicular mobilization may cause temporary improvement in hearing for a few years before the sensorineural deafness neutralizes the hearing gain.

**Osteogenesis imperfecta**

* (fragilitas osseum, van der Hoeve's and de Kleyn's syndromes)

This is a rare disease belonging to a group of hereditary disorders of collagen. The otological features of osteogenesis imperfecta are a progressive conductive and sensorineural deafness, the absence of a Schwartz sign and the absence of vertigo. Tympanometry shows absence of the acoustic reflex with a very high compliance value.

The deafness of osteogenesis imperfecta may be treated by stapedectomy but operation must be delayed until all spontaneous fractures have ceased. A high incidence of floating footplate has been found at operation and increased likelihood of sensorineural deafness occurs after surgery for this condition.

**Sensorineural deafness**

Although pure cochlear otosclerosis is now recognized as a clinical entity by an increasing number of otologists, there are many who remain sceptical about it and the incidence of this manifestation is unknown, and diagnosis is difficult (Schuknecht, 1983).

Progressive sensorineural hearing loss may be the result of one of the rare classified dominant inner ear diseases such as Alport's syndrome, or Norrie's disease, and deafness in retinitis pigmentosa may present in adolescence or early adult life, but in a large number, no definitive diagnosis can be made.
In the present state of our knowledge, it is not possible to exclude otosclerosis as a cause of the sensorineural deafness in some of the patients in this unclassified group.

Otosclerosis can lead to a very severe hearing loss and it must be differentiated from late syphilis of the temporal bone, Ménière's disease and unrecognized ototoxicity.

**Treatment of otosclerosis**

The majority of patients with otosclerotic deafness can be helped by surgical or non-surgical methods and with the improvements in the design and construction of hearing aids, there are few that cannot be given some help.

**Medical treatment**

**The place of fluoride treatment**

In 1964, Shambaugh and Scott suggested that sodium fluoride, in moderate doses, might promote recalcification and reduce bone remodelling in an actively expanding otosclerotic lesion. In the human subject, fluoride is most effective on the active focus and less so on the mature lesion.

Otosclerotic foci show a tendency to be more active in young persons and less active in older people, although all stages can be found at any age. It should be appreciated that a mature focus can become active again and this may be the result of hormonal activity such as pregnancy, puberty or the menopause. The natural tendency for the active lesion in otosclerosis to become recalcified is inconstant and may be feeble. Shambaugh believed that sodium fluoride, in moderate doses, assists this natural tendency of the focus to become recalcified and inactive, and the evidence in favour of this is given as: fading of the injection of the mucous membrane over an active focus (Schwartze sign); stabilization of the progressive sensorineural deafness which is so often found in otosclerosis; reduction of tinnitus; improvement of mild vestibular symptoms; and X-ray demonstration of recalcification of the focus. Bretlau et al (1985) reported on an experimental and clinical evaluation of sodium fluoride treatment. The results showed that using the calcium/phosphorus ratio as an indication for bone maturity, sodium fluoride could stabilize otospongiotic lesions in retaining calcium relative to phosphorus. The results supported the view that sodium fluoride can change otospongiotic, active lesions to more dense, inactive otosclerotic lesions.

Fluoride is a trace element found in widely varying concentrations of ground water, that is between 0.1 and 16 parts per million. Some local authorities add fluoride to the drinking water to bring the concentration to one part per million and this has proved to be very beneficial in the prevention of dental caries in school children. Bernstein, Sadowsky and Hagstead (1966) studied the incidence of osteoporosis in rural communities in North Dakota, where the farming population remained in the area for a lifetime, and it was found that where there was an abnormally low fluoride content in the drinking water, osteoporosis was four times more common than in areas with a high content. A similar study of otosclerosis by Daniel (1969) showed that stapedial fixation was four times as high in the low area compared with that in the high fluoride area.
Gristwood (1966a), in Australia, reported on the unusually high incidence of the truly obliterated footplate, and it has been the experience of most Australian otologists, that the incidence of the thick and obliterated footplate is in the region of 30%. Gristwood and Venables (1975) have pointed out that the surface water in the most densely populates areas of South Australia is deficient in fluoride ions and it was not until 1971 that fluoridation of metropolitan water supplies was commenced.

**Action of fluoride**

Fluoride reduces osteoclastic bone resorption and increases osteoblastic bone formation. The work of Causse and Chevance (1973) suggested, in addition, that in otosclerosis fluorides have an antienzymatic action on proteolytic enzymes which are cytotoxic to the cochlea and produce sensorineural deafness. In a series of over 4000 patients treated with fluorides, in Chicago, USA and Béziers, France, very few have experienced improvement of the sensorineural element of their deafness, but it has become stabilized in over 80%.

**Indications for sodium fluoride therapy**

Sodium fluoride therapy is indicated in the following groups of patients (Shambaugh and Scott, 1964):

1. patients with surgically confirmed otosclerosis who show progressive sensorineural deafness disproportionate to age
2. patients with pure sensorineural deafness whose family history, age of onset, audiometric pattern and good auditory discrimination indicate the possibility of cochlear otosclerosis
3. patients with radiological demonstration by polytomography of spongiotic changes in the cochlear capsule
4. patients with a positive Schwartze sign.

**Preoperative treatment**

When the patient has an otosclerotic focus which shows activity, as evidenced by a positive Schwartz sign, progressive sensorineural hearing loss, and radiological evidence of a demineralized focus in the cochlear capsule, both Shambaugh and Causse believed that a substantial reduction in vascularity and remodelling of the focus will result from fluoride treatment.

**Postoperative treatment**

If patients are found to have an active focus at operation, fluoride therapy is prescribed for 2 years or longer (Cause and Causse, 1979).
**Contraindications to sodium fluoride therapy**

Sodium fluoride therapy is contraindicated in the following groups of patients:

1. patients with chronic nephritis with nitrogen retention
2. patients with chronic rheumatoid arthritis
3. patients who are pregnant or lactating
4. in children before full skeletal growth has been completed
5. patients who show an allergy, as demonstrated by an itching rash
6. patients with skeletal fluorosis. This is a rare condition seen in certain areas of India.

**Dosage and administration of sodium fluoride**

When there is evidence of an active lesion, a daily dose of sodium fluoride of 50 mg is given for 2 years and this can be increased to 75 mg daily in very active cases with a positive Schwartze sign. When there is evidence of stabilization of hearing, fading of the Schwartze sign, and radiological signs of recalcification of the focus, a daily maintenance dose of 25 mg is given for the rest of the patient's life. In the UK, enteric coated capsules of 20 mg are available and may be supplemented with calcium and vitamin D (BPC).

**Adverse effects of sodium fluoride therapy**

Gastric disturbance is the most common side-effect which is largely prevented by taking enteric coated capsules of sodium fluoride after meals. Patients with a peptic ulcer may complain of a flare up of their symptoms and the treatment must be stopped. An increase of joint symptoms may occur in those with chronic arthritis. A return to the previous state is rapid after cessation of treatment.

There is the remove possibility of skeletal fluorosis being produced and a skeletal survey should be made at the beginning of treatment, and repeated at intervals.

There is still a widespread prejudice and almost an emotional dislike of fluoride therapy by many members of the medical profession, which is not justified and is the result of ignorance about the facts of this form of treatment. At the present time, fluoride therapy is the only known method of promoting recalcification and inactivation of an actively expanding focus of otosclerosis. There is also evidence that sensorineural deafness may be stabilized or even improved in patients who receive fluoride medication.

**Hearing aids**

The modern transistorized hearing aid with an air conduction receiver gives good results in the great majority of patients with otosclerotic deafness and a bone conduction aid
is rarely prescribed, but may be of value in those with bilateral fenestration cavities. Auditory training and rehabilitation are helpful and those with poor discrimination and severe hearing loss should be advised to have instruction in lip reading.

Many patients prefer natural hearing to the use of a hearing aid and there is evidence that stapedectomy may reduce the rate of cochlear dysfunction which affects all patients with otosclerosis and although surgery is the best method of treatment for otosclerosis if it is successful, there is a high price to pay in the event of failure.

**Surgical treatment**

**Historical**

It is interesting to remember that although the first attempt at mobilization of the stapes was carried out over 100 years ago, it was not until 1958 that John Shea, in Memphis, described the operation of stapedectomy.

The first operation of stapedectomy was carried out by Jack of Boston, Massachusetts, in 1891. He undertook an operation for the removal of the drumhead, malleus and incus, as advocated by Kessel in 1878 for cases of chronic sepsis. During the operation, he found the stapes to be carious and removed this also. In the morning after the operation, the patient informed him that she heard sounds 'never heard before'.

It was unfortunate that, in other hands, stapedectomy proved to be dangerous and was strongly condemned by leading authorities of the time, including Politzer, who have his enormous authority to cautioning against such a procedure and it was not until 1958 that John Shea had the courage to try again and established the modern operation of stapedectomy on a proper footing.

The next stage in the surgical treatment of otosclerosis was concerned with the establishment of an indirect method that allowed the inner ear fluids to move again, under the influence of sound stimuli. The fenestration operation started around 1914 by Jenkins, was developed by Holmgren (1923), Barany (1924) and Sourdille (1930) and later by Lempert (1938); it lasted until 1952 when the operation of mobilization of the stapes was described by Rosen in New York. Early results were good but refixation was common and stapedectomy replaced the mobilization operation. In 1958, Shea introduced the modern operation of stapedectomy which is the basis of all the operations which have been developed since that time. Shea's contribution to the surgery of otosclerosis was monumental and he is rightly regarded as the originator of modern surgery for otosclerosis.

**Indications for surgery**

The majority of patients with a conductive deafness caused by otosclerosis can be treated by stapedectomy and, in general, a patient who will benefit from an operation will also hear satisfactorily with a hearing aid.

The average patient with otosclerosis and a bone conduction level of 0-25 db in the speech range, and an air conduction of 45-65 db, is a suitable candidate for surgery (Goodhill,
1979). The air bone gap should be at least 15 dB and there should be a speech discrimination score of 60% or more for a good hearing improvement.

In the era of fenestration surgery, patients with very severe hearing losses were not suitable for operative treatment, but with the advent of stapedectomy this is no longer the case and patients with hearing losses in the 90-100 dB range and no measurable cochlear reserve on speech discrimination, may still be suitable for operative treatment to enable them to use a hearing aid which was previously of no help. This last group of patients, although small, is the only one where operative treatment is essential as there is no alternative method available. 'The ultimate aim is restoration of available cochlear function, even though this may not carry with it the possibility of unaided hearing' (Goodhill, 1979).

Contraindications to surgery

Morrison (1979) listed 16 contraindications to operation in otosclerosis:

1. The presence of general medical disease when the patient is unfit for surgery, or where the expectation of life is limited.

2. Old age; in those over the age of 70 years there is a 40% chance of discrimination becoming worse, and the risk of fistula formation is greater in the older age group. Unless there is some special reason for operation, a hearing aid should be advised.

3. Most surgeons would not advise operation in children, but Robinson (1983) and von Haacke (1985) have reported good results in young people between the ages of 16 and 21 years.

4. In conductive losses from other causes, the stapes should not be touched. This applies particularly to stapes fixation caused by tympanosclerosis as stapedectomy carries with it a high incidence of sensorineural loss.

5. If other conditions are present, such as otitis externa, or a perforation, stapedectomy is contraindicated until they have been successfully treated.

6. If there is early fixation with a small degree of hearing loss, operation is probably not necessary, although some surgeons might consider stapes mobilization in such cases.

7. In unilateral otosclerosis, surgery may not be necessary, but many patients find loss of binaural hearing a great handicap, and in these cases operation is justified.

8. If the patient has only one hearing ear, operation is not justified unless a hearing aid does not give relief.

9. In stapedial and cochlear otosclerosis, with a poor air-bone gap, operation is not advised if a hearing aid can be used.
(10) The presence of vertigo and clinical evidence of labyrinthine hydrops is a contraindication to operation as there is an increased risk of a 'dead ear' from damage to a distended saccule during operation.

(11) Morrison is of the opinion that revision stapedectomy is dangerous because fine adhesions may exist between the footplate area and the saccule or cochlear duct. If the small fenestra operation is carried out, this criticism does not apply and good results are possible in the hands of the expert.

(12) Second ear stapedectomy is still controversial because of the risk of immediate and delayed sensorineural hearing loss which, in rare cases, can be bilateral. Vestibular damage can occur with permanent loss of coordination. The advantages of bilateral stapedectomy, if it is successful, are the restoration of binaural hearing and the ability to localize the direction from which sound is coming. The majority of surgeons in North America who are specialist 'otosclerosis' surgeons carry out bilateral operations if the criteria are right, and in specialist clinics in Europe this is also the case (Causse and Causse, 1980). Many surgeons, and especially those who do not specialize in the surgical treatment of otosclerosis, feel that the patient should be allowed the safeguard of being able to wear a hearing aid, if necessary in the second ear and, in the UK, bilateral stapedectomy is becoming less common than in the past.

(13) In the young adult with a rapidly spreading stapedial and cochlear otosclerosis and a positive Schwartze sign, surgery should be delayed until the activity is controlled by fluorides.

(14) Stapedectomy is contraindicated in pregnancy, an operation should be delayed for 12 months after parturition.

(15) Stapedectomy may be inadvisable on those whose occupations demand considerable physical strain, in those engaged in sport and in airmen, especially those flying small unpessurized aircraft, as there is an increased risk of perilymph fistula.

(16) If there is evidence of poor eustachian tube function in one ear, detected by tympanometry, and there is bilateral otosclerosis, it is advisable to operate on the ear with normal atmospheric middle ear pressure rather than the poorer hearing ear.

**Preoperative counselling of the patient**

As there is an alternative method of treatment, a hearing aid, which in most cases is satisfactory, it is essential to explain to the patient the advantages and possible disadvantages of surgery. In a suitable case there is at least an 85% chance of obtaining a good hearing improvement. About 10% gain only slight improvement of hearing and the remaining 5% may expect some degree of sensorineural loss after operation, which may become total in perhaps 2% (Shea, 19850. It should be explained to the patient that the operated ear may fail after an initially good result, and this can occur many years later. Slight vertigo, for a few weeks after operation is common, and a transient weakness of the facial muscles can occur. If bilateral stapedectomy is carried out the possibility of alteration of taste from chorda tympani damage must be mentioned. The patient must be warned against violent nose blowing at all times, as
this can lead to a fistula. Flying is contraindicated for 2 weeks after surgery and strenuous exercise, or the lifting of heavy weights, must also be avoided for a similar period.

The surgeon who does not tell the patient of the possible risks of operative treatment is, today, likely to become involved in medicolegal problems.

**Surgical technique**

The technique of operation is fully described elsewhere (Schuknecht, 1971; Beales, 19810 and the figure shows the various types of operations performed today.

The surgeon will use the technique which he has found to be the most satisfactory. A prosthesis is most commonly used for the reconstruction of the ossicular chain and that made from Teflon is the most widely employed. Some surgeons use a stainless steel piston, while others, a wire prosthesis - the 'Schuknecht method'. A few surgeons avoid the use of a prosthesis by using the crura of the stapes which remain after the footplate has been removed or fenestrated. This latter method is not always technically possible and long-term results are not as satisfactory as those obtained by the use of a prosthesis.

In recent years, it has been shown that the risks of damage to the internal ear at operation and the long-term risk of perilymph fistula is less if a small fenestra is made in the posterior part of the footplate (Marquet, Creten and van Camp, 1972; Marquet, 1983, 1985).

**Small fenestra stapedectomy**

Marquet claimed that this method has the following advantages:

1. The fine instruments used with this technique prevent the risk of tearing of the mucous membrane of the structures of the vestibule.

2. The calibrated hole in the centre of the footplate, avoids rupture of the annular ligament, and so the vestibular endothelium is not disturbed and the contents of the vestibule are undamaged.

3. The prosthesis does not penetrate more than 0.1 mm into the vestibule and this avoids the risk of tearing, or irritation, of the underlying membranous structures. The growth of the vestibular endothelium beneath the lower end of the prosthesis is rapid and is guided by the meniscus of the perilymph. The inner ear is sealed rapidly from the middle ear as an extremely small opening has been made which is closed by the end of the piston.

4. The small curvature of the meniscus of perilymph prevents the entry of waste particles of bone, which in any case are very small.

5. The piston is firmly held in position at both ends, no pendulum movement can take place and the tip remains in the centre of the footplate perpendicular to it.
Vein graft-Teflon piston interposition operation

This method has been used in the Causse clinic in Béziers, France, since 1962 and over 20,000 operations have been performed by this technique which is a combination of the vein graft stapedectomy and Teflon piston technique (Causse, 1964; Causse and Causse, 1984). The advantages claimed for this modification of the Shea Teflon piston operation are:

1. Immediate closure of the oval window fenestra with no risk of the Teflon piston being manipulated in the open window, or dropped into it, when attempts are made to place it in position.

2. The tip of the piston is protected by soft tissue and this is an additional safeguard for the underlying membranous structures in the vestibule.

3. The strong seal over the oval window fenestra leads to a reduced tendency for perilymph fistula.

4. A further advantage is that an immediate seal of the window is obtained making it possible to monitor the progress of the patient more accurately than with other methods which produce a fistula and rely on spontaneously healing for it to close. Postoperative audiograms in the latter case do not give useful information for some time, and so immediate postoperative monitoring of the patient is of little value.

Large fenestra stapedectomy: wire and fat graft

The Schuknecht operation is described in detail in the monograph *Stapedectomy* (Schuknecht, 1971). This has proved to be a satisfactory procedure and it is used by many surgeons today (McGee, 1969).

The advantages of the large fenestra operation are that it is relatively easy to carry out in most cases, an immediate seal of the oval window is obtained by the fat graft, and the use of a stainless steel wire prosthesis makes accurate placement of the graft possible.

The disadvantages of the procedure are that removal of the whole or greater part of the footplate is a more traumatic procedure, and that there is an increased risk of damage to the underlying membranous structures in the vestibule; the incus is left bare with a diminished blood supply and a greater risk of necrosis and if the wire is crimped too tightly, the terminal portion of the long process may be damaged.

Schuknecht has shown, by post-mortem studies, that after some operations the wire wanders to the edge of the oval window and conductive loss develops. The rare complication of a granuloma of the oval window can occur after this procedure.

Use of the argon laser in stapedectomy

The potential value of the laser in middle ear surgery is considerable, since there is elimination of mechanical trauma, tremendous accuracy and reduction of bleeding. The CO₂
laser, used in other branches of otolaryngology, cannot be used for operations on the middle ear as it gives rise to inner ear damage.

Perkins (1980) using a laser focal spot size of 50-100 microns, makes multiple small holes in a rosetta fashion around the perimeter of the desired aperture and the central bone is removed with special superfine 45° pick. An aperture slightly larger than 0.6 mm is made in the footplate to accommodate the wire piston assembly, covered with a thin graft of autologous vein. If no vein is used, there is less difficulty in placing the prosthesis into the fenestra. McGee (1983) and Portmann (1983) have reported their results with the argon laser in stapedectomy.

This new method makes it possible to create a small fenestra without significantly fracturing the footplate and it should eliminate the problem of the floating footplate.

Problems found at operation

Although many stapedectomy operations are straightforward and present little technical difficulty, anatomical and pathological variations can be encountered which may present great difficulty, and while the experienced surgeon may be able to overcome them with a successful result, the less experienced may be wiser to abandon the operation.

The most common abnormalities are discussed below.

Abnormalities of the facial nerve

Dehiscences of the facial nerve are not uncommon and in about 0.5% of middle ears there is a sizeable dehiscence, so that the nerve bulges down and obscures the arch and footplate. In some cases, it is possible to displace the nerve upwards and complete the operation, but if footplate surgery is likely to be blind, it is safer to abandon the operation. Very rarely, the facial nerve takes an anomalous course, either splitting to surround the stapes or coursing inferior to the oval window (Hoogland, 1977).

Persistent stapedial artery

A persistent stapedial artery of sufficient size to prevent the completion of the operation is very rare and is found in 0.2% of operations. A small vestigial vessel is not uncommon and must not be damaged as it can cause troublesome bleeding.

Perilymph flooding

This is a rare complication. Causse and Causse (1980) have only encountered it as occurring six times in more than 20,000 operations, an incidence of 0.0287%. It is seen in an ear with an abnormally patent cochlear aqueduct and polytomography before operation may show an abnormally-shaped vestibule. The complication is more common in ears with congenital fixation of the footplate. If a small safety hole is made in the footplate before the crura are detached, the condition will be detected and it may then be possible to close it by a connective tissue graft placed between the footplate and the crura.
In other cases, it may be possible to seal the 'perilymph gusher' with a soft tissue graft and the prosthesis put into position in an attempt to hold the graft in contact with the oval window. The flow of cerebrospinal fluid may last for several days and a severe sensorineural hearing loss is likely to occur with this complication.

**Floating footplate**

This is a potentially serious complication and may result in a 'dead ear' if attempts are made to extract the footplate, which in some cases becomes hinged on itself, or even disappears from view. A preliminary drill hole in the footplate, before attempts to remove the crural arch are made, is a wise precaution and will often prevent the complication. If the footplate is visible, it may be possible to remove it by manipulation and extraction with a fine hook, or a small drill hole may be made at the margin of the oval window and fine hook used to remove it. If it cannot be removed without excessive manipulation it should be left in place, a soft tissue graft placed over the oval window and the operation abandoned. Some authorities apply a prosthesis from the incus to the floating footplate, if it remains slightly hinged inwards, and good results have been reported from this procedure.

**Depressed footplate, submerged footplate**

This is more common than 'floating footplate'. The footplate may be totally submerged and this is caused by trying to remove a floating footplate, or the posterior part may become submerged when the fixation of the footplate is confined to the anterior part.

No attempt should be made to retrieve the submerged footplate by instruments as this may cause severe cochlear damage. Roche, Wayoff and Moeller (1971) described a method of dealing with this complication, which is not damaging to the contents of the vestibule. Drops of blood are poured laterally into the vestibule and when it is full of blood and a clot has formed, which takes 10-12 minutes, the clot is removed by a lateral application of the sucker bringing the footplate to the surface.

**Presence of blood in the vestibule**

Excessive bleeding during operation is a hazard that many otologists have to face in the UK if they use general anaesthesia as too many anaesthetists do not think that 'hypotensive' anaesthesia is justified in stapedectomy. The benefits of a dry field cannot be overemphasized and if the surgeon cannot persuade his anaesthetist to provide this he would be advised to use local anaesthesia. There is still some disagreement about the possible serious effects of leaking blood into the vestibule. Linthicum and Sheehy (1969) could find no evidence of any detectable ill-effects from this complication, while Smyth and Hassard (1978) believed that labyrinthine trauma from this cause cannot be dismissed. Preoperative fluoride therapy may help in reducing the activity and thus the vascularity of otosclerotic bone.

**Tympanic membrane tear**

If a small tear of the drum is found at the end of the operation and it is only a slit, it is covered with gelatin sponge. A larger tear is closed by rotating the flap and covering it
with gelatin sponge. Healing almost always occurs. If inadequate flaps have been made and this is associated with excessive bone removed, a defect may be formed at the end of the operation and this should be covered with temporalis fascia placed beneath the edge of the drum and on the adjoining meatus.

**Obliterative otosclerosis**

This condition is less common than it used to be. It requires special treatment which is discussed in a later section.

**Damage to the chorda tympani nerve**

During a stapedectomy operation, it is frequently necessary to displace the chorda tympani nerve to gain adequate exposure, and there is controversy concerning the advisability of stretching the nerve or cutting it. It should be appreciated that if the nerve is cut, it will produce permanent loss of sensation of taste in the anterior two-thirds of the tongue on the same side and no re-innervation of the taste buds can take place, either from the chorda tympani nerve of the opposite side or the posterior third of the tongue supplied by the glossopharyngeal nerve. Permanent loss of chorda tympani innervation results in atrophy of the taste receptors in the anterior two-thirds of the tongue; the dorsum of the tongue becomes smooth and pale. The patient may not complain of the loss of taste sensation, if one nerve is cut, as the tongue retains sensation in 66% of its surface (Diamond and Frew, 1979).

If the nerve is stretched during operation, a persistent abnormal sensation in the tongue may occur, described by the patient as salty, or metallic, and this is caused by paraesthesia of this sensory nerve. Cutting the nerve may also produce these unpleasant sensations of taste. If the nerve is displaced but not divided the taste disturbance is less (Bull, 1965; Wiberg, 1971).

Bilateral loss of the chorda tympani nerve produces marked symptoms in the majority of patients and, in addition to the loss of taste, there is loss of the secretomotor supply to the submandibular and sublingual salivary glands which produces an uncomfortable dry mouth. If at all possible, the surgeon must preserve the chorda tympani nerve, and this is essential in bilateral operations.

**Obliterative otosclerosis**

Special considerations of technique must be applied to the massive otosclerotic focus filling in and obliterating the oval window as the early attempts to drill out the oval window were accompanied by a high incidence of sensorineural deafness and reclosure of the oval window by regrowth of otosclerotic bone (House, 1962; Schuknecht, 1963; Shea and Sanabira, 1963).

Gristwood (1966b) reported an unusually high incidence of the truly obliterated footplate seen in 350 consecutive operations for otosclerosis. It has been the experience of Gristwood and other Australian otologists that the incidence of the thick footplate in Souther Australia is not known, but it is thought that the deficiency of fluoride ions in the drinking water and the late fluoridation of water supplies, which was not started until 1971,
metropolitan areas, may be a factor. The most common finding was that about 50% of those with a thick and obliterated footplate developed their hearing loss during childhood or adolescence, and 80% of this group had noticed some hearing impairment before the age of 25 years. It was also found that the obliterated case could not be identified before operation by audiometry and that the condition was rarely unilateral.

Gristwood described three varieties of obliterative oval window otosclerosis.

**Truly obliterated footplate**

In this condition, the stapes footplate is replaced by a massive otosclerotic focus that fills in the oval window niche. The rim of the footplate cannot be identified and the crura of the stapes may be buried.

**Solid partly-obliterated footplate**

The footplate was found to be diffusely and greatly thickened, but a rim of delineation, often spurious, could be seen over a small segment of its circumference, the remainder of the margin being obliterated.

**Solid spuriously delineated footplate**

This is a rare type in which a complete gutter of delineation surrounds an apparently thick solid footplate. The spurious nature of the delineation is only revealed when attempts to remove either half of the footplate fail because of the obliteration deeper in.

**Solid delineated footplate**

This is the thick biscuit or rice grain footplate which, although diffusely thickened, retains a delineated rim and an intact annular ligament. This type of footplate may be firmly wedged in the oval window and it can be pushed into the vestibule during operation giving rise to a 'floating footplate'.

**Narrowed oval window niche**

Otosclerotic foci around the oval window may lead to a marked narrowing of the niche which produces a slit-like effect at the oval window. Attempts to remove the footplate or make a fenestra within it should not be made until the overhanging bone has been removed and the footplate can be seen.

**Sensorineural deafness in otosclerosis**

Sensorineural deafness is frequently associated with the conductive hearing loss of otosclerosis, but there is still argument about the exact mechanism by which it occurs. There is controversy about the concept of 'cochlear otosclerosis' which is a sensorineural hearing loss caused by otosclerosis of the labyrinth in the absence of stapes fixation. Shambaugh (1965), Derlacki and Valvassori (1965) and Balle and Linthicum (1985) have produced strong arguments for supporting the theory of cochlear otosclerosis while, on the other hand, Gross
(1969), and Schuknecht and Kirschner (1974), and Schuknecht (1983) have failed to show otosclerotic foci of significant size or incidence in the temporal bones of patients with pure sensorineural deafness of unknown cause.

The possible causes of the cochlear degeneration seen in otosclerosis are:

1. bony invasion of the scala tympani of the cochlea (Politzer, 1894)

2. circulatory changes in the cochlea as a result of abnormal bony foci (Mayer, 1911; Ruedi, 1965)

3. damage to the cochlea by toxic metabolites from abnormal bone (Siebenmann, 1912; Witmaack, 1919; Chevance et al, 1970).

**Bony invasion of the scala tympani of the cochlea**

In the very early descriptions of the disease by Politzer (1894), Habermann (1904) and Siebenmann (1912), sporadic cases are mentioned showing bone formation in the scala tympani which were thought to be caused by otosclerosis. In 1921, Lange found the scala tympani to be partially filled with newly formed bone tissue into which the otosclerotic process of the labyrinthine wall had penetrated.

Nager and Fraser (1938), in their paper on bone formation in the scala tympani in otosclerosis, stated that the main change occurs in the labyrinthine capsule with the inner ear showing only minor alterations. After the examination of a large number of temporal bones, they found that in rare cases there was extensive bone formation in the scala tympani, and in the more advanced cases it was almost filled with new bone. They believed that the cause of this in the scala tympani was the result of the otosclerotic focus in the wall of the labyrinth producing a certain alteration, or irritation, of the endosteal layer and perilymphatic spaces leading to circumscribed fibrosis and bone production. This type of bone formation in the inner ear is found only in otosclerosis, but it is a rare and uncommon cause of the inner ear deafness which is so common in this condition.

**Circulatory changes in the cochlea as a result of abnormal bony foci**

Ruedi (1965) re-examined Otto Mayer's theory that venous obstruction caused by invasion of the root of the spiral lamina in the basal turn of the cochlea by otosclerotic bone, gave rise to incompetence of the venous drainage of the anterior and middle spiral veins, leading to neuroepithelial degeneration of the inner ear. Ruedi described how the actively growing otosclerotic focus advanced, giving rise to thrombosis in the vessel adjacent to it. The vessels became walled in, so that a sharp demarcation was apparent between the new vascular channels of the otosclerotic focus and the old vessels of the otic capsule. It was noticed that each focus developed its own self-contained, largely autonomous vascular system, and it was found that a connection between a wide capillary of the old otic capsule and the vascular space of an active otosclerotic focus could develop. When the otosclerotic lesion had penetrated the region of the promontory to appear under the mucous membrane, shunts were often seen between the blood vessels of the otosclerotic deposit and those of the mucosa.
These vascular shunts are well known clinically as the 'flamingo blush' first described by Schwartze, and when seen on examination, are an indication of active otosclerosis.

Ruedi also demonstrated vascular shunts between otosclerotic blood vessels and spiral capillaries, which caused marked congestion in the region of the modiolus and he was of the opinion that the formation of new lamellar bone within the inner ear was caused by this stasis, as opposed to Nager's theory that it was the stimulation of the osteoblastic activity of the endosteal capsule.

Ruedi's final investigation, after establishing the presence of the shunts, was to determine whether the atrophy of the labyrinth could be the result of the disturbances in the inner ear brought about by the otosclerosis. He found, in seven out of 10 temporal bones examined, that the organ of Corti was disintegrated or missing altogether, with a degeneration of the corresponding nerve fibres and ganglion cells. In the majority (six out of seven bones), he detected a shunt in the region of the spiral capillary and the inferior spiral vein. In one of these there was no sign of a venous shunt but an obliterated artery, thought to be the vestibulocochlear, and thrombosis of this accounted for the disintegration of the neuroepithelium and atrophy of the stria vascularis, within the basal turn, seen in the specimen.

Although Ruedi believed that a vascular aetiology accounted for all the inner ear changes seen in otosclerosis, it is only in advanced disease that such abnormalities are seen. The sensorineural hearing loss so common in otosclerosis cannot be explained, in all cases, as being the result of venous congestion alone and his theory is only applicable in some cases.

It is necessary to examine the other theory, of a humoral factor, to explain more satisfactorily the phenomenon of sensorineural degeneration in otosclerosis.

**Damage to the cochlea by toxic metabolites from the abnormal bone**

In 1912, Siebenmann postulated that the abnormal bone of a focus of otosclerosis, which was invading the labyrinth, poured out inflammatory products into the fluid and these contained toxic metabolites which caused the labyrinthine lesions. Witmaak (1919) also assumed that degeneration of the labyrinth was caused by the diffusion into the labyrinthine fluids of an acid liberated by otosclerotic lesions dissolving the bone.

The actively growing deposit of otosclerosis, as it erodes the endosteum, comes into close relationship with the perilymph of the basal scala tympani. Such active foci have a rich blood supply and extensive marrow tissue; the spaces of the latter may communicate directly with the scala tympani, so that the perilymph flows, not only over the otosclerotic bone, but also into the spaces, allowing mixing of their contents.

It is surprising that, until recently, so little attention has been paid to the humoral theory, for there is such a close relationship between the actively growing deposit of otosclerosis and the perilymphatic spaces. In 1958, Harrison and Naftalin formulated a theory of the active circulation of the labyrinthine fluids which suggested that the inner ear damage in otosclerosis is humoral in origin. They believed that perilymph is formed by ultrafiltration from blood vessels in the perilymphatic space. The perilymph, as a result of the hydrostatic
pressure in the general circulatory system, passes across Reissner's membrane and the basilar membrane as a plasma transudate and reaches the scala media. The plasma transudate is then converted into endolymph by a specific process of the stria vascularis, which replaces sodium from the plasma transudate with potassium, by a low energy exchange mechanism analogous to the resorption process of the renal tubules.

If metabolites and other breakdown products of the otosclerotic process were to contaminate the perilymph they could in fact pass across Reissner's membrane and the basilar membrane, with the perilymph, and on reaching the scala media cause damage to the organ of Corti. A simpler explanation of the route of entry of toxic products is through the canaliculi.

In 1970, a research project was undertaken by a biochemist, two histopathologists, an enzymologist and an otologist from three different centres (Paris, Copenhagen and Béziers), which has led to further development of the theory that the inner ear damage in otosclerosis may be humoral in origin (Chevance et al, 1970).

They found that osteoclasts are rarely, and only exceptionally, found in the extension zone of the focus, or in the marrow spaces that constitute the active or otospongotic focus. This confirms the observations of Ogilvie and Hall (1953) who had noted that in the diffuse form of otosclerosis 'the osteoclasts were remarkable for their scarcity, small size with degenerate cytoplasm and nuclei, and loss of direct application to the bone...'. It has been generally believed that these cells are responsible for the entire bony resorption which takes place in the lytic phase of the otosclerotic lesion.

Chevance et al have been able to demonstrate that apart from fibroblasts, fibrocytes, osteoblasts, and osteocytes there is, in addition, a special type of cell, containing lysosomes which are dense vesicular bodies in the cytoplasm. The frequency of this cell, its location and morphology indicated that, in their opinion, it was a histiocyte taking an active part in bone resorption.

These cells were most often found in the 'front' of the otosclerotic process and the bone surrounding them showed the presence of lysis. It is well known that lysosomes contain a number of hydrolases with a very high enzymatic content and the activity of acid phosphatases is generally considered to be the best index of lysosomal content. It was found that the histiocytes exhibited strong acid phosphatase activity and these workers are of the opinion that the histiocytes play the decisive role in the process of otosclerotic resorption.

In addition to the demonstration of the presence of histiocytes in the active focus, otosclerotic microfoci have been found beyond the advancing edge of the lesion, and in these the lytic and rebuilding phases were found to be proceeding simultaneously.

The perilymph of patients subjected to stapedectomy operations, with the presence of otosclerosis confirmed by biopsy, has been examined: six enzymes have been identified: phosphatasic acid, collagenase, alpha-chymotrypsin, lactic dehydrogenase, ribonuclease and trypsin. These enzymes control the evolution of the otosclerotic microfoci and they also pass into the labyrinthine fluids through the cochlear barrier, previously thought to be impassable, entering through the canaliculi.
The actual passage of these enzymes has been demonstrated in a series of perilymph specimens, first studied by Adams' method (Adams and Tuqan, 1961), later by qualitative study and finally by quantitative methods using a microelectrophoretic technique (Uriel and Avrameas, 1964; Uriel, 1971).

Perilymph specimens were studied by multiple statistical analysis and it was found that:

1) proteases or hydrolases enter the labyrinthine fluids in about 75% of cases of otosclerosis and this corresponds to the 75% incidence of cochlear degeneration which is seen in patients with clinical stapedial otosclerosis.

2) statistical correlation have been arrived at by standard tests, and binary and threefold correlations have been established between the proteolytic activity of the perilymph and the progressive sensorineural hearing loss which is seen in 75% of the cases with stapedial fixation from otosclerosis.

A correlation was also seen between the proteolytic activity of the perilymph and impairment of the posterior labyrinth, shown by the torsion swing test and electronystagmography, in patients without clinical symptoms of vertigo.

The enzymatic concept of otosclerosis

The experimental findings of Chevance, Causse and their co-workers have led them to postulate the theory of the enzymatic concept of otosclerosis.

The process begins in one or more of the numerous cartilaginous rests scattered through the enchondral layer of the otic capsule. Hydrolytic enzymes and proteases, causing cellular destruction, spread from the original focus to the different parts of the cochlea. If the focus is close to the stapediovestibular joint the process of bone rebuilding may produce a fixation of the stapes footplate and a conductive hearing loss. If the proteases and proteolytic enzymes reach the inner ear a sensorineural hearing loss occurs, and if the enzymes reach the posterior labyrinth vertigo may be caused. If the focus is situated far from these sites, the disease may never be detected clinically.

It is well recognized that conductive deafness in otosclerosis may exist without substantial hearing loss, but a sensorineural hearing loss that is disproportionate to the age of the patient is commonly associated with the conductive deafness. The sensorineural hearing loss may precede fixation, although it is usually associated with it. It is also recognized that a gradually developing sensorineural deafness occurs in many patients who have had a successful stapedectomy operation, and this also is often disproportionate to the patient's age.

If otosclerosis of the cochlear capsule can cause sensorineural hearing loss when there is stapedial otosclerosis, it can cause sensorineural hearing loss when there is no stapedial fixation and when this occurs, the condition is known as cochlear otosclerosis.
The enzymatic concept of otosclerosis, elaborated by Chevance and Causse and their colleagues, is of considerable interest as it explains many facets of the disease which still remain obscure, and it explains the long, slow and variable progress of the disease.

These workers believe that otosclerosis is a local disease in which there is an upset of the equilibrium between enzymes and antienzymes in the microfoci of otosclerosis and this gives rise to variable clinical results; for example if the focus is stapedial a conductive loss occurs, but if the focus is outside the region of the footplate a sensorineural deafness may result, and if the focus is in the region of the vestibule, vertigo may result. This theory gives strong support to those who believe that medical treatment, by antienzymes or enzyme inhibitors, is important in the treatment of this disease.

The belief that sensorineural hearing loss can occur in a pure form, as the result of otosclerosis without a conductive hearing loss, has been strongly criticized (Schuknecht and Kirschner, 1974; Schuknecht, 1983). The criticism is based entirely on histological examination of temporal bones, is dogmatic, and does little to help in the explanation of the obscure aspects of this disease.

Audiometric studies were carried out by Glorig and Gallo (1962) who compared bone conduction levels of patients with otosclerosis with air conduction levels in the general population. The assumption was made that, because the hearing losses found in the general population are largely sensorineural, the comparisons would be valid. Their results indicated that otosclerosis does not increase the sensorineural hearing loss above that to be expected in the general population and audiometric patterns for higher frequencies, in those with otosclerosis, resemble those found in general populations. In patients over the age of 60 years, it was found that the sensorineural hearing loss in high frequencies was greater in patients with otosclerosis than in the general population. This finding contradicts their conclusions.

Although otologists are in agreement that gross lesions cause sensorineural deafness in otosclerosis by direct invasion of the scala tympani of the cochlea, and gross lesions interfere with the circulation of the stria vascularis and this may also give rise to sensorineural deafness, there is still controversy concerning the humoral theory.

Causse and Chevance have developed the humoral theory, first postulated by Siebenmann in 1912, and their theory of enzymatic concept of otosclerosis is the only one that attempts to explain many of the enigmas of this disease.

**Diagnosis of sensorineural deafness in otosclerosis**

In 1978, Shambaugh pointed out that, before Lempert's fenestration operation for otosclerosis came into general use, few clinicians in North America were able to diagnose stapedial ankylosis caused by otosclerosis. As recently as 1931-1932, not one patient coming to the Massachusetts Eye and Ear Infirmary during those 2 years was diagnosed as having otosclerosis. He believes that the situation concerning pure cochlear otosclerosis is similar today in that this diagnosis is denied in some large clinics and is made with hesitation in others.
Shambaugh and Holdermann, in 1926, gave three criteria necessary for the probable diagnosis of cochlear otosclerosis and these were:

(1) an insidious onset beginning in early adult life
(2) the absence of any reason for the nerve loss
(3) conductive deafness in other members of the immediate family.

Shambaugh (1966) gave six reasons for suspecting that otosclerosis may be the cause in cases of pure sensorineural deafness:

(1) a positive Schwartze sign, in one or both ears
(2) a family history of surgically confirmed stapedial otosclerosis
(3) the presence of symmetrical sensorineural hearing loss in both ears, one of which has stapes fixation
(4) a flat, rising, or a 'cookie-bite' audiometric air conduction curve with unusually good speech discrimination for someone with a pure sensorineural loss
(5) pure sensorineural hearing loss beginning insidiously in early, or middle, adult life and progressing with no apparent cause
(6) the demonstration of stapes fixation in a patient with previous pure sensorineural deafness of no apparent cause.

Causse, Shambaugh and Chevance (1977) have described three categories of diagnostic criteria for making a diagnosis of cochlear otosclerosis.

**Criteria of presumption**

There is a slowly progressive hearing loss in childhood of a sensorineural type which becomes worse at puberty, or at period of endocrine activity, in a family with a history of a progressive sensorineural hearing loss.

If a sensorineural hearing loss is aggravated in a woman by pregnancy, the menopause, or by treatment with oestrogens.

If there is good discrimination for speech in a patient with sensorineural deafness using a hearing aid and especially if there is good discrimination in noisy surroundings.

**Criteria of probability**

If there is a positive Schwartz sign in one or both ears, if the audiogram shows a sensorineural loss with a 'cookie-bite' curve and if there are positive polytomographic findings in the cochlear capsule.
Criteria of certainty

If, in a case of progressive sensorineural deafness, there develops an 'on-off' impedance effect or diphasic impedance change indicating impending fixation of the stapes and if, in a case of slowly progressive pure sensorineural deafness, the beginning of an air bone gap develops.

Kelemen and Linthicum (1969) found that severe sensorineural hearing loss was usually associated with extensive invasion of the cochlear capsule by otospongiotic bone, but mild degrees of sensorineural hearing loss were associated with lesser foci which did not always reach the cochlear endosteum.

Radiological demonstration of cochlear otosclerosis

Conventional radiography is of little value in the diagnosis of otosclerosis and linear tomography does not give adequate information about the very small structures in the temporal bone. Multidirectional hypocycloidal polytomography is of considerable value and Derlacki and Valvassori (19650 have developed this technique.

It is necessary for the lesion to be greater than 1 mm for it to be visible and the density of the focus must be different from that of the normal capsule for it to be detected. The normal capsule of the labyrinth is the densest bone and cannot become more sclerotic, but it can become thicker when mature otosclerotic bone increases the thickness of the capsule, which then appears roughened, or scalloped on its edges caused by the irregular outline of the new bone. Derlacki and Valvassori have shown that capsular changes can be demonstrated in 65% of patients with confirmed stapedial otosclerosis and in 30% of patients with clinical findings suggestive of cochlear otosclerosis.

Applebaum and Shambaugh (1978) stated that: 'Caution must be exercised in the interpretation of subtle polytomographic changes in the cochlear capsule and restraint used in the X-ray diagnosis of pure cochlear otosclerosis until there is evidence of correlation with pathological material'.

High resolution computerized tomography

This method has proved to be valuable in assessing the pathology and extent of chronic suppurative otitis media, and precise information concerning the normal anatomy of the ossicles, facial nerve, tegmen and semicircular canals. It is of value in the differential diagnosis of a conductive deafness as it will reveal, for example an interrupted ossicular chain from a lesion of the incus. With improvements in technique, this method may prove to be of value in the study of labyrinthine otosclerosis (de Groot, 1985).

The perilymph fistula after stapedectomy

This is a serious complication as it is potentially dangerous from the risk of meningitis and it gives rise to hearing loss which will progress if the fistula does not close, either by spontaneous healing, or as the result of a revision operation.
The signs and symptoms of perilymph fistula were first described by Lewis (1961) and by Farrior (1962), and the complication, at one time thought to be unusual, is now accepted as being the most common single complication of stapedectomy.

Fistulae occur after all operations on the stapes footplate and Table 14.2 shows the incidence with various types of operation from a survey of a considerable number of operations which were carried out by Harrison, Shambaugh and Derlacki in 1970.

**Table 14.2. Symptoms and findings**

<table>
<thead>
<tr>
<th></th>
<th>Primary fistulae</th>
<th>Secondary fistulae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dysequilibrium</td>
<td>77%</td>
<td>61%</td>
</tr>
<tr>
<td>Hearing loss</td>
<td>71%</td>
<td>78%</td>
</tr>
<tr>
<td>Tinnitus</td>
<td>45%</td>
<td>44%</td>
</tr>
<tr>
<td>Fluctuating hearing</td>
<td>42%</td>
<td>83%</td>
</tr>
<tr>
<td>Discrimination loss</td>
<td></td>
<td>72%</td>
</tr>
</tbody>
</table>

(Reproduced from Moon (1970) by kind permission of the Editor of *The Laryngoscope*)

**Diagnosis of perilymph fistula**

The symptoms of a perilymph fistula are a fluctuating hearing loss, tinnitus, a feeling of fullness in the ear and vertigo. The symptoms are those of labyrinthine hydrops, which this condition can simulate.

The fistula may be primary, dating from the time of operation when there is failure of the seal of the oval window, or it may be secondary, when it can appear many months or even years after the original operation.

**Primary perilymph fistula**

When the opening, created by the surgeon in the oval window region, fails to heal after the operation, a disturbance of equilibrium persists in the days and weeks after operation, until vestibular paralysis and compensation occurs. In other patients, there may be brief periods of vertigo continuing over a long period.

**Secondary perilymph fistula**

The characteristic symptom of secondary perilymph fistula is a change of hearing coming on after an interval, which may be months or years after a successful operation; associated with this are feelings of fullness, tinnitus and dysequilibrium. There may be
considerable variation in the symptoms but a conductive deafness may be the early sign of a fistula and this may precede a serious irreversible labyrinthine lesion (Goodhill, 1979).

The symptoms and findings in a review of 49 cases of perilymph fistula are given in Table 14.3 (Moon, 1970). Sometimes the patient may give a history of symptoms developing after an incidence such as severe nose blowing, strenuous exercise or flying in an unpressurized aircraft, but often no precipitating factor may present and the patient may not seek advice until there is a considerable degree of sensorineural deafness.

Table 14.3. Hearing loss

<table>
<thead>
<tr>
<th></th>
<th>Primary fistula</th>
<th>Secondary fistula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensorineural</td>
<td>16 (52%)</td>
<td>7 (39%)</td>
</tr>
<tr>
<td>Mixed</td>
<td>13 (42%)</td>
<td>5 (28%)</td>
</tr>
<tr>
<td>Conduction</td>
<td>2 (6%)</td>
<td>3 (17%)</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>3 (17%)</td>
</tr>
<tr>
<td></td>
<td>31</td>
<td>18</td>
</tr>
</tbody>
</table>

(Reproduced from Moon (1970) by kind permission of the editor of The Laryngoscope)

Clinical findings in perilymph fistula

The clinical examination of the ear is usually normal, rarely the tympanic membrane may be retracted or there is evidence of fluid in the middle ear.

Audiometric tests

Hearing tests carried out soon after the onset of a fistula will show findings similar to those seen in labyrinthine hydrops, that is a pure tone sensorineural hearing loss, in the low frequencies initially, followed by a flat loss which fluctuates. There may be recruitment and short increment sensitivity index (SISI) scores are often above 75%. In the early stages, discrimination scores fluctuate with the pure tone threshold, but later they may be disproportionately lower than expected when compared with the stapedius reflex threshold. In some cases, and particularly when vertigo is the main complaint with little or no depression of pure tone levels, there may be a markedly diminished speech discrimination score. It has already been pointed out that a variable conductive loss may occur without a sensorineural component, and this is characteristic of the 'slipped strut', an early technique now seldom performed.

Vestibular tests

Hallpike caloric test

The characteristic finding is canal paresis, or hypoactive response, and this may be present at an early stage of the condition. It must be appreciated that after stapedectomy there
is a high incidence of diminished caloric response and so the significance of the caloric test
is difficult to evaluate and of little value in the diagnosis of a fistula.

Electronystagmography

Electronystagmography may reveal a directional fixed positional nystagmus but this
cannot be relied upon as an indication of a fistula.

Fistula test

Fistula test with the pneumatic otoscope may be helpful but have been found to be
negative in one-third of cases. The negative pressure fistula test with electronystagmography
produces nystagmus with the quick phase away from the affected ear. Fistula test with
electronystagmography and the impedance bridge have superseded the older methods as they
give a higher degree of accuracy.

Diagnosis of perilymph fistula using
electronystagmography and impedance bridge

If tympanometry is carried out after normal stapedectomy with the opening into the
oval window sealed, the change of pressure will usually produce nystagmus which can be
detected on the electronystagmographic tracing. The changes of pressure produced by
tympanometry, if a fistula is present, do not lead to corresponding pressure changes in the
vestibule of the inner ear as the perilymph leaks through the fistula and so there is no
nystagmus.

Daspit, Churchill and Linthicum (1980) have found the electronystagmographic fistula
test to be the most valuable and positive of all the tests. They used the Madsen impedance
bridge; the canal (probe) ear pressure was increased to + 200 mm H₂O, held at this level for
15 seconds and then rapidly decreased to - 400 mm H₂O. An electronystagmographic
recording was made throughout this procedure, which was repeated two or three times, with
a visual inspection for rotatory nystagmus; the patient was also asked if there was any feeling
of giddiness, or any condition similar to the symptoms that had been experienced. The fistula
test was considered to be positive if nystagmus was elicited, especially in the absence of
spontaneous nystagmus.

When a positive result was obtained, a similar procedure was performed on the other
ear together with a routine test of positional nystagmus which, if present, could influence the
test results. All recordings were carried out with eyelids closed.

Safety of the test

The pressures used in impedance measurements were compared with those used in
pneumatic otoscopy where a positive pressure as high as + 300 mm H₂O and as low as - 600
mm H₂O could be obtained. These levels exceeded any that were used with the impedance
bridge and it was considered that the test was a safe procedure.
Results of electronystagmographic fistula test

Daspit, Churchill and Linthicum (1980) reported that the electronystagmographic fistula test is of considerable value, with a degree of accuracy greater than the fistula test with pneumatic otoscopy. Caloric tests, tragal compression and a Valsalva manoeuvre were found to be of little value in the diagnosis of perilymph fistula.

Aetiology of perilymph fistula

Primary fistula

The surgeon creates a fistula at every stapedectomy operation and relies on the natural process of healing, or in some techniques a graft of soft tissue, to seal the opening which has been made into the vestibule. In most operations, there is enough surgical trauma to the oval window mucoperiosteum to lead to the production of an inflammatory repair envelope around the prosthesis sealing the opening into the oval window. Fistulae are more common with plastic prostheses than with interposition techniques; however, the hearing results using prostheses are better.

There is no doubt that a small fistula remains after many stapedectomy operations with incomplete closure of the air bone gap and the hearing result may be acceptable to the patient. Although perilymph fistulae usually lead to a sensorineural hearing loss this is not always the case and a persisting conductive loss after an operation, which appeared to be satisfactory at the time, should warn the surgeon that there may be a perilymph fistula and a revision operation to close it will be the best line of treatment. It must be appreciated that a small fistula may become larger under the influence of barotrauma; a sensorineural hearing loss will follow and it may then be too late to save the hearing.

Secondary or acquired fistula

Secondary perilymph fistulae are usually the result of barotrauma which breaks the fragile seal and can occur at any time after operation. In most cases, the stapedius tendon has been cut and a sudden change of intratympanic pressure may produce an abnormal movement of the prosthesis, giving rise to a rupture of the oval window seal.

The following case records from the author's practice are examples of fistulae developing after stapedectomy operations.

Case record - secondary perilymph fistula from barotrauma

Female aged 47 years: a stapedectomy-Teflon piston with vein graft had been performed 18 months previously, with a good hearing result. After a severe cold, the patient blew her nose very vigorously and complained of slight vertigo and hearing loss. A revision operation 4 weeks after these symptoms developed revealed a fistula close to the inferior margin of the oval window. The oval window was regrafted with vein, a new Teflon piston placed in position and the hearing was partially preserved.
Case record - primary and secondary perilymph fistulae

Female age 49 years: the patient has a stapedectomy with Teflon piston performed by another surgeon one year before she was referred to the author. The operation had produced some hearing gain but incomplete closure of the air-bone gap. Slight vertigo had persisted since the operation and some months later this became worse and the hearing disappeared. When seen she had a severe sensorineural deafness with marked vertigo and loss of vestibular function in the operated ear.

A revision operation showed that the Teflon piston had fallen off the incus and was lying in the vestibule and there were three fistulae visible in the membrane clothing the oval window. As there was no useful hearing and severe vertigo a labyrinthectomy was carried out and the oval window grafted with vein.

This is an example of a primary fistula resulting from a loosely attached Teflon piston and secondary fistulae had also developed. When this piston fell into the vestibule a 'dead ear' resulted and the vestibular system was severely damaged.

This case illustrates the importance of closing a Teflon piston after it has been applied to the incus. If the piston is opened too widely the edge of the 'eye' may be damaged and it may never close properly.

Case record - fistula 20 years after a successful stapedectomy

Male aged 59 years: the patient had a fenestration operation on the left ear in 1952 and a right stapedectomy operation, polyethylene strut and vein graft of the oval window in 1959. The operations were performed by the late Sir Terence Cawthorne and both were successful. In 1979, 20 years after the stapedectomy operation, the patient complained of a small hearing loss and slight vertigo when he carried out yoga exercises.

A revision operation on the right ear revealed that the tip of the polyethylene strut had penetrated the vein graft and there was a slight leak of perilymph. Necrosis of the tip of the long process had occurred, but the strut was still attached to the incus by a strand of mucous membrane. The strut was removed and the oval window regrafted with a vein graft. A slight sensorineural hearing loss resulted from the fistula but the speech frequencies were not affected. The patient did not wish for further surgery and obtained good hearing with an aid.

Prevention of perilymph fistula

The very thin membrane which will develop to close the oval window if fat or gelfoam is used, can be avoided if the oval window is covered with a vein graft. If the greater part of the footplate is removed, not only is there a greater risk of sensorineural deafness being produced by such a traumatic procedure, but there is a greater risk of a fistula developing later.

The small fenestra stapedectomy with or without a soft tissue graft is an advance on techniques where a large opening is made in the footplate.
The interposition operation, when the posterior crus of the stapes is used to make contact with a soft tissue graft closing the opening in the oval window, is the safest technique for prevention of a fistula.

**Eustachian tube function**

Hemenway, Hildyard and Black (1968) found that perilymph fistula accounted for 30% of poor results in a series of 1788 operations and they found that the most common condition present at the onset of symptoms was inadequate eustachian tube function.

They believe that it is most important to question prospective patients about their occupation and to investigate the eustachian tube function. If a patient is a pilot, if his hobby is mountain climbing, ski-ing, water ski-ing or diving, he is advised to wear a hearing aid.

**Advice given to the patient after operation**

It is important to warn the patient who has had a stapedectomy operation that:

1. nose blowing should be avoided and the mouth should be kept open on coughing and sneezing
2. flying or going over a mountain pass should be avoided for at least 10 days after operation, or when an upper respiratory tract infection develops
3. diving when swimming should be avoided
4. lifting heavy objects should be avoided
5. any hearing loss, vertigo or ear infection must be reported immediately.

When eustachian tube dysfunction develops after operation, Hemenway and his colleagues placed ventilation tubes in the tympanic membrane.

**The treatment of perilymph fistula**

The treatment of perilymph fistula is a tympanotomy at the earliest possible moment, with an attempt to close the fistula.

When the leak is detected the fistulous track is excised and the prosthesis removed with great care. The opening in the vestibule is covered with a soft tissue graft which is held in place by another prosthesis. A disadvantage of a two-stage method of closing a fistula is that the graft may float off with a recurrence of the fistula as there is no prosthesis to hold it in place.

All methods of repairing a fistula that have been described, rely on the application of a living graft to close the defect. It would seem logical to believe that if the original stapedectomy had included a graft to seal the oval window there would be fewer postoperative perilymph fistulae.
Results of treatment of fistula of the oval window

Unless early treatment is instituted, the chances of restoration or improvement of hearing are small and in some cases a troublesome vertigo may remain. It is imperative that the surgeon must be fully aware of this complication and realize that some techniques are safer than others. The use of gelfoam to seal the oval window produces a very thin membrane, and gives the highest incidence of fistula formation. Most surgeons have abandoned this technique today. The true small fenestra technique as practised by Marquet, Creten and van Camp (19720 is a safe method and the small fenestra stapedectomy, with vein graft and Teflon piston, as practised by Causse has also proved to be safe.

If the results of treatment of perilymph fistula are to show improvement, early diagnosis and immediate revision surgery are essential.

Revision operations

Conductive deafness may occur after a successful stapedectomy and when a prosthesis has been used, there are four principle causes: necrosis of the tip of the incus; loose attachment between the incus and the prosthesis; detachment of the prosthesis from the incus; and displacement or dislodgement of the prosthesis from the oval window area.

Recurrence of otosclerosis may spread from the anterior footplate area and recurrence of the lesion can lead to a closure of the oval window area even if the whole footplate has been removed. Recurrence of the bony deposit may occur after a stapedioplasty (Portmann interposition) and the author has noticed this in 8% of operations carried out by this method.

Dawes and Curry (1974) described their experiences of 82 revision operations giving special consideration to 50 operations in 44 patients, with a minimum follow-up period of 12 months; operative and postoperative details were known in over 1000 stapedectomy operations. These authors described the causes of failure in the two groups, of immediate and delayed conductive loss, and the results of revision surgery in both.

Immediate

The causes of early failure were found to be incus necrosis and loose fit of the prosthesis; in some cases, no cause could be found. The results of treatment proved to be worthwhile with a success rate of 50%.

Delayed

When the original Shea operation was being carried out, the causes of late conductive deafness were found to be necrosis of the lenticular process of the incus, displacement of the strut and new bone formation. In the piston cases, six losses were due to detachment from the incus and four of 'short piston'. The importance of not overstretching the 'eye' of the piston and closing it over the long process has been mentioned in an earlier section.
Results of treatment of delayed conductive loss

Dawes and Curry (1974) found that the results of revision surgery, after an initial good result from stapedectomy were good, but if a sensorineural deafness is to be prevented, early revision in the period soon after operation must be avoided.

The development of obliterative otosclerosis, or closure of the round window membrane is, in general, a contraindication to further surgery. The exact procedure to be adopted depends on the findings, but Morrison (1979) has stated that re-opening of the vestibule carries a 50% risk of inner ear damage; he has found that it is worthwhile attempting reconstruction of the sound-conducting mechanism after an assembly failure and the experienced operator can obtain success rate in the region of 50%.

Sensorineural deafness after operation

In the majority of cases, hearing loss after stapedectomy is caused by cochlear damage and a sensorineural deafness results. In some cases, the cause is a failure of the linkage system, producing a conductive deafness which is often associated with a sensorineural loss. Treatment of conductive deafness after operation is discussed in the section on revision operations.

Sensorineural deafness after operation may occur in the immediate postoperative period, in the intermediate period weeks or months after operation, or be delayed for months or even years after surgery.

Immediate sensorineural deafness after operation

The reported incidence of severe sensorineural deafness following stapedectomy varies from 0.5 to 4% and it is important to realize that these are the figures from a series of operations by expert surgeons with a special interest in stapedectomy. The results of the occasional operator are not reported and it is likely that the incidence of cochlear damage is much higher when the surgeon is inexperienced.

Smyth and Hassard (1978) reported an incidence of 'dead ear' of 3.5% (713 operations). Morrison (1962, 1979) has shown that in a series of 1000 operations, there was a hearing loss of 4% in the first 50, 2% in the next 50, no immediate losses in the next 500 and 0.25% in the remaining 400 operations.

Causes of hearing loss after operation

The causes of cochlear loss produced by operation are numerous - they are the direct result of trauma of varying types to the inner ear at the time of, or soon after, operation.

All operations involve the possibility of trauma to the inner ear; some techniques are more traumatic than others and the pathology of the lesion will influence this. In addition, a small group of patients is particularly sensitive to the creation of a window in the footplate of the stapes and so there is always the risk of this disaster after every operation, even by the
most expert surgeon. This risk is small and indeed almost non-existent with some techniques, if correctly managed.

The causes of immediate sensorineural deafness include: acoustic trauma from drilling; excessive movement of the stapes producing an hydraulic effect; rupture of the membranous inner ear; rapid loss of perilymph; footplate fragments or bone dust in the vestibule; and the floating footplate. Attempts at removal of the last of these may result in a ‘dead ear’ and it is essential that this complication is correctly managed.

**Acoustic trauma**

The modern microdrill is a safe instrument if it is used correctly. The drill must be light, preferably fixed to a small motor which allows slow rotary motion, and the drill ends must not be toothed unless there is an obliterative footplate, and this condition requires a special technique which is discussed elsewhere.

**Excessive movement of the stapes**

If an attempt is made to remove a prematurely mobilized footplate, and this can occur when there is minimal fixation, an hydraulic effect can be produced which is damaging to the membranous structures in the vestibule. It is a wise precaution to make a small opening in the footplate, with a slowly rotating microdrill before attempting to detach the crura from the footplate, and is a precaution that may prevent the hydraulic effect.

**Rupture of the membranous inner ear**

Meticulous technique and the making of a small fenestra should prevent this complication, but if small particles of bone do enter the vestibule, no attempt should be made to remove them either by instruments or suction.

**Rapid loss of perilymph**

This may be caused by the use of suction in the oval window which must therefore be avoided. It is occasionally seen in an ear with an abnormally patent cochlear aqueduct, when cerebrospinal fluid will enter the ear. The treatment has been described in the section on problems found at operation.

**Presence of blood in the vestibule**

This condition has already been discussed. It is unlikely that blood in the vestibule will cause any damage to the inner ear. The problem is the difficulty in dealing with the pathology found at operation when the operative field is obscured. In clinics which specialize in the surgery of otosclerosis, a dry field is achieved by suitable anaesthetic techniques.
Treatment of postoperative cochlear loss

If a technique is adopted which does not lead to a fistula after operation for example, the ‘vein graft-interposition’ operation or the true small fenestra technique, it is possible to obtain complete closure of the air bone gap and avoid postoperative high tone loss.

Causse et al (1970) are of the opinion that careful monitoring of the hearing after operation is of vital importance since it may be possible, if a sensorineural hearing loss is detected within a few hours of its appearance, to reverse the hearing loss by medical treatment.

The monitoring of the patient involves strict audiometric surveillance by means of bone conduction audiometry and Weber tests of the pure tone and speech variety. Speech and pure tone audiometry are carried out later and the final speech and pure tone audiogram is made on the twentieth postoperative day. After discharge the patient is instructed to report immediately to the surgeon, by telephone, if there is any sudden hearing drop, or the onset of tinnitus or vertigo.

The treatment of sensorineural deafness after operation is similar to that given for Ménière's disease and consists of the repeated injections of nicotinic acid intravenously, three to five times per day. Intravenous heparin is given in small doses, as it is believed to act as a vasodilator, an antispasmodic and as an agent that helps to absorb exudates. In large doses, over 150 mg/day, it acts as an anticoagulant. Hydrocortisone is also used, in gradually decreasing doses, as it is believed that it protects cell membranes, and has an antiinflammatory, antioedematous and antihaemorrhagic action. Sodium fluoride is added to this basic treatment for antienzymatic action on the cochlear lesions.

Medical treatment of sensorineural deafness after stapedectomy is carried out by few surgeons. Diagnosis is difficult as there is loss of discrimination for a time after most stapedectomy techniques. This is caused by the fistula created at surgery which usually closes spontaneously. Audiometry after operation often shows an incomplete closure of the airbone gap and a high tone loss in the immediate postoperative period. The audiometric pattern improves during the course of a few weeks after operation but the high tone loss takes longer and may never recover completely.

If medical treatment can lead to recovery of sensorineural hearing loss after stapedectomy, it should be tried more frequently although it will remain difficult to say if a successful outcome is the result of therapy, or due to the remarkable power of the inner ear to recovery after injury.
Chapter 15: Diseases of the temporal bone

Gerald B. Brookes and John B. Booth

Many different systemic diseases may involve the temporal bone and they invariably result in a sensory hearing loss; occasionally there are associated vestibular symptoms and, in some instances, middle ear function is also compromised.

Several diseases have been excluded from this chapter, or considered only briefly, as they are covered more appropriately in other sections. Thus, the many causes of severe childhood deafness, in particular teratogenic, hereditary and metabolic, are largely excluded. Secondary involvement of the temporal bone by neoplasms, reticuloses, or by the leukaemias are also described elsewhere, together with the diseases of the cardiovascular, haemopoietic, respiratory and renal systems (Chapter 17). This chapter concentrates upon disorders of bone which may involve the petrous temporal structures and those caused by infective, granulomatous, metabolic and dietary-induced diseases. The developing contemporary field of autoimmune inner ear disease is also considered.

Systemic bone diseases

The bony labyrinth differs histologically and biologically from all other skeletal tissues. Maurer (1967) studied the mineral content of the bone of the otic capsule and ossicles, and compared it to the composition of bone from the mastoid cortex and general skeleton. He found that the calcium and phosphorus content of the woven bone of the otic capsule and ossicles was significantly greater than that of the ordinary haversian bone of the mastoid cortex and other regions. In addition, alkaline phosphatase activity was one-third to one-sixth lower in this woven bone, indicating that there are fundamental metabolic differences compared to general skeletal bone. Recent animal studies have shown that otic bone takes up radioactively labelled calcium significantly slower than does femoral bone, a reflection of its reduced metabolic rate (Ross, 1979). It is also relevant that the metabolic regulation of the entry of calcium into bone varies with both sex and age (Bronner, 1973; Preston et al, 1975). There is a reduced entry of calcium in women, compared with men and with increasing age. These basic physiological differences between otic capsule and other bone will clearly affect the likelihood of preferential involved of the petrous temporal bone as a localized manifestation of a more generalized bone disorder.

The temporal bone may be affected by many specific conditions (Table 15.1). Table 15.2 summarizes the biochemical, radiological and other characteristics encountered in the most important of these conditions. Somewhat paradoxically, however, the temporal bone is relatively infrequently involved in many of the generalized systemic bone diseases. Perhaps the lower metabolic rate of the bony labyrinth confers some degree of protection, although it must be appreciated that any cochleovestibular symptoms are probably often overshadowed by other more generalized features.

Direct involvement of the otic bone which supports and protects the delicate cochlear and vestibular neuroepithelial structures, by other rarefactive or sclerotic processes, can lead to secondary degenerative changes in the spiral ligament, stria vascularis and cochlear hair cells, either by local ischaemia or by the toxic effect caused by the release of enzymes, as has
been postulated and generally accepted in cochlear otosclerosis. This is the likely pathogenesis in most conditions, although, in addition, sustained biochemical aberrations may cause adverse effects in other ways. Calcium is involved with many cellular functions, including the regulation of membrane permeability and the control of neuromuscular excitability. Active transport mechanisms, which maintain the differential biochemical integrity of the inner ear fluids which is vital for normal cochlear function, are probably calcium dependent. Deficiency of ionized calcium may also adversely affect transmission of the nerve action potentials generated by the cochlea by inhibiting the release of transmitter substances at the neural synapses.

**Table 15.1. Systemic bone diseases**

1. Osteogenesis imperfecta (Van der Hoeve syndrome)
2. Osteitis deformans (Paget's disease)
3. Fibrous dysplasia
4. Osteopetrosis
5. Neurofibromatosis
6. Genetic craniotabular hyperostoses
   - hyperostosis corticalis generalisata
   - sclerosteosis
   - congenital hyperphosphatasia
   - progressive diaphyseal dysplasia
7. Genetic craniofacial dysplasias
   - craniometaphyseal dysplasia
   - frontometaphyseal dysplasia
8. Craniofacial dysostosis
9. Osteopathia striata

**Osteogenesis imperfecta**

Osteogenesis imperfecta or fragilitas ossium is a relatively rare disease. Its incidence varies between 2 and 15 per 100,000 births (Smärs, 1961; Morrison, 1967; Pedersen, 1985). It is an hereditary disorder of collagen synthesis (Smith, Francis and Haughton, 1983) and occurs in two main forms. In the congenita form, multiple fractures occur *in utero* and early death is commonplace. In the tarda form, multiple fractures occur with relatively minor trauma in childhood but tend to become less frequent after puberty. Abnormal fracture alignment frequently results in excess callus formation and skeletal deformity of the limbs. It is generally accepted that the tarda form has a dominant mode of inheritance with variable penetrance. Thus asymptomatic 'carriers' exist in some families. Sporadic cases have also been encountered. The congenita form has a recessive mode of inheritance.

The chief manifestation is spontaneous fractures which occur in more than 95% of cases (Smärs, 1961). These usually follow relatively minor trauma and may exceed 60 in number in any one individual. Eighty-five per cent of cases have blue sclerae, which may also be seen in other conditions where a collagen differentiation defect is present, for example Ehlers-Danlos syndrome and Marfan's syndrome. Many healthy children under 3 years of age also have blue sclerae, so that scleral colour is an unreliable diagnostic feature. Approximately 50-605 of affected individuals eventually develop a hearing loss (Smärs, 1961;
Table 15.2. Summary of features of specific conditions affecting the temporal bone

<table>
<thead>
<tr>
<th>Condition</th>
<th>Type of hearing loss</th>
<th>Biochemistry</th>
<th>Radiology</th>
<th>General features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osteogenesis imperfecta</td>
<td>Conductive and/or sensorineural</td>
<td>Ca and PO$_4$ normal</td>
<td>Varied - demineralization and sclerosis produce mottled appearances</td>
<td>Spontaneous fractures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alkaline phosphatase occasionally raised</td>
<td>Excess callus formation</td>
<td>Blue sclerae</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acid phosphatase normal</td>
<td></td>
<td>Joint hypermobility</td>
</tr>
<tr>
<td>Paget's disease (osteitis deformans)</td>
<td>Conductive and/or sensorineural</td>
<td>Ca usually normal</td>
<td>Varied - lytic, sclerotic and mixed phases</td>
<td>Skull - great increase in thickness of both tables, particularly outer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PO$_4$ hypercalcaemia - immobilization</td>
<td>? patchy sclerosis - woolly appearance</td>
<td>Platybasia; basilar impression</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alkaline phosphatase elevated in active disease</td>
<td>X-ray pelvis including femoral heads</td>
<td>Osteoporosis circumscripita - patch of reduced density resembling bony defect</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acid phosphatase may be raised</td>
<td></td>
<td>Pathological fracture</td>
</tr>
<tr>
<td>Fibrous dysplasia</td>
<td>Conductive</td>
<td>Ca usually normal</td>
<td>Varied - monostotic/polyostotic appearances - same</td>
<td>Multiloculated cystic lesion (bone frequently expanded)</td>
</tr>
<tr>
<td></td>
<td>Rarely sensorineural</td>
<td>PO$_4$ always normal</td>
<td>Occ. lesion more diffuse ground-glass appearance due to multiple line trabeculae</td>
<td>Occ. lesion more diffuse ground-glass appearance due to multiple line trabeculae</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alkaline phosphatase may be raised in active disease, especially polyostotic form</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Skeletal survey to exclude polyostotic
Pathological fracture
Café-au-lait pigmentation may be present (either type)

Osteopetrosis
(a) Albers-Schönberg
Conductive
Occ. mixed
Ca normal
PO₄ normal
Alkaline phosphatase may be markedly elevated
Acid phosphatase may be markedly elevated
Urinary HDP usually normal
   Symmetrical increase in bone density; bones appear structureless
   Sclerotic foci - 'bones within bone'
   Thickening of vertebral end-plates ('rugger jersey')
      Thick dense brittle bones
      Pathological fracture
      Facial palsy
   Occ. osteomyelitis of mandible after dental extraction
   Mild anaemia

(b) Malignant recessive
Sensorineural
As above
   Transverse bands in metaphyseal regions of long bones and longitudinal striations
   Proximal humerus and distal femur - flask-shaped
   Vertebræ - rugger jersey
      Facial palsy
      Blindness
      Pathological fracture
      Mental retardation
      Liver and spleen enlargement
      Haemolytic anaemia and thrombocytopaenia

Genetic craniotabular hyperostoses
(a) van Buchem's (autosomal recessive)
Conductive and/or sensorineural
Ca normal
PO₄ normal
Alkaline phosphatase frequently raised (50-250%)
   Diffuse, symmetrical increase in bone density
   Cortical bone - abnormally thick but bones not increased in size
   Hyperplasia diaphysis long and short bones
   Endosteal thickening diaphysis - tubular bones
      Normal stature
      Facial palsy
      Clavicles - thickened and palpable
Overgrowth of brow and mandible

(b) Sclerosteosis (autosomal recessive)
Conductive and/or sensorineural
Ca normal
PO₄ normal
Alkaline phosphatase markedly elevated in nearly all patients
Acid phosphatase normal
Bones show increased density but only minor degree of bony modelling, if present
Progressive bony thickening
Tubular bones markedly undermodelled with lack of usual diaphyseal constriction
Syndactyly and digital malformation
Facial paralysis
Tall stature
Distortion of face and jaw
Chronic headache
Raised ICP
Anosmia
Majority Afrikaners

(c) Congenital hyperphosphatasia (autosomal recessive)
Conductive with decreased bone conduction
Ca normal
PO₄ normal
Alkaline phosphatase consistently elevated
Acid phosphatase consistently elevated
Similar to Paget's
Marked irregular thickening of skull
? Narrowing of EAM
Tubular bones - width greatly increased, bowing and lacking of modelling
Multiple fractures
Dwarfing
Blue sclerae
(? increased serum uric acid and leucine aminopeptidase)

(d) Progressive diaphyseal dysplasia (autosomal dominant)
Combined with big air-bone gap
Ca normal
PO₄ normal
Alkaline phosphatase normal
Acid phosphatase normal
Generalized sclerosis of skull base; vault less commonly severely affected
Marked thickening of cortices of leg bones and medullary canals narrowed; external bony contours irregular

Morrison, 1975; Quisling et al, 1979; Pedersen, 1985). When multiple fractures, blue sclerae and deafness occur together they constitute the syndrome ascribed to van der Hoeve and de Kleyn (1918). It is now known that this eponymous association is rather unsatisfactory because the syndrome was in fact described 6 years earlier by Adair-Dighton (19120, while Bronson (197) independently published 19 cases of the same triad at an earlier date. In some family members, hearing impairment and blue sclerae are present without the tendency to fractures (Morrison, 1979; Stoller, 1982).

Altered collagen synthesis results in defective connective tissue with a tendency to hypermobility and laxity of joints, 'thin' skin and subcutaneous bruising. The abnormal formation of dentine and cracking of the overlying enamel results in yellow-stained irregular teeth, the so-called amelogenesis imperfecta. The appearances are reminiscent of tetracycline staining of the permanent teeth. This feature is found in about 155 of patients with osteogenesis imperfect and may be the only manifestation. The diagnosis of this feature is made radiologically by demonstration of obliteration of the root canals.

**Otological features**

Characteristic features of the hearing loss in osteogenesis imperfecta are its age of onset and progression. Although only 10-20% of affected individuals will be deaf in childhood or adolescence, by middle age the figure exceeds 50% (Smärs, 1961; Pedersen, 1985) and usually progresses significantly from the third decade. The hearing loss may increase during pregnancy, while rather surprisingly, there is no correlation between its severity and that of the disease as indicated by the degree of physical handicap.

The hearing loss in osteogenesis imperfecta is clinically indistinguishable from otosclerosis. Characteristically it commences soon after puberty when fractures become less frequent. A conductive component is present in nearly 80% of cases, although more often than not this is part of a mixed loss. The deafness can be entirely sensorineural and total deafness may result in a few instances.

Tympanometry studies using a probe tone of 220 Hz show a tendency to high normal or raised compliance values. Although fixation of the stapes footplate is invariably present in cases with a conductive loss, hypermobility of the tympanic membrane (Carruth, Lutman and Stephens, 1978; Pedersen, 1984, or fracture or aplasia of stapedial crura may coexist (Shea and Postma, 1982; Pedersen, 1985). Carruth, Lutman and Stephens (1978) suggested that the reduced stiffness of the fibrous layer of the tympanic membrane, which has the same embryological origin as the sclera, was the more important factor leading to increased membrane mobility, possibly due to defective cross linkage between the circular and radial fibres. In ears with a fracture of the stapedial arch, very high compliance values are present combined with a stapedius reflex of high amplitude providing there is not too large a contralateral conductive hearing loss. Carhart notches are not seen, and despite the widespread changes in the temporal bone neither is the Schwartze sign.

Vestibular symptoms have been reported as rare (Smärs, 1961; Morrison, 1979; Quisling et al, 1979) or as frequently as 20% of affected cases (Shea and Postma, 1982; Pedersen, 1984). Johnsson et al (1982) described extensive bilateral endolymphatic hydrops in a case where temporal bone microdissection was undertaken. Morrison (1979) described
two patients with amelogenesis imperfecta and Ménière's syndrome, in whom abnormal sclerosis of the otic capsule was demonstrated on polytomography. However, secondary hydrops appears to be an unusual feature of the condition.

Changes in the labyrinthine capsule on petrous temporal bone tomography are virtually indistinguishable from those of labyrinthine otosclerosis. Demineralization, which is perhaps more widespread, and sclerosis produce a mottled appearance which is, however, not so marked as in Paget's disease of bone.

Histologically, there are some similarities to otosclerosis, although the disorders are considered distinct entities (Wullstein, 1960; Bretlau, Jorgensen and Johansen, 1970; Shea and Postma, 1982; Pedersen, 1985). In about two-thirds of cases stapedial fixation is due to a focal lesion in the footplate which, histologically, resembles the early active stages of otosclerosis. However, there is a greater degree of disorganization in the new bone formation in the osteogenesis imperfecta footplate compared with that seen in otosclerosis (Brosnan et al, 1977). In other cases, fixation is the result of a diffuse structural alteration of the entire footplate. Biochemical assays of serum calcium, phosphorus and calciferol are normal, which alkaline phosphatase levels may occasionally be elevated. Photon absorptiometry has demonstrated that patients with osteogenesis imperfecta have a reduced thickness of cortical bone, while other generalized features include reduced dermal and central corneal thickness (Pedersen, 1985). These features are not found in otosclerosis. It is considered very likely, therefore, that the temporal bone features in osteogenesis imperfecta represent a local manifestation of the generalized skeletal and connective tissue disorder.

Treatment

There is no known curative treatment for the condition. In a typical case, new fractures cease to occur in adolescence, but skull involvement continues causing the characteristic 'soldier's helmet' appearance and deafness. Rehabilitation using an appropriate hearing aid is the mainstay of treatment, although stapedectomy may have a place in patients with a large air-bone gap and good cochlear function.

Surgical results are generally satisfactory and can give hearing improvement similar to that obtained in otosclerosis if delayed until several years after the cessation of fractures (Patterson and Stone, 1970; Kosoy and Maddox, 1971; Shea and Postma, 1982; Stoller, 1982; Pedersen, 1985). The fixed footplate is often very thick and soft, while middle ear mucosa around the oval window appears to be more vascular than normal. A high risk of a 'floating' footplate has been reported (Kosoy and Maddox, 1971; Brosnan et al, 1977), although this is not the experience of others (Pedersen, 1985). Extra care is required not to fracture the long process of the incus when crimping a wire prosthesis.

Paget's disease (osteitis deformans)

Sir James Paget described the detailed clinical and pathological features of this bone disease in 1877. The alternative term osteitis deformans introduced by Czerny in 1873 is inappropriate because there is no evidence that the basic pathology is inflammatory, and marked skeletal deformity rarely occurs. The disease is characterized by spreading osteolytic and osteoblastic changes, most frequently affecting the pelvis, lumbar spine, skull, femur and
tibia. However, the archetypal patient displaying the full clinical picture with an enlarged skull, progressive kyphosis, bowed legs and short stature is now rarely seen. It affects males four times more often than females and has a curious racial and geographical distribution, being very common in the UK (Woodhouse, 1973; Detheridge, Guyer and Barker, 1982), where estimates suggest that some three-quarters of a million people have the disease. The incidence is also high in Australia and New Zealand and in other populations of British origin, such as North America and South Africa. Surveys have revealed a marked geographical disease variation, and within the UK the prevalence has been shown to be considerably higher in Lancashire than elsewhere, but decreasing from high to lower levels over short distances (Barker et al, 1980).

As described by Paget himself, the onset of the disease occurs in middle age. It is rarely seen before the age of 40 years and is more commonly encountered after the age of 55 years. Hereditary aspects are not easy to evaluate because of this relatively late age of onset, but it has been thought to be inherited by a simple autosomal Mendelian dominant gene (McKusick, 1972).

Three-quarters of patients with the disease have pelvic involvement, while the skull is affected in some 28%. An increased tortuosity and hypertrophy of the anterior terminal branch of the superficial temporal artery may be seen in many patients with skull involvement in Paget's disease, but it is by no means characteristic of the condition. Of those with widespread active disease, bone pain is a troublesome symptom, and probably occurs in as many as 20% sufficient to warrant treatment. Expansion of bones around foramina at the base of the skull and in the orbit can lead to neurological defects and optic atrophy. Early workers suggested that narrowing of the internal auditory meatus and the nerve channels in the bony modiolus with compression of the nerve fibres might account for the sensorineural loss, but this is not supported by histological studies (Schuknecht, 1974).

While the exact aetiology is unknown, it is now widely accepted that Paget's disease is an example of primary osteoblast dysfunction in which the pathogenesis involves an increase in the number and activity of osteoblasts. The stimulus for this increase is unknown, but as a result of the bone resorption, there is a compensatory increase in bone formation, leading to a greatly enhanced rate of bone turnover. The normal lamellar structure of the collagen of the ground substance becomes grossly distorted and replaced by adjacent areas of osteolytic and sclerotic bone of increased vascularity. This results in bone softening, a tendency to fractures and deformity and typical biochemical changes. The serum calcium is usually normal, even though the rate of turnover of calcium in bone is enormously increased. Immobilization as a result of this disease, however, causes even greater bone resorption and formation so that both hypercalcæmia and hypercalciuria can occur. Serum alkaline phosphatase activity is elevated in active disease, particularly if it is widespread. Activity of this enzyme is related to bone formation by osteoblasts and probably also by osteocytes. Serum acid phosphatase is an index of osteoclastic activity and is often increased in Paget's disease, particularly when the alkaline phosphatase is quite high, but its measurement is of little diagnostic value. Urinary hydroxyproline is an amino acid found exclusively in collagen and levels may be greatly elevated in Paget's disease, when the condition is active, reflecting the breakdown of bone collagen.
The most interesting recent hypothesis is that the disease results from a slow virus infection of the osteoblasts. Rebel et al (1980) demonstrated inclusion bodies only in the osteoblasts, which are morphologically analogous to those seen in proven paramyxovirus (PMV) infections - measles or respiratory syncytial virus. Clinicopathological aspects of Paget's disease have several features in common with other proven slow virus disorders, and Harvey (19840 has recently reviewed the evidence for this proposed association. If a viral aetiology is confirmed, co-factors are almost certainly necessary, perhaps on a genetically susceptible background.

**Otological features**

Despite the frequency of Paget's disease, it is only rarely recognized as a cause of deafness in clinical practice. In many instances the disease may be asymptomatic apart from the otological features and the diagnosis can therefore easily be missed. However, in other cases, although hearing loss is present it may not be directly due to the disease. In patients with deafness due to Paget's disease, one would usually expect to see obvious signs in the plain skull X-rays. Davies (1968) reviewed 236 patients with the disease, finding skull involvement in 70% and deafness in 41%. Of the 97 patients with deafness, there was no radiological skull abnormality in 14. Vertigo and tinnitus, which was characteristically pulsatile, were present in 36% and 32% respectively. Harner, Rose and Facer (1978) studied 1066 patients with objective evidence of Paget's disease over a 5-year period. More than 43% had a hearing loss which was usually sensorineural. However, when the records were carefully reviewed they concluded that the hearing loss was not usually part of the disease process and most patients had no direct evidence of temporal bone involvement. In their series, 17% of patients had tinnitus and 22% dizziness. The most common vestibular symptoms were postural and positional unsteadiness. However, in those with radiological evidence of skull involvement, the incidence of mixed hearing loss was statistically greater than expected and the incidences of tinnitus and dizziness were also higher than in the group as a whole.

The type of hearing loss most commonly encountered is progressive and mixed with both conductive and sensorineural components (Davies, 1968). It is usually fairly symmetrical. In the earlier stages of the disease, conductive deafness is present in more than two-thirds of affected ears. Davies found that the air-bone gap averaged 30 dB for females and 20 dB for males, and was most marked at the 500 Hz frequency. The stapedius reflex is often present and preserved with moderate conductive hearing losses. By contrast, in patients with otosclerosis and in osteogenesis imperfecta, as little as 15 dB of hearing loss due to stapedial fixation abolishes the reflex. The greater age of onset also helps to distinguish Paget's disease from otosclerosis.

There are still relatively few histological studies of the temporal bone in Paget's disease. Changes are rarely present in the stapes footplate, while pagetic changes in the other ossicles and the formation of bony spurs in the epitympanum interfering with incudomalleal mobility are the common findings accounting for a conductive hearing loss (Davies, 1970; Schuknecht, 1974).

A progressive sensorineural hearing loss mainly affecting the higher frequencies is seen in 20% of patients and can also be associated with an additional conductive element (Davies, 1968). Pagetoid osteitis involving the endosteal layer of the otic capsule results in
degenerative changes in the stria vascularis with atrophy of both the cochlear duct and vestibular labyrinth (Kornfield, 1967; Rüedi, 1968; Lindsay and Lehman, 1969; Schuknecht, 1974). The basal turns of the cochlea are most severely affected and Schuknecht suggested a local toxic effect caused by pagetic disease of the bony labyrinth, similar to that observed in cochlear otosclerosis. Secondary endolymphatic hydrops of the cochlear duct and saccule, and atrophy of the membranous semicircular canals have been described. The vascular shunts connecting vessels of diseased pagetic bone with those of the spiral ligament described by Rüedi (1968) have not been confirmed by others. Thus, in the early stages, the inner ear loss is mainly sensory with relatively well preserved speech discrimination, but later, secondary neuronal degeneration occurs. Bony softening and deformity of the skull base can lead to acquired basilar impression and possibly sensorineural hearing loss by torsion of the eighth nerve or its associated vasculature. Vestibular symptoms are usually rather non-specific, taking the form of transient vertigo or imbalance, although exceptionally they assume a Ménière-like character when secondary hydrops has occurred.

In the early stages, small areas of lucency and dense patches which fade into one another are seen on X-ray. There is often a typical mixture of lytic and sclerotic areas and the skull is thick where it is affected, predominantly over the vertex. Some coarse trabeculae are nearly always visible except in the most advanced cases. Osteoporosis circumscripta is a different manifestation of the disease causing a total radiographic disappearance of bone which always stops short of involving the whole structure (Kasabach and Gutman, 1937; du Boulay, 1980). The radiological appearance of the temporal bone in the established disease is pathognomonic and variations from minimal demineralization of the petrous apex to demineralization of the entire petrous pyramid including the otic capsule are encountered.

The temporal bone changes frequently correlate with the degree of skull involvement. In the initial stage when extensive demineralization primarily affects the medial aspect of the petrous pyramid, the labyrinthine capsule stands out more clearly than normal. Involvement of the internal auditory meatus consists of demineralization of the walls without evidence of narrowing and, when surrounded by featureless homogeneous pagetoid bone, it may no longer be identifiable as a distinct structure. The otic capsule is spared until advanced changes are present. Involvement of the labyrinthine capsule begins in the outer periosteal layer; the middle endochondral layer is more resistant and the greatest resistance is present in the endosteal layer, but with extensive involvement these three layers can no longer be distinguished. Eventually the medial ends of the petrous pyramids become tilted upwards due to bone softening causing acquired basilar impression. High resolution computerized tomography may yield additional information about bone architecture (Lloyd, Phelps and du Boulay, 1980; Swartz et al, 1985).

**Treatment**

It is generally agreed that the results of reconstructive middle ear surgery are unsatisfactory in Paget's disease. There are several reasons for this surgical pessimism. There is no consistent defect responsible for the conductive loss and, indeed, several may coexist in some cases. The frequently associated sensorineural hearing loss is another significant factor mitigating against the prospects of a successful surgical outcome. Perhaps it sensitizes the cochlea to further diminution of function during the footplate manipulations of a
stapedectomy procedure. Finally, and probably most important, the long-term results in most reported cases are poor.

Morrison (1975) performed stapedectomies on two patients with 40-50 dB air-bone gaps. In each case the stapes was found to be normal. Both patients experienced a hearing gain which was unfortunately only temporary and was followed by progressive conductive and sensorineural hearing loss. This experience has been shared by others (Sparrow and Duval, 1967; Davies, 1968). Stapes or ossicular mobilization has also generally produced a less than favourable long-term outcome. Morrison (1975) described two good hearing results after mobilization which reverted to preoperative levels within a few months. A normally mobile stapes with or without a mobile malleus handle may, however, provide scope for other reconstructive techniques which can be worth pursuing, particularly in the younger patient.

The effects of medical treatment with calcitonin on hearing loss have been studied by several groups, although with conflicting results. Calcitonin causes a rapid inhibition of osteoblast activity, while continued therapy leads to a reduction in the rapid turnover of calcium and a gradual remineralisation of bone (Woodhouse, 1973). Successful treatment results in a fall in the serum alkaline phosphatase and urinary hydroxylproline excretion. A typical protocol consists of daily subcutaneous injections of 10-50 mg of calcitonin which can be reduced to an alternate day regimen when biochemical parameters become normal, after about 2 weeks. Shai, Baker and Wallach (1971), Morrison (1975 and Moffat, Morrow and Simpson (1977) all reported hearing improvement following calcitonin treatment, while Grimaldi, Mohamedally and Woodhouse (1975) and Walker et al (1979) found no significant differences between treated and untreated groups. The Otologic Medical Group of Los Angeles have very recently reported the results of a comprehensive study of calcitonin therapy in this disorder (El Sammaa et al, 1986). Twenty six patients with hearing loss due to Paget's disease seen by one clinician received calcitonin regularly for periods ranging from 5 to 8 years and were compared to 19 patients, seen concurrently by other colleagues, who received no treatment. They found that, although there was no significant hearing improvement in the treatment group, their hearing thresholds were effectively stabilized, in contrast to the untreated group in whom a mean increase hearing loss of more than 25 dB was observed. Such long-term treatment is certainly expensive and may be affected by antibody formation with calcitonin of porcine or salmon origin.

Disodium etidronate (EHDP) is a diphosphonate which seems to possess all the biological properties of pyrophosphate including the ability to inhibit bone resorption. The drug appears to inactivate osteoclasts and osteoblasts and these effects have led to its clinical usage in Paget's disease (Kanis and Russell, 1981). Although the drug is effective, long-term administration may result in histological osteomalacia. It has the distinct advantage that it may be taken orally, but so far, only one short report of its use in the deafness of Paget's disease has been published (Gennari and Sensini, 1975). Five patients were treated and their pure-tone audiograms showed a significant improvement in the air conduction threshold of greater than 15 dB in three cases. Recently, it has been shown that short-term high dosage treatment with EHDP may well maximize suppression of disease activity but decrease exposure to unwanted secondary effects (Preston et al, 1986).

Severe hearing loss, particularly in younger adults, with evidence of rapidly progressive disease would seem a clear indication for medical treatment, while the enhanced
patient acceptability of EHDP, as a result of oral administration, makes the decision for a therapeutic trial in other cases easier to make. Such treatments are clearly not devoid of risk and must be undertaken in close conjunction with a metabolic physician.

**Fibrous dysplasia**

Fibrous dysplasia is a fairly common benign disorder of fibro-osseous tissue of unknown aetiology which was not recognized as a specific disease entity until the 1940s. It can affect one or several bones and while the dominant features are skeletal, occasionally certain endocrinopathies, abnormal pigmentation of skin and mucous membrane, and other abnormalities may form part of the disease process. The craniofacial skeleton is a predilective site and the temporal bone is affected in more than 15% of cases with skull involvement. For many years, fibrous dysplasia of bone was not distinguished from primary hyperparathyroidism, and both kinds of osseous lesions were described pathologically and radiologically as osteitis fibrosa cystica.

Three separate types of fibrous dysplasia are now described.

**Type I: monostotic**

This type is limited to one bone, usually the femur, tibia, ribs or facial bones. The mandible and maxillae are the most frequent sites of facial bone involvement.

**Type II: polyostotic**

In this type more than one bone is involved, most frequently of the lower limbs. In the skull, the lesser and greater wings of the sphenoids, and the vertical and horizontal processes of the frontal bones are mainly affected. The frontal and sphenoid sinuses are frequently obliterated.

**Type III: disseminated and extraskeletal manifestations**

This is also known as the McCune-Albright syndrome (McCune, 1936; Albright et al, 1937). Bone distribution is similar to the polyostotic form but is commonly unilateral, with areas of skin hyperpigmentation and endocrine disturbances, particularly hyperthyroidism. The disorder primarily affects females who characteristically display precocious puberty.

The monostotic form, which accounts for about 70% of cases (van Tilberg, 1972), generally becomes arrested at puberty. The polyostotic form, on the other hand, may progress beyond the third or fourth decades. Initial clinical symptoms usually appear during childhood or early adolescence - a period of active skeletal growth (Lichtenstein and Jaffe, 1942) - and include pain, deformity and recurrent fractures.

In the disease, normal bone is replaced by fibrous tissue consisting of spindle cells and poorly formed trabeculae of immature woven bone. Increased osteoblastic and osteoclastic activity is usually present and islands of cartilage may be observed. It primarily involves cancellous bone, although tissue expansion may give rise to distortion and structural weakness. As the lesions enlarge, the overlying bony cortex becomes thinner, although its
histological structure usually remains normal. The disease has been considered variously as an arrest of bone maturation (Reed, 1963), as a disturbance of postnatal cancellous bone maintenance (Aegerter and Kirkpatrick, 1968), or as a misdifferentiation of the bone-forming mesenchyme (Lichtenstein and Jaffe, 1942). Carcinomatous degeneration is very rare (Schwartz and Alpert, 1964) and has never been reported in the temporal bone.

Otological features

In 1982, Nager, Kennedy and Kopstein reviewed the literature and summarized the findings in 69 cases of fibrous dysplasia involving the temporal bone. The male to female sex incidence was 2:1 and a majority of the patients had the monostotic form of the disease. The mean age of onset of the clinical symptoms was 15 years, although the range extended to 59 years. The mean age at clinical presentation was 28 years.

The commonest presenting symptoms were progressive hearing impairment (57%), localized swelling of the temporal bone (51%) and progressive bony occlusion of the external auditory meatus (42%). About 15% of the patients with hearing loss had a total or profound sensorineural deafness and the remainder had an early conductive loss. Vestibular symptoms and tinnitus were uncommon. In 11 cases, marked constriction or obliteration of the external auditory meatus was associated with an underlying epidermoid inclusion cyst or cholesteatoma. The pathogenesis is similar to other situations with acquired stenosis of the meatus, when desquamation of normal meatal skin and tympanic membrane continues medial to an obstruction (Brookes and Graham, 1984. Labyrinthine involvement was present in three of the cases; five developed facial nerve paralysis. For this reason an obliterated external auditory meatus should be explored surgically and reconstructed. Three patients presented with massive temporal bone involvement and features of an intracranial space-occupying lesion. The increased size of the temporal bone was usually postauricular often causing an anteroinferior protrusion of the auricle, but occasionally swellings of the preauricular and supra-auricular regions were present. Blockage of the eustachian tube leading to serous otitis media may occur. Rarely bone narrowing of the internal auditory meatus develops with progressive impairment of function of the seventh and eighth cranial nerves.

Typically the serum calcium and phosphorus levels are normal, while the alkaline phosphatase level may be raised in the presence of an active lesion. If several bones are involved hyperparathyroidism must be carefully excluded, although on occasions it appears that the two conditions may occur together. X-ray studies generally reveal an enlarged temporal bone associated with sclerosis, or a uniform 'ground glass' appearance. Areas of radiolucency and cortical thinning may occasionally be seen. The radiological appearance of the disease is a function of its histological structure. A predominance of osseous elements renders the lesion more opaque, while the mixture of fibrous and bony elements produces the 'ground glass' appearance. The predominance of fibrous elements produces a radiolucent cyst-like picture. The high resolution CT features have recently been documented (Swartz et al, 1985).

Treatment

At present there is no known conservative treatment for the control of fibrous dysplasia. Nevertheless, the prognosis is usually good and the decrease in disease activity at
puberty is greater in the monostotic form. The presence of a lesion in the temporal bone does not in itself justify surgical intervention. However, more than one-half of the patients will probably undergo operative treatment. The main indication is external auditory meatus stenosis, while reduction of the unsightly local swelling for cosmetic reasons accounts for most of the other cases. The diseased bone has characteristic macroscopic features. It is vascular, spongy and crumbly with a gritty consistency and can be readily removed by curettage. Half the cases reviewed by Nager, Kennedy and Kopstein (1982) underwent two or more operative procedures, but surgery was rarely curative. Management should therefore be conservative. Spontaneous decrease in disease activity may well help to reduce the recurrence in rate. Radiotherapy appears to have a predisposing propensity to malignant generation of lesions in other sites (Schwartz and Alpert, 1964).

**Osteopetrosis (marble bone disease)**

Osteopetrosis is a rare inherited bone disorder which occurs as a benign dominant form, otherwise known as Albers-Schönberg disease, and a malignant recessive form. Pathologically there is a failure of resorption of cartilage and excessive formation of immature bone leading to thickening of the cortex and narrowing or obliteration of the medullary cavity. This may cause anaemia and a susceptibility to infection. Failure and impairment of bone maturation result in thick, dense and brittle bones. The skull may become extremely thick and when remodelling involves the cranial foramina, stenosis and compression of emergent nerves and vessels may occur. The optic, trigeminal, facial and auditory nerves are those most frequently affected (Myers and Stool, 1969; Hamersma, 1970).

**Otological features**

Histological studies of temporal bones show that the labyrinth and ossicles mainly consist of dense calcified cartilage. Typically, pneumatization of the mastoids is absent. The internal auditory meatus may be narrowed, but the otic capsule remains unaffected (Myers and Stool, 1969; Hawke, John and Bailey, 1981). The serum alkaline and acid phosphatase may be markedly elevated, while the urinary hydroxyproline levels are usually normal (Johnston et al, 1968).

Most of the patients with malignant recessive disease die in early childhood and certainly none survive into their twenties. The associated hearing loss in these cases is sensorineural. In contrast, many patients with the benign disease may be asymptomatic, the diagnosis only being made radiologically. Common symptoms are bone pain and fractures. The hearing loss is usually conductive, but occasionally, is mixed and is caused by impaired ossicular mobility by osteopetrotic bone (Jones and Mulcahy, 1968; Hamersma, 1970). Recurrent facial palsy, which behaves like a typical Bell's palsy, is a frequent manifestation. There is a tendency to progressive residual facial weakness with synkinesis and contracture. Clinical experience indicates that surgical intervention to alter the natural history of these recurrent facial palsies should ideally include decompression of the proximal facial nerve in the fallopian canal by a middle fossa approach.
Neurofibromatosis

This is a common disorder of neural tissue which was described by von Recklinghausen in 1882. It is characterized by multiple areas of cutaneous pigmentation (café-au-lait spots), multiple naevi and neurofibromata of peripheral or cranial nerves. Within the cranial cavity, neurofibromata most often occur on the eighth nerve and are frequently bilateral (see Chapter 21). In addition, there is an increased incidence of gliomata and meningiomata, which may be multiple. The disease is familial with an autosomal dominant inheritance, although sporadic cases do occur.

Bone lesions occur in about one-half of the cases (Hunt and Pugh, 1961; Nordin, 1973; Beighton, 1978). Common skeletal abnormalities include severe scoliosis, defects of the walls of the orbits, erosive defects caused by adjacent neurogenic tumours, apart from disorders of bone growth. The facial bones, mandible, occipital and temporal bones may be deformed and hypoplastic. The figure shows the famous patient of Sir Frederick Treves, Joseph Merrick (alias the elephant man), who was treated at the London Hospital. It can be seen that he had marked narrowing of the right external auditory meatus resulting in a conductive hearing loss. There is no evidence, however, that one of his numerous misfortunes included an acoustic neuroma.

Genetic craniotabular hyperostoses

Hyperostosis corticalis generalisata (Van Buchem's disease)

This disease was first described by Van Buchem and his colleagues in 1955, who have since added further reports (Van Buchem et al, 1962; Van Buchem, 1971). It is an autosomal recessive condition, in which normal stature but overgrowth of bone in the skull and skeleton are associated with facial palsy and conductive deafness.

There is osteosclerosis of the skull, mandible, clavicle and ribs and hyperplasia of the diaphyseal cortex of the long and short bones. The skull and mandible may enlarge from the age of 10 years onwards with thickening of the calvaria, skull base and clavicles. The facial paralysis may be unilateral or bilateral, and the gradually symmetrical hearing loss may be noted from the early teenage years. In some a sensorineural hearing loss and in others a mixed loss may occur. Optic nerve involvement is a late complication. The serum calcium and phosphorus remain normal, but the alkaline phosphatase is frequently raised by as much as 50 to 250%.

Sclerosteosis

This is an autosomal recessive condition in which skeletal overgrowth is associated with syndactyly and digital malformation; facial palsy and deafness are common complications and raised intracranial pressure may develop (Truswell, 1958).

The hearing loss may be bilateral, sensorineural, mixed, or conductive. Facial nerve paralysis is often unilateral in childhood, becoming bilateral in late adolescence. There is also decreased sensory function of the ophthalmic and maxillary divisions of the fifth cranial nerve, anosmia and chronic headache.
The alkaline phosphatase is markedly elevated in nearly all patients, although other biochemical skeletal indices are usually normal. Radiologically, the bones show increased density but abnormalities of bone modelling, if present, are of minor degree (Beighton, Crenin and Hamersma, 1976; Beighton, Durr and Hamersma, 1976).

**Congenital hyperphosphatasia (osteoectasia)**

This is a rare autosomal recessive condition with skeletal deformity developing in the second or third year of life. It is associated with dwarving, fractures and blue sclerae. There is marked irregular thickening of the skull and enlargement of the calvaria. The external auditory meatus may become narrowed and there is a progressive mixed hearing loss, which becomes evident from the fourth to the fourteenth year. Typically the hearing thresholds average about 70 dB. The serum alkaline and acid phosphatase levels are both consistently elevated.

**Progressive diaphyseal dysplasia**  
*(Camurati-Engelmann's disease; osteopathia hyperostotica sclerositans multiplex infantilis)*

This is an autosomal dominant condition principally involving the long bones, but the skull may be mildly affected. Generalized sclerosis of the base, similar to osteopetrosis, may be seen but in the vault of the skull fewer bones are involved and are less severely affected.

Sparkes and Graham (1972) have reported the case of a 26-year-old man with progressive hearing difficulty leading to total deafness on the right side associated with a facial paralysis. Bilateral decompression of the slit-like internal auditory meatus was carried out and some initial improvement was noted. More recently, two cases who underwent surgery have been described (Miyamoto, House and Brackmann, 1980). The first was a 26-year-old man who complained of bilateral hearing loss, right-sided facial paralysis and chronic unsteadiness. X-rays showed bilateral massive overgrowth of dense bone involving the petrous apex and mastoid bone. Both internal auditory meatus were partially obliterated by such bone. The second case was that of a 30-year-old woman with bilateral sensorineural hearing loss, occurring suddenly 14 months earlier on the right side and 9 months later on the left. Both cases were explored surgically by a middle cranial fossa approach, the first to improve the facial nerve function and the second to decompress the internal auditory meatus on the right side. Following surgery, the hearing of the second patient has remained stable and further X-rays did not show evidence of recompression.

The genetic craniofacial dysplasias, craniofacial dysostoses and osteopathia striata are extremely rare conditions. They are usually only seen in infancy and are listed in Table 15.1 for completeness.

**Dietary and metabolic diseases**

**Osteomalacia (vitamin D deficiency)**

Vitamin D deficiency has recently been recognized as an uncommon cause of bilateral sensorineural hearing loss (Brookes and Morrison, 1981; Brookes, 1983). It is a condition
which occurs primarily in Asian immigrants and socio-economically deprived populations. Since changing hospital appointments to a predominantly middle class practice in postgraduate hospitals without a metabolic medical unit on site, one of the authors (GBB) has not seen a single new case for well over 2 years.

Vitamin D refers to a group of steroids which play an essential role, with parathyroid hormone, in the regulation of calcium and bone metabolism. The main metabolic pathways is shown in the figure. Most is synthesized in the skin and, under normal circumstances, dietary requirements are minimal.

Rickets and osteomalacia are the juvenile and adult forms respectively of a group of disorders characterized by defective mineralization of bone and usually result from quantitative and qualitative impairment of vitamin D activity. A less common cause is hypophosphataemia and secondary hyperparathyroidism is occasionally associated. A high incidence of osteomalacia has recently been recognized among Asian immigrants living in the UK, due to a combination of dietary and genetic factors (Editorial, 1976). In the classical deficiency state, the serum calcium and phosphate levels may be low, while the alkaline phosphatase is usually elevated. These biochemical parameters are often normal, however, due to compensatory metabolic mechanisms. Reduced mineralization may produce an altered trabecular bone pattern and pathological fractures on X-ray, but radiology in most early cases is normal, when the clinical condition is termed 'biochemical osteomalacia'. Serum assay of metabolic derivatives of vitamin D - 25-hydroxy vitamin D, the storage form, and 1,25-hydroxy vitamin D, the active form - are invariably low in vitamin D deficiency states including biochemical osteomalacia.

**Otological features**

The otological features and treatment results of 27 patients presenting to the London Hospital with deafness and low vitamin D levels have recently been summarized (Brookes, 1985a). More than half were Asian immigrants and two-thirds reported associated tinnitus. Vestibular symptoms were infrequent. Nearly 50% had a progressive cochlear deafness. A characteristic trough-shaped pure-tone audiogram centred around 1-2 kHz frequencies was seen in two-thirds of these cases. Figure is the audiogram of a 35-year-old Asian man at presentation. Three months later, when the diagnosis was established, his hearing had fallen to a mean level of 85 dB. Electrocochleography showed features of endolymphatic hydrops. Cochlear tomography demonstrated bilateral demineralization. However, this has only been present in less than 15% of cases. All except one of the remaining patients in the London Hospital series had otosclerosis.

Covell first reported the histopathological effects of acute vitamin D deficiency in 1941. He studied a group of rats who were maintained on a vitamin D deficient diet for 3 weeks, followed by a vitamin replacement diet for 1 week. Pathological features were thus modified by various degrees of healing. Newly formed osteoid was found in the periosteal and endochondral layers of the otic capsule, together with slight degenerative changes in the cochlear nerve.

The effects of acute vitamin D deficiency alone on both cochlear function and morphology have recently been studied in the albino rats (Brookes, Lilly and Hawkins, 1983).
A significant reduction in the amplitude of the brainstem evoked responses and impaired mean hearing thresholds were seen in the vitamin D deficient animals, following a vitamin depleted diet for 10 weeks, compared with a control group. Preliminary morphological studies showed narrowing and, in some places, obliteration of the capillaries in the stria vascularis, features suggesting early strial atrophy.

**Treatment**

Patients have been treated with replacement vitamin and mineral supplements, the dosage being dependent upon the degree of deficiency. Those with a 25-hydroxy vitamin D level of 5-10 ng/mL have received combined vitamin D and calcium tablets, two or three per day, to provide a dose of 1000-1500 units of vitamin D. Patients with levels less than 5 ng/mL have received treatment with the parent vitamin D₃ compound, calciferol, in doses of 3000-6000 units per day. Calcium and occasionally phosphate supplements have been added to this latter group if the patient's general diet was considered unsatisfactory. Careful biochemical monitoring is essential during replacement treatment because prolonged increases in plasma calcium and phosphate may lead to extraskeletal calcification. Overall, the results have been generally disappointing, with a significant (greater than 10 dB) hearing improvement occurring in less than 15% of cases.

**Vitamin D resistant rickets (hypophosphataemic)**

Familial hypophosphataemic vitamin D resistant rickets is the commonest form of the genetically determined osteomalacias. It is due to a reduced renal tubular reabsorption capacity for phosphate and is most frequently transmitted as an X-linked dominant condition. Sporadic cases due to a new mutation are not uncommon. Davies, Kane and Valentine (1984) recently described the results of their survey of 16 families with the condition and found a high incidence of sensorineural hearing loss in 25 patients. General skeletal radiographs show osteosclerosis with an increase in bone density and a coarsened trabecular pattern (Davies and Stanbury, 1981). The petrous temporal bones in many of the 25 cases also showed a generalized increase in bone density, and in some, narrowing of the internal auditory meatus was present. Similar radiological features were reported by Stamp and Baker (1976) who described two children from a first cousin marriage. The audiological features indicated a cochlear dysfunction but did not, however, support the original theoretical pathogenesis for hearing impairment suggested by Stamp and Baker, which was a retrocochlear loss due to pressure on the cochleovestibular nerve bundle in the narrowed internal auditory meatus. Nearly 75% of the cases were subsequently found to have typical features of endolymphatic hydrops on transtympanic electrocochleography (O'Malley et al, 1985), while two displayed classical features of Ménière's syndrome.

The other main form of hypophosphataemic osteomalacia is recessive in type. Weir (1977) described two pairs of siblings who were known to suffer from this disorder. Three out of four developed some degree of sensorineural deafness, and all demonstrated the radiological finding of marked narrowing of the internal auditory meatus. In the X-linked hypophosphataemic variety, alkaline phosphatase levels return to normal on cessation of growth, but in the recessive form continued biochemical activity persists on attaining adult stature and maintenance therapy with vitamin D is necessary.
Vitamin D intoxication

Cohen et al (1979) reported a patient with pseudohyperparathyroidism, who had continued to take calciferol 2.5 mg daily. Four years later a severe conductive hearing loss was present, and examination showed marked calcification of the tympanic membranes and cornea. Radiological investigation demonstrated extensive calcification of the kidneys and blood vessels, while the mastoids were cellular. Unfortunately the hearing loss was unchanged by treatment. One of the authors (GBB) has encountered a similar case. in 1972, a 4-year-old child, whose father was a serviceman stationed abroad, was eventually found to be suffering from a very rare growth disorder due to a primary growth hormone deficiency. The diagnosis of rickets had been made initially and calciferol treatment taken for more than 2 years. A bilateral hearing loss was present in addition to partial blindness and impaired growth. Calcification of the tympanic membranes and cornea was present, although the nature of the hearing loss could not be fully evaluated.

Osteoporosis

Most cases of osteoporosis are classified as idiopathic and typically affect the spine and long bones in the elderly. Pathologically there is a reduction in total bone mass due to loss of both the trabecular bone matrix with widening of the vascular channels and deficient mineralization. Radiologically there is rarefaction of bone, which is indistinguishable from osteomalacia. However, in this latter condition the histopathology is quite different because the bone matrix framework remains intact. Blood biochemistry is normal, although metabolic studies may show a negative nitrogen balance and evidence of calcium malabsorption.

Otological features

One of the very few accounts of the otological features associated with osteoporosis was reported by Henkin, Lifshitz and Larson (1972). They diagnosed a sensorineural deafness, significantly greater than their age related mean level, in five or seven patients with confirmed osteoporosis who presented with severe bone pain. The hearing loss commenced at the onset of symptoms of bone disease or soon after and was almost invariably bilateral and progressive. Temporal bone radiology showed increased sclerosis of the otic capsule in five cases.

The biochemistry is frequently normal and the diagnosis may not be straightforward. Normal serum calcium, phosphate and alkaline phosphatase indices are also often seen in vitamin D undernutrition when clinical features of osteomalacia are also frequently absent and radiological bone changes are only found in the well established case. The association of osteoporosis and sensorineural loss clearly requires further investigation. The potential benefit of such studies for the hearing impaired population could be enormous. It is common knowledge that the body's positive calcium balance deteriorates with increasing age, particularly in postmenopausal women when plasma oestrogen levels are no longer maintained. It is quite possible therefore that this condition may well be an important contributory factor in the aetiology of presbyacusis, perhaps in association with relative vitamin D undernutrition which is also associated with increasing age. It is of great interest that the current treatment advocated for osteoporosis consists of a vitamin D metabolite, in conjunction with oestrogens in postmenopausal women. Calcium supplements are not
considered necessary providing that the diet is satisfactory (Crilley et al, 1981). The efficacy of such treatment on pre-existing hearing loss requires further study.

**Hyperparathyroidism**

The disorder may be primary, usually due to a parathyroid adenoma, or secondary, due to chronic renal disease. Occasionally it may be associated with osteomalacia. When the condition causes skeletal changes due to mobilization of phosphorus and calcium from bone, it is termed osteitis fibrosa cystica or von Recklinghausen's disease of bone. Plasma calcium levels are high and invariably diagnostic. Phosphate levels are often low, while elevation of the alkaline phosphatase, an index of osteoblastic activity, reflects bone involvement.

The condition is only rarely encountered in otological practice. Rüedi (1968) described the temporal bone changes in two patients with osteitis fibrosa cystica, and Lindsay and Suga (1976) subsequently reported another. The histopathological features were very similar to those seen in Paget's disease. Morrison (1979) detailed the clinical features of one case; a 64-year-old man presenting with a one-month history of a rapidly progressing hearing loss. Calcium deposits were observed beneath the tympanic membrane and a mixed hearing loss was found on pure-tone audiometry. The patient was lost to follow-up, but terminal hypercalcinosis was subsequently diagnosed a few months later.

**Acromegaly**

Acromegaly is a chronic disease of middle life resulting from the action of excessive growth hormone usually caused by an eosinophil adenoma of the anterior pituitary gland. It occurs after fusion of the bony epiphyses and is characterized by enlargement of the bones, especially of the hands, feet, skull and mandible. The enlargement of bones is caused by deposition of new bone upon the surface of original cortex causing an increase in thickness but not in length. About 30% of patients develop over diabetes mellitus.

**Otological features**

Richards (1968) investigated 15 patients. Five ears showed a marked conductive deafness, but otherwise the remainder developed a sensorineural loss which was substantially lower than in the 'normal' population, with the general tendency for the hearing loss to deteriorate with age. There was no relationship with the duration of the disease or the plasma growth hormone levels and hearing loss. Subsequently Doig and Gatehouse (1984) assessed the hearing in 56 patients with acromegaly requiring pituitary surgery and compared them with matched controls. They were unable to find any significant difference in hearing levels between the two groups nor any correlation with diabetes, growth hormone levels, blood pressure or other factors. In addition, no change in the hearing occurred after surgery to remove the tumour. In this series, three ears of the acromegalics showed evidence of otosclerosis compared with one in the control group.

Three cases of acromegaly with temporal bone involvement were reported by Graham and Brackman (1978). Radiology demonstrated massive thickening of the mastoid cortex and posterior bony canal wall with secondary lengthening of the bony external meatus. Some overgrowth diminishing the lumen also occurred. However, the internal auditory meatus,
The effects of syphilis on the temporal bone are often seen in clinical practice. It is a disease which should be suspected in any patient presenting with tinnitus and/or vertigo and/or sensorineural hearing impairment, particularly if fluctuant and of sudden onset. Prompt recognition and treatment may halt or possibly reverse the progressive audiovestibular symptoms, and prevent the development of serious systemic involvement in the tertiary stage, if this is not already present. These serious systemic features include cardiac and aortic involvement and parenchymatous neurosyphilis, manifested by general paralysis of the insane and tabes dorsalis. Both the congenital and acquired forms of syphilis can be complicated by inner ear disease.

The last half century has witnessed a dramatic decline in the number of reported new cases. Thus the incidence of new cases of congenital disease in the UK fell from 2439 in 1931 to 1223 in 1950 and more recently the numbers have stabilized at about 150 per annum (Chief Medical officer, 19740. in 1980, only eight new cases were diagnosed in children under 2 years of age (British Medical Journal, 1982). The universal antenatal serological screening programme in the UK has undoubtedly played an important part in the control of congenital syphilis; an untreated syphilitic mother has about a 50% chance of bearing a syphilitic child. Failure to eliminate this form of the disease altogether is probably due to the difficulty in administering antenatal care to some social groups. During the same period, the overall reported incidence of new cases of both congenital and acquired types fell from the post-war peak of nearly 28.000 cases per year to about 4.500 cases in 1980. The current prevalence in 1984 was 6.4 cases per 100.000 (British Medical Journal, 1986). A transient rise in the incidence was noted during the early 1970s and has been attributed to male homosexual transmission. Currently well over 50% of syphilitic infections in men are reported to have been homosexually acquired. The male:female incidence is now about 4:1 and new cases of acquired syphilis are about 25 times as frequent as congenital ones.

Diagnosis

Of the established screening tests for syphilis, the Venereal Disease Research Laboratory slide test (VDRL) is most commonly undertaken in clinical practice. Although the test is frequently negative in previously treated cases, and false positives may occur, it does give an indication of disease activity. It is invariably strongly positive in high dilution in early untreated cases and is usually accompanied by an elevated erythrocyte sedimentation rate.

More specific serological tests are now routinely employed, for example Treponema pallidum haemagglutination test (TPHA); Treponema pallidum immobilization test (TPI) and the fluorescent treponemal antibody absorption test (FTA abs). Of these the FTA abs is the most sensitive (Dunlop, King and Wilkinson, 1969; Hughes and Rutherford, 1986). A positive result confirms previous syphilitic infection but does not reflect disease activity and stays positive even following adequate treatment.
Examination of the cerebrospinal fluid in patients with syphilitic ear disease is essential to look for possible evidence of central nervous system involvement which is more likely to be seen in the late acquired form. Typical cerebrospinal fluid abnormalities of neurosyphilis, apart from positive serological tests, include slightly raised globulin and IgG levels and a lymphocytosis. Such investigations and treatment are best coordinated by a venereologist, who will also need to examine possible contacts in cases of acquired syphilis.

**General features**

Congenital syphilis may be associated with other abnormalities outside the cochleovestibular systems. The ocular manifestations of interstitial keratitis and choroidoretinitis result in corneal opacity in about 90% of patients with otological symptoms. Such features may only be apparent on careful slit-lamp examination by an ophthalmologist and may be of diagnostic value. Hutchinsonian thickened wedge-shaped incisors which are occasionally notched are found in 20% of cases. The typical facies of frontal bossing of the skull due to periostitis of the cranial bones and saddle nose due to involvement and collapse of the nasal septal cartilage and bone are only present in about 10% of cases (Morrison, 1975; Belal and Linthicum, 1980). Other features such as 'sabre tibia' are rare.

Tabes dorsalis and general paralysis of the insane are manifestations of neurosyphilis and both are now rare. The neurological features include 'lightning' pains, early optic atrophy, Argyll Robertson pupils, bladder dysfunction and sensory loss from dorsal column involvement resulting in impaired vibration sense and joint disruption - Charcot's joints (Catterall, 1977). However, previous treatment which may have been inadequate often results in atypical features.

A not infrequent clinical dilemma is posed by patients from the West Indies, Central America and Africa, who may display positive serological test results and similar clinical manifestations but who are suffering from yaws. This disorder is caused by a different spirochete, *Treponema pertenue*, and typically is spread by direct contact among children. Old scarring from previously healed cutaneous ulcers is characteristically present on the lower legs. When these scars are absent, the patient from these countries should certainly be considered to be suffering from syphilis and treated accordingly.

**Otological features**

**Histopathology**

Two distinct types of histopathology are recognized. Treponemal labyrinthitis is the typical lesion in early congenital syphilis, and meningolabyrinthitis in the acute meningovascular phase of secondary and tertiary disease. In this latter form, the small blood vessels of the meninges show endarteritis obliterans. There is increased fibrosis of the meninges, with small areas of the necrosis and a diffuse infiltrate by plasma cells and lymphocytes. The eighth nerve may be involved in association with the infective basal meningitis, and the inflammatory process spreads from the spiral ganglion to the cochlear duct and membranous labyrinth (Goodhill, 1939).
In late congenital and acquired disease, the main lesion is a rarefying gummatous osteitis of the temporal bone with secondary involvement of the membranous labyrinth (Mayer and Fraser, 1936; Goodhill, 1939; Schuknecht, 1974). All three layers of the otic capsule are involved in the osteitis, which is associated with underlying endarteritis and infiltration with chronic inflammatory cells and multinucleated giant cells. The inner ear features are dominated by endolymphatic hydrops and progressive degeneration of the neuroepithelial structures, particularly the cochlear neurons and organ of Corti, which may be severe.

It has long been held that the pathogenesis of the hydrops is probably by direct involvement of the endolymphatic duct which becomes obliterated. However, treponemal spirochetes have been found in many different sites in humans with late syphilis following treatment, including the aqueous humour of the eye, cerebrospinal fluid, synovial fluid, temporal artery, lymph nodes and liver (Collart, Borel and Durel, 1964; Smith and Israel, 1967; Goldman and Girard, 1967; Rice, Jones and Wilkinson, 1969; Mack et al, 1969; Dunlop, 1972). This continued presence of spirochetes in spite of apparently adequate previous antibiotic treatment, may well be a significant factor in the pathogenesis of the hearing loss (see below; Immunology and the temporal bone).

**Early syphilis**

Congenital syphilis is contracted by the developing fetus in utero as a consequence of acquired maternal syphilis. The early infantile form is usually fatal due to multisystem involvement which dominates the features of otolabyrinthitis. As noted above, it is now exceedingly rare in the UK. Probably about 50% of cases develop bilateral hearing loss eventually. Earlier studies, for example Karmody and Schuknecht (1966), tended to underestimate the incidence because of the proportion of younger individuals who could be expected to develop symptoms later on.

Secondary syphilis is typically, although not exclusively, seen in adult homosexual men. The first symptoms last for a few weeks and include malaise, slight pyrexia, non-specific headaches, skin eruptions, pharyngitis and lymphadenopathy. They are relatively trivial and are hence frequently ignored by the patient until sudden hearing loss develops which is often bilateral. There may be some transient vestibular symptoms which are frequently positional in character and tinnitus. Ocular palsies and facial paralysis may occur as well in the acute meningovascular type of secondary disease. The sensorineural hearing loss preferentially affects the high frequencies; elevated stapedius reflex thresholds, possibly with reflex decay, are frequently present. Speech discrimination is often significantly worse than is suggested by pure-tone audiometry and the caloric responses are reduced. Increased latency and/or reduced wave V amplitude on brainstem evoked audiometry has been recently reported (Rosenhall, Löwhagen and Roupe, 1984). These audiovestibular symptoms may be partly reversible. If left untreated, the infection tends to run a benign course but the hearing loss remains.

**Late syphilis**

Late syphilis affects the temporal bone between 10 and 50 years after the primary infection. Once established, the untreated disease carries a poor prognosis with relentless
progression to profound deafness, although fluctuations are common. There are some grounds, however, for optimism with antitreponemal agents and systemic steroids.

In general, the clinical features are similar in both the congenital and acquired forms of the disease, although the former is more common in females. It is often difficult to assign a patient to one of these groups, particularly since previous antibiotics have invariably been taken. The otological features in congenital cases can occur at any stage, but they are uncommon after middle age. In contrast, patients with late acquired disease are usually over 40 years of age. The hearing loss is typically symmetrical in congenital cases but more frequently unilateral in the acquired group, sometimes for many years. In about 20% the onset of aural symptoms is sudden and fluctuations are seen in 30%, particularly in early stages (Hahn, Rosin and Haskins, 1962; Dawkins, Sharp and Morrison, 1968; Kerr, Smyth and Cinnamond, 1973). Apart from fluctuation, there are other features which closely mirror the symptoms of Ménière's disease and are a reflection of the underlying endolymphatic hydros (Schuknecht, 1974). The early hearing loss is sensory in character with predominantly low or peaked patterns of pure-tone audiometry. Half the patients exhibit episodic attacks of vertigo which may be indistinguishable from those occurring in classical Ménière's disease.

The results of transtympanic electrocochleography in a series of 18 cases of late syphilitic deafness have been described by Ramsden, Moffat and Gibson (1977). An enhanced negative summating potential (SP) was found in nearly 80% of ears tested in association with a small cochlear microphonic (CM), both features indicating established endolymphatic hydrops. The summating potential characteristically affected the descending limb of the compound action potential (AP). This feature, however, is not pathognomonic and in the authors' experience occurs relatively infrequently. Syphilitic hydrops tends to remain relentlessly active in the majority of cases, in contrast to idiopathic Ménière's disease where only a relatively small proportion of patients have hydropic pathology which is not self-limiting to some degree. Secondary neuronal degeneration associated with more profound degrees of hearing loss is therefore more frequent. The pattern of pure-tone audiometry now becomes flattened or high-tone in character. Alteration of the stapedius reflex to a retrocochlear pattern with elevated thresholds and decay is now evident in association with a relative greater impairment of speech discrimination.

Progressively severe peripheral vestibular damage leading to increasing imbalance and ataxia is also quite common. However, compensation for such a slowly developing deficit can significantly reduce the degree of disability, particularly in the younger patient, and may only come to light on formal vestibular assessment.

Two eponymous otological phenomena which are sometimes present in late congenital syphilis are worthy of mention. Hennebert's (1911) sign consists of a transient positive fistula test without clinical evidence of middle ear disease. Tullio's sign consists of transient vertigo and nystagmus following exposure to sudden high intensity sound. These phenomena are believed to be due to sound energy transmission through the stapes footplate on to the distended saccule, and are occasionally seen in other diseases associated with endolymphatic hydrops.
Treatment

Penicillin is still the most effective antibiotic for the treatment of syphilis. Its main bactericidal effect occurs when the organisms are dividing. This has been shown to take place much less rapidly in the late form of the disease, and hence the duration of treatment is as important as the maintenance of effective serum concentrations. In the presence of confirmed allergy, one of the cephalosporins is probably the second choice of drug to use.

The proven effective therapeutic regimen consists of 600,000 units of procaine penicillin by intramuscular injection daily for 21 days. This aqueous solution only has to be injected once a day and results in an effective serum level for 24 hours (Catterall, 1977). Oral probenecid 500 mg 6-hourly inhibits excretion of the drug and helps to raise tissue levels. This regimen has proved satisfactory for outpatient treatment (Dunlop, Al-Egaily and Houang, 1981). An alternative protocol which is probably as effective in patients who show good treatment compliance is high-dose ampicillin. A dosage of 1.5 g is prescribed four times daily for 4 weeks (Adams et al, 1983). Unfortunately, there is no evidence that penicillin treatment alone prevents the progression of cochleovestibular manifestations.

There is now, however, considerable clinical evidence that systemic steroids alone can improve the hearing at least temporarily, in up to 50% of cases with late syphilitic deafness (Hahn, Rodin and Haskins, 1962; Karmody and Schuknecht, 1966; Morrison, 1969; Kerr, Smyth and Cinnamond, 1973) and suggests an immunological basis for at least part of the hearing loss. Steroids are also indicated to prevent the adverse effects of a possible Herxheimer reaction. This is a systemic phenomenon occurring within 2-12 hours of the first antitreponemal injection and is characterized by fever, followed by headache, malaise, flushing and sweating. The reaction lasts a few hours and is often accompanied by worsening local tissue involvement and has been known to cause sudden increased hearing impairment. The reaction has been attributed to complement activation and to complex immunological reactions involving a hypersensitivity response to the disintegration productions resulting from sudden destruction of large numbers of spirochetes (Catterall, 1977).

Prednisolone 30 mg 8-hourly is therefore commenced prior to institution of antitreponemal treatment and continued for 4 weeks. Others have preferred to use ACTH (Kerr, Smyth and Cinnamond, 1973; Adams et al, 1983). If there is no evidence of improvement in the auditory and vestibular symptoms by 6 weeks, it is discontinued. Improved hearing thresholds are more likely in patients with fluctuant symptoms and are an indication for longer term treatment on a maintenance dose of 2.5-5 mg daily. Unfortunately, any hearing gains often relapse on withdrawal of steroids which may well therefore need to be taken on a long-term basis to maintain improvement. Of course, prolonged steroid treatment has well recognized side-effects and the decision to maintain steroids must be weighed carefully in each individual case. Discontinuation of steroids should be followed by a further course of antibiotics. Initial optimism about the successful outcome of treatment of late syphilis with penicillin and steroids has been tempered in recent years, although long-term results show that this regimen frequently prevents further hearing impairment and almost invariably preserves some hearing (Adams et al, 1983).
Tuberculosis

Increasing numbers of patients with tuberculosis are currently presenting to various specialist departments in the UK, most often from among immigrant communities. Unfortunately it can no longer be considered a disease of the past. Although the infection primarily affects the middle ear, it may cause secondary involvement of the bony labyrinth.

Otological features

The possibility of tuberculous involvement is usually entertained by the presence of certain atypical features of chronic suppurative middle ear disease. Windle-Taylor and Bailey (1980) recently comprehensively reviewed a series of 22 patients with tuberculous ear disease who presented to The Royal National Throat, Nose and Ear Hospital, London, over a 30-year-period and found one-half to be under 20 years of age. None had a past history of pulmonary tuberculosis, although 18% had previously diagnosed disease at other sites. The middle ear features are dominated by the presence of florid, pale granulation tissue. Occasionally, as in other granulomatous disorders, the tympanic membrane may be intact, but more often breakdown has occurred, characteristically resulting in multiple perforations. Coexistent secondary infection by other organisms is frequently found.

Concomitant sensorineural hearing loss is encountered much more frequently than in 'conventional' chronic suppurative otitis media, and often results in a disproportionately large hearing loss. Windle-Taylor and Bailey did not detail the precise sensorineural hearing loss, but their data indicated that 60% had inner ear involvement, and in 25% this loss was total.

Treatment

Management obviously involves surgical excision and drainage of middle ear and mastoid disease in conjunction with antituberculous treatment. As in patients with syphilis, referral to a physician for general assessment, coordination of medical treatment and tracing of possible infective contacts is mandatory. Although there have been isolated reports of ototoxicity by rifampicin and ethambutol the risk is very considerably lower than following streptomycin therapy, which has therefore been largely discontinued.

Sarcoidosis

Sarcoidosis is a rare systemic granulomatous disease of unknown aetiology. Head and neck manifestations are uncommon and, when encountered in otolaryngological practice, the disease usually involves the parotid gland, facial nerve, nasal cavity and larynx. The nervous system is affected in only 5% of cases, although this rises to 50% if uveoparotid fever is present. The central nervous system lesion is presumed to be a granulomatous meningitis that directly infiltrates the cranial nerves or causes them to be compressed from involvement of adjacent intracranial structures. Any of the cranial nerves may be affected by the facial nerve is most frequently involved (see Chapter 24) while the eighth cranial nerve is fourth in order (Hybels and Rice, 1976). The disease has a higher incidence rate among negroes and Puerto Ricans in America.
The organs most affected are the lymph nodes, lung, liver, spleen, skin and eyes, but any tissue may be affected and certain manifestations are known to be associated with particular HLA types. The course of the disease is usually chronic with minimal constitutional upset.

Serum angiotensin-converting enzyme levels are raised in nearly two-thirds of cases of active sarcoidosis, but false positive elevation of this enzyme can occur. False positives, however, are extremely rare in the Kveim test. de Remee and Rohrbach (1980) noted that serum angiotensin-converting enzyme levels closely paralleled and occasionally antedated changes in clinical status in patients either undergoing spontaneous remission or being treated with steroids and suggested that enzyme determination should be of value in management. However, it must be appreciated that serum angiotensin-converting enzyme levels may also be raised in other conditions, such as Gaucher's disease and leprosy.

All patients with the disease should have assessment of their liver and renal function. The alkaline phosphatase is frequently raised and may be due to involvement of either liver or bone. Approximately 5-10% of patients with sarcoidosis have elevation of their serum calcium and this is thought to be due to hypersensitivity to vitamin D. There is hypoglobulinaemia in about 25% and this may also reflect disease activity. Electrophoresis of the serum proteins usually shows increased alpha-2 and gamma-globulins. The full blood count is frequently normal but erythrocyte sedimentation rate may be raised in the active stages. It is a characteristic feature of sarcoidosis that infiltration of old scars often occurs and these may provide welcome biopsy material.

**Otological features**

Sarcoidosis involving the ear may be associated with other signs such as uveitis (80%), parotid swelling (20%), facial nerve palsy (43%) and lymphadenopathy (55%). However, 40% of cases have shown no other neurological involvement.

The hearing loss may be sudden, fluctuating or progressive and the degree may vary from slight to severe to even total loss. It is usually bilateral although one side is more affected. Pure-tone audiometry may show either a high or low frequency loss while caloric testing usually shows reduced or absent responses (Gristwood, 1958; Hooper and Holder, 1970; Kane, 1976). The mechanism by which the deafness is caused is undecided. From the 36 recorded cases it would appear that the hearing loss is most probably sensorineural, but electrocochleography in two recent cases suggested the lesion may be retrocochlear with normal hair cell function (Majumdar and Crowther, 1983).

The temporal bones from a 32-year-old man deaf for 5 years from central nervous system sarcoidosis, have been examined histologically (Babin, Liu and Aschenbrener, 1984). It was found that the acoustic, vestibular and facial nerves were involved in a striking perivascular lymphocytic infiltration resulting in myelin and axonal degeneration. The cochlear and labyrinthine neuroepithelium and stria vascularis had degenerated. Babin, Liu and Aschenbrener hypothesized that sensorineural deafness and vestibular dysfunction in sarcoidosis start as a reversible neuropathy; in some patients an ischaemia secondary to the vasculitis results in irreversible damage to the inner ear neuroepithelium.
Steroids remain the only form of treatment but their effectiveness is not assured, especially in those with a profound or total hearing loss.

**Histiocytosis X**

Eosinophilic granuloma, Hand-Schüller-Christian disease and Letterer-Siwe disease are considered to be related disorders because of the similarity in the pathological lesions which consist of an inflammatory reticuloendotheliosis (Lichtenstein, 1953). There are, however, major differences in the severity and prognosis of the disorders (see also Chapters 10 and 23).

**Eosinophilic granuloma**

Eosinophilic granuloma is the mildest form of these granulomatous disorders. The features of 19 cases recorded over a period of nearly 40 years at the Armed Forces Institute of Pathology Registry, Washington, DC, have been reviewed by Sweet, Kornblut and Hyams (1979). Eosinophilic granuloma occurs typically in children and young adults, and there is a male predominance. It usually appears as a solitary osteolytic lesion in the long bones, skull including the temporal bone, ribs and vertebral. It was considered for some time that there are no systemic manifestations, but later findings have suggested that multiple sites can be involved by the disease (Michelson and Bonfiglio, 1977). Although the tumour-like disorder is usually initially asymptomatic, growth progression in the temporal bone eventually may produce erosion of the mastoid cortex, tegmen, tympanic or sigmoid plates, and the bony labyrinth, leading to pain and local tenderness.

Histopathology demonstrates sheets of benign histiocytes and scattered collections of small eosinophils. There may be areas of haemorrhage and necrosis with giant cells (Schuknecht, 1974). Treatment is by local curettage with low dosage irradiation, and is invariably curative.

**Hand-Schüller-Christian disease**

Hand-Schüller-Christian disease usually appears in childhood before 5 years of age, but has been reported in young adults. Multiple lesions similar to eosinophilic granuloma are present at diagnosis or develop within a few months. Skull lesions are quite common and may involve the temporal bone sometimes before other features are apparent (Tos, 1966). Destruction of the temporal bone may be associated with secondary infection and otorrhoea. Lesions may occur in the scapulae, ribs and long bones, while infiltration may result in hepatosplenomegaly and lymphadenopathy. Systemic manifestations include pyrexia, anorexia, and recurrent upper respiratory tract infections. Perihylar infiltration may be evident on chest X-ray examination.

This disorder is progressive and invariably the outcome is fatal in the young, although spontaneous regression may occur. Low dosage chemotherapy may be employed to control systemic manifestations.
**Letterer-Siwe disease**

This is a rare disease which may well not be a true histiocytic granuloma, but possibly an unusual form of histiocytic lymphoma. Certainly it has the appearance and behaviour of a malignant tumour of reticulum cells. It occurs in children under 3 years of age and is rapidly fatal. The main clinical features include destructive skeletal lesions especially in the skull, hepatosplenomegaly, lymphadenopathy and widespread replacement of bone marrow which results in a bleeding diathesis and recurrent infections. Lopez-Rios, Benitez and Vivar (1968) described the temporal bone pathology of a typical case.

Apart from the local symptoms due to secondary infection, hearing loss, reduced vestibular function, facial palsy and involvement of cranial nerves in the jugular foramen are commonly seen with larger lesions involving the temporal bone.

**Immunology and the temporal bone**

Since the turn of the century, the recognition and development of the field of immunology has been one of the most significant advances in medicine. It is, however, only relatively recently that the impact of immunological processes in various aspects of otolaryngology has become apparent. Basic concepts are covered in Volume 1, Chapter 18 and this section will assume a fundamental knowledge of many of these principles.

There are several specific types of immune response which are now recognized. The most useful classification of tissue-damaging hypersensitivity reactions between antigen and antibody is still that devised by Gell and Coombs (1968). They distinguished three types of initiating mechanisms involving humoral antibodies and a further type involving cell-mediated antibodies associated with delayed hypersensitivity reactions.

Clinical experience suggests that the inner ear may be involved in any of these types of immunological reaction. The otological picture is usually one of sudden or rapid bilateral hearing impairment which is frequently fluctuant and often associated with tinnitus. There may be aural pressure or fullness, with variable vestibular symptoms which can frequently be mild and transient but uncommonly acute and severe. The symptomatology may show close similarities to Ménière's disease and indeed, perhaps these disorders are different parts of the same spectrum of cochleovestibular disease. The presence of systemic clinical features depends on the particular mechanisms involved but are invariably conspicuous by their absence.

**Types of immune response**

**Type I**

The type I reaction (anaphylactic) described by Gell and Coombs occurs as a result of free antigen interacting in the tissues with cell-bound antibody. Within minutes of exposure to the sensitizing antigen, activation of enzymes in the tissues causes the release of vasoactive substances from mast cells or basophils which increase capillary permeability, alter vascular tone and stimulate smooth muscle contraction. Many allergic reactions take place locally where antibody is bound and do not necessarily induce a severe generalized anaphylactic
response. Allergies, particularly those due to foods or chemicals, are believed to be related to cochleovestibular disorders (Boyles, 1984). Eliminating the offending allergen from the diet in conjunction with antiallergic drug therapy may reverse a long-standing sensorineural loss (Clemis, 1974; Shambaugh, 1981). The importance of allergic processes in otology is, in the authors' opinion, to be regarded with some degree of scepticism. One of us (GBB) has, however, managed a 36-year-old man with an 18-month history of bilateral Ménière's syndrome, which was undoubtedly initiated or at least aggravated by milk intolerance. Dietary management enabled his 40 dB fluctuant hearing loss to stabilize at a near normal level and he required no further specific treatment.

Type II

The type II reaction (cytotoxic) occurs when free circulating antibody interacts with fixed antigen which already forms part of a cell surface or tissue membrane. The invariable result is membrane change and in the case of a cell results in lysis and death. This reaction involves complement fixation and activation. Recent evidence from immunofluorescent studies (Arnold and Gebbers, 1984) suggests that the mechanism may well be important in some types of immune-mediated inner ear disorders, perhaps on occasion in combination with delayed cell-mediated activity (see later).

Type III

When both antigen and antibody are freely circulating, the resulting circulating immune complexes are still on occasions able to provoke a tissue response, the type III reaction. Immune complexes are usually rapidly and harmlessly removed from the circulation by the phagocytic cells of the reticuloendothelial system. They can, however, become harmful if they are deposited in body tissues when complement activation enhances local inflammatory processes and cell damage. Immune complex reactions may be related to autoimmunity, or may also occur in response to exogenous antigens such as microorganisms and drugs. Their role in the cause of various disease processes has attracted much attention in recent years. The subject has been well reviewed by Plotz (1982) and Heaney (1982). Recognized clinical disorders which are probably mediated by immune complexes range from the classic anaphylactic serum sickness reaction to disorders which are relevant to otology. These include systemic lupus erythematosus, polymyositis, relapsing polychondritis and the various types of vasculitis, including polyarteritis nodosa, Wegener's granulomatosis, temporal arteritis, Behçet's disease and Cogan's syndrome. These disorders are considered later.

The tissues involved in these type III hypersensitivity reactions depend on the size and specificity of the complexes. Biologically active complexes are of intermediate size and are poorly cleared from the circulation. They may become arrested on the endothelial lining of small blood vessels or in other tissues. Some tissues contain specific receptors for components of the immune complexes and, hence, may become preferentially involved to produce isolated organ or system disorders. Immune complex and complement activation in a vessel wall leads to a local inflammatory reaction, increased vascular permeability and permanent vessel damage.

In the otological context, the vessels of the stria vascularis may be a possible location for immune complex deposition, while the capillaries of the endolymphatic sac are another.
The cochlear capillaries are non-fenestrated (Juhn and Rybar, 1981) and differ from the capillaries of the endolymphatic sac, which are fenestrated (Lundquist, 1976) and arise from the external carotid system. The endolymphatic sac capillaries almost certainly have a filtration function and interference, in this context by antigen-antibody complexes, may lead to inner ear fluid imbalance and secondary hydrops. Leone, Feghali and Linthicum (1984) described the temporal bone features in a patient who died of Wegener's granulomatosis. They found preferential involvement of the endolymphatic sac capillaries, but not those of the cochlea and suggested that a similar pathology in other types of immune complex-mediated autoimmune disease could explain the frequent occurrence of Ménière-like symptoms and underlying hydrops causing sudden or progressive cochlear hearing losses. The recent evidence implicating the endolymphatic sac as the site of the primary immune response of the inner ear may also help to explain these features (see below).

**Immunology of syphilis**

One disease in which there is mounting evidence to support an immunological basis for the cochleovestibular features in some cases is syphilis. Thus the fluctuant nature of the early auditory symptoms, which are often bilateral and not infrequently associated with underlying endolymphatic hydrops, are also typically seen in other conditions where immune processes are considered aetiologically relevant. Sudden onset or deterioration of symptoms is a feature which is also shared with these other disorders. However, the most cogent support comes from the beneficial symptomatic response, at least temporarily, to systemic steroids even in the absence of bactericidal antibiotic treatment (Hahn, Rosin and Haskins, 1962; Karmody and Schuknecht, 1966; Morrison, 1969).

The general role of circulating immune complexes in the pathology of syphilis has been suspected for many years since their local accumulation was demonstrated in cases with syphilitic nephropathy (Braunstein et al, 1970; Bhorade et al, 1971; Kaplan et al, 1972). More recently, free circulating complexes have been identified in the serum of humans (Sølling et al, 1978; Engel and Diezel, 1980; Wozniczko-Orlowska and Milgrom, 1981) and animals (Baughn, Tung and Musher, 1980) with this disease by various immunological techniques. Thus Engel and Diezel (1980) found elevated immune complexes by a precipitation method in 41% of a series of 51 patients with early syphilis. Moreover, the complexes only decreased to normal limits in about one-half of the cases following treatment. By specific tests using dissolved complexes they were able to show that the complexed antibodies are specific antitreponemal antibodies. This result indicates the persistence of viable *Treponema pallidum* organisms after treatment, and corroborates the reports of earlier workers who had demonstrated organisms in various sites, such as lymph nodes, aqueous humour and cerebrospinal fluid, under similar circumstances by conventional microbiological techniques (Collart, Borel and Durel, 1964; Smith and Israel, 1967; Goldman and Girard, 1967; Rice, Jones and Wilkinson, 1968; Dunlop, King and Wilkinson, 1969; Mack et al, 1969; Dunlop, 1972). A number of different immunological aberrations have been described following treponemal infection and were reviewed by Sell and Norris (1983). Although the significance of these is not fully understood, it appears that an important phenomenon is the specific activation of suppressor mechanisms. These interfere with the mounting of an adequate cell-mediated immune response and facilitate the survival of the organisms (Leven, Wright and Turk, 1971).
Brookes (1985b) suggested that continuous antigenic stimulation resulting from a persisting low-grade syphilitic infection, either locally in the temporal bone or elsewhere, may lead to continuous and excessive immune complex production with secondary pathological changes including inner ear involvement. Thus two out of 26 patients with 'unexplained' progressive sensorineural hearing loss associated with elevated circulating immune complexes had syphilis. In fact one of these had the highest levels of complexes recorded in the series.

It has been generally accepted for some time that the Herxheimer reaction in response to drug therapy of syphilis is caused by massive destruction of treponemes followed by release of antigen and its reaction with antibodies (Catterall, 1977). Although direct syphilitic infection of the labyrinth undoubtedly occurs, it may well be that a more common pathogenesis for the otological features involves a phenomenon which is somewhat analogous to a chronic Herxheimer-type response. In theory, one might expect that inner ear involvement would thus be confined predominantly to the group of patients with persisting abundant immune complexes. Prospective clinical studies are clearly required to investigate this possible association.

It must be stated, however, that the precise role of immune complexes in the pathogenesis of sensorineural hearing loss remains to be defined. The association was reported by Kanzaki and Ouchi (1981) and Stephens, Luxon and Hinchcliffe (1982). Recently, the current state of knowledge in this field in relation to otological disorders has been comprehensively discussed and illustrated by reference to specific case histories (Brookes, 1985b, 1986). Although circulating immune complexes may effect a final common pathophysiological pathway in various types of cochleovestibular disorder, the possibility that they are merely secondary by-products resulting from local tissue damage in the inner ear, although less likely, cannot be definitely discounted.

Type IV

Cell-mediated delayed hypersensitivity reactions (type IV) occur as a result of preliminary sensitization of T lymphocytes in the recirculating pool of immunologically competent cells. These subsequently become arrested and interact at the site of local concentration of antigen liberating chemotactic factors leading to the infiltration of macrophages which cause tissue damage. Some tissue antigens are functionally sequestrated from the blood and reticuloendothelial system and do not produce an antibody response. However, when the tissues are damaged, a cell-mediated response may be induced following antigen release which can result in a secondary immune response in similar tissues, as in sympathetic ophthalmia. In this condition an immune-mediated chronic inflammatory disorder follows trauma or surgery to the contralateral eye. Recently Harris, Low and House (1985) have postulated the likelihood of an analogous otological disease which they termed sympathetic cochleolabyrinthitis. As in sympathetic ophthalmia (Glynn and Holborrow, 1964), humoral antibodies causing immediate type II cytotoxic reactions can probably also occur. In other situations, an inner ear infective condition may prime a cell-mediated otological immune response. Perhaps this is the pathogenesis of 'delayed endolymphatic hydrops', a clinical entity described by Schuknecht (1978).
Autoimmune inner ear disease

Although their role is not fully defined, these immunological mechanisms, either independently or possibly synchronously, may all contribute to the development of autoimmune inner ear disease.

Lehnhardt first postulated the concept of inner ear autoimmunity in 1958, on the basis of clinical observations in cases of recurrent bilateral sudden hearing loss. Various animal studies subsequently documented the model of immunopathological effects on the inner ear (Beickert, 1961; Terrayama and Sasaki, 1968; Quick, 1975; Arnold, Weidauer and Seelig, 1976). More recently Yoo et al (1983a, b) reported the induction of autoimmune sensorineural hearing loss in rats, and later described the development of endolymphatic hydrops in the guinea-pig by stimulating autoimmune to inner ear collagen.

The possible role of the various parts of the inner ear in such processes is now becoming clearer. Rask-Anderson and Stahle (1980) suggested that the inner ear possessed its own immunodefence system on the basis of experimental work in animals. They described the presence of a rich network of lymphatic capillaries and venules surrounding the endolymphatic sac and duct in guinea-pigs, and the interaction between macrophages and lymphocytes within the sac lumen. From these observations they concluded that the inner ear has the cellular components necessary for generating an immune response, and that the main site of antigen processing may be the endolymphatic sac. Harris (1983, 1984) was able to demonstrate the formation of specific antibody in the perilymph of guinea-pigs following inoculation, and suggested that a blood-labyrinth barrier analogous to the blood-brain barrier existed with respect to immunoglobulin equilibrium. This hypothesis of an inner ear immunodefence system primarily located in the endolymphatic sac was subsequently supported by the studies of Arnold, Altermatt and Gebbers (1984), who observed free and tissue-bound IgA and IgG immunoglobulins restricted to the endolymphatic sac region in human ears. Tomiyama and Harris (1986) have added complementary confirmation by demonstrating a reduced perilymph antibody response to antigen challenge following endolymphatic duct destruction.

McCabe was the first to bring autoimmune inner ear disease to the attention of otologists in 1979. This disorder is now becoming generally accepted as an uncommon, quite well defined, but poorly understood entity. The term may well embrace several different clinical syndromes, which could explain why both cell and humoral mediated pathways appear to be involved in the pathogenesis (Veldman et al, 1984). It may occur as a primary autoimmune disorder or may appear as an occasional local manifestation of a major systemic disorder due to an underlying immune system defect (Tables 15.3 and 15.4). This distinction is certainly not rigid, since systemic features may take several years to develop after the initial otological symptoms.

Otological features

McCabe described 18 patients seen over a 10-year period who presented with a similar clinical course and showed a uniform treatment response. The main features consisted of progressive sensorineural deafness, often bilateral, reduced vestibular responses, symptoms of pressure and tinnitus and very occasionally disruption of soft tissue of the middle and
external ear with facial paralysis. It was a disorder of young people in their 30s and 40s and the deafness progressed over weeks to months. Just under 20% went on to develop autoimmune diseases in other organ systems (McCabe, 1981). The lymphocyte inhibition test, in which the patients’ own lymphocytes are challenged against inner ear antigen, was positive in about 25%. Treatment with steroids and cyclophosphamide either produced sustained hearing improvement or stabilization. The validity of the clinical concept of autoimmune deafness has been supported by some other workers (Shea, 1982; Hughes et al, 1983a, b), although soft tissue destruction and facial paralysis has only rarely been encountered in these reports.

Table 15.3. Otological 'immune' disorders

<table>
<thead>
<tr>
<th>(1) External ear</th>
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<tbody>
<tr>
<td>(a) relapsing polychondritis</td>
</tr>
<tr>
<td>(b) necrotizing external otitis</td>
</tr>
<tr>
<td>(2) Tympanic membrane and middle ear</td>
</tr>
<tr>
<td>(a) homograft tympanoplasty</td>
</tr>
<tr>
<td>(b) tympanosclerosis</td>
</tr>
<tr>
<td>(c) otosclerosis</td>
</tr>
<tr>
<td>(d) chronic otitis media with effusion</td>
</tr>
<tr>
<td>(e) chronic suppurative otitis media with cholesteatoma</td>
</tr>
<tr>
<td>(3) 'Autoimmune' inner ear disease</td>
</tr>
<tr>
<td>(a) localized</td>
</tr>
<tr>
<td>(b) systemic</td>
</tr>
</tbody>
</table>

(After Veldman et al, 1984.)

Table 15.4. Systemic 'immune' diseases which may develop otological involvement

| (1) Systemic lupus erythematosus     |
| (2) Vasculitis                       |
| (a) hypersensitivity vasculitis      |
| (b) polyarteritis nodosa             |
| (c) Wegener's granulomatosis         |
| (d) temporal arteritis               |
| (e) Cogan's syndrome                 |
| (f) Behçet's syndrome                |
| (3) Relapsing polychondritis         |
| (4) Polymyositis and dermatomyositis |
| (5) Immunodeficiency diseases        |
| (a) T-cell deficiency                |
| (b) B-cell deficiency                |
| (c) disorders of phagocytosis        |
| (d) complement system disorders      |

Unfortunately, there are no diagnostic laboratory criteria and often only a beneficial response to treatment has allowed a 'therapeutic' diagnosis to be made. Cell-mediated immunity may be assessed by the lymphocyte migration inhibition test, in which the patient's
blood leucocytes are challenged with an antigenic extract of inner ear membrane (McCabe, 1979), or by a lymphocyte transformation test (Hughes et al, 1983a). However, a negative result does not necessarily exclude the diagnosis. The levels of serum immunoglobulins are of little relevance, but assay of circulating immune complexes and complement may indicate enhanced immune activity perhaps due to an immune complex disease if the levels are persistently raised. In addition, a raised erythrocyte sedimentation rate may reflect systemic disease activity.

**Treatment**

Many, but not all, patients respond to systemic steroids. Recommended regimens suggest prednisolone 20 mg four times daily for 10 days before reducing to a maintenance dosage of 5-10 mg on alternate days for 3-6 months in the face of continuing clinical improvement and lack of toxicity. In the authors' experience much lower dosages can often lead to improvement and reduce the unwanted side-effects, such as increased weight gain and dyspepsia. The figure illustrates the beneficial response to low dose dexamethasone in a 60-year-old man with a 10-year history of bilateral hearing impairment associated with raised circulating immune complexes. The figure shows the efficacy of low-dose prednisolone in a young girl with a 3-year history of immune-complex associated sensorineural hearing loss, who was able to discard her hearing aids completely after treatment.

Failure to respond to steroids may be an indication for immunosuppressant treatment using azathioprine or cyclophosphamide, but each case must be considered on its merit. Certain patients may also show improvement with plasma exchange treatment. This is invariably of a relatively temporary nature, lasting at most 3 months but which may 'buy time' in the management of problem cases (Hamblin, Mufti and Bracewell, 1982; Brookes and Newland, 1986).

**Connective tissue diseases**

Certain of the systemic connective tissue disorders which may produce inner ear involvement are now considered more fully. These may affect many organs and systems and largely, but by no means exclusively, show pathological changes in collagen, namely mucoid degeneration, fibrinoid necrosis and hyalinization. There is a significant female predominance and many of the disorders often commence in young adults in their 20s and 30s. There is now considerable evidence to support the view that many, if not all, are immunologically-mediated disorders, largely on the basis of demonstrable antibodies. However, definitive proof of an autoimmune aetiology is still lacking in most. It should be appreciated that this is a spectrum of disorders and some patients may show features of more than one of the various diseases.

Conditions characterized by immunologically-induced inflammation and necrosis of blood vessels, constitute the hypersensitivity vasculitides; the varies features are dependent on the particular organs and blood vessel sites involved. The specific predilections of involvement enable the group to be divided into several distinct types, the principal ones being systemic lupus erythematosus, polyarteritis nodosa, Wegener's granulomatosis, temporal arteritis, Cogan's syndrome and Behçet's disease. The pathogenesis is multifactorial, although in many instances the lesions are believed to be due to reaction to the deposition of immune complexes in vessel walls (Table 15.5).
Systemic lupus erythematosus

Systemic lupus erythematosus is the archetypal multisystem connective tissue disorder in which an autoimmune aetiology is most certain. The final common pathological process in many organs is immune complex deposition. Typically, lupus erythematosus cells (polymorphs with large engulfed basophilic material) are present and the serum antinuclear factor is positive. The erythrocyte sedimentation rate is very high and anaemia if frequently present. Although well over half the patients have central nervous system involvement, producing cranial neuropathies, otological involvement has only been reported rarely (Sheehy, 1981; Hamblin, Mufti and Bracewell, 1982; Caldarelli, Rejowski and Corey, 1986; Bowman et al, 1986).

Otological features

Sudden sensorineural hearing loss is a common feature in these reports. In the case described by Hamblin, Mufti and Bracewell (1982), a moderately severe cochlear hearing loss had commenced abruptly in a 47-year-old female about 6 weeks after the onset of her systemic symptoms. Treatment with prednisolone 40 mg daily for 2 weeks produced general improvement but the deafness remained. Subsequently plasma exchange treatment effected immediate and complete restoration of hearing, enabling reduction of steroids to a maintenance level of 5 mg daily. A single plasma exchange was repeated at approximately 6-monthly intervals to reverse the recurrent hearing loss which ensued. The dramatic response to plasma exchange infers a vascular mechanism and it was suggested that circulating immune complexes could cause sludging in the microcirculation of the stria vascularis.

Caldarelli, Rejowski and Corey (1986) reported the onset of bilateral profound sensorineural loss associated with mild unsteadiness over a period of 3 weeks. Systemic lupus erythematosus was diagnosed after a full metabolic profile investigation, and despite aggressive treatment with prednisolone initially at 100 mg daily in conjunction with the immunosuppressant drug cyclophosphamide 100 mg 6 hourly, a profound deafness remained. They postulated an underlying mechanism of microinfarction of capillaries or arterioles in the temporal bone, a pathogenesis characteristic of systemic lupus erythematosus in the central nervous system.

More recently, Bowman et al (1986) reported their experience of nine patients with systemic lupus erythematosus and associated hearing loss. It is of interest that the diagnosis was made prior to otological symptoms in four patients and after the onset of the hearing loss in the other five. The same group then carried out a prospective study of 30 further patients who had been hospitalized because of an exacerbation of their systemic lupus erythematosus. They found an 8% incidence of substantial previously undetected hearing loss without attributable cause and strongly suspected a causal association. The hearing loss, however, could not be correlated to age, sex, disease activity, organ system involvement, laboratory test abnormalities or duration of symptoms.

Polyarteritis nodosa

Polyarteritis nodosa is a systemic necrotizing vasculitis of small and medium-sized arteries which demonstrates a 3:1 male:female predominance. There is frequently involvement
of the renal, coronary, hepatic and visceral circulations, while an elevated erythrocyte sedimentation rate, anaemia and leucocytosis are invariably present.

Otological features

Deafness is unusual and of the sensorineural type (Druss and Maybaum, 1934; McNeill, Berke and Reingold, 1952; Rose and Spencer, 1957; Welsh and Welsh, 1963; Peitersen and Carlsen, 1966; Wing and Bulteau, 1967; Gussen, 1977; Lake-Bakaar and Gibbs, 1981). In rare instances, it has been the presenting symptom. As with other disorders associated with vasculitis, the onset is often sudden and typically bilateral and symmetrical. Investigations always display cochlear features and fluctuating symptoms may be seen. Exceptionally, middle ear granulation tissue may be present causing a conductive component, although this feature is more typical of Wegener's granulomatosis. This tissue response occurs with involvement of arteries in the middle ear mucosa, a pathological feature. The other histopathological findings are described in Chapter 17. Significant hearing improvement following the administration of systemic steroids (Peitersen and Carlsen, 1966) and steroids combined with the immunosuppressive drug chlorambucil (Wing and Bulteau, 1967) has been reported.

Wegener's granulomatosis

Wegener's granulomatosis is a discrete syndrome of necrotizing granulomatosis, vasculitis of the small arteries and veins of the upper and lower respiratory tract and kidney with less frequent involvement of other organs. There may be difficulties in differentiating this disorder from polyarteritis nodosa before the full complex develops. Patients will usually present to the otolaryngologist with persistent epistaxis, and systemic features include pyrexia, weight loss, anaemia, leucocytosis and an elevated erythrocyte sedimentation rate. The average duration of untreated disease is about 6-9 months, and death is usually a result of renal failure.

Otological features

Ear involvement has been reported in 15% and 36% of cases in two large series (Blatt et al, 1959; Kornblut et al, 1980) and may be the presenting feature. The higher incidence is probably a more realistic one, because early confusion of the disorder with lethal midline granuloma undoubtedly resulted in the inclusion of cases which were not Wegener's granulomatosis in the former series. The hearing loss seen in most patients is usually conductive. Seromucinous otitis media is an early feature and may lead to frank otorrhoea (Karmody, 1978; Kornblut, Wolff and Fauci, 1982; McDonald and de Remee, 1983). On occasions the tympanic cavity becomes filled with granulomatous tissue in which giant cells may be found, and may be associated with ossicular damage (Blatt and Lawrence, 1961; Densert, Rausing and Toremalm, 1969; Friedmann and Bauer, 1973). Clinically, these patients still present as chronic middle ear effusions but, at myringotomy, there is usually excessive bleeding and a middle ear space cannot be identified through the granulation tissue. One of the authors (GBB) has recently managed such a case with a bilateral mixed hearing loss. Systemic steroids produced a significant hearing improvement. However, concomitant sensorineural hearing loss is not common (Blatt and Lawrence, 1961; Cody, 1971). In the case
described by Blatt and Lawrence, direct spread of granulomatous tissue through the round window resulted in destruction of the membranous labyrinth.

Although Wegener's granulomatosis has a sinister reputation, there is growing optimism for survival using combination regimens of steroids and cytotoxic immunosuppressant drugs (see also Chapter 10).

**Temporal arteritis (giant cell arteritis)**

Pyrexia, bitemporal headaches, and tender palpable thickening of the temporal arteries are the main features of this condition which occurs in the older age groups. The underlying vasculitis is primarily confined to the extracranial arteries which may undergo aneurysm formation, stenosis and even occlusion. Blindness occurs in about 30% of untreated cases due to involvement of the ophthalmic artery. Characteristically the erythrocyte sedimentation rate is extremely high and serum globulins are increased.

**Otological features**

Rapidly progressive hearing loss with vertigo has been described, presumably due to involvement of the internal auditory artery (Cody, 1971; Healy and Wilske, 1978). In the case reported by Cody, the cochleovestibular signs were partly reversible with systemic steroids.

**Cogan's syndrome**

Cogan's syndrome is a very rare condition in which a non-syphilitic interstitial keratitis is associated with fluctuant but aggressive cochleovestibular damage (Cogan, 1945). It usually affects young adults and the ocular and otological symptoms commence suddenly and often almost simultaneously.

**Otological features**

The hearing loss is sensory in type and invariably bilateral. It progresses rapidly, although fluctuation may occur and is associated with episodic vertigo, tinnitus and aural pressure, constituting a Ménière's syndrome. Ultimately the deafness becomes profound and may be total. Vestibular assessment reveals significantly reduced or absent responses on caloric stimulation. In contrast, the ophthalmic features consisting of irritation, lacrimation, photophobia and blurred vision typically progress more slowly. Patchy corneal infiltration is associated with neovascularization in the advanced stages.

There is now considerable evidence to support an autoimmune aetiology (McCabe, 1979; Hughes et al, 1983b; Arnold and Gebbers, 1984; Brookes, 1985b). Hughes et al (1983b) described the result of comprehensive immunological testing of two cases and found evidence of cell-mediated autoimmunity. In the two cases reported by Brookes (1985b) very high levels of circulating immune complexes were found. These levels were observed to fluctuate in accordance with temporary systemic improvement induced by active treatment. Thus there could well be a role for immune complex assay in conjunction with erythrocyte sedimentation rate estimation as a useful clinical assessment of disease activity. Finally, Arnold and Gebbers (1984), using indirect immunofluorescent techniques, have recently demonstrated IgG and IgA
antibodies against human cornea and IgG antibodies against human inner ear tissue in the serum of a patient with Cogan's syndrome. The regions of the inner ear where these reactions took place were the stria vascularis, Reissner's membrane, spiral ligament and dark cell areas. This study complements the known main histopathological features in the temporal bone which include endolymphatic hydrops, degeneration of the organ of Corti and severe neuronal loss with infiltration with lymphocytes and plasmacytes in the region of the spiral ligament (Fisher and Hellstrom, 1961; Wolff and Bernard, 1965). Some cases of Cogan's syndrome are associated with systemic involvement consistent with polyarteritis nodosa and it has been suggested that the disorder may be a localized manifestation of the latter type of vasculitis.

Systemic steroids do not usually prevent the relentless progression towards severe cochleovestibular dysfunction. On the basis of the authors’ recent experience with two cases, early administration of immunosuppressive drugs is advocated. Indeed, the prognosis is so poor that there could be a place for intermittent plasma exchange therapy early in the natural history (Brookes, 1986).

**Behçet's disease**

Behçet's disease is a very uncommon chronic relapsing inflammatory disorder. The original classic symptom triad of uveitis and orogenital ulceration is now recognized as part of a multisystem vasculitic disorder which is very probably immunologically mediated. A comprehensive review of this condition has recently been published (Lehner and Barnes, 1986) and includes informative reports of contemporary research progress.

**Otological features**

Little attention has been paid to the otological aspects. Brama and Fainaru (1980) investigated 16 consecutive patients and found that 62% had features of inner ear involvement, which typically commenced about a decade after the initial manifestations of the disease. Hearing loss is almost always bilateral and sensory in type, although only slowly progressive. It is frequently associated with vestibular symptoms.

**Relapsing polychondritis**

This disease entity was first described by Jaksch-Wartenhorst in 1923 and is characterized by an inflammatory reaction occurring in the cartilage of several different organs. Other early features include tender swelling of nasal septum and costal cartilages, perhaps associated with an underlying cough and dyspnoea from involvement of the larynx and trachea.

**Otological features**

The auricles are first affected in about 90% of cases (Ödkvist, 1970) resulting in pain, swelling and erythema. They are very tender on palpation and very frequently associated with upper cervical lymphadenopathy.

Chondritis of the cartilage of the eustachian tubes may lead to serous otitis media, while involvement of the external auditory meatus may also contribute to a conductive
hearing loss. Sensorineural hearing impairment can occur independently or in conjunction with the conductive loss (Rabuzzi, 1970; Cody and Sones, 1971; Damiani and Levine, 1979). Eighty per cent of the patients studied by Cody and Sones had a sensory hearing loss which was usually bilateral and either of sudden onset or progressed over a period of a few weeks. Many of the cases also had vestibular symptoms with abnormalities on caloric testing.

The condition has been considered an autoimmune disorder for some years mainly because of the undoubted efficacy of corticosteroids in reducing the inflammatory response. Cody and Sones reported some recovery of hearing in patients with early sensorineural involvement, although relapses tended to occur when this drug was discontinued or when the dosage was markedly reduced. More recently, direct immunofluorescence examination of auricular cartilage, obtained from patients with the disease, has demonstrated deposits of immunoglobulins and the C3 component of complement at the chondrofibrous junction (Valenzuela, 1980).
Chapter 16: Sensorineural hearing loss

J. E. T. Byrne and A. G. Kerr

The clinician finds himself faced with a difficult diagnostic prospect each time he is confronted by a patient with sensorineural deafness. In this chapter an attempt is made to devise a practical approach to this problem in the everyday setting of the otolaryngology clinic.

Usually the patient has been aware of a hearing loss, but sometimes is not until attention has been drawn to it, for example, in a pre-employment or some other routine medical examination. Not infrequently the remarks of family or friends will be the stimulus to seek an otological opinion, often because of a tendency to turn up the television volume to the annoyance of the family.

Our aim is to devise a method which will chart a direct and useful route through the symptoms and signs of sensorineural deafness towards the identification and management of the underlying pathology, a means by which the benefits of knowledge, experience and intuition, may be put to best use. Unfortunately, a diagnosis of the pathology will frequently elude us and, in some instances, the most important objective will be a negative one, that is to find out what is not wrong.

In the outpatient clinic

An initial long and detailed history may be wasteful of time and a brief and general otological history is taken first. This is followed by clinical examination of the ear, including an assessment of the hearing by tuning fork tests. A pure tone audiogram is then carried out with the measurement of speech discrimination ability in each ear.

With the information gleaned from these initial steps, a more specifically directed history, examination and investigations may then be indicated.

History

Initially, enquiry is directed towards obtaining the patient's outline of his symptoms. When did he first notice hearing impairment? Was it of sudden or gradual onset? Is it unilateral or bilateral? Which ear does he consider to be the better? Is the hearing loss progressive, static or fluctuant? Is there or has there been otorrhoea? Were any incidents or specific circumstances associated with the onset of the deafness? How does the hearing loss affect him in his everyday life? Has he any tinnitus or vertigo?

Examination

A first requirement is the adequate visualization of both tympanic membranes. When the external auditory meatus is occluded by wax, hairs or debris, there may be a temptation to proceed with audiometry on the assumption that the bone conduction curve will at least give an idea of the severity of the sensorineural component of the deafness. This is not necessarily so. A small conductive component can convert a severe sensorineural deafness
into an apparently profound deafness. It is imperative that the ear canals are clear before carrying out audiometry. It is at this time that one ought to detect, and indicate to the audiology technician, an ear canal that may collapse under the pressure of the earphone.

An assessment of the overall ability to communicate will be made at this time and it is easy to eliminate any possibility of lip reading, by talking to the patient while cleaning out the ears and inspecting the tympanic membranes. Such an assessment is of importance both clinically and in medico-legal cases.

In clinical assessment of speech discrimination, it may be essential to mask the contralateral ear with the Barany noise box.

Routine use of tuning fork tests is an important clinical discipline. Patients not infrequently have uncharacteristic difficulty when presented with choices and allowance must be made for incorrect tuning fork responses occurring in patients who are unable to accept what to them is conflicting information from their senses, for example the lateralization to the deaf ear in conductive hearing loss. It may be helpful to use both the 256 Hz and 512 Hz tuning forks. In compensation cases the responses to the tuning fork tests sometimes suggest a lack of cooperation.

**Audiometry**

Simple pure tone and speech audiometry (PBmax), with masking, have become the anchor of the clinical approach to sensorineural hearing losses. These routine measurements are generally very reliable, although constant vigilance should be maintained with regard to spurious audiometric responses.

The frequencies normally measured are 250 and 500 Hz, 1, 2, 4 and 8 kHz. In many situations it is desirable to include the 3 and 6 kHz frequencies. Measurement of these latter frequencies is required for certain pre-employment examinations including military service and also may be useful in cases of mild noise-induced hearing loss.

In our everyday practice we consider the lower limit of normal hearing to be 20 dB.

Speech scores are measured, based on 25 phonetically-balanced words, presented at approximately 40 dB above the average pure tone threshold for 500 Hz, 1 and 2 kHz (Kerr and Smyth, 1972). There is no necessity at this stage for a time-consuming speech discrimination curve.

**Evaluation of the audiogram**

In the absence of a conductive loss there will be three groups:

(1) bilateral hearing loss
(2) unilateral hearing loss
(3) those found to have apparently normal hearing.
In each group, it is important to consider two points:

(1) is the recorded pure tone loss consistent with the clinical assessment?
(2) is the speech discrimination score consistent with the clinical assessment?

In unilateral hearing loss, with normal hearing in one ear, there should be no difficulty in communicating in the normal clinic situation.

**Bilateral sensorineural hearing loss**

In bilateral sensorineural deafness one should note whether the loss is symmetrical or nearly so, and how good or otherwise, the speech discrimination is in each ear.

In general clinical practice, the commonest cause of bilateral sensorineural deafness is presbyacusis. Schuknecht (1974) has described four types.

*Sensory presbyacusis* is due to loss of hair cells, possibly secondary to initial loss of supporting cells. This starts at the base of the cochlea and slowly progresses apically. Consequently the low frequencies are untouched initially with a steep fall off in hearing in the high frequencies. Speech discrimination in quiet surroundings remains good unless the speech frequencies become affected.

*Neural presbyacusis* is due to loss of auditory neurons. The whole length of the spiral ganglion is affected, but this is more marked at the basal turn. All the frequencies tend to be involved, but the higher frequencies are usually more affected. The prominent feature is a disproportionately severe loss of speech discrimination.

*Atrophy of the stria vascularis* gives a flat audiogram with good speech discrimination. (Although this is a degenerative condition it may also occur in younger people.)

*Inner ear 'conductive' deafness* gives the well known ski-slope audiogram with only slightly impaired speech discrimination.

It is not uncommon to find combinations of two or more of these degenerative processes in the one patient.

It is worth noting that the factors influencing speech discrimination scores are the severity of the loss for the speech frequencies, the angle of the audiometric curve, the presence or absence of recruitment and the number of available neurons in the auditory nerve.

*Industrial noise-induced deafness* is also common in many practices.

Before making a diagnosis of industrial noise-induced hearing loss, a careful work history should be taken. This should include some assessment of the noise exposure, its duration and probable levels. If the person has consistently to shout to communicate with colleagues close by, then there is a strong likelihood that the ambient noise is 90 dB(A) or above.
It is important that a diagnosis of noise-induced deafness should not be made simply on the patient's statement that his work is noisy. 'Noisy' is a relative term, but hair-cell damage does not usually occur in exposure to levels of less than 85-90 dB(A) for an average 40-hour week. A number of patients are likely to engage in litigation against their employers in respect of noise damage. A careful history is important and one must be circumspect in what one says lest a patient is induced to set off on a spurious and potentially embittering claim.

Frequent mention is found in the recent literature to losses arising from the leisure activities of young people, including acoustic trauma from fireworks and noise damage from personal stereos, discos and rock concerts. However, as long as they are not working in noisy environments, the risk to the audience is probably small because of the relative shortness of the periods of exposure. There is a definite risk for the performers, particularly if they engage in long practice sessions in small rooms.

*Ototoxic hearing loss* is usually bilateral and symmetrical. In those drugs which cause irreversible hair cell damage, the diagnosis usually becomes apparent from the history. However, in the reversible types, such as salicylate deafness, probing may be necessary because some patients fail to admit to the consumption of aspirin or related drugs.

Salicylate deafness characteristically produces a 'flattish' hearing curve accompanied by good speech discrimination. It will usually reverse on withdrawal of the drug.

A *dish-shaped audiogram* is occasionally found, in which the curve exhibits a moderately severe loss for the middle frequencies and good hearing for the high and low frequencies. It is usually without obvious cause and is, by custom, attributed to heredity.

*Asymmetrical bilateral hearing loss* is probably most commonly found following *weapon firing*, particularly one which is fired from the shoulder. The worse hearing is usually in the ear closer to the muzzle. Enquiry in these cases should be made into the type of weapons fired, for example, high or low velocity, whether or not fired from the shoulder, the frequency of use and number of rounds. Other weapons such as anti-tank weapons, rocket launchers, and mortars should also be enquired about. A history of tinnitus or temporary threshold shift immediately after firing, will indicate ears at risk. When patients are asked about weapons they will sometimes forget to mention sporting weapons including shotguns. Members of shooting teams are particularly at risk. It is useful to remember that some earplugs or earmuffs may not provide adequate ear protection against high velocity weapons.

Asymmetry of high frequency loss may be associated with *head injury*. Hearing loss is more probable in these cases if there is a history of unconsciousness following the injury. In general, the longer the period of unconsciousness, the greater the likelihood of a consequent hearing loss. Unconsciousness, bleeding or cerebrospinal fluid leak should be enquired about in deafness associated with *head injury*.

Hearing loss in late *Ménière's disease* may be bilateral and non-fluctuant. Speech discrimination will, at that stage, usually be significantly reduced. Hearing loss associated
with congenital or late syphilis is usually bilateral and the speech discrimination tends to be reduced and to fluctuate.

**Bilateral acoustic neuromata** are rare but must be kept in mind and the deafness may or may not be asymmetrical. Generalized neurofibromatosis or a positive family history increase suspicion of this condition.

Each of the causes of unilateral deafness may, of course, occur either bilaterally, or in combination with each other, or with any of the causes of bilateral deafness, resulting in a bilateral sensorineural deafness which is usually asymmetrical.

**Unilateral sensorineural hearing loss**

Unilateral hearing loss is frequently of sudden onset. Trauma including head injury, acoustic accident, blast injury, and damage at surgery, will come to mind early in consideration of unilateral hearing loss. There continue to be the sporadic cases of sudden hearing loss which are attributed to some interference with the cochlear blood supply, a viral infection, Reissner's membrane rupture, or perilymph leak. Some cases may, with careful questioning, be found to be due to childhood mumps, half-forgotten head injury, or possible perinatal causes. A significant number of cases will be seen for which no cause can be determined.

It is in the unilateral group that one is most commonly placed in the position of excluding an acoustic neuroma. Obviously it would not be practical to perform a computerized tomographic (CT) scan and evoked response audiometry on every patient with asymmetrical or unilateral deafness. Hence it is important to make, where possible, an accurate diagnosis of the pathology so as to limit the number of cases where expensive investigations are required.

**Deafness with normal pure tone audiometry**

Not infrequently, patients complain of hearing loss where an audiogram shows normal pure tone hearing and excellent speech discrimination. There probably are two categories of this syndrome. The first, and more common, could be called the 'auditory inferiority complex' group. These patients are insistent that they have difficulty in hearing which is usually more marked in background noise. Once they have decided that their hearing is impaired, they tend to blame their ears for hearing difficulties rather than the speaker or the background noise. The clinician will reassure these patients that they have 'normal hearing' and in most cases that is usually all that is needed. The reassurance often produces a dramatic improvement in their ability to hear.

The second group is one described by Pick and Evans (1983). They described patients who have abnormal difficulty in hearing in background noise despite having a normal pure tone audiogram. The problem is due to impairment of frequency resolution and the diagnosis depends on a 'comb-filtered noise test' which, at present, is not in general clinical use. They considered that the condition represents an early stage of hearing damage.
A diagnosis of neurosis in a patient should be made very reluctantly. Pressure on the central auditory pathways by a tumour has been known to cause severe reduction in speech discrimination in the presence of satisfactory or minimally reduced pure tone hearing loss. Exotica of this type are extremely rare but will arise from time to time so as to remind us of the dangers of attaching to patients the label 'neurotic'.

**Fluctuating hearing loss**

In taking a history of hearing loss it is important to ask specifically of the patient as to whether the hearing is fluctuant. Care must be taken in assessment of this symptom as occasionally the patient may be describing the variation in ability to hear in quiet and noisy surroundings.

Fluctuating hearing loss usually results from a small number of clear-cut pathological entities. The most common of these is middle ear pressure change, resulting in minor degrees of conductive hearing loss.

The most common cause of fluctuation of inner ear function is endolymphatic hydrops which occurs in Ménière's disease and syphilitic labyrinthitis. Perilymph fistula is a rare cause of fluctuating inner ear function.

In *Ménière's disease*, the history of tinnitus and associated episodic rotatory vertigo will determine the 'true' Ménière's, but this leaves a number of cases of low frequency loss which may or may not have tinnitus or dizziness. These may be 'early' cases of Ménière's disease. The disease is usually unilateral in the early stages and speech discrimination is generally well preserved until the later stages.

In *congenital* or *late syphilitic labyrinthitis*, the hearing loss fluctuates and the associated vertigo is episodic and rotatory in the early stages. In the later stages with destruction of vestibular function, it becomes constant and is described simply as unsteadiness. A history in early life of treatment, usually injections, for 'eye trouble' (interstitial keratitis), will suggest the diagnosis. Wassermann and Kahn tests will frequently be negative and the fluorescent treponemal antibody absorption (FTA abs) test will be of most help. The loss is usually bilateral and asymmetrical. In established cases, speech discrimination tends to fluctuate more than the pure tone hearing.

Perilymph fistula presents a difficult diagnostic problem and is discussed in Chapter 7.

**Mixed sensorineural/conductive hearing loss**

Mixed sensorineural and conductive deafness presents a challenge to the physiological measurement technician and it is here that one most commonly encounters spurious audiometry. It is always important to ensure that the audiometric findings and clinical judgement are in agreement, especially if there is any question of surgery. A speech discrimination test (PBmax), with adequate masking of the other ear, will provide confirmation that the ear is serviceable or otherwise, and should not be overlooked.
The measurement of bone conduction is a rather artificial concept since it is not necessarily a true reflection of the function of the inner ear. It is well known that the middle ear makes a contribution to bone conduction and that correction of a middle ear conductive lesion causes an apparent improvement in inner ear function. The best known example is the Carhart notch in otosclerosis, but this may also be seen in chronic suppurative otitis media and secretory otitis media. The apparent inner ear hearing loss caused in this way may be reversible.

It has long been accepted that chronic suppurative otitis media is often accompanied by sensorineural hearing loss related to the chronic suppurative otitis media but not due to the effect of conductive deafness on bone conduction. Toxins, it has been said, have damaged the inner ear. Walby, Barrera and Schuknecht (1983) have confirmed, in a clinical study of 87 patients with unilateral uncomplicated chronic otitis media, that an abnormality of bone conduction does exist. However, in a study of 12 pairs of temporal bones with unilateral chronic otitis media, there was no evidence that the disease resulted in damage to the inner ear. They concluded that the sensorineural loss is due to altered mechanics of sound transmission.

There has been debate about the cause of the sensorineural deafness that is often seen with otosclerosis. Schuknecht (1974) has put forward good evidence that otosclerosis only rarely results in sensorineural loss in the absence of a conductive loss. He also has shown that there is no consistent histological explanation for the sensorineural loss found in ears with otosclerosis.

However, all the other causes of sensorineural hearing loss also may occur in association with any of the conductive lesions. One cannot reasonably assume that inner ear function will necessarily improve with correction of the conductive component. Indeed, this carries the risk of surgical trauma with an increase in the sensorineural deafness.

In cases of industrial noise exposure, a concomitant conductive hearing loss may afford some protection to the inner ear. This is supported by unilateral cases of conductive hearing loss where inner ear function in the 'protected' ear is better than in the 'unprotected' one. However, not all investigations have confirmed this concept of protection for the inner ear by conductive deafness.

Suspected malingering or feigned hearing loss

One must always be aware of the possibility of non-organic hearing loss. This, in the main, will arise in the litigant and less frequently is psychogenic. Public awareness of excessive noise as a cause of hearing loss has resulted in increased interest in civil action in this respect. The individual concerned may occasionally succumb to the temptation to exaggerate the condition.

Suspicion will usually arise in the first few minutes of the interview with the patient. Not infrequently he will, in a rather obvious manner, fail to hear his name being called. In the initial stages of the interview each question may have to be repeated but will usually be heard on the second time, despite the clinician keeping the volume of his voice at the same level. Later, as the interview comes to include questions which the patient feels are important
to his case, such as enquiries designed to confirm the absence of other causes, he will tend to hear on the first occasion!

In psychogenic cases, suspicion may also arise when the patient appears to have a relative lack of concern about an apparently severe hearing loss.

At audiometry, attempts are made to exaggerate the audiometric results. Suspicion of this will arise when the recorded hearing levels are inconsistent with his ability to hear the spoken word.

**Sudden hearing loss**

Sudden hearing loss presents a therapeutic dilemma. There are two schools of thought, broadly represented by nihilism and those who advocate simultaneous multiple drug therapy. The fact that early treatment appears to achieve better hearing need only mean that there is a high rate of spontaneous recovery and that the inclusion of early cases boosts the results! Controlled trials have failed to produce convincing evidence of success and often have produced conflicting conclusions.

If one considers the potential aetiological factors in sudden deafness, then certain treatments, for example steroids, could aggravate the problem they were intended to help; the deafness of viral labyrinthitis may be exacerbated by steroids. For those with a compulsion to prescribe active treatment there is little to be said against bed-rest accompanied by carbon dioxide inhalations in an effort to improve cochlear blood flow.

In cases of acoustic incident a period of avoidance of noise exposure is advocated.

**Immune sensorineural deafness**

There is increasing interest in inner ear autoimmune disease as a cause of sensorineural hearing loss. There is no doubt that immune disorders can cause deafness which may reverse with steroid therapy. However, increasing numbers of alleged cases of immune sensorineural deafness are being reported. Many of these may be due to immune reactions but, so far, no clear pattern of clinical presentation has emerged and much more work will be required. Meanwhile one must guard against spurious claims and poorly controlled trials of expensive but dubious treatment regimens.

**General management**

There is no doubt that demands and expectations with regard to hearing vary from person to person. The person with a hearing loss will, in the main, have five concerns:

(1) how bad is his hearing loss?
(2) can it be reversed?
(3) will it be progressive?
(4) how will it affect his future?
(5) what can be done to help cope with the handicap?
The extent of the deafness is clearly explained to the patient. He is frequently relieved to hear that he has not been imagining things and that his family have been justified in their complaints. The simple explanation that with a high tone loss one expects increased difficulties in noisy places is found by many patients to be reassuring.

The prognosis of the loss has then to be considered. Unfortunately, most sensorineural deafness is irreversible in our present knowledge, and this should be explained. Treatment is obviously required for certain conditions such as an acoustic neuroma or syphilitic deafness. Most cases will not improve. Indeed, although some may be static, most will progress slowly. Thus it has usually to be clearly explained that the loss will be permanent, but that any progression in the deterioration of hearing will be very gradual and that the patient will not become completely deaf.

Very occasionally young adults present with hearing problems where the prognosis will affect career choices. Care must be taken to avoid both the optimism that can leave him in a blind alley in middle life, and the pessimism that can put him there instantly. The question of the patient's future must be given serious consideration whether or not the matter is raised.

The adult audiology volume (Volume 2) contains chapters on rehabilitation and hearing aids in the management of sensorineural deafness. All that need be said here is that the main factors in success with a hearing aid are the ability to discriminate speech and the motivation to receive help from the aid. When both are poor the outlook is bleak. However, a positive approach from the otologist is of immense help. Constructive advice should be given on the selection and use of an aid, of avoiding if possible, communication in noisy places and of the importance of non-auditory clues. Finally, it is reassuring for the patient to know that almost everyone with deafness experiences frustration with himself and irritation from his family.
Chapter 17: Sudden and fluctuant sensorineural hearing loss

John B. Booth

Since this chapter first appeared in the last edition, there have been many contributions on the subject of sudden hearing loss but almost no new forms of treatment. The cause always remains the main challenge and must, therefore, be sought. Adopting an apathetic or nihilistic approach, because many cases improve spontaneously, will not lead to further understanding nor to the finding of new ways of treatment.

Many of the causes are in themselves extremely rare, not only in otological practice, but still more so to the general family practitioner. Many too, are associated with other symptoms which will initially, and quite rightly, command much greater attention even when the patient may have been admitted to hospital. These will often come within the specific causes listed in Table 17.1. It should be appreciated at the outset that much of what has been written on this subject contains two ingredients - the case report(s) followed by the theory of causation. Byl (1984) has reported a most helpful prospective study over 8 years of 2225 patients who presented with sudden deafness.

Table 17.1. Some causes of sudden or fluctuating sensorineural hearing loss

Cochlear

(1) Inflammatory - eg, viral, bacterial, spirochaetal
(2) Traumatic
(3) Vascular
(4) Haematological - eg, anaemia, embolism, coagulation disorders
(5) Connective tissue disorders - eg, polyarteritis nodosa, Cogan's syndrome
(6) Endolymphatic hydrops, including Ménière's disease
(7) Metabolic disorders
(8) Ototoxicity
(9) Skeletal system - otic capsule

Retrocochlear and central nervous system

(1) Meningitis - all forms
(2) Multiple sclerosis
(3) Sarcoidosis (see Chapter 15)
(4) Friedreich's ataxia
(5) Amyotrophic lateral sclerosis
(6) Vogt-Koyanagi-Harada syndrome
(7) Xeroderma pigmentosum
(8) Tumours - eg, acoustic neuroma, carcinomatous neuropathy
(9) Central deafness

Idiopathic
For the patient to obtain diagnosis and treatment, he has to present to the doctor either in his local surgery or office, and the family practitioner must then decide to refer him to the specialist immediately if much of the treatment advocated is to be beneficial. Sudden deafness is an emergency but all concerned have to realize this. Balanced against the serious cases needing immediate help, come the vast majority never seen by a doctor, yet alone a zealous otologist, and these patients may think that the hearing loss will recover as it did previously when they last 'had a cold'. Fortunately, in many cases of sudden deafness the presentation does show a difference which alerts both doctor and patient. The condition provides a continuing diagnostic and intellectual challenge embracing the whole of sensorineural hearing loss.

It is important to recognize that the classification given in Table 17.1. cannot be rigidly applied. Often two or more conditions may coexist in one patient, while some of the diseases listed may damage hearing at more than one anatomical level. The review of specific causes which follows must therefore seem somewhat diffuse, and it must include some material which is also mentioned in Chapters 15, 16, 19 and 20.

Specific causes

Many of the cases reported seem to be isolated incidences. What can we learn from these widely varying aetiologies? In many the incidence is statistically no greater than chance, but in some the clinical and audiometric pattern, together with temporal bone findings, are of great importance. It should also be remembered that in several of the causes, hearing loss is but one manifestation of a systemic disease from which the patient may also have a generalized toxaemia, metabolic or other major disturbance. In some of these, the deafness occurs when the disease is at its height and is noticed only later when the patient's health improves sufficiently for him to be aware of his misfortune.

Cochlear cause

Inflammatory

Bacterial

Acute otitis media

While the vast majority of acute otitis media never develop sudden deafness, a small proportion do and this may only become apparent in later life when it is noted that the child is turning the only hearing ear towards the sound source or the patient becomes aware of the fact that he cannot use the telephone on that side.

Typhoid fever

Escajadillo, Alatorre and Zarate (1982) have reported six cases of pathologically confirmed cochleovestibular lesions due to typhoid fever. The lesions occurred between the second and third weeks of the disease, and more often in females. In some of the patients the lesions were reversible. In all but one case the hearing loss was bilateral and slight to
moderate in degree and when associated with reduced labyrinthine function on caloric testing this was unilateral and occurred more often on the left side.

**Syphilis**

Either in the congenital or the acquired form, this all-invasive disease can cause sudden deafness. Karmody and Schuknecht (1966) reported congenital syphilis as a cause resulting in a profound and usually bilateral loss; especially in younger patients. They also emphasized that the deafness is usually very sudden and may be partially asymmetric, possibly with fluctuation.

In the milder case, the hearing loss may be more marked in the low and high frequencies rather than the more conventional flat pattern. It is frequently accompanied by poor speech discrimination. About 5% of patients with late syphilis of the temporal bone present with sudden deafness, while sudden deteriorations in one or both ears occur at later stages of the disease in a further 15%. Sudden bilateral loss in the patients with acquired disease is unusual (Morrison, 1975).

The otological symptoms of late congenital syphilis may be almost indistinguishable from those of Ménière's disease.

**Mycoplasma pneumoniae**

While *Mycoplasma pneumoniae* is a common aetiological factor in a variety of respiratory diseases, involvement of the nervous system has only been observed in perhaps 5% of cases. Meningoencephalitis, cerebellitis, myelitis, and cranial nerve palsies have all been described. Reports of this organism as a cause for sudden deafness are few indeed. Rowson, Hinchcliffe, and Gamble (1975) mentioned as a cause in their epidemiological study of patients with acute hearing loss. Jaffe (1975) isolated *M. pneumoniae* in seven patients. More recently Shannon et al (1982) reported a single case in a girl aged 11 years 6 months with left-sided deafness, tinnitus and vertigo, whose investigations indicated a profound hearing loss with reduced labyrinthine activity following caloric stimulation. Brainstem evoked responses showed clear complexes but the transmission time was prolonged and the cochlear microphonic appeared to be abnormal. Three days after commencing treatment with doxycycline, the hearing on the affected side had virtually returned to normal and the discrimination had improved from 40 to 100%.

Nishioka et al (1984) have reported an 11-year-old girl who suffered from infection with *Mycoplasma pneumoniae* with primary atypical pneumonia, complicated first by meningitis followed by a mild bilateral acute otitis media with subsequent severe mixed hearing loss; the final outcome after the middle ear infection had settled, was that she was left with a bilateral high degree sensorineural hearing loss, more marked in the low and middle frequencies. Throughout the course of her serious illness she was treated with a variety of agents including minocycline and steroids. There was no impairment of any of the other cranial nerves and likewise no evidence of labyrinthine involvement.
Bullous myringitis

The possible pathology and clinical aspects of this condition have been discussed previously (see Chapters 3 and 7). Rarely, it may be associated with a sensorineural hearing loss, often of sudden onset. Merifield (1962) reported two cases. The first was a 22-year-old girl who developed a severe bilateral hearing loss, predominantly sensorineural, associated with tinnitus. It is interesting that she received not only a broad spectrum antibiotic for a 10-day period but also prednisone which was later decreased and discontinued. One month later, she had attained near normal hearing levels but after a further week, that is 5 weeks from the original presentation, she had again developed sudden hearing loss on one side. After a further 2 months, the hearing had again reverted to normal. The second case was a 31-year-old female with a unilateral, predominantly sensorineural loss, which returned to its probable earlier near normal level in just over 2 weeks. Wetmore and Abramson (1979) reported three cases, all unilateral (two male) with moderate to severe mixed hearing losses, although predominantly sensorineural, all of which were untreated and whose subsequent audiograms showed normal hearing.

More recently, a prospective study has been reported by Hoffman and Shepsman (1983) on 15 patients with 21 ears diagnosed as bullous myringitis, seen over a 2-year period. Seven ears demonstrated a sensorineural hearing loss and seven a mixed loss. Recovery of hearing was complete in eight of the 14 years. Five of the 14 ears experienced persistent high frequency loss but this study demonstrated a much higher incidence of hearing problems in this condition than had previously been thought to occur.

An excellent review of the aetiology of this condition and the possible role of mycoplasmas was reported by Roberts (1980). He could find evidence of only one positive culture of *M. pneumoniae* and he stressed the considerable difficulties of obtaining uncontaminated specimens in this condition.

Finally, it should not be forgotten that two types of non-suppurative complication may occur in this condition: single or multiple cranial nerve lesions and/or meningoencephalitis. The former may be transient or permanent and most commonly the facial and auditory nerves are affected; typically a lower motor neuron paralysis results from facial nerve involvement and either division of the auditory nerve may be affected individually or together. Two types of meningoencephalitis may occur. The first appears close to the onset of the bullous lesion and the second post-infectious' type, 3 weeks later.

Chlamydia

The genus Chlamydiaceae comprises two species - *C. trachomatis* and *C. psittaci*. The first is well known and causes a variety of ocular and genital infections in man, the best known being trachoma. The second is less often encountered in man but causes several infections in animals, for example psitacosis, ornithosis. In recent years, *C. psittaci* has been shown to cause endocarditis in man and is well recognized although infrequently as a cause of ocular infections.

Darougar et al (1978) have reported a case with long-standing interstitial keratitis and uveitis associated with a marked otological syndrome and fatal cardiovascular lesions. The
girl had a sudden bilateral hearing loss, tinnitus and imbalance. The deafness was initially moderate, sensorineural and symmetrical, with poor speech discrimination. Treatment with prednisolone failed to improve the hearing loss which fluctuated, but always relapsed leading ultimately to almost total loss. Later *C. psittaci* was isolated from the eye and the patient received two course of doxycycline, which helped the kerato-uveitis, but otherwise after treatment, there was a definite increase in the intensity of the clinical signs and the number of recurrences.

Hearing loss due to middle ear infections, in association with eye infections with Chlamydia have been reported previously (in adults) (Gow, Ostler and Schachter, 1974). More recently the use of direct fluorescent antibody tests for *C. trachomatis*, previously used in examining cervical and urethral specimens, enabled Banks, Vanden Driesen and Stark (1985) to test the fluid from the middle ear in children with otitis media with effusion (glue ear) in central Australia, which is an area endemic for trachoma, and showed an apparent 67% positive result. However, these results have been challenged and appear atypical (Retting, 1985).

**Viral**

**Mumps**

Patients with mumps infection may have a benign, complicated or even lethal course. The disease is usually more severe in adults. Hearing loss is uncommon, occurring in less than 0.1% of cases, but adolescents and adults are more likely to be affected. Although encephalitis occurs in less than 0.1% of patients, up to 23% are said to develop clinical meningitis. Most reported cases (80%) of sensorineural hearing loss are unilateral (Davis and Johnsson, 1983).

Murakami and Muzushima (1985) reported 53 cases seen over a 10-year period. The hearing loss in their patients was exclusively unilateral, profound or total and permanent, and more than 45% of the patients developed disequilibrium of vestibular origin. As might be expected, two-thirds of the patients were under 10 years of age, with an equal sex ratio. They considered that the haematogenous infection 'theory' was the most valid, causing inflammatory changes in the stria vascularis of the cochlea, resulting in severe impairment of the endolymphatic system. They proposed 'viral endolymphatic labyrinthitis' as the possible pathogenesis of the deafness.

By an unusual combination of events, Westmore, Pickard and Stern (1979) were able to obtain a specimen of perilymph from a patient with mumps who had developed sudden deafness. This 26-year-old woman with bilateral otosclerosis had previously undergone a right stapedectomy with an excellent result. One year later she developed sudden symptoms of mumps and within 2 days over a period of 4 hours developed total deafness on the operated side. She was seen 3 days later, but as it was thought that a perilymph leak might have developed and in the hope that this could be restored by surgery, the ear was re-explored. At operation there was no evidence of fistula formation and after the Teflon piston was removed, a sample of perilymph was aspirated and sent for culture, subsequently growing mumps virus.
Measles (rubeola)

It has long been known that measles can cause inner-ear deafness and estimates vary widely but in post-war years it seems to be between 5 and 10% of cases. Measles is an important cause of acquired deafness. Before the introduction of rubeola vaccine, 3-10% of acquired deafness in children was secondary to measles. The incidence of deafness following rubeola has been reduced dramatically since the introduction of the vaccine and is now less than one per 1000 cases.

Children with labyrinthine involvement usually develop abrupt bilateral hearing loss along with the measles rash. However, some children develop only unilateral deafness retaining normal hearing in the opposite ear. The characteristic audiogram is an asymmetric, bilateral hearing loss affecting hearing at higher more than lower frequencies which is usually permanent. Tinnitus and vertigo may accompany the hearing loss and up to 72% of patients have absent or diminished caloric responses in one or both ears (Davis and Johnsson, 1983).

Measles has also been reported as producing congenital deafness in a child whose mother had the disease in pregnancy; immunization against measles in pregnancy has been implicated in two congenital cases.

Chickenpox (varicella)

Nervous system complications of chickenpox are relatively infrequent and include cerebellar ataxia, aseptic meningitis, acute transverse myelitis, chicken-pox-Reye syndrome and less commonly, aphasia, hemiplegia and seventh cranial nerve palsy.

Bhandari and Steinman (1983) reported the case of a 14-month-old infant who developed bilateral sudden deafness. Brainstem auditory responses could not be evoked and there was no subsequent improvement.

Varicella zoster virus

Herpes zoster oticus is well known by all otologists, and sudden deafness with facial palsy forms part of the Ramsay Hunt syndrome. From a clinical standpoint, many patients afflicted by this virus present early because of their symptoms. In zoster deafness the site is sometimes neural, sometimes sensory but most often mixed. This is confirmed by a recent study by Abramovich and Prasher (1986) who investigated 13 patients with Ramsay Hunt syndrome. Electrocochleography in five showed a normal action potential (AP) and the summating potential (SP) was not enhanced. (SP/AP ratio 21%). Brainstem auditory evoked potentials on the affected side were clearly abnormal in seven. The latencies of waves III and V were prolonged, including one who had a normal pure-tone audiogram and in one case deranged. Four of the seven patients were re-tested 6 months after clinical recovery of their vesicular eruption and found to have normal brainstem evoked potentials. A slight tendency for greater abnormalities was noted in patients with complete facial paralysis.

Steroid therapy has been tried in this condition with excellent results and the risks of disseminating the virus seem to be more theoretical than real. However, it would seem that this form of medication may have been superseded by the use of acyclovir (9-2
hydroxyethoxy-methyl-guanine); this antiviral agent is a DNA nucleoside analogue which inhibits virus DNA replication, thus halting the cell cycle. Acyclovir is relatively insoluble in water and crystalizes in the renal tubules. As a result, it is essential to ascertain that the patient has good renal function throughout therapy and the agent itself is better given intravenously (5 mg/kg three times per day). Hall and Kerr (1985) reported successful treatment of seven patients, using acyclovir therapy, producing a striking improvement in the toxaemia associated with this condition. Of the six patients who had total facial paralysis, four recovered completely, one almost completely and one showed no recovery at 3 months. Of three patients with sensorineural hearing loss, two regained their hearing and their associated vertigo resolved rapidly. The patient with residual deafness and a total facial paralysis had brainstem involvement.

Stafford and Welch (1986) have reported the successful treatment of five patients using a different regimen. The acyclovir was initially administered intravenously for a minimum of 3 days accompanied by high dose oral steroids for 5 days. Treatment with acyclovir was continued orally for a further 2-week period.

**Infectious mononucleosis**

The nervous system may become involved in some 1% of cases of infectious mononucleosis and such complications as lymphocytic meningitis, encephalomyelitis, polyneuritis and mononeuritis have been described (Gautier-Smith, 1965). Considerable difficulty in diagnosis may occur when several cranial nerves are affected at different intervals during the illness, as similar combinations may be found in other neurological syndromes such as the Guillain-Barré syndrome (Owen, 1952; Fiese, Cheu and Radding, 1953).

Schnell et al (1966) reviewed 1285 patients seen at the Mayo Clinic over a 14-year period and concluded that 12 fulfilled their criteria. Of these, one (the only female), showed a temporary bilateral hearing loss on the fourteenth day, 7 days after admission; the audiogram showed a 60 dB hearing loss at 2000 Hz which gradually improved and was normal one year later. In their cases with neurological complications, the process was self-limiting and of relatively short duration; the average total duration of illness was 25 days. The authors were particularly interested in the electroencephalographic findings but these showed no specific diagnostic features. However, the consistent presence of abnormalities in the EEG during the acute phase of the illness corroborates the other evidence of cerebral involvement. They emphasized that the neurological manifestations of infectious mononucleosis alone were indistinguishable from certain other viral and non-viral encephalomyelopathies and neuropathies.

Taylor and Parsons-Smith (1969) reported a patient who developed other cranial nerve signs; Petheram (1976) described a patient whose infection was characterized by a severe autoimmune haemolytic anaemia with autoantibody of anti-i specificity. Further cases have been documented by Gregg and Schaeffer (1964), Jaffe (1967) and most recently by Beg (1981). Site of lesion tests in these cases have indicated cochlear damage and in the two cases reported by Beg, brainstem evoked responses were normal as were caloric tests. Only the first and last cases mentioned have been bilateral and all but one have occurred in females! As also might be expected in this condition, the patients are young, only one being just over 30 years of age.
Traumatic

Electricity

It is generally considered that individuals unlucky enough to be struck by lightning are either killed or suffer no untoward effects. While reports are few, lightning may affect the ears. Most occur while the individuals are conversing on the telephone during a thunderstorm (Weiss, 1980) and Kristensen and Tveteras (1985) reported two patients who received injuries simultaneously while telephoning each other a few hundred metres apart. This possibility is now so well recognized that advice is given by the telephone companies themselves not to make calls during this period, particularly when the thunderstorm is overhead.

The most frequent damage is acoustic rupture of the tympanic membrane caused by the sonic shock wave emanating from the access of the lightning channel. This can occur whether the lightning strikes the person himself or the ground nearby. Burning of the skin surrounding the ear may be seen and an exit burn on the feet may also occur when the skin is wet. Although the perforation is usually unilateral, bilateral rupture has been reported (Wright and Silk, 1974). Sensorineural hearing loss may also occur and this too may be bilateral; the loss is usually transient but may last for a longer period, although it is seldom permanent. Ipsilateral peripheral facial nerve palsy, which recovered spontaneously, has been reported (Weiss, 1980). Bergstrom et al (1974) reported the temporal bone pathology of one of their four cases who dies 5 days after being struck. This showed tympanic membrane rupture, middle ear and mastoid effusion of pus and blood, total rupture of Reissner's membrane, degeneration of the stria vascularis and organ of Corti, oedema of the intracanalicular portion of the facial nerve and herniation of portion of the cerebellum into the internal auditory meatus. More recently, Poulsen and Knudstrup (1986) reported a case where lightning had caused inner ear damage and an intracranial haematoma which was subsequently successfully treated by surgery.

Radiotherapy

Radiotherapy given to head and neck tumours regularly involves its application to the ear and organ of Corti. For many years it was considered that the cochlea was resistant to radiotherapeutic injury. This was strongly challenged first by Leach (1965) and later by Moretti (1976). Further details will be found in Chapters 4 and 7.

Postoperative

Several cases of deafness following surgery have been reported. It seems most generally accepted that these are due to microembolism involving the cochlear division of the internal auditory artery (Jaffe, 1967). Brownson, Stroud and Carver (1971) carried out audiograms in a series of 50 patients before and after cardiopulmonary bypass surgery but none of the patients showed any postoperative loss. Single cases following bypass surgery were reported by Arenberg, Allen and De Boer (1972), and Wright and Saunders (1975). In neither case did the hearing recover and in both it was the left ear that was affected. More recently Plasse et al (1980) reported seven cases of sensorineural deafness from a series of 7000 patients who underwent cardiopulmonary bypass surgery. Again the hearing loss was in one ear only and developed immediately after the operation. Four of the seven patients
showed improvement in hearing after the initial loss, although in no case did the hearing return completely to normal. There was no predilection as to which ear was affected.

Millen, Toohill and Lehman (1982) reported five further cases of sudden sensorineural hearing loss following non-otological surgery. Two of these were bypass procedures both producing hearing problems in their left ear.

Other neurological complications of coronary artery bypass surgery have recently come under scrutiny in several centres and those in Newcastle reported earlier by Shaw et al (1985) have been compared with studies elsewhere (Shaw, 1986). The two major aetiological factors cited in the causation of neurological damage in heart surgery are hypoperfusion of the central nervous system, and embolization. A whole series of factors are now under scrutiny such as the study of membrane versus bubble oxygenators.

Perhaps it may be added as an interesting footnote that the effect of hypothermia upon the electrocochleogram and auditory evoked responses was investigated by Kusakari et al (1984) in 10 children undergoing open heart surgery. The latencies of N1, waves III and V were prolonged. The summing potential was increased by hypothermia and never disappeared; on rewarming the summing potential appeared first, followed by N1, and finally waves III and V. Conversely, raising the body temperature by 1°C in nine subjects significantly shortened the latency of wave V, while there were similar though less consistent changes in other waves (Bridger and Graham, 1985).

Postoperative vestibular dysfunction following head and neck surgery was investigated by Johnson et al (1985); 80 patients had normal vestibulo-ocular responses preoperatively, but on their first test after operation 58% had significant vestibulo-ocular response abnormalities and even at one year after surgery, 20 (43%) continued to demonstrate vestibular abnormality.

Transient hearing loss, occasionally associated with vestibular symptoms, has been reported on a few occasions following the use of water-soluble contrast media for lumbar myelography. Two cases have been reported following the use of metrizamide (Grant et al, 1985). The low frequency sensorineural hearing loss was considered to be the result of increased stiffness of one or both of the inner ear membranes. Nelson and Lamb (1985) reported hearing impairment in one case. They subsequently investigated 10 patients, five of whom received iohexol and five iopamidol, but the audiograms remained normal and showed no change after lumbar myelography. It was noted that the course of the hearing impairment in these patients was similar to that of the cortical absorption of contrast medium after myelography and of the associated electroencephalographic changes. It may be remembered that for a period the use of meglumine diatrozoate (Hypaque) was advocated in the treatment of sudden sensorineural hearing loss as it acted in a similar way to glycerol (Emmett and Shea, 1979).

Hammar (1981) noted that the side-effects of intrathecally-injected contrast media were more frequent in patients with reflux and stasis of the contrast substance in the ventricular
system combined with a damaged ependyma. The cause of the side-effects was the penetration of the contrast agent into the brain parenchyma.

**Anaesthesia**

Much has been written in recent years about the effect caused by nitrous oxide on the middle ear pressure during general anaesthesia and as to whether the gas is given by inhalation or ventilation. Richards, O'Neill and Wilson (1982) emphasized that there is a large degree of variation between the studies, between children and adults and of course in the concentration of nitrous oxide in the inspired gas. However, even if the same concentrations of nitrous oxide are used, different rates of pressure increase occur in different individuals and this may be related not only to variations in perfusion of the middle ear mucosa but also the volume to area ratio of the tympanomastoid air spaces; indeed the four highest values they recorded were in those whose mastoids were radiologically sclerotic!

Patterson and Bartlett (1976) reported four cases of hearing impairment after anaesthesia, three receiving ear surgery and a fourth who underwent an orthopaedic operation but was already suspected of having a perilymph leak from a previous stapedectomy (which was subsequently confirmed at operation and closed). In all four, the hearing returned.

Davis, Moore and Lahiri (1979) reported the case of a patient who one year previously had undergone a successful left stapedectomy with complete closure of the air bone gap and who subsequently underwent a hysterectomy operation. This was followed by a 20-25 dB conductive hearing loss which persisted thereafter.

An occasional complication of nitrous oxide anaesthesia may be either a tympanic membrane perforation or haemotympanum; these are more likely to occur where an old perforation has healed with a neomembrane (Perreault et al, 1982). Owens, Gustave and Sclaroff (1978) reported two cases both of whom had previous anaesthetics for ear surgery whose tympanic membranes ruptured on the opposite side when a further intervention was required (one for abdominal pain and the second for a urethroplasty); both ruptures healed spontaneously.

Marsh et al (1985) carried out a study of auditory and vestibular function and hyperbaric oxygen on 11 normal adult men exposed to 100% oxygen at 303 kPa (3 atm) absolute. No alterations in either function were detected although there was some elevation of the pure-tone thresholds at that pressure level which appeared to reflect in large part the effects of the pressure rather than the oxygen itself; there was no worsening of hearing over the 3 hour exposure.

The use of hyperbaric oxygen therapy has been investigated in soldiers following acute acoustic trauma and reported by Pilgramm and Schumann (1985).

It should be remembered that the inhalation of pure oxygen causes cerebral vasoconstriction.
Vascular

While vascular disease or its effect are frequently proposed as the principal cause of cochlear-type sudden hearing loss, the number of occasions when they have definitely been implicated is relatively few. It is therefore perhaps worth examining some of the conditions or factors which may be related.

Hypertension

An early study between sensorineural hearing loss and arterial hypertension by Hansen (1968) was uncontrolled and unconvincing. Drettner et al (1975) looked at a series of cardiovascular risk factors including blood pressure and heart rate but could find no significant correlation between these and sensorineural hearing loss when assessing 1000, 50-year-old men. Studies of the cochlear and vestibular arteries, as well as the labyrinthine arteries, showed that they remain patent at all ages (Fisch, Dobozi and Greig, 1972). No close relationship between the changes in the inner ear and the supplying vessels has been found, nor in patients dying of hypertensive disease. Similarly there is no evidence of atherosclerosis occurring in any of the smaller vessels supplying the ear.

Earlier there was considerable interest in the work of Rosen (Rosen et al, 1962; Rosen and Olin, 1965; Rosen, Olin and Rosen, 1970), who investigated the Mabaan tribe in southeast Sudan and was impressed by their superior hearing, compared with those living in industrial areas of the USA; their blood pressure remained constant throughout life and coronary heart disease is unknown. A similar study on the inhabitants of Easter Island has recently been reported (Goycoolea et al, 1986). The median hearing thresholds of natives who had always lived on the island were similar to those of female citizens in the USA.

Recently a single patient, a young man, has been reported who developed a sudden loss of hearing in one ear and in whom investigations revealed a total deafness and failure of the vestibular system on the affected side. This was attributed to a sudden rise in blood pressure in a man with secondary hypertension of renal origin due to polycystic kidneys (Nofal, 1985).

Inflammation of the vessels as in cranial arteritis may present to the otolaryngologist as headache, facial palsy, hearing loss, dysphagia, jaw claudication, lingual Raynaud's phenomenon, and tongue infarction. Sensorineural hearing loss with vertigo has been described but no case of sudden deafness has yet been reported (Sofferman, 1980). Occlusion of the vertebral and basilar arteries has been reported in a single case associated with marked atherosclerotic changes in the vessel walls and an aneurysm of the left vertebral artery (Kitamura and Berreby, 1983). Ectasia of the basilar artery is a rare cause of sensorineural loss and this is usually unilateral and progressive, accompanied by vestibular symptoms and other neurological abnormalities. Vertebral arteriography and other invasive studies have now been replaced by computerized tomographic (CT) scanning in making the diagnosis. Plain radiology of the internal auditory meatus may be normal.

The secondary effects of vascular obstruction to the inner ear in experimental animals is well known. A study of seven patients with sudden unilateral partial vestibular loss has been described by Lindsay and Hemenway (1956). The findings in a 57-year-old man who
had sudden onset of dizziness and unilateral deafness 2 months prior to death have been reported by Gussen (1976). More recently, Sando, Ogawa and Jafek (1982) have reported the inner ear pathology including temporal bone findings following injury to the eighth cranial nerve and the labyrinthine artery. The first case, in which both the nerve and the artery were surgically severed, revealed severe pathological changes in the cochlea including complete loss of the organ of Corti and moderate pathological changes in the fairly well-preserved vestibular end-organs. In the second case, in which the nerve only was sectioned but the artery preserved, the organ of Corti and vestibular end-organs appeared to be well preserved and normal. These findings suggest that the blood supply from the labyrinthine artery plays a major role in maintaining most of the structures in the inner ear except for the endolymphatic sac and that the vestibular end-organs are more resistant than the organ of Corti, to the effects of damage to the labyrinthine artery.

**Buerger's disease (thromboangiitis obliterans cerebri)**

Cerebral involvement in patients with Buerger's disease is rare. It has been estimated as less than 0.5%. Kirikae et al (1962) have reported a single case. A moderate smoker, after developing intermittent claudication, noted a hearing loss on the same side. While an injection of vasodilator drugs improved the leg, there was no improvement in the hearing loss. Five years later the radial artery of the opposite side became slowly occluded over 2 months. At surgery, part of the artery was excised and the diagnosis was confirmed histologically. Seven months after the operation, the patient became suddenly deaf on the same side (that is the opposite side to the earlier loss). Both sides showed a sensorineural loss with absence of recruitment (see also Polyarteritis nodosa).

**Hypercoagulation**

In addition to the clinical syndromes with known haematological characteristics, a further, less well-defined group exists whose common feature can best be described as 'hypercoagulation'. The clinical diagnosis of hypercoagulation is characterized by recurring episodes of thrombophlebitis and sometimes pulmonary embolism. The work of Jaffe (1975) showed that the two-stage prothrombin technique measuring the prothrombin consumption rate was the most accurate test.

It is known that the stria vascularis has a slow blood flow with a high haematocrit value. It has therefore been suggested that stasis of blood flow and accelerated coagulation may be the twin interrelated factors responsible. However, at this stage almost no other further work in this field has been carried out, and it should be noted that while viral diseases may cause haematological conditions, for example haemolytic anaemia, there is no evidence of hypercoagulability in such patients except perhaps when their illness is at its most extreme.

Fibrinolytic activity and capacity were studied by Bomholt, Bak-Pedersen and Gormsen (1979) in a group of 18 patients with sudden sensorineural hearing loss and were found to be reduced in 12. Five of the patients had associated triglyceridaemia; similarly, five patients with decreased fibrinolytic activity later went on to develop Ménière's disease (Bomholt, 1980).
Noda et al (1985) investigated 16 patients with vertigo (no mention is made of hearing loss or audiological tests) in whom no significant difference could be found in the fibrinogen, or plasminogen content nor the fibrin-degradation product level and healthy adult controls. Similarly, no difference could be found in the alpha 2-macroglobulin content, alpha 1-antitrypsin or C1-inactivator content between the two groups. However, there was a significant difference in the antiplasmin activity and antithrombin activity and between the ADP- and collagen-induced platelet aggregations which were decreased in the patients with vertigo.

**Viscosity**

Ischaemia is not only determined by vascular disease but also by blood viscosity and it has been suggested that particularly in patients with sudden deafness increased blood viscosity may play a role, but this has never been proven. Recently, Browning, Gatehouse and Lowe (1986) investigated the relationship between hearing threshold and blood viscosity, plasma viscosity, and haematocrit in 49 patients with idiopathic hearing loss. They established that hearing thresholds were unrelated to haematocrit or low shear blood viscosity but hearing impairment at high frequencies was directly related to high-shear blood viscosity and inversely related to high-shear blood viscosity and inversely related to plasma viscosity. The derived measure of red cell rigidity was significantly related to hearing thresholds at all frequencies. The significant negative relationship between plasma viscosity and pure-tone hearing thresholds is perhaps contrary to expectations, but of even more interest is their finding that the greater the high shear blood viscosity, the poorer the sensorineural thresholds. High-shear blood viscosity, once corrected for the haematocrit and divided by plasma viscosity (relative viscosity), is a measure of red-cell rigidity or lack of deformability under shear. It is unknown whether this lack of red-cell deformability is a primary or secondary phenomenon. Conversely, the high-shear viscosity values were all within the normal range and in conditions such as haemolytic anaemia, in which red cells are less deformable, there is no known association with hearing impairment. This situation is not dissimilar from the finding of fluctuating hearing in some patients with secondary hyperlipoproteinaemia, whereas so far hearing loss has never been reported in association with the primary condition.

The influence of blood viscosity on cochlear action potentials and oxygenation has been investigated in the guinea-pig (Hildesheimer et al, 1982). Perfusion of the ear with high viscosity blood showed a rise in the action potential threshold in 56% of animals and in one-third there was a significant fluctuation of the action potential response.

**Haematological**

**Haemopoietic system**

Anaemia, as such, has rarely been reported as being associated with deafness, sensorineural or otherwise. Morrison and Booth (1970) reported two patients with profound anaemia (haemoglobin levels of 0.62 µmol/L) associated with iron deficiency - both had a sudden bilateral total loss and neither showed any improved following transfusion.

More recently, Morrison (1978) has reported a 58-year-old woman who awoke with sudden total bilateral deafness whose electrocochleogram confirmed that there was no action potential or cochlear microphonic on either side. She was found to have some megaloblastic
change in the bone marrow and a plentiful supply of iron; she had a moderate anaemia due to folic acid deficiency. No recovery has taken place in the hearing.

Deafness may be associated with Fanconi's anaemia - constitutional aplastic anaemia (Harada et al, 1980). Tinnitus has recently been reported as the presenting symptom in a case of pernicious anaemia, with normal hearing, which resolved with treatment (Cochran and Kosmicki, 1979).

**Polycythaemia vera**

In polycythaemia vera, the viscosity of the blood is increased five to eight times normal; the total red cell count becomes elevated by 20-50% and the total blood volume is increased to two to three times normal. These alterations affect the peripheral blood by causing engorgement of the capillaries, venules and arterioles with high viscosity, slowly circulating oxygen-deficient blood. When Vaquez first described polycythaemia in 1892, he noticed tinnitus and vertigo among the primary symptoms.

It had been indicated in an earlier report on two patients with a bilateral sensorineural hearing loss, that the hearing fluctuated in relation to the viscosity of the peripheral blood and that the level improved after phlebotomy. However, Kenyon, Booth and Newland (unpublished data, 1984), in a small series of patients with this condition treated by the same procedure and a separate group with Waldenstrom's macroglobulinaemia, treated by cell separation, showed that while the viscosity changed after 'treatment', there was no observable change or improvement either in the pure-tone audiogram, or in the susceptance or conductance on otoadmittance measurements (220 and 660 Hz).

Cerebral blood flow in polycythaemia is significantly reduced. In a study on 15 patients, lowering of the haematocrit by venesection increased the cerebral blood flow and reduced whole blood viscosity at all shear rates, the effect being greatest at low shear rates; plasma viscosity was also reduced but the changes were less striking (Thomas et al, 1977). Brown and Marshall (1982) investigated the effect of plasma exchange on blood viscosity and cerebral blood flow in eight normal subjects. The exchange resulted in significant reductions in plasma viscosity, whole blood viscosity, globulin and fibrinogen concentration without affected packed cell volume. Reduction in whole blood viscosity was more pronounced at low shear rates but, despite the fall in viscosity, there was no significant change in cerebral blood flow. Within the circulation, blood is subjected to continuously varying shear rates and because the viscosity of blood varies with the shear rate a single measurement of viscosity cannot be applied to blood throughout the circulation. Within the microcirculation however, shear rates are mostly very high. The apparent viscosity of the blood in very narrow tubes decreases as the diameter of the tube is reduced as an axial migration of the red cells occurs. In the study by Brown and Marshall, changes in blood viscosity without changes in arterial oxygen content did not alter the cerebral blood flow.

**Sickle-cell disease**

While sickle-cell disease is not generally considered as a cause of deafness, it has been shown by Todd, Serjeant and Larson (1973) that sensorineural hearing loss of apparently gradual onset can occur. This loss is only reported in the homozygous disease (abnormal
haemoglobin S-SS disease). Both ends of the audiometric range may be affected but more often the higher tones. The sickling phenomena occur and crisis develops when certain intermolecular hydrophobic bonds form with subsequent polymerization. Any decrease in the PO$_2$ with associated hypoxaemia can initiate the process and the concomitant stasis, hyperviscosity, or acidosis significantly increases the likelihood of sickling. The end effect is tissue hypoxia. In the inner ear it is considered that the sickling and impaired blood flow in the cochlear venous system with secondary anoxia of the hair cells and stria vascularis are the most likely causes of the sensorineural hearing loss. Todd, Serjeant and Larson (1973) found a sensorineural loss in 22% of their 83 patients. They considered two possible pathological causes - anaemia and thrombosis. The haemoglobin level in SS disease was considered unlikely to reflect the oxygen carrying capacity since the decreased oxygen affinity of haemoglobin S allows greater oxygen release/gram haemoglobin than in haemoglobin A. Furthermore, the oxygen affinity is lower in cases with lower haemoglobin levels. The pattern of hearing loss in SS disease is similar to that in certain animal studies which show a low-grade continuous venous thrombotic process. However, they were unable to find a correlation between the irreversibly sickled cells and the hearing loss in their small group.

The haemolytic process characteristic of sickle-cell disease is associated with increase of bone-marrow activity. Active bone marrow is present in the petrous temporal bone in SS disease but Serjeant, Norman and Todd (1975) failed to find evidence that this caused any narrowing of the internal auditory meatus or compression of the eighth cranial nerve. In this condition the hearing loss may be gradually progressive, fluctuant or sudden in onset; in the last, partial or almost total recovery may occur (Morgenstein and Mannace, 1969; Urban, 1973; Orchik and Dunn, 1977). There is some dispute as to whether the number and frequency of the haemolytic crises may be a factor (Berry, 1975; Friedman et al, 1980). Sensorineural hearing loss in patients with sickle cell disease may also be related to the increased susceptibility to bacterial meningitis. Neurological involvement is a common complication of sickle cell disease and vestibular dysfunction may occur. Morrison and Booth (1970) reported one case of bilateral deafness in sickle cell trait (haemoglobin S and C) which they presumed to be thrombotic.

Sickle cell thalassaemia has been described in two out of a family of four sisters, another of whom had sickle cell trait and the fourth was normal. The two sisters with sickle cell thalassaemia showed symptoms of vertigo or hearing involvement, and vertigo after strenuous exercise. One sister with unilateral hearing loss subsequently developed a sudden, almost identical loss in the other ear, but unfortunately follow-up was impossible (Marcus and Lee, 1976).

Waldenstrom's macroglobulinaemia

This condition, which tends to occur in elderly males, is characterized by retinal changes, an abnormal bleeding tendency from mucous membranes, generalized weakness and dyspnoea. Fundamental to the diagnosis is a raised sedimentation rate and marked increase of serum globulin level, in the form of a narrow, dense band in the 62 region. The abnormal macroglobulin coats the platelets and reduces their adhesiveness; it also interferes with fibrin polymerization.
It is most often met in otolaryngological practice as a cause of epistaxis or bleeding from the gums, but a few cases of sudden deafness have been recorded, although vertigo may be the earliest symptom (Coyle et al, 1961; Afifi and Tawfeek, 1971). Immediate diagnosis is essential if the patient is to be prevented from probable permanent bilateral deafness. The optic fundus must be examined and may reveal gross retinal haemorrhages or central vein thrombosis. Ruben et al (1969) reported a case developing first in one ear and 10 months later in the other. Subsequently both ears deteriorated to an almost total loss and, while vestibular function was lost in the second ear, that on the original side remained normal. Wilkinson, Davidson and Sommaripa (1966) reported another bilateral case.

In 1963, Solomon and Fahey reported 10 patients and their treatment by plasmapheresis. Vertigo and nystagmus were reported in two patients while audiometry showed some degree of bilateral hearing loss, especially in the high frequencies, in five. Additional information is given on two; the first complained of progressive deafness and tinnitus but, after intensive plasmapheresis, her auditory acuity improved and tinnitus diminished. The second patient developed horizontal and vertical nystagmus and progressive vertigo but, after plasmapheresis, the vertigo and nystagmus gradually disappeared.

**Cryoglobulinaemia**

Cryoglobulins are proteins which precipitate in the cold and redissolve on warming. They may occur in small amount in systemic lupus erythematosus and other ‘connective tissue’ disorders and may be associated with multiple myeloma or macroglobulinaemia. Almost two-thirds are mixtures of IgG and IgM molecules, while a further one-quarter are G myeloma proteins and less than 10% are macroglobulins.

The characteristic clinical signs are purpura, arthralgia and a Raynaud-like phenomenon in the lower extremities. Patients with progressive sensorineural deafness, tinnitus and vestibular problems have been reported but neurological involvement is infrequent (Nomura et al, 1982).

**Leukaemia**

The first account of leukaemia of the inner ear was presented by Politzer in 1884; the patient experienced bilateral, severe deafness one year before death. The various forms of leukaemia may affect the ear but it is usually the middle ear that is involved. Otological complications occur almost invariably in those patients with the acute forms, particularly acute lymphocytic leukaemia. The changes seen in the temporal bone fall into three categories: leukaemic infiltration, haemorrhage, and infection.

Leukaemic infiltration may occur in the mucoperiosteum of the middle ear following the mucous membrane folds but this may extend on to the ossicles and the sheaths of the tendons of the intratympanic muscles. Infiltration into the bone marrow spaces of the petrous apex frequently occurs and also, to a lesser extent, within the ossicles. Infiltration into the inner ear is uncommon. Haemorrhage into the inner ear is also uncommon.
Sudden deafness and/or vertigo is reported in acute leukaemia and seems to occur most often in the acute stem-cell type. As a general rule, the otological symptoms appear to be more associated with infiltration and seem to be based on the degree.

Haemorrhagic changes in the temporal bone are more frequently seen in patients with acute lymphocytic leukaemia than the other forms. Patients with acute leukaemia suffer a bone-marrow failure with a resultant thrombocytopenia and other coagulation defects such as hypofibrinogenaeemia may occur. Disseminated intravascular coagulation and secondary fibrinolysis may also occur.

Connective tissue disorders

Systemic lupus erythematosus

Systemic lupus erythematosus (SLE) is a multi-system disease associated with high titres of circulating autoantibodies, most commonly the antinuclear factor and the antibody to double-stranded DNA. Joint and skin involvement are the most common presenting features (see Chapter 15).

Polyarteritis nodosa

Polyarteritis nodosa is a systemic vasculitis of unknown aetiology, involving mainly small and middle calibre arteries. The lesions are segmental with a predilection for the bifurcation of the vessels. The disease process spreads longitudinally along the arterioles and eventually involves accompanying venules. In the later stages, the vessels undergo fibrinoid necrosis, mainly in the media layer, with loss of elastic fibres in the elastic membrane of the arterial wall. In the classical form of polyarteritis, all three stages may occur simultaneously. Typically the distribution of the disease in the body spares the small vessels of the lung and spleen.

Deafness in this condition is itself unusual and only on rare occasions has it been the presenting symptom. The deafness is sensorineural. Late-Bakaar and Gibbs (1978) reported a case with profound bilateral deafness and sudden tinnitus; electrocochleography pointed to an end-organ impairment. Before treatment, the patient's hearing improved to within normal limits. Subsequently her polyarteritis nodosa was treated with prednisolone and there has been no recurrence of the deafness. Peiterson and Carlson (1966) reported a case, also with bilateral, and almost symmetrical, gradually deteriorating hearing loss. Subsequently the hearing fluctuated. After an interval of more than 6 months, polyarteritis nodosa seemed the most likely diagnosis and she was treated with prednisolone which brought about a considerable hearing improvement. The remaining reported cases totalled only approximately a dozen. The only common feature would seem to be that deafness is sensorineural and bilateral. In most of the earlier reports, minimal details are available. Later in the disease, or perhaps already present, other lesions of polyarteritis nodosa will be found in the body and it is by these that the diagnosis is made.

Gussen (1977) examined the temporal bone of a 66-year-old woman with polyarteritis nodosa who became deaf 7 months before death. Polyarteritis nodosa of the left internal auditory artery was demonstrated with fibrosis and bone formation involving the cochlear and
vestibular systems. Jenkins, Pollak and Fisch (1981) reported a 48-year-old man in whom the onset of sudden unilateral deafness and vertigo occurred 7 months prior to death as one of the earlier manifestations of the disease. Audiometric studies showed complete deafness on the left side together with a non-functioning labyrinth on caloric testing; there was a mild mixed hearing loss on the right. Subsequent examination of the temporal bones showed small vessel arteritis in the dural and subarcuate vessels on both sides.

A third case with temporal bone studies has now been reported (Adkins and Ward, 1986). They described the findings in a 60-year-old man with well documented hearing loss who had rheumatoid arthritis, polyarteritis nodosa and otosclerosis. Polyarteritis nodosa extensively involved the subarcuate arteries on the left side and the arteries in the facial canal in its vertical and horizontal portions; the changes were especially prominent in the region of the geniculate ganglion and also involved the superficial petrosal artery.

In 1974, Sergent and Christian reported an interesting series of seven adult patients who developed a sudden hearing loss (bilateral in three, unilateral in four) due to serous otitis media. Clinically these patients resembled others with vasculitis - neurological signs, renal disease and systemic symptoms were the dominating features. It is important therefore for the otologist to realize such a combination of symptoms in these circumstances and to look further than the end of a ventilation tube. More recently Hill, Graham and Gikas (1980) reported a case of a female who earlier had presented with nasal and pharyngeal symptoms associated with decreased auditory acuity and bilaterally thickened hypomobile tympanic membranes. Four years later, a right myringotomy revealed the middle ear space to be completely obliterated by fibrous tissue. On the left side there was thick fibrous hypertrophic mucosa filling the middle ear space. Histologically these changes were interpreted as being consistent with leucocytoclastic vasculitis.

**Wegener's granulomatosis**

While pathologically there may be difficulties in differentiating this from polyarteritis nodosa, clinically the two conditions are usually quite different in their presentation. Cases of polyarteritis nodosa seldom present to an otolaryngologist, while most will see Wegener's granulomatosis in their career and it will frequently present because of nasal symptoms. Similarly, while clinically it is different from lethal midline granuloma, pathologically these two may also present problems; the latter is considered by some to be another variant of polyarteritis nodosa. Indeed Wegener himself in 1939, stated that polyarteritis nodosa was a common finding in patients with lethal granulomata of the midline facial tissues (quoted by Duvall, Nelms and Williams, 1969).

Wegener's granulomatosis has three principal components:

1. necrotizing granulomatosis lesions in the upper or lower respiratory tract or both

2. generalized focal necrotizing vasculitis involving both arteries and veins, almost always present in the lungs and more or less widely disseminated in other sites

3. glomerulitis, characterized by necrosis and thrombosis of loops or lobes of the capillary tuft, capsular adhesions, and evolution as a granulomatous lesion.
Wegener discovered the necrotizing granuloma in post-mortem tissue studies of three patients who had died of fulminant sepsis. Although the pathology predominantly involved the upper and lower respiratory tracts, a generalized vasculitis was also found, as well as evidence of end-stage glomerulonephritis. The disseminated vasculitis may involve both small arteries and veins and any organ system may be involved with granulomatous changes as disease progresses.

DeRemee et al (1976) reported a series of 50 patients over a 10-year period in which the ear was the most frequently involved site (37 patients), followed by the lung (35 patients) and kidney (23 patients). Karmody (1978) reported five patients seen over a 7-year period in which the ear was the presenting site. Illum and Thorling (1982) reported a series of 17 patients of whom 10 exhibited otological symptoms and in seven of whom it was the presenting sign.

Cogan's syndrome

In 1945, Cogan reported four cases of non-syphilitic keratitis characterized by vestibular and auditory disorders. He noted that in syphilitic keratitis only 4% of the patients developed deafness, and that this did not occur until months or even years after the keratitis. He saw his first four cases all within one year and was impressed that while the corneal changes progressed relatively little, the vertigo became incapacitating and the deafness progressive and ultimately profound. Norton and Cogan reviewed the cases again in 1959. They confirmed the ocular signs of patchy, deep corneal infiltrates which tend to fluctuate in intensity and distribution, usually located in the periphery, and accompanied by deep corneal vascularization if they persist long enough. No evidence of syphilitic infection, by the tests then available, could be found. However, the sensorineural hearing loss is progressive, often sudden in onset, and always associated with tinnitus and vertigo. Very occasionally, the vestibular/auditory symptoms have preceded the eye changes but only by a few weeks or a month or so in all reported cases. More than three-quarters of the cases have occurred in patients under 30; two have been associated with pregnancy.

Haynes et al (1980) carried out detailed investigations into 13 of Cogan's original series of 30 patients and also reviewed 111 patients from the literature. They again confirmed that while vestibular/auditory symptoms may appear before or after the onset of interstitial keratitis, they usually occur within 1-6 months of the onset of eye symptoms and progress to deafness over a period of 1-3 months. In their own series an elevated erythrocyte sedimentation rate was the most common abnormal laboratory finding (100%) followed by raised serum cryoglobulins (23%). Studies during flares of the disease showed C3 and C4 levels were normal and circulating immune complexes by the C1Q-binding assay failed to be demonstrated. Haynes et al (1981) prospectively followed six patients with Cogan's syndrome who were treated within 4 weeks of the acute onset of the hearing loss. Within 1-2 weeks after the initiation of corticosteroid therapy, all six demonstrated improved hearing thresholds for pure tones and suprathreshold speech discrimination results which have since been maintained. No retrocochlear abnormalities were found in any patient. Hughes et al (1981) reported cellular immune testing on two patients; lymphocyte migration inhibition tests on stimulation with inner ear membrane antigen were positive in both.
McDonald, Vollerstein and Younge (1985) reviewed their experience of 18 patients with Cogan's syndrome. Thirteen showed a typical presentation with audiovestibular symptoms quickly followed by the ocular findings. Five patients had an atypical presentation, two of whom had severe bilateral audiovestibular dysfunction 2 years before the onset of the classic ocular symptoms and signs. Reviewing 78 previously published cases, they noted that one-third of the patients had abdominal findings, most commonly gastrointestinal haemorrhage; one-quarter of the patients had cardiac involvement (aortic insufficiency was the most significant lesion) and there are several reports of such patients undergoing cardiac surgery. A number of patients are on record as developing systemic vasculitis in the course of their disease and in a few cases it has led to their death.

Bicknell and Holland (1978) reported two patients in whom neurological problems were prominent and a review of 79 cases in the literature showed that more than one-half had involvement of the nervous system. Clinical syndromes of acute inferior cerebellar artery occlusion have also occurred on two occasions. It remains undecided whether Cogan's syndrome is a separate entity. Cases of systemic involvement tend to be labelled as polyarteritis nodosa.

Treatment with steroids remains the recommended treatment supplemented in the more progressive case by immunosuppressive drugs for example azathioprine, cyclophosphamide, or chlorambucil. Plasma exchange has been successfully used on two occasions when other treatment has failed to halt the progress of the condition (Brookes and Newland, 1986). Serial audiometry in many cases has proved to be a satisfactory barometer for increasing or decreasing medication (McDonald, Vollerstein and Younge, 1985).

Veldmann (1986) has reported a case of immune-mediated sensorineural hearing loss which presented with sudden deafness - case 2, a 23-year-old female who was later found to have a rare complement deficiency.

Endolymphatic hydrops

Hallberg (1956) thought that not more than 5% of all cases of sudden hearing loss eventually developed Ménière's disease. He found only 57 such cases in his review of 1270 patients. Two cases of sudden hearing loss which showed endolymphatic hydrops at autopsy have now been reported (Takahara et al, 1974; Sando et al, 1977). Ménière's disease due to endolymphatic hydrops, as opposed to conditions producing a Ménière-like disorder, displays a characteristic pattern (see also Chapter 19). It is well known that it may fail to oblige by producing its principal symptoms simultaneously and the fluctuant hearing associated with this condition has become a subject of particular interest.

Recent investigations have shown the possibility that Ménière's disease may have an autoimmune basis. HLA typing in a series of 41 patients with Ménière's disease, showed that 75% on class I typing were found to have the HLA-Cw7 antigen. No differences were found between males and females, unilatera or bilateral disease or the side affected. The very close association with Cw7 and to a lesser extent with A1 and B8 antigens suggests that an autoimmune reactivity could be involved in the pathogenesis of this disease (Xenellis et al, 1986). Leone, Feghali and Linthicum (1984) have suggested that the endolymphatic sac with its fenestrated capillaries might be damaged by immune complexes, whereas the capillaries
of the cochlea being non-fenestrated would be better protected. An isolated defect of the complement system could also be the initiating cause of the disease. It is also known that stress can affect the immunological system and lead to exacerbation of symptoms in autoimmune disease.

Brookes (1986) investigated circulating immune complexes in Ménière's disease. He studied 66 patients in whom 36 were found to have significantly raised levels; the incidence was 57.1% in the group with active Ménière's disease, 50% in the group in which it was quiescent and 40% in the group where it was inactive, but these differences were not statistically significant. In 20 of the 36 patients, IgM alone was the complex that was raised. In the same group of 36, 83% also had increased C1Q complement levels in the complexes. However, there was no correlation at all between the presence of serum autoantibodies and raised circulating immune complexes.

**Glycerol dehydration test**

When this test was originally introduced by Klockhoff and Lindblom in 1966, it was hoped by this means to select those case of Ménière's disease whose hearing and other symptoms would be improved by diuretic therapy - the drug chosen was chlorthalidone which promotes sodium excretion without great potassium loss. Later, they took as significant, a rise of at least 10 dB in three adjacent octave bands or speech discrimination improvement exceeding 12%. No effect was seen in more advanced cases of Ménière's disease where a non-fluctuating hearing loss was present or in sensorineural loss of less specific types. Snyder (1974) felt that a pure tone threshold improvement of 15 dB was more likely to be significant; he also noticed that the changes were more marked in the low tones and the significant change was in the speech discrimination score. This test combined with transtympanic electrocochleography (Gibson, Moffat and Ramsden, 1977; Moffat et al, 1978) has extended its diagnostic usefulness and provided much information about the electrophysiological changes occurring in the cochlea. They found that in some 65% of patients with Ménière's disease, a large DC potential is present which causes an apparent widening of the summating potential/action potential (SP/AP) wave form. This potential is thought to be a summating potential which has been enhanced relative to the action potential component and is directly related to the presence of endolymphatic hydrops. During glycerol dehydration, the marked negative summating potential is seen to decrease. The positive result to glycerol testing can only occur if the patient has a fluctuating hearing loss due to endolymphatic hydrops and the hearing is impaired at its lower level at the time of testing. Gibson, Moffat and Ramsden (1977) suggested that the enhanced negative summating potential was related to an increased production of non-linear electrical activity due to the endolymphatic hydrops affecting the symmetry of the basilar membrane vibration. The glycerol is administered orally (1.5 mg/kg body weight) in the fasting state and the test can only be considered positive if there is an increase in serum osmolality of at least 10 mOs/kg to verify the effectiveness of the dehydration. The figure (Gibson and Morrison, 1983) shows the changes after one hour where the amplitude of the action potential appeared to diminish by 12%; in this case a large summating potential was present. A 'negative' glycerol dehydration test (no significant change in pure-tone threshold or speech discrimination) is meaningless if there has been less than 10 mOsm/kg increase in plasma osmolality; a 'negative' result coupled with a greater than 10 mOsm/kg change is meaningful.
Studies on inner ear impedance in patients undergoing the glycerol dehydration test have indicated that the pure-tone audiogram (the average threshold levels at 250, 500 and 1000 Hz) in Ménière's disease has shown changes which can be correlated with the maximal conductance. The conductance at 660 Hz represents the measure at which the least opposition to sound waves through the middle ear occurs and the frequency most likely to change with changes in inner ear impedance. In normal ears and in hydroptic ears in the absence of adequate dehydration, there is no change in the maximal conductance. However, there is a significant relationship between the improvement in mean speech discrimination score and the increase in conductance in hydroptic ears and proportionately in the low tone hearing improvement. With this technique it has been found that for every 1 mmol of change in maximal conductance there will be a 16.2% improvement in the mean speech discrimination score (Morrison, Moffat and O'Connor, 1980). Studies in another patient combined audiometry and the results of the glycerol dehydration test with those of surgery, one month, 6 months and 8 months postoperatively (Moffat, 1979).

Other substances that raise the serum osmolality and that diffuse and spread rapidly in the inner ear fluids, such as ethanol or mannitol, do not result in hearing gains in patients with endolymphatic hydrops. While glycerol has been found to increase the cochlear blood flow, ethanol and mannitol have no such effect. Likewise following the oral administration of urea (20 g) in humans, there is a modest elevation of plasma osmolality (7.7 mmol/kg), but neither the urea test nor that which frusemide (furosemide) has found popularity except in certain centres (Imoto and Stahle, 1983).

Isosorbide

Kitahara et al (1982) have reported the use of isosorbide, a dehydric alcohol formed by the abstraction of two molecules of water from one of sorbitol, which is known for its effect as an osmotic expanding agent. The endolymphatic pressure was reduced by its administration in guinea-pigs with hydrops while in a controlled trial of 102 patients with Ménière's disease, it produced an improvement in dizziness and tinnitus, but no mention was made of any effect upon the hearing levels.

Acetazolamide test

Acetazolamide is a water soluble sulphonamidic derivative and a specific inhibitor of the widely distributed enzyme carbonic anhydrase. This reaction is fundamental to the production of either acid or alkaline secretions, and a high concentration of carbonic anhydrase is found in various secretory cells. Work by Erulkar and Maren (1961) in the cat, led to the surprising finding that the tissues of the cochlear partition possess the highest known concentrations of carbonic anhydrase of any organ assayed. The highest concentrations were found in the apical turn of the cochlea and saccus endolymphaticus, progressively lower concentrations in the middle and basal turns, and the lowest in the vestibule. It was noted that after the administration of intravenous acetazolamide the volumes and pressures of the perilymph and endolymph appeared considerably reduced. A dose of 5 mg/kg of intravenous acetazolamide caused enzyme saturation which was sufficient to produce a metabolic acidosis and mild diuresis (Maren, 1963). It was considered, therefore, that this drug might have a diagnostic use in the investigation of patients with Ménière's disease but without the side-effects of glycerol. Acetazolamide 500 mg in aqueous solution is injected intravenously over
one minute (dose range 5.1-11.9 mg/kg) and the electrocochleogram monitored continuously for 45 minutes. Pure-tone and speech thresholds are also carried out before and after the test; plasma osmolality measurements before and after the test are also made. There is usually an initial fall in osmolality with subsequent recovery. It is though that these variations in osmolality may produce osmotic gradients which lead to secondary endolymph volume changes inducing a transient increase in the endolymphatic hydrops. Electrocochleographic recordings showed an enhanced negative summating potential commencing within 10-15 minutes of drug infusion, reversing towards the pre-infusion base line level at 45-60 minutes. No change was seen in normal subjects or in those with other cochleovestibular pathology. The additional advantage of the test is that it may be carried out in those patients whose Ménière's disease is in remission, producing a small drop in the pure tone and speech thresholds which subsequently returns to normal and thereby helps to confirm the diagnosis (Brookes, Morrison and Booth, 1982; Brookes et al, 1982).

Maren and Robinson (1960) studied the cerebrospinal fluid pressure changes in hydrocephalics following intravenous acetazolamide. The temporal relationship between the transient cerebrospinal fluid pressure rise and drug infusion found in those patients is almost identical to the relationships observed with the electrocochleographic summating potential amplitude changes. However, a trial of oral acetazolamide concluded that there was no place for its use in the medical treatment of Ménière's disease (Brookes and Booth, 1984).

Watanabe and Ogawa (1984) demonstrated carbonic anhydrase activity in the dark cells of the vestibular labyrinth and in the stria vascularis of the guinea-pig. Localization of the enzyme was very similar between the dark cells and the intermediate cells but the marginal cells had a different localization pattern. In the marginal cells, carbonic anhydrase activity was observed on the lateral plasma membrane of the apical area and a few apical vesicles, in the cytoplasm of capillary endothelial cells and the fibrocytes of the spiral ligament. They considered that carbonic anhydrase may play a major role in water and electrolyte transport in both the dark cells and stria vascularis.

**Inhalation of carbon dioxide**

It has been known for many years that carbon dioxide is a potent cerebral vasodilator, but for this to be achieved it is usual to use a mixture containing at least 10% CO₂ (Pollock et al, 1974). Prazma (Prazma, 1978; Prazma et al, 1979) showed, in guinea-pigs, that extreme hypercapnia caused an increase of the endocochlear potential; as the latter increased, so the cochlear microphonic decreased. They concluded that the enzyme carbonic anhydrase may participate in the generation of the endocochlear potential. However, inhalations of 10% CO₂ in man may cause a dangerous increase in arterial blood pressure. Using inhalations of 5% CO₂ and 95% O₂ for a period of 20 minutes in a small series of patients with Ménière's disease, the cochlear microphonic increased in some but there was no change in the summating potential and no obvious decrease in the width of the action potential (Booth, 1980).
Metabolic disorders

Renal failure

The analogy between the nephron and the organ of Corti is one which has become more frequent particularly with the increasing numbers of patients with renal failure who may be treated by haemodialysis or transplantation. It must be remembered that many of such patients have of necessity received ototoxic drugs, either to control their infection or to promote diuresis. Certain studies therefore, are not only of interest but helpful to the otologist, who is now more frequently involved with the management of such cases.

Yassin, Badry and Fatt-Hi (1970) found that the degree of hearing loss was directly related to the degree of hyponatraemia irrespective of the level of the blood urea. Urea by itself was non-toxic to the cochlear end-organs and the cochlear affections were greatly improved by correcting the renal failure and restoring the serum sodium. Eighty per cent of the cases with acute renal failure were improved by treatment, but only 52.4% in those with chronic forms.

Oda et al (1974) have shown that in a study of 290 patients with chronic renal failure, 43 developed a significant hearing loss which could be attributed to the therapy of the kidney problem. None of the patients were complaining of hearing impairment before the kidney treatment was started. Five patients treated with less than 60 haemodialyses showed no subjective hearing loss; three who had received more than 260 haemodialyses and multiple transplants complained of hearing and vestibular difficulties. During haemodialysis frequent and intense osmotic changes occur. Johnson and Mathog (1976) noted fluctuations in hearing in a single dialysis period, but could find no correlation with corresponding changes in blood urea nitrogen, creatinine, Na, K, Ca, glucose, mean blood pressure level or weight.

Quick (1976), in a prospective study of a large series of patients receiving dialysis and/or transplantation, found that a hearing loss occurs quite frequently and while one factor might trigger off the loss, it was a combination effect of many factors, but this was not a simple addition of effects, more a potentiation. In his series, one in six had some form of hearing disorder. Six patients experienced sudden hearing loss and while a hypercoagulative state was evident in one patient, when the loss followed bilateral nephrectomy and splenectomy, there was no apparent cause in the others.

Kligerman et al (1981), in a prospective study of 67 patients with chronic end-stage renal failure, noted a trend which appeared to suggest an association between haemodialysis and high frequency impairment, the degree of hearing loss did not vary with the length of treatment. Likewise, there was a striking similarity between the audiological findings obtained for all subjects with high frequency impairment, irrespective of medical treatment.

More recently, Hutchinson and Klodd (1982) assessed a series of 15 patients under the age of 60, suffering from chronic renal failure who were being treated by haemodialysis. They eliminated from their study any patient who was diabetic or in whom the cause of renal failure was considered to be congenital. Each patient was tested once when the effects of the renal failure were most severe and they were about to undergo dialysis. They were tested using pure-tone audiometry, acoustic reflex thresholds and reflex decay tests,
electronystagmography and brainstem auditory evoked responses. They concluded that when ototoxic drugs, noise exposure, diabetes, congenital nephritis, and age above 60 years are eliminated, that although individual abnormalities will occur, chronic renal failure does not in itself produce a clinically significant hearing loss; neither does it produce an abnormality of the peripheral or central vestibular function that is clinically significant; nor did it produce an abnormality within the brainstem that affects the auditory or vestibular brainstem function from the clinical standpoint.

Finally, perhaps a cautionary note should be introduced for those who acquire iron overload due to severe anaemia and frequent transfusion requirements associated with haemodialysis. Long-term desferrioxamine was given at each dialysis (40 mg/kg) to a 26-year-old woman to reduce her serum ferritin (Guerin et al., 1985). As this fell to normal after 7 months' medication, she complained of decreased hearing and an audiogram revealed a sensorineural hearing deficit with raised threshold in the mid-high frequency range. As medication continued, her hearing worsened and it was therefore decided to discontinue this. Within 3 weeks her hearing and the audiogram improved; the hearing returned to normal within 5 weeks. Continued use of desferrioxamine when the serum ferritin has reached normal levels therefore seems unwise and serial audiometry would seem prudent. Desferrioxamine is now widely used in patients with chronic renal failure to treat aluminium osteodystrophy.

**Alport's syndrome**

Occasionally Alport's syndrome has been mentioned in relation to sudden hearing loss. Alport (1927) himself reported a relationship between nephritis and deafness and noted a familial occurrence. The aetiology of the hearing loss has never been clearly defined. Characteristically it varies in severity with the family, is slowly progressive and the high frequencies are those most severely affected. Myers and Tyler (1972) suggested that there may be as many as five variants - renal disease with organ of Corti damage, renal disease with spiral ganglion cochlear neuron loss, renal disease and deafness but no histological ear lesion, renal disease without deafness, and finally deafness without renal disease. Hearing loss with normal or only mild renal changes is especially typical of female members of affected families.

The commonest presenting signs are hypertension, proteinuria, and haematuria. Gubler et al. (1981) reported a series of 58 cases in one of whom, a male child, deafness was the presenting symptom. Some degree of hearing loss may be present by the time the renal lesion is diagnosed and in their series, 37 patients showed a hearing loss, in 22 of whom the defect was diagnosed by audiometry and in 15 there was an apparent hearing impairment. In eight of their patients the first audiogram was normal! The hearing loss is of the slowly progressive symmetrical sensorineural type which is often not significant until the second decade, appears to affect the male much more than the female, and is always bilateral. The rate of progression of the hearing loss is no greater in those receiving haemodialysis or showing hypertension. Three types of pure tone audiometric pattern have been described - trough-shaped, sloping and flat (Rintelmann, 1976). Gleeson (1984) noted unequal recruitment throughout the auditory range with a trend to it being greater in the middle frequencies, producing dynamic compression at 2 kHz. Speech reception thresholds are in agreement with pure tone averages and speech discrimination scores are consistent with the audiometric configuration. Brainstem auditory evoked responses were normal. Gleeson (1984) reported a series of 11 patients (from
nine families) including seven with functioning transplants, one on regular haemodialysis, another on continuous ambulatory peritoneal dialysis and two (both female) still with functioning kidneys.

**Renal transplantation**

Hearing improvement in sensorineural deafness has been reported in two papers. Mitschke et al (1975) noted this in eight out of 10 patients with a cochlear loss; the two who had Alport's syndrome failed to improve. Paradoxically McDonald et al (1978) have reported six cases with this syndrome who have undergone transplantation; of these, one patient who received a cadaver kidney had a substantial improvement, the remainder (two received allograft kidneys from living, related donors) obtained stabilization of hearing (follow-up period - 3 years).

Quick (1976) reported a hearing loss in four patients after transplantation. Occasionally hearing loss was noted during transplantation and consideration was given as to whether this was due to the administration of frusemide (furosemide) but it was felt that the irrigation of the wound and peritoneal cavity prior to wound closure with neomycin was more likely; as a result this practice was discontinued.

More recently Jordan et al (1984) have reported on seven patients with Alport's syndrome, four of whom underwent transplantation and three who were treated by dialysis; (as might be expected all those undergoing transplant had previously been on dialysis, three for 2 years and one for 3 months). One patient with a mild pre-transplant deficit had a slight improvement in hearing 2 years later; a second patient with a mild hearing loss had no change after 18 months; the patient with a severe deficit has not exhibited any change in the hearing 10 years after surgery and the patient with the moderate hearing loss showed significant deterioration 2 years after transplantation. Of the three patients with Alport's syndrome in the dialysis group, it was only a boy who was diagnosed at the age of 4 years, had his first audiogram at the age of 11 and who commenced dialysis at the age of 20, whose hearing showed a mild loss over a 9-year period. The two other patients revealed a moderate hearing loss which was not progressive.

In the series reported by Gubler, three patients underwent transplantation of whom one was observed to have a hearing improvement (see also Duvall, Nelms and Williams, 1969).

So far, liver transplantation in children, which now has a one-year survival rate of over 70% using the immunosuppressive regimen of cyclosporin and prednisone, has not been associated with known inner ear problems, although middle ear effusion has been noted (Reilly et al, 1984).

**Renal tubular acidosis**

In some patients with renal tubular acidosis there is an association with nerve deafness. This condition is one of disordered tubular function, characterized by a sustained metabolic acidosis and hyperchloraemia and an inappropriately high urinary pH. Classical renal tubular acidosis (type I) is a distal tubular defect, while type II is characterized by defective bicarbonate reabsorption in the proximal tubules. It is classical (type I) renal tubular acidosis
which may be associated with deafness. While the condition may be sporadic there are many incidences of familial occurrence showing an autosomal dominant mode of transmission (Dunger, Brenton and Cain, 1980). There is also an association between renal tubular acidosis and enzymatically inactive red cell carbonic anhydrase B. Studies indicate that the synthesis of the two major isoenzymes, carbonic anhydrase B and C are controlled by a separate locus. Carbonic anhydrase B has less enzymatic activity and lower affinity for acetazolamide than type C. Families exhibiting renal tubular acidosis and the carbonic anhydrase B inactivity also exhibit nerve deafness (Shapira et al, 1974).

**Diabetes mellitus**

A relationship between diabetes and sensorineural hearing loss was first reported by Jordao in 1857. An excellent review by Taylor and Irwin (1978) endeavoured to put this into perspective and made the following points from their own initial survey and from the literature. The incidence of sensorineural hearing loss in diabetes will very largely depend on the limits of ‘normality’ and therein the statistical methodology. Second, nearly all the work has naturally been carried out in the group of diabetics most likely to be affected, that is those on insulin. They were careful to limit their upper age range to 50 years, thereby reducing the effect of presbyacusis. They noted that a diabetic with a family history had significantly better hearing thresholds than those without. They found that the diabetics, as a whole, were deafer particularly in the lower frequencies, than the controls and gradually approached each other in the middle range (1-4 kHz) and were similar at 8 kHz.

Peripheral and central neuropathies are well known in diabetes mellitus and the vestibular neurons may also be affected.

Friedman and Schulman (1975) studied 20 diabetic patients with peripheral neuropathy; 55% had a symmetrical hearing loss of the sensorineural type, involving at least one frequency, although none gave a history of hearing loss or ear disease. The hearing loss was unrelated to age, and the impairment was similar at low and high frequencies, with maximum deficiency between 750 and 2000 Hz.

Sieger et al (1983) reported a study in children but found no statistically significant differences in auditory function between insulin-dependent diabetics and normal controls, between the diabetics in good or poor control, or between diabetics with or without neurological or vascular complications. Brainstem responses also showed no difference between the two groups.

A small group of patients suffering idiopathic sudden hearing loss was investigated by Wilson et al (1982) to find out if there was a possible relationship to diabetes but no correlation could be found in the audiological pattern; a similar incidence of recovery was noticed in the two groups through the middle frequencies; however, the diabetic patients failed to recover as well in the high frequencies. Brainstem evoked responses also showed no abnormality and no evidence of retrocochlear dysfunction or pathology.

Mehra et al (1985) investigated a series of 102 patients with diabetes and peripheral neuropathy to see if such patients were prone to dysfunction of the inner ear. Only 26 gave a history of hearing loss of mild degree, while 17 had tinnitus, and 18 complained of vague
giddiness. Investigations showed that one-half demonstrated some sensorineural hearing loss but when corrected for ageing, only 24 showed a mild loss (20-30 dB). Eleven out of 91 showed markedly diminished caloric responses but all of these were in the older age group and had long-standing diabetes. Brainstem auditory evoked responses were carried out in 20 diabetic patients and a matched group of normal controls; there was a no difference in the latency of wave V and wave II, although waves III, IV and V were delayed in the diabetic patients.

Almost all studies on diabetic patients have been on those who are insulin-dependent, but Piras et al (1985) have reported a series of 30 diabetics of whom 27 were insulin-independent. Eight of the total group showed vascular lesions inherent to diabetics. They carried out auditory and vestibular studies both on the diabetic group and a similar number of normal controls and found that the influence of the disease was almost non-existent and the cochleovestibular response was similar in both groups.

Two centres in the UK (Nottingham and Cardiff) have combined in recent years. Gibbin and Davis (1981) investigated 50 diabetic subjects, 22 of whom were insulin-dependent, the remainder being managed by other regimens and 50 control subjects. No significant differences were found between the two groups on pure-tone audiometry or speech testing, nor between those who were insulin-dependent and those on different treatments.

Miller et al (1983) from the same two centres investigated hearing loss in patients with diabetic retinopathy. They found that the hearing thresholds of patients with known diabetic retinopathy did not differ significantly from those of a control population. However, using a more subtle psychoacoustic test - filtered speech task - a definite difference in hearing acuity between the two groups was demonstrated. The patient sample was made up of 15 women and 18 men of whom 18 had adult onset and 15 juvenile onset diabetes. The psychoacoustic test 0 four-alternative auditory feature speech identification test - could not be applied to all patients because of the reduction in their visual acuity. Sixteen patient completed the full-spectrum speech test and there was no significant difference between these results and those from the normal population. However, use of the filtered four-alternative auditory feature test showed significantly poorer speech perception in the diabetic group. The filtered test removes the normally important mid-frequencies emphasizing reliance on high frequencies; the filtered form of the test is expressly designed to try to exclude possible damage specific to the basal end of the cochlea. Perhaps somewhat perversely the hearing thresholds at the high frequencies were actually greater in the controls than in the diabetic patients! It has been suggested from these two studies that it is possible that there is a subpopulation of diabetic patients who suffer from subtle retrocochlear losses. However, as has already been pointed out above, brainstem auditory evoked responses have hitherto shown no difference between diabetic and non-diabetic subjects.

It should be remembered that there is a wide variation in the instance of diabetes mellitus and it is evident that this is related to the prevalence of obesity. Basal insulin secretion is directly related to relative body weight in both diabetics and non-diabetics. Maintaining ideal body weight reduces plasma insulin requirements and improves the metabolism of all tissues; high levels of circulating insulin may have a role in the development of atherosclerosis.
Hyperlipidaemia (hyperlipoproteinaemia)

When considering this condition as a cause of fluctuating hearing loss, it is important to stress at the outset, the difference between primary and secondary hyperlipidaemia (Chait, 1974). There is a large number of conditions causing secondary hyperlipidaemia, the most common of which are diabetes, alcoholism, chronic renal failure and gout. Pregnancy may also be a cause and oral contraceptives have been shown to elevate the plasma triglyceride in most subjects taking them. It is therefore essential to exclude these secondary causes, if not at the time of the original sampling, at least when the fasting lipids are being checked.

The next factor to be taken into account is the incidence of hyperlipidaemia, not in populations elsewhere in the world, but in the same part of the same country. Cholesterol levels have been shown to vary widely between countries and between different parts of the same country, for example Finland and Yugoslavia. A survey in the north-east of London of 276 carefully screened men and women, aged 20-69 years, showed that 4.3% of men and 4.8% of women (aged 40-69) had serum cholesterol values exceeding 7.8 mmol/L (300 mg/100 mL); 14% of men and 3% of women had triglyceride levels greater than 2.0 mmol/litre (180 mg/100 mL). By these definitions, 18% of men and 8% of women had hyperlipidaemia (Lewis et al, 1974).

It cannot be stressed enough that great care is required in carrying out these investigations and relating them to statistics of 'normal controls' in the same geographical area and to the normal levels for the individual laboratory and the methods adopted.

Booth (1977) investigated 44 patients with premature bilateral sensorineural hearing loss, without vertigo, and failed to find any incidence greater than in the local general population and no patient requiring treatment other than by a modification of their diet. Further cases have confirmed this finding and none so far has shown any significant improvement in hearing; conversely there has also been no progression apart from age-related changes.

Drettner et al (1975) in a study of 1000, 50-year-old men investigated a number of cardiovascular risk factors to see if they might be of importance in the development of sensorineural hearing loss. No significant correlations were found and included among the risk factors which were studied were serum cholesterol, serum triglycerides, uric acid and glucose tolerance. Spencer (1981) has now carried out the largest series associating abnormal lipids and inner ear symptoms. Of his 1419 patients, 18.4% were classified as having type IIA or pure hypercholesterolaemia with normal triglycerides; 6.3% had type IIB primary hypercholesterolaemia associated with lesser hypertriglyceridaemia, while by far the largest part showed a type IV primary hypertriglyceridaemia with a lesser elevation of the cholesterol level. However, the incidence of obesity in these patients has varied from 72 to 100% depending upon the type of disorder and whether it was associated with an elevated glucose tolerance. In his patients, by reversing their dietary habits by cutting out refined carbohydrates, reducing the intake of saturated fats and by increasing the amount of dietary fibre, avoidance of additional salt and sugar, and obtaining ideal body weight, he has reported improvements in hearing and has found similar therapy of value in treating patients with Ménière's disease. Moffat, Booth and Morrison (1979) carried out detailed investigations including metabolic studies into 27 patients with Ménière's disease, but found no increased
abnormality on glucose tolerance testing, fasting serum cholesterol and triglyceride levels, or estimations of thyroid stimulating hormone. A similar evaluation was carried out by Kinney (1980) in 134 patients showing a high correlation of abnormal carbohydrate metabolism (Shaur test) and hyperlipidaemia. Pullen et al (1985) in a study on 30 patients with migraine and 15 with Ménière's disease reported what they believe is an association between hyperinsulinism and these conditions.

Recently Karjalainen et al (1986) carried out oral glucose (75 g) tolerance tests and measured plasma insulin levels in 74 patients with Ménière's disease and 74 control subjects. They could find no significant difference in fasting and 2-hour blood glucose or insulin levels between the two groups.

**Hypothyroidism**

Schuknecht (1974) found the literature up to that time unconvincing on the relationship between acquired idiopathic hypothyroidism and sensorineural hearing loss, although commented that clinicians seemed to have the impression that there probably was such an association. Post (1964) investigated 42 patients - seven with spontaneous primary hypothyroidism and 35 hypothyroid patients with treated carcinoma of the thyroid. He noted that slow mentation while hypothyroid may be interpreted by the patient as a subjective hearing loss. None of the patients with sensorineural loss attained entirely normal hearing when euthyroid. He was unable to demonstrate any specific correlation between age, degree of hypothyroidism and resulting deafness. He was also unable to determine the time required for patients to remain hypothyroid before experiencing a hearing loss. Stephens and Hinchcliffe (1968) found a significant correlation between the diagnosis of myxoedema, and fatigue or temporary threshold drift measured at 8000 Hz by the Carhart technique. Stephens (1970) later confirmed that this was not an artefact relating to age, but a true finding. He suggested that the sensorineural lesion in myxoedema lies proximal to the hair cells. Meyerhoff (1976) reviewed the possible relationship between all forms of reduced thyroid function and hearing loss; under the heading 'non-genetic acquired' he reiterated the claims made up to that time, that is there was no definite association.

Two more recent papers continue to highlight the conflicting evidence. van't Hoff and Stuart (1979) have reported an incidence of deafness of 85% in a consecutive series of 48 patients with myxoedema. The more severe the disease, the higher was the incidence of deafness; there was no difference between the effect on the high or low frequencies and in some cases the loss was unilateral. Testing after the patients became euthyroid showed improved hearing in 73% of ears. The percentage returning to normal (23%) showed no significant difference in the proportion of severe (20%) to mild myxoedema (26%). Repeat testing after becoming euthyroid, failed to show any further improvement. Age did not appear to be a factor in the cause of deafness in myxoedema. While severity of myxoedema was associated with a higher instance of deafness, no other relationship could be found between severity in myxoedema and a variety of other neurophysiological measurements. van't Hoff and Stuart were in no doubt that the deafness was sensorineural.

Parving, Parving and Lyngsøe (1983) in a series of 15 patients with confirmed myxoedema, median age 76 years, demonstrated a bilateral symmetrical or nearly symmetrical sensorineural hearing loss in all patients before treatment. Treatment with L-thyroxine in this
group of elderly patients showed no improvement in hearing sensitivity and the group demonstrated neither more nor less hearing loss than other hearing-impaired patients of the same age group.

An interesting study comparing the hearing of otherwise normal schoolchildren, in a province in China (Yan-You and Shu-Hua, 1985) in a known area of endemic iodine deficiency, showed the mean hearing level was significantly lower than that of children in a non-endemic control area and that after 2 years of taking iodized salt the mean hearing level approached that of the controls; prior to prophylaxis the mean hearing level was 17.4 dB, after one year it had been improved to 13.9 dB and after the second year to 7.6 dB.

Recently, Hall et al (1985) reported a prospective study undertaken to compare the auditory acuity in hypothyroid patients and to assess the effect of thyroxine on these thresholds, for a mean period of 5.7 months (range 2-24 months). Auditory thresholds were reduced over all frequencies but the difference being significant only at 2000 and 4000 Hz. Speech discrimination was also significantly reduced in both ears. With thyroxine there was a small improvement in pure-tone thresholds and speech discrimination; this was only significant at 4000 Hz in both ears.

More recently Parving et al (1986) have reported the audiological and temporal bone findings in myxoedema. They investigated 15 patients with confirmed myxoedema with a median age of 48 years before and after treatment with L-thyroxine. No improvement in hearing sensitivity could be demonstrated either in the younger patients (age 32-60 years) or in the older group (64-95 years). When compared to an age and sex-matched unscreened population, the myxoedematous patients did not demonstrate any different degree of hearing loss. Histological investigation of the temporal bones from an 83-year-old woman with myxoedema, however, showed no morphological changes or deposition of glycosaminoglycans, changes which were compatible with true age-related hearing loss. They concluded that those series which had previously indicated a hearing improvement after restoring the patients to a euthyroid state had been carried out on only a very limited number of patients and when the sample was larger no abnormal hearing levels could be found either before or after treatment in myxoedema.

Crifo et al (1980) in a retrospective survey of 46 congenital hypothyroid cases found severe and profound hearing loss in the five cases with dyshormonogenesis whereas the one-third of patients with thyroid agenesis presented with only a mild or moderate hearing loss.

Vanderschueren-Lodeweyckx et al (1983) and Debruyne, Vanderschueren-Lodeweyckx and Bastijns (1983) reported a series of 45 children with thyroid agenesis, hypogenesis or dyshormogenesis with adequate substitution therapy; the majority (80%) had normal auditory thresholds while the remainder exhibited a sensorineural loss of differing degree in half of whom this was important. No relationship between the hearing acuity and bone age at diagnosis of hypothyroidism or the aetiology of thyroid function could be found. The first case of sensorineural deafness in congenital hypopituitarism with severe hypothyroidism in an 18-year-old boy has been reported but in spite of satisfactory replacement therapy there was no improvement in his audiological function (DeLuca et al, 1985).
Himelfarb et al (1981) have attempted to correlate changes in the brainstem electric responses of patients with thyroid dysfunction (six hyperthyroid; six hypothyroid). A good correlation was observed between the brainstem conduction time and level of serum tetraiodothyronine (T4; thyroxine). In untreated hyperthyroidism, the brainstem conduction time was decreased and in some patients the brainstem electric response was characterized by high amplitude waves, sharp peaks and jittery contours becoming smoother in pattern and more well-defined after treatment.

In untreated hypothyroidism, the brainstem electric response was generally characterized by prolonged conduction time, diminished amplitudes, flattened peaks and poor synchronization; in the older patients the changes in wave pattern were more pronounced. Brainstem conduction time appears to be a sensitive index of the thyroxine-dependent cellular status in the neural pathways of the brainstem.

Lolas et al (1977) found low amplitudes of the brain potentials evoked by visual stimuli in hypothyroid subjects.

Experimental work by Meyerhoff (1979) on the guinea-pig after induced hypothyroidism, measuring the interwave intervals for the N_1 and N_2 response at the round window and vertex identified elevated auditory thresholds. The interwave intervals for the N_1N_2 response at the round window as well as the interwave intervals for the brainstem response were normal once threshold had been achieved. Meyerhoff concluded from this that the lower central auditory pathways were functioning normally and this eliminated the delayed conduction of auditory response to the brainstem as a possible mechanism and identified the cochlea as the site for the hearing loss associated with hypothyroidism. He was able to support this as the site of the lesion for the sensorineural hearing loss by morphological and biochemical findings. It should perhaps be emphasized that these animals were rendered experimentally hypothyroid during gestation with radioactive iodine-131 or propylthiouracil (both methods produced the same auditory results). More recently Ben-Tovim et al (1985) induced myxoedema in adult albino rats using oral propylthiouracil. They found minor changes in the amplitudes of all auditory brainstem response waves without any correlation with the serum T4 levels. They measured a conspicuous, dynamic, and reversible change in the amplitude of the third wave which correlated directly with the T4 (thyroxine) level in the rats’ blood. Their findings in the rat indicate a lesion in the auditory tracts in the brainstem but mainly in the superior olivary complex in the central auditory pathway.

**Propylthiouracil**

A single case is on record of a young girl who developed hyperthyroidism with a diffuse goitre. She received propylthiouracil for 10 months before complaining of tinnitus and a fluctuating hearing in the left ear (cochlea). After discontinuing medication, she underwent a subtotal thyroidectomy followed by a complete return of the hearing to normal after 2 weeks, but the mild tinnitus persisted (Smith and Spaulding, 1972).
Ototoxicity

This subject is discussed more fully in Chapter 20. It is well known that several types of medication particularly certain groups of antibiotics can cause sudden hearing loss, and likewise some diuretic agents.

However, here certain other 'drugs' - alcohol, tobacco, marijuana - are included for the sake of completeness.

Alcohol

Under ordinary circumstances, plasma osmolality is determined primarily by the concentration of inorganic ions; other substances contribute to it and, in certain pathological states, may cause appreciable elevation of the plasma osmolality over that contributed by inorganic ions alone, for example diabetes mellitus and uraemia. The elevation of plasma glucose and urea levels is well recognized as capable of causing notable changes. Ethyl alcohol by virtue of its low molecular weight (46) might be expected to have a marked osmotic effect per unit mass present in plasma. Ethyl alcohol is ingested in quantities amounting to many grams at a time and is rapidly absorbed from the stomach, and like urea but unlike glucose, has ready access to intracellular water, causing pronounced changes in intracellular osmolality. Alcohol is therefore probably the commonest cause of the hyperosmolar state (Robinson and Loeb, 1971). Other alcohols, for example glycerol (a trivalent alcohol) and isosorbide (a dihydric alcohol) are used either diagnostically or therapeutically as hyperosmolar agents.

Spitzer and Ventry (1980) showed significant differences between alcoholic subjects and controls for acoustic reflex measurements, and tests of central auditory dysfunction (staggered spondaic word test, synthetic sentence identification). Approximately half of the alcoholics yielded results consistent with brainstem pathological features. However, there was no difference between the two groups in respect of pure-tone hearing loss or discrimination loss.

Tobacco poisoning (cigarette smoking)

Zelman (1973) found that at all frequencies the percentage of hearing loss was greater for smokers, being most apparent in the higher frequencies, in his investigation of 1000 consecutive candidates for audiometry; the tone frequency pattern of hearing loss did not differ between smokers and non-smokers. Drettner et al (1975) investigated a number of cardiovascular risk factors, included among which was the smoking habit. They compared 509 smokers with 276 patients who had never smoked, but could find no significant differences in hearing loss related to smoking habits per se. Marston, Sterrett and McLennan (1980) investigated the effect of cigarette smoking on tympanic membrane otoadmittance characteristics; they could find no significant difference between the two groups. Experimental work by Maffei and Miani (1962) on the guinea-pig showed that chronically intoxicated animals always showed degeneration of the neurosensory epithelia and of some specific cochlear structures besides the tubal mucosa.
Marijuana (Cannabis sativa l.)

Marijuana minimally affects the sensory acuity (Caldwell et al, 1969) but in chronic users significantly changes vestibular functions (Spector, 1974). The first only occurs while under the influence of the drug, and so far there is no evidence that either produces a long-term effect.

Skeletal system and otic capsule

Conditions under this heading are considered more fully in Chapter 15 but may rarely cause sudden cochlear hearing loss. Metastatic carcinoma may also occasionally occur in the ear producing such an effect and should not be overlooked.

Relapsing polychondritis

Ocular inflammatory lesions, hearing loss, and dizziness are frequent manifestations of this condition. While the hearing loss may be secondary to a middle ear problem resulting from involvement of the eustachian tube cartilage, sensorineural deafness may also occur. In several of the reported cases the hearing loss has accompanied either an abrupt cessation of steroid therapy or a drastic reduction in the level of medication. Specialized audiometric tests show the loss to be of the cochlear type. The condition is dealt with more fully in Chapter 15.

Hoshino et al (1978, 1980) have described a single case of a 56-year old female who suffered sudden deafness during the course of relapsing polychondritis. Audiometry showed a complete hearing loss in both ears and caloric testing did not elicit any responses. The patient was treated continuously with steroids which were supplemented over the last 6 years of her life with azathioprine before she died of gastrointestinal haemorrhage. They reported the temporal bone changes including scanning electron microscopy in this patient and described findings similar to those of viral deafness with endolymphatic labyrinthitis.

Hydralazine-induced relapsing polychondritis has been recorded as an adverse reaction to this drug, developing almost exclusively in patients who are slow acetylators (females who are also slow acetylators and are HLA-DR4 positive, when treated with hydralazine, are at serious risk of contracting systemic lupus erythematosus syndrome).

Retrocochlear (eighth nerve) and central nervous system

Meningitis

Leptomeningitis still causes a few cases of sudden deafness - it is typically bilateral, and total or subtotal. It may occur as a complication of acute otitis media, and is usually pneumococcal in origin. Tuberculous meningitis may still rarely be encountered and the cranial nerves may be involved by the arachnoiditis and adhesions in spite of modern therapy; as in other bacterial forms of meningitis both the cochlear and vestibular nerves may be affected (McCabe, 1975).

Acute meningovascular syphilis still occurs and may present to the otologist.
Viral disease may also cause meningitis, although it is infrequently the cause of sudden deafness.

**Multiple sclerosis**

Deafness in multiple sclerosis seems more likely to occur during the first 4 years of the presentation of the condition, but thereafter there is no relationship between the hearing loss and the duration of the disease. It has been estimated that some 3% of patients have a hearing problem but a higher percentage, perhaps 25%, are troubled by vertigo at some stage during the disease. The disparity between the pure tone result which may be good and speech discrimination scores which are often poor is well recognized.

Luxon (1980) in a retrospective analysis of 309 unselected patients with brainstem disorders found 52 (16.8%) with multiple sclerosis. However, only two patients complained of deafness at the time of presentation. Forty per cent of the group suffered a unilateral deficit and in common with other brainstem lesions, the frequency distribution revealed a loss in the high frequency range in 60% of the patients. No characteristic audiometric pattern was found but in both bilateral and unilateral deafness 'island loss' occurred most commonly.

It will be remembered that Dix (1965) in a series of 31 cases of multiple sclerosis of unilateral deafness paid particular emphasis to the phenomenon of loudness reversal and illustrated this in a case which showed recovery of the loudness function after its original absence.

Quine et al (1984) have shown that patients with multiple sclerosis experience hearing loss specifically for shifts of tone frequency. Tests of central auditory dysfunction may be helpful, for example binaural fusion, dichotic sentences. Hausler, Colburn and Marr (1983) reported a series of 26 patients with multiple sclerosis with normal audiograms and good speech discrimination, but they often performed abnormally on the spatial and lateralization discrimination tests. They found that patients with clearly abnormal interaural time just-noticeable differences also have abnormal brainstem evoked potentials on at least one side.

Recently Jerger et al (1986) have examined the morphology of the acoustic reflex in 122 patients with 'definite' multiple sclerosis. They found an abnormality in some dimension in 75%, most commonly in one or more of the three relative amplitude indices (afferent, efferent or central pathway). The mean average pure-tone hearing threshold (500, 1000 and 2000 Hz) was 11 dB for the poorer and 7 dB for the better ear; 80% had a mean hearing threshold for the poorer ear no worse than 20 dB. The mean value for the frequencies 1000, 2000 and 4000 Hz, were 15 dB for the poorer and 10 dB for the better side; 77% had a mean hearing threshold for these frequencies of no worse than 20 dB in the poorer ear.

Grénman (1985) has carried out a detailed neuro-otological and audiological study of the involvement of the audiovestibular system in multiple sclerosis. He examined 70 patients and found a good correlation between his results and the clinical findings of cerebellar and brainstem lesions, and this was most apparent in the vestibular tests (smooth pursuit, saccadic eye movements and optokinetic nystagmus).
Because by definition multiple sclerosis is a disease characterized by multiple areas of demyelination of the central nervous system, the clinical diagnosis depends on the demonstration of two or more lesions. For this reason, non-invasive techniques of investigation are of particular value and brainstem auditory evoked potentials have proved most welcome to the neurologists who have traditionally used binaural stimulation (Robinson and Rudge, 1977). The benefit of auditory monaural stimulation in this condition has been emphasized by several authors (Prasher and Gibson, 1980). The binaural technique produces a greater amplitude response with greater inter-test consistency but this is only true in eliciting brainstem electric response abnormalities in cases with clinically definite criteria. In the group of patients with possible multiple sclerosis, abnormally late waves may be seen on ipsilateral or contralateral stimulation.

Unlike normal subjects, there is no increase in wave V amplitude on binaural stimulation in a large majority of patients with multiple sclerosis who have no hearing deficit. The first stage of bilateral innervation occurs at the level of the superior olivary complex. Binaural stimulation may be incomplete at this level, so that only the subsequent waves originating from the brainstem nuclei caudal to the superior olivary complex will result in increased amplitude on binaural stimulation. Prasher, Sainz and Gibson (1982) showed that the mean amplitude of wave V in patients with multiple sclerosis did not alter significantly when stimulation was changed from one ear to the other or even when both ears were stimulated simultaneously; the majority of their patients showed a decrease in amplitude on binaural stimulation. In patients with chronic disease, the amplitude of wave V was small and was not affected by changing from monaural to binaural stimulation. Their studies showed that the brainstem potentials in patients with multiple sclerosis who have no hearing deficit, did not increase in amplitude on binaural stimulation.

Daugherty et al (1983) reported nine cases of multiple sclerosis all of whom included hearing loss as a prominent complaint. Seven of these underwent brainstem electric response testing. The hearing loss was unilateral in seven and bilateral in two and was a feature of the initial attack in four patients and occurred within one year of onset in a further two. In two, clinical remission was accompanied by improvement in the brainstem response. Tinnitus and/or vertigo accompanied the hearing loss in five of the nine and all had some other concurrent neurological symptoms or signs. Seven patients underwent electrophysiological studies, only one of whom had a normal brainstem response. There is no single characteristic pattern either in this or other series but prolongation of wave V latency appears to be the most consistent finding. By contrast, Chiappa et al (1980) reported brainstem auditory evoked responses in 202 patients with 'definite', 'probable', or 'possible' multiple sclerosis, but no patient presented with hearing difficulties. Only a few patients in their series had formal audiograms and all of these were normal. Using monaural stimulation, 68% had normal brainstem responses. In those showing abnormal responses, there was no significant correlation between the multiple sclerosis classification and the abnormality in brainstem response. In the abnormal group, 13% had only interwave latency abnormalities, 55% had only wave V amplitude abnormalities, and 33% had abnormalities of both interwave latency and wave V amplitude.

Only relatively few patients are reported as developing acute hearing loss and two recent reports of such patients undergoing brainstem auditory evoked responses are of interest. Jabbari, Marsh and Gunderson (1982) reported two cases of acute unilateral deafness whose
responses showed an absence of waves II and V in the first and the presence of only wave I in the second. Fischer et al (1985) reported 12 patients with definite multiple sclerosis who experienced an acute hearing loss during a relapse of the demyelinating disease, in a series of 705 patients. Responses were recorded in all 12 patients, during the relapse with acute hearing loss in four and after the relapse with hearing loss in the remaining eight. During the relapse with hearing loss, brainstem electric responses abnormalities were present in four, wave I being absent in two. Responses were also noted to improve substantially when recorded after the relapse in two of the three patients in whom such records were made. Brainstem electric response recordings were abnormal on the side of the earlier hearing loss in five of the eight patient investigated after the relapse. Fischer et al considered that the lesion causing unilateral hearing loss in multiple sclerosis could be situated in the cochlear nerve or close to its entry zone in the brainstem. In the classical case of a predominant, if not exclusive, central demyelination in multiple sclerosis, peak 1 remains present, well-shaped and of normal latency in most patients who have not experienced an acute episode of hearing loss in the course of their disease. Fischer et al reported an absence of wave I in only five cases in a series of 340 patients without a history of hearing loss. Arnold and Bender (1983) reported a case of particular interest in whom hearing tests were carried out over a 6-year period prior to the apparent development of multiple sclerosis. In spite of the subjective left-sided hearing loss, all the patient's investigations including specialized tests showed no abnormality. Brainstem auditory evoked responses using monaural stimulation showed that the latencies beyond wave II were delayed, particularly wave V. One month after the investigations, the patient was struck and killed by lightning. Histopathological examination of the brainstem showed extensive demyelination with specific sites of involvement in the superior olive, lateral lemniscus, and inferior colliculus.

Recently, Ferguson, Ramsden and Lythgoe (1985) sought to determine whether the combination of brainstem auditory evoked potentials and the blink reflex would yield a higher rate of abnormality than each test performed separately. In a series of 50 patients with multiple sclerosis (definite - 30, probable - 10, possible - 10) using monaural stimulation, they found that 64% had abnormal responses. The blink reflex was elicited using electrical stimulation to the supraorbital nerve. Fifty-two per cent had an abnormal blink reflex, but when the results were combined with the brainstem electric response, 76% were abnormal. In this series, symptomatic deafness was present in 20%.

Recently, magnetic resonance imaging (MR) has been shown to be of particular value in demonstrating plaques of demyelination including those in the brainstem. Cortical deafness in multiple sclerosis is a particularly rare event. Tabira et al (1981) reported such a case with complete recovery from total deafness following stages of auditory agnosia and pure word deafness. The otological and neurophysiological studies suggested lesions in the subcortical white matter.

_Friedreich's ataxia_

In Friedreich's ataxia there is no relationship between the progressive clinical involvement and the degenerative changes affecting the peripheral nerves. Pelosi et al (1984) investigated a series of 15 patients of whom only five had a hearing difficulty (three mild, one moderate and one severe). However brainstem electric responses were completely dissociated from the hearing disorder, being normal in one patient and abnormal in the
remaining 12 investigated. Five showed severe abnormalities and there were mild to moderate abnormalities in the remaining seven, but wave I was present in all of this group. Patients without clinical acoustic disturbances showed abnormalities in brainstem response to the same degree or even greater than those who had a mild or moderate sensorineural hearing difficulty. However, the findings were significantly correlated with the level of clinical disability generally.

Visual evoked potentials showed abnormalities which corresponded to the severity of the clinical ophthalmological disturbance but were unrelated to the duration or severity of the clinical condition. Somatosensory evoked potentials showed findings which were also unrelated to either the duration or severity of the clinical conditions. Jabbari et al (1983) studied five children in an effort to find out the primary site of auditory dysfunction in classic Friedreich’s ataxia; none of the children had any hearing complaints and all were tested soon after the onset of symptoms. The brainstem evoked potentials indicated dysfunction of the auditory system in the pontomesencephalic region. Acoustic reflex studies on two of the patients also suggested involvement of the brainstem auditory pathways. Wave I was retained in all patients and they thought it unlikely therefore that there was significant dysfunction of the spiral ganglia.

**Amyotrophic lateral sclerosis (van Laere’s disease)**

Cristovao et al (1985) have reported a family with this condition showing cochleovestibular involvement. This is an uncommon pattern of the disease and in the non-familial type such involvement has not been reported. The older two members of the family, aged 19 and 15 years, reported hearing loss as the first manifestation and on testing the eldest showed a severe bilateral sensorineural hearing loss with very poor discrimination scores, pathological decay of the stapedius reflex bilaterally, asymmetry of the horizontal optokinetic nystagmus and bilateral absent responses in rotatory and caloric vestibular tests. The younger member (aged 12) had no complaints and normal hearing but pathological decay of the stapedius reflex at one frequency in one ear was noted. Only the eldest member showed other neurological involvement which was severe by that time.

**Vogt-Koyanagi-Harada syndrome**

In 1926, Harada described what he believed to be a distinct entity comprising bilateral detachment of the retina, uveitis, mild meningeal irritation and ‘dysacusia’. It is now generally considered that this ‘disease’ forms part of the now combined syndrome. Vogt in 1906, noted the association between bilateral uveitis, alopecia, vitiligo, poliosis (whitening of the hair) and ‘dysacusia’. (Koyanagi described his variant in 1929 - this brought vitiligo and the deafness together.) Most of the reported cases have occurred in people of pigmented race. The principal feature is the prolonged bilateral uveitis, causing blindness. The hearing loss develops at or near the time the blindness occurs; it is also usually bilateral, of varying degree, frequently associated with tinnitus and vertigo. The ear symptoms begin to improve after 1-3 weeks as the tinnitus and vertigo subside, gradually returning to normal. Vision often returns to normal in 2-6 months, but glaucoma and cataract may continue as complications. The vitiligo, poliosis and alopecia usually appear when the uveitic begins to improve. Rosen (1945) reported one case and reviewed those then in the literature - a total of 45; Maxwell has reported another (1963). Schuknecht 91974) noted that ordinarily three stages may be
recognized in the disease: the meningeal, the ophthalmic and the convalescent. The meningeal stage is present in at least 50% of the patients and may last from 2-4 weeks. The hearing loss may occasionally be unilateral and need not always recover. The cause remains unknown.

**Xeroderma pigmentosum**

Xeroderma pigmentosum is a rare autosomal recessive condition first described by Kaposi in 1874. Clinically the patients present with an abnormal sensitivity to sunlight, this is characterized by the appearance of a delayed yet marked erythema of skin exposed to ultraviolet light. Subsequently pigmented macules appear together with telangiectasia and skin atrophy and, in time, multiple cutaneous neoplasms develop. The condition is associated with abnormalities of excision and repair of DNA segments damaged by ultraviolet light. Complementation studies have shown seven different types of the condition, all of whom have an excision repair defect; there are still others known as xeroderma pigmentosum variants, in which no such defect is evident, but in whom synthesis of DNA is still abnormal with slow maturation of new DNA chains. Neurological abnormalities have also been described, particularly peripheral neuropathy and changes in the central nervous system may also occur. deafness has also become recognized as being associated with this disease.

Longridge (1976) studied a pair of siblings and came to the conclusion that the disorder was central and not cochlear in origin. He based this opinion on absent stapedial reflexes, and absence of tone decay and a speech audiogram which he considered to be worse than would have been anticipated from the pure tone audiogram. More recently, Kenyon et al (1985) reported three cases in whom detailed neuro-otological investigations had been carried out. These patients had widely differing ages (16, 46 and 57 years) and two showed a high and one a low tone recruiting hearing loss; brainstem auditory evoked responses obtained in one patient were completely normal and only mildly deranged in another strongly suggesting the origin of the deafness to be more peripheral than the brainstem. Although the deafness was bilateral, in none of the patients was it entirely symmetrical. The vestibular pathways appear to be involved, but apparently to a lesser extent than the auditory ones and vestibulo-ocular reflex suppression is abnormal. The two older patients showed evidence of a mild supranuclear palsy that was only apparent on volitional movement.

**Tumours**

**Acoustic neuroma**

Few would regard this as a common tumour and in relation to the vast number of cases of all forms of unilateral sensorineural hearing loss investigated in clinics, the number of confirmed cases is infinitesimal. However, its clinical interest makes every clinician feel this effort to be well worthwhile and the satisfactory surgical removal rewarding, thereby entirely vindicating the investigative time involved. Those who see these tumours but infrequently or rarely, may be surprised to learn that they can present as sudden deafness. It is of the greatest importance that this should be thoroughly understood and, even though the deafness may no longer seem worth treating, it is always worth investigating as thoroughly as circumstances allow.
It is interesting to note that Cushing in 1914 mentioned that two cases had sudden hearing loss as a manifestation of cerebellopontine angle tumour, but it was not described as the presenting symptom in the English literature until 1956 by Hallberg (see also Hallberg, Uihlein and Siekert, 1959). In addition, Edwards and Paterson (1951) mentioned five patients whose hearing loss was described as abrupt in their review of 157 cases. Higgs (1973) reported that 10% in his series of 44 patients presented with sudden deafness. Morrison (1975) showed that no less than 17% of his patients presented in this way. More recently several papers have appeared reporting cases which have presented with sudden deafness. Pensac et al (1985) in a retrospective analysis of 506 patients with surgically proven cerebellopontine angle lesions seen over a period of 14 years, found 77 (15.2%) who presented in this way (69 acoustic neuromata, seven meningiomata and one malignant cholesteatoma). They could find no characteristics which distinguished these cases from the remainder. Twenty-four were small lesions (up to 1.5 cm); 28 were medium-sized (1.6-2.9 cm) and 25 were large (3.0 cm or greater). The hearing patterns were in the same proportions as those for acoustic tumours generally; several had hearing losses which improved before they could be tested. Eleven had reasonably normal audiometric findings (tumour size 1-4.5 cm); the patient with the largest tumour (4.5 cm) had a pure tone threshold of 50 dB with 100% speech discrimination! Chow and Garcia (1985) reported a patient with sudden hearing loss whose hearing returned to normal 2 weeks later only to fall again 4 weeks later, with normal caloric responses and speech discrimination at that time of 24%, then recovering within 6 weeks to 76%. A CT scan showed a 1.5 cm mass and the patient refused surgical treatment.

If only this were all! Berg et al (1986) reviewed patients with 133 tumours seen over a 10-year period, of whom 17 (13%) had presented with sudden hearing loss. Of these, four (23%) had recovered auditory function before surgery - three spontaneously and one after steroid therapy. One case, in addition to the sudden deafness, had a progressive facial palsy, which was treated with steroids leading to almost complete return of facial motor function (tumour 1.5 cm); the tinnitus and vertigo also resolved. Another patient in their series had three episodes of sudden hearing loss over one year, plus tinnitus, but no vertigo; the first two episodes resolved within 72 hours (tumour 1.5 cm). However, no bilateral tumours have yet been reported as presenting in this way. Of the 16 cases who presented with sudden idiopathic deafness reported by Morrison (1975) and who proceeded to advanced meatal studies, five were found to have slight enlargement of the internal meatus but no tumour!

Conversely, in the series of more than 1200 cases of sudden deafness reported by Shaia and Sheehy (1976) almost 1% had an acoustic tumour. They found nothing to distinguish these cases from the group as a whole, other than the fact that 50% had a profound or total loss of hearing; 70% had a reduced vestibular response and all had an enlarged internal auditory meatus.

Finally, Clemis, Mastricola and Schuler-Vogler (1982) reported three cases of sudden hearing loss postoperatively in the contralateral ear of patients with an acoustic tumour.

**Metastases in cerebellopontine angle**

Secondary deposits may occur in the cerebellopontine angle from primary disease in the breast, bronchus and prostate.
Carcinomatous neuropathy

Peripheral neuropathy caused by malignant disease ranks second to the Guillain-Barré syndrome. Conversely, unexplained peripheral neuropathy should be the signal to search for malignant disease.

The highest incidence of this condition has been found in patients with carcinoma of the lung, ovary and stomach, and lowest in the rectum, cervix and uterus. Other malignant diseases may also have an associated involvement - progressive multifocal leucoencephalopathy is linked with Hodgkin's disease, lymphosarcoma and some other reticuloses. There is also an unusual form of encephalomyelitis nearly always associated with oat-cell bronchial carcinoma.

No particular association with either branch of the eighth nerve has so far been shown (Henson and Urich, 1982). Hearing loss has been reported in carcinomatous meningitis and five such cases have been seen in which the hearing loss was the presenting symptom (Alberts and Terrence, 1978).

Central deafness

'Central' deafness may be unilateral or bilateral but it is the latter type that seems to yield the most helpful information so far. It should be stressed that cases are rare, autopsy reports are few and that there is no uniform pattern of hearing loss. However, certain features appear to give some diagnostic and investigative guide.

Jerger et al (1969) and Jerger, Lovering and Wertz (1972) have reported two cases in great detail. Both were cases of bilateral temporal lobe damage, both males. Both experienced transient aphasia but no hearing problems after the first side (left) episode. Both reported severe hearing loss after the second (right) episode. In both, the presumed sensitivity loss had essentially recovered within 3 months of the second episode; both showed marked inability to recognize either single words or sentences. However, there was one significant difference and that was in their ability to localize sound; in the younger case this was impaired but not in the older.

In the first (younger) patient, it was concluded that he had experienced occlusion of the terminal branches of the middle cerebral artery on each side at different points in time, resulting in bilateral partial cerebral hemisphere infarction, maximal in the temporal lobes, and producing the clinical picture of cortical deafness. In the second case, at his second admission, angiography showed occlusion of the major middle cerebral trunk with anastomotic filling in a retrograde manner from the parieto-occipital branch of the right posterior cerebral artery. This patient had a third and final admission, 6 months later for acute cerebral infarction with right hemiplegia and aphasia; he died one week later of an acute myocardial infarct. Examination of the brain revealed bilateral and symmetrical areas of softening of the posterior segments of the superior temporal gyri, these were caused by cystic infarcts; the major arteries displayed moderate atherosclerosis but there was no evidence of embolism.

More recently, Earnest, Monroe and Yarnell (1977) have reported a case of a man (left-handed) who subsequently had bilateral cerebral infarcts that caused a non-fluent aphasia,
oral apraxia, and deafness and who, at the age of 27, had a mitral valve prosthesis fitted and received subsequent anticoagulation. They expressed the view that the cortical clinical syndrome of pure word deafness in many cases is probably a less severe form of cortical deafness and is due to less extensive bilateral temporal grey matter lesions. Strictly white matter lesions may produce cases of either syndrome.

Graham, Greenwood and Lecky (1980) carried out brainstem evoked responses on a 47-year-old woman (right-handed) who 3 years before had a mitral valve replacement. She was thought to have suffered three separate embolic lesions of cardiac origin, the first to the left temporal cortex producing dysphasia, 6 months after operation, (an isotope scan at that time showed a left homonymous hemianopia) and the third to the right temporal lobe, resulting in total deafness. The first and third events represent left and right middle cerebral artery embolism and the second, right posterior cerebral artery embolism. She also suffered a series of epileptic fits. A CT scan and isotope scan showed bilateral temporal infarction and a right occipital infarct. Galvanic responses were negative. No cortical electrical response activity could be obtained but stapedius (acoustic) and postauricular myogenic responses were both present. A similar diagnosis to the other cases reported has been made, that is bilateral temporal lobe infarction of embolic origin. In addition to reporting their own case, Graham, Greenwood and Lecky (1980) gave an excellent review of the earlier literature and of the four cases published since 1969 making a total of 12 in all prior to their own study.

Cortical encephalitis

Diffuse cortical encephalitis causes an auditory aphasia when both temporal lobes are involved; the patients have normal pure-tone audiograms but no understanding of speech. The diagnosis is confirmed by EEG and the condition may develop over weeks or months with periods of fluctuation and acute episodes. Morrison (1975) reported three cases, all adult females, in all of whom the sudden hearing loss occurred relatively late in the disease but all made good recoveries after treatment with steroids followed by ACTH. However, one has continued to have occasional episodes of auditory aphasia.

Recently, it would appear that a new syndrome has been described which afflicts women in the third or fourth decade of life, is characterized by a subacute encephalopathy with sensorineural hearing loss and retinal artery branch occlusions, and shows no clinical or laboratory evidence of visceral lesions. It is associated with sclerosis of the media and adventitia of small pial and cortical vessels. Monteiro et al (1985) have recorded two cases and reviewed the four reported previously. Hearing loss was present in all patients and was the first symptom in two and bilateral in all but one; tinnitus was described in three. Pure-tone audiometry showed bilateral asymmetric sensorineural hearing loss with a preferential loss in the low and middle frequencies. Speech discrimination was poor in the ear on the more involved side. Brainstem auditory evoked responses were normal in the three patients tested. They felt it unlikely, therefore, that the deafness was of eighth nerve origin but was more attributable to cochlear damage. Magnetic resonance imaging was obtained in only one patient but this showed changes compatible with a small brain infarct in the white matter, as suspected clinically. Treatment with prednisone was given to all patients, but in three, progression of symptoms led to additional therapy with cyclophosphamide; it is noteworthy that none of the three patients receiving cyclophosphamide developed new symptoms. None
of the patients had recurrence of symptoms after the disease subsided. However, treatment brought about no improvement in any of the six patients.

Alzheimer's disease

Central auditory function has been investigated by Grimes et al (1985) in 38 patients with Alzheimer's disease (36 right-handed). Significant relationships were observed between the dichotic scores and intelligence quotient, cortical atrophy in the temporal lobes, and cerebral glucose metabolism in the left temporal lobe. Specifically it was impairment in dichotic performance that was related to cerebral atrophy, not a general deficit in ability to hear. The presence of dysfunction was related to the severity of atrophy and hypometabolism in the temporal lobes. The contralateral ear effect for dichotic performance was consistent with dichotic speech recognition in patients with other temporal lobe lesions.

Idiopathic

Pathogenesis

There have been two 'rival' theories as to the causation of the idiopathic case - viral and vascular. It has been known for a long time that certain viruses, for example mumps, measles, rubella, can cause sensorineural deafness, that the finding of a preceding 'viral' infection in many cases of sudden loss, varying in incidence from 30-40% according to the author, made the association of ideas, if not facts, irresistible (for example van Dishoeck and Bierman, 1957). Conversely, the suddenness of onset made the analogy with similar events in the cardiovascular system equally attractive to the opposing school (for example Hallberg, 1956). As many of the cases occurred in patients over 40 years of age, the association looked even more tempting. Attempts have been made to reconcile these view points. The theory of membrane breaks or ruptures has also been put forward.

It is traditional in otology to try to match the clinical picture with the findings from the temporal bone laboratory, wherever possible. As in many other otological conditions, few patients die of their disease, so the interval between the event, in this case sudden deafness, and autopsy may be long, and reparative processes will have been at work. Alternatively, the end may come very rapidly from overwhelming disease, which in itself may complicate the histological picture. However, all this is familiar and expected by temporal bone experts.

Membrane breaks

In an effort to understand the causation of sudden hearing loss, Simmons in 1968, considered the history and clinical findings in patients with this problem. He noted that all but two were under 45 years of age and that many could date their sudden onset to a particular day and time and he was struck by the association of a 'popping', 'clicking' preceding the hearing loss or of the sudden development of a marked roaring tinnitus. He also asked whether the patient's physical activity at the time could have caused any increase in the intrathoracic or intracranial venous or cerebrospinal fluid pressure, or if more than a modest amount of alcohol had been drunk beforehand. He postulated that perhaps there was a disruption to the cochlear membranes which subsequently healed, in a similar manner to that in experimental animals exposed to intense sound. He reported a series of 15 patients and
commented in this, and in a later paper discussing 56 patients (Simmons, 1973), that very few noticed vestibular symptoms at the time, but on questioning transient unsteady feelings were present in one-third; a few were frankly vertiginous. He observed that untreated, there appeared to be an improvement in the hearing, sometimes quite suddenly, even after quite long intervals. He therefore advocated that nothing which would raise the pressure in the inner ear or might otherwise injure it further, for example high intensity audiometry, should occur in order to facilitate healing of the cochlear membranes.

Reports of three temporal bone studies have now been published, all by Gussen (1981, 1983), showing cochlear membrane rupture in patients with sudden hearing loss. In the first report, she demonstrated the ruptures occurring in the left temporal bones of two patients, one as a result of barotrauma associated with sudden deafness, tinnitus and some vertigo and the second in a patient with profound deafness in a previously normal hearing ear. Both occurred as ruptures of Reissner's membrane at the junction of the ductus reuniens with the caecum vestibulare portion of the cochlear duct. With healing, a balloon-like structure formed from the rupture site into the adjacent vestibule, resulting in a secondary ruptured saccule duct in one case and in collapse of the saccule in the second. Gussen stressed the left-sided preponderance of such ruptures and the vulnerability of the ductus reuniens junction with the cochlea. The third patient also showed rupture of the cochlear membrane in the left ear following episodes of vertigo, but later by sudden loss of the hearing on that side. Because of continuing unsteadiness, the patient subsequently underwent a left labyrinthectomy, but 2 months later had a sudden loss of hearing in the right only hearing ear. She was considered to have vertebrobasilar arteriosclerosis and died of a massive stroke 4 years later. Two healed ruptures were demonstrated on the right side, and one in the area of the promontory. The latter was adherent to the saccule, distorting it inferiorly. In the left temporal bone, a healed rupture was demonstrated at approximately 5 mm distal to the labyrinthectomy obliteration.

Koskas, Linthicum and House (1983) described membranous ruptures which they found only in patients with Ménière's disease and occurred more frequently in Reissner's membrane than in the vestibular membrane. Of the 12 bones from patients with Ménière's disease which they examined, two had no hydrops and were therefore excluded. Hydrops in Reissner's membrane as a result of congenital syphilis was found in two bones. They described three different types of rupture, the most common of which, found in nine bones, was in the shape of a balloon and the connective tissue had formed to seal off Reissner's membrane.

Symptomatology

'Sudden hearing loss is a symptom in search of a diagnosis' (Simmons, 1973). It will be readily apparent that many of the causes of sudden hearing loss are in themselves rare. Many of them are discussed in other chapters. The preceding section is devoted to excluding the specific causes, thereby leaving the so-called 'idiopathic' losses - still the largest single group and constituting the everyday case - for treatment according to 'site-of-loss'.

For the purist, 'sudden' hearing loss means an instantaneous event; 'rapid' hearing loss means deafness occurring over a short period of time, for example hours. If the loss subsequently improves, either spontaneously or as a result of treatment, then some would label this 'fluctuant'! It should be appreciated that cases may present in any of these ways and
the distinction between them from a diagnostic viewpoint is frequently somewhat artificial. It will become apparent that such divisions should not be interpreted too rigidly.

**Age and sex distribution**

In the 1220 cases reported by Shaia and Sheehy (1976), age at onset of the symptoms was as follows:

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 30</td>
<td>13%</td>
</tr>
<tr>
<td>30-39</td>
<td>13%</td>
</tr>
<tr>
<td>40-49</td>
<td>21%</td>
</tr>
<tr>
<td>50-59</td>
<td>22%</td>
</tr>
<tr>
<td>60-69</td>
<td>18%</td>
</tr>
<tr>
<td>70 years +</td>
<td>13%</td>
</tr>
</tbody>
</table>

Three-quarters of the patients therefore were over the age of 40, but 1.4% dated the onset of their sudden hearing loss below the age of 10. Four per cent had a sudden bilateral loss, and one-half of these were simultaneous. Only one-quarter of the 1220 patients were seen within one month of onset. As all series show that the best results are obtained in those receiving their treatment within 15 days of onset, it will be immediately appreciated how vast is the wastage of untreated cases. in all series, the sex distribution is approximately equal at all age groups.

**Precipitating factors**

Many published series state an incidence of a preceding viral infection in 30-40%.

Almost every virus has been reported or implicated as a causative factor in a proportion of these cases, but certain facts should be considered before such an aetiology is too readily accepted.

The viruses which have been suggested as causing sudden hearing loss may be divided into three groups. The first of these consists of viruses causing acute respiratory diseases such as influenza, parainfluenza and rhinoviruses. Such infections are very common. Adults suffer on average four to five respiratory infections a year, so that about one-third of any group of adults will give a history of a respiratory infection within the preceding 4 weeks. There is no confirmed evidence of a seasonal incidence as might be expected for the respiratory viruses and none following an epidemic such as might be expected after influenza. Although a high incidence might be expected in children because they sustain more infections than adults none such has been reported (Rowson, Hinchcliffe and Gamble, 1976).

The second group includes poliovirus, coxsackie virus, rubella, Epstein-Barr virus, adenovirus type 3 and herpes simplex virus. Following such infections, occasional cases of sudden hearing loss have been reported, but they are very uncommon. The third group comprises three viruses - mumps, measles and varicella zoster, all of which are known to produce sudden deafness.
Other symptoms

Many patients with sudden hearing loss can state the day, date and time that it occurred, or that they awoke with it. Others may recall severe physical effort at the time of onset. Nearly always it is a dramatic, well-remembered event. Pain or a feeling of pressure may be present in the affected ear, but so far no particular prognostic significance has been found to be attached to this. Tinnitus occurs in approximately 80% of cases usually starting with, and alarmingly as, the deafness. In approximately 25% the tinnitus may precede the deafness by minutes or hours, very occasionally by some days. Vertigo is commonest in those with a probable vascular aetiology. It carries a poorer prognosis for hearing recovery, while tinnitus apparently does not affect the outcome. Danino et al (1984) found tinnitus to be a favourable prognostic sign and felt that its presence seemed to indicate that cells were still functioning and therefore may recover. Tinnitus was present in 71% of the patients who recovered compared with 39% who did not. Conversely they agreed that vertigo is a bad prognostic factor (24% in the recovery and 54% in the non-recovery group).

In the series of Shaia and Sheehy (1976), 60% of patients had no vestibular symptoms, 22% had them initially, and 18% persistently.

Vertigo of any duration associated with the hearing loss is an indication to investigate the patient very thoroughly, and the possibility of an acoustic neuroma should never be overlooked.

There is a series of reports of patients who after developing sudden deafness, subsequently go on to develop episodic vertigo characteristic of endolymphatic hydrops. Wolfson and Leiberman (1975) recorded five such cases. The interval in their cases ranges from 6-10 years. After long observation, destruction labyrinthectomy was carried out with complete relief of the vertigo. Nadol, Weiss and Parker (1975) reported 12 cases, with vertigo developing from 1 to 68 years later! They found the long interval particularly puzzling. Few of the 12 had any coincidental vestibular symptoms at the time of onset of the sudden deafness. Again labyrinthectomy was curative. Both groups of authors question whether the cause could be Ménière's disease.

Investigation of sudden or fluctuant sensorineural hearing loss may require:

**Haematology**

- Haemoglobin, full blood count, erythrocyte sedimentation rate, prothrombin time
- Paul Bunnell screening test and titre (Epstein-Barr virus)
- (Blood for viral studies - repeat specimen will be required after 2-3 weeks to assess change in titre)
- Syphilis serology (full - including fluorescent treponemal antibody-absorption (FTA-ABS) test and *Treponema pallidum* haemagglutination (TPHA) test)
- Sickle-cell test (if appropriate and haemoglobin electrophoresis)
- Fasting serum lipids (after 12-14 hours complete fast and 45 minutes total body rest; no stasis during blood withdrawal, that is no sphygmomanometer or other occluding cuff)
- Glucose tolerance test
- Serum electrolytes including urea, calcium, phosphorus, phosphate, uric acid, etc.
Electrocardiogram

Radiology

Chest X-ray
Mastoids (plain films)
Internal auditory meatus (tomography, preferably hypocycloidal polytomography)
CT scan (air CT studies)
Magnetic resonance imaging

Audiometry

Pure-tone audiogram
Tone decay test (Carhart)
Speech audiometry
Acoustic impedance measurements including stapedius reflex thresholds and decay
Fistula test (electronystagmography + impedance) if appropriate
Electrocochleography
Brainstem electric response audiometry
Promontory stimulation (if no hearing present)

Lumbar puncture

For routine cerebrospinal fluid examination, serology, Lange curve and immunoglobulins.

It must be remembered that when a patient with sudden hearing loss presents within the early stages, that is under 15 days, everyone carrying out investigations wants to help simultaneously. At the receiving end of this investigative enthusiasm and energy, lies a patient! Many of these investigations are time-consuming (for example glucose tolerance tests) and as they yield the least urgent information they should be left until last. Those conditions encompassed by the taking of blood on a rested, fasted patient can all be accomplished in a single venepuncture the morning after admission. Lumbar puncture if considered necessary (which is seldom now the case) should be left until last, as after this the patient may have much discomfort in the back and the head. To follow this with any procedure requiring mobility, mental attention and cooperation or the maintenance of a prolonged position is cruel.

Audiometry

A patient with sudden hearing loss needs first the simplest tests, of pure-tone thresholds, acoustic impedance measurements (except in cases of suspected oval or round window rupture or perilymph fistula); stapedius (acoustic) reflex thresholds and tone decay (Carhart). Tests of longer duration can be more conveniently carried out later on. It should be remembered that tones above 85 dB can cause temporary threshold shift even in a normal ear. In an already damaged cochlea, the possibility of further damage by test tones at high intensities is very real (Simmons, 1973).
From the simple pure-tone test, two most interesting prognostic factors have been reported (Mattox and Simmons, 1977). First, the less obvious, is the significance of the test frequency of 8 kHz, and the second is the shape of the audiogram. In their series they noted that all but one patient with an upward-sloping auiogram had complete or good recovery. Conversely all but two patients with a severe downward slope had a fair or poor recovery. Flat and less severe down-sloping patterns fell between the two extremes. Expressed in another way, if the threshold loss, going from the apex to the base of the cochlea was either improving or stable at 8 kHz, the prognosis for a good or complete recovery was 78%. If there was no hearing at 8 kHz, regardless of the hearing at other frequencies, the same prognosis was only 29%. Recovery was always better at the apex of the cochlea, than at the base. This seemed independent of the contour of the severity of the loss on the initial threshold audiogram. It should be remembered that these findings were noted on untreated patients.

In the series reported by Shaia and Sheehy (1976), 12% showed a low-tone loss, 32% a flat loss and 31% a high-tone loss. However, 25% showed a profound or total loss. It is this last group which deserves special mention and again they may be subdivided - first into those with a severe loss and second those with a total loss.

In the same series, of the 10 patients who were found to have acoustic tumours, five had a total loss. Those with severe losses may show some hearing at both low and high frequencies but none in the mid-range.

Audiometry in sudden hearing loss serves two purposes - first, to assess the day-to-day level of the loss by the level of the pure-tone threshold, and second to determine the site of the lesion. The site is of particular importance in determining the treatment. Many of the patients showing a retrocochlear pattern have the contour shown and frequently they will be in the younger age group, that is below 40.

In the group with a total loss, the primary audiometric tests will be of no avail in helping the worried clinician or patient, but electrocochleography has a useful part to play. Graham et al (1978), used transtympanic electrocochleography to test 70 patients with sudden hearing loss. Of particular interest are the 24% where threshold audiometry was impossible. Of these 17 patients, a result was obtained indicating a retrocochlear pattern in seven. In the remaining 10 patients, neither a cochlear microphonic nor an action potential was found, suggesting a cochlear loss, with or without retrocochlear involvement. In two of these patients, the promontory electrode was used to provide direct stimulation to the cochlea and this evoked a subjective sensation of sound, suggesting that the cochlear nerve was intact to some extent (House and Brackmann, 1974; Graham and Hazell, 1977).

Tonndorf (1980) believed that the combination of hearing loss, recruitment, poor speech discrimination and tinnitus, which is characteristic of acute cochlear disorders can be accounted for on the basis of decoupling of hair cells from their drive system, the tectorial membrane; the magnitude of the hearing loss depends on the degree and number of hair cells involved.
Vestibular tests

These have a particular place in those patients with sudden hearing loss which has been accompanied by vertigo, but in most instances such tests can be deferred until all the necessary audiometric tests have been completed, and the patient's morale is beginning to improve. They are never urgent.

Electronystagmography is often helpful; it is of special benefit in diagnosing vertebrobasilar insufficiency or other possible vascular causes of positional nystagmus.

It may be combined with impedance testing to demonstrate a possible perilymph fistula (see Chapter 14 on otosclerosis).

Management

Three unfavourable prognostic factors are known - the shape of the audiogram, especially the degree of involvement at 8 kHz, the severity of the hearing loss, and the presence of vertigo. It is also known that in the idiopathic case, there will be spontaneous improvement within 15 days in 50-60% of cases. However, failure to investigate patients will inevitably lead to a missed diagnosis and a missed opportunity for treatment.

Patients with a cochlear (sensory) loss should have a daily pure-tone threshold audiogram under identical test conditions and ideally speech audiometry and discrimination scores should also be carried out on a daily basis. Those who fail to show spontaneous improvement under observation by the tenth or twelfth day should be offered treatment. On occasions, the pattern of hearing loss has been shown to change from neural to sensory as 'improvement' occurs (Stephens, Swisher and Novotny, 1967).

Increasing cochlear blood flow

Vasodilators

There is little or no evidence that these are of proven value. The difference between the autoregulatory mechanisms in the circulation of the brain and of the inner ear have often been ignored; the cerebral circulation is practically unaffected by variations in the systemic blood pressure. Experimental work in animals (the cat) has shown that vasoconstrictor drugs such as angiotensin produce, with some delay, a moderate increase in perilymphatic PO$_2$. Drugs inducing vasodilatation, such as histamine, are followed by the opposite effect. The changes observed in the perilymphatic PO$_2$ after injection of vasoactive drugs indicate that there is a direct correlation between the systemic blood pressure and inner ear oxygenation. The evidence therefore implies that vasodilator drugs should be abandoned (Yagi, Fisch and Murata, 1978).

Glycerol has been found to increase the cochlear and cerebral blood flow significantly after intravenous administration experimentally in the rabbit (Larsen, Angelborg and Hultcrantz, 1982).
**Low molecular weight dextran (Rheomacrodex)**

Among the aetiological factors proposed in sudden hearing loss is hypercoagulability of the blood. Low molecular weight dextran by intravenous infusion has therefore been recommended. This preparation with a molecular weight of 40,000 is available as a 10% solution, either in 5% dextrose or in normal saline. It is contraindicated in patients with cardiac failure and bleeding disorders and has on rare occasions proven fatal (Zaytoun, Schuknecht and Farmer, 1983). Dextran forte increases capillary blood flow in general by hypervolaemic haemodilution and by decreasing factor VIII; this decreased blood viscosity results in increased cardiac output and tissue blood flow. Dextran forte has a half-life of 5 hours in the circulation. Experiments in guinea-pigs, by Hultcrantz et al (1985), showed an increase in the cochlear blood flow of 75%, but this soon reached a steady state and fell as soon as the infusion was ended. The compound action potentials were initially improved during the haemodilution. In practice, in human patients with sudden hearing loss, it has so far proved disappointing.

**Stellate ganglion block**

This induces an increase in blood flow by ceasing the action of the cervical sympathetic nervous system. The vasodilatation produces an immediate response but has not been found to be of benefit after 2 weeks of the onset of sudden deafness. Of the several methods of estimating cochlear blood flow in animals, only one appears to have any practical application in man. The ultrasonic Doppler method has been used to demonstrate the vertebral artery blood flow but this gives no direct indication of the perfusion of the inner ear. Using this method, the vertebral blood flow in 10 patients with sudden deafness was estimated before and after stellate ganglion block (Sano et al, 1985). Using the blood flow index it was found that the flow in the vertebral artery on the 'blocked' side was greatly increased but with little change on the 'unblocked' side.

**Inhalation of 5% carbon dioxide: 95% oxygen (carbogen)**

Using the polarographic technique, Nagahara, Fisch and Yagi (1983) and Fisch (1983), measured the oxygen tension in human perilymph. Following the inhalation of carbogen (5% CO₂ : 95% O₂) they demonstrated two different patterns of disturbed perilymphatic oxygenation; in sudden deafness and sudden cochleovestibular loss of inner ear function, there were low initial values but a normal response to inhalation, while patients with a slowly progressive sensorineural hearing loss showed normal initial values but a low response to carbogen. In a group of seven patients who presented with sudden deafness with or without vertigo but normal caloric responses, there was an initial value of perilymphatic oxygenation of 8.6 mmHg which rose after 13 minutes to an average of 14.8 mmHg (an increase of 175%). No significant correlation could be found between the hearing loss, or the initial value and maximal response to carbogen inhalation. Likewise there was no significant correlation between the initial value of oxygenation and the time interval between the onset of deafness and the measurement, that is the duration of the disease. In four patients with some cochleovestibular loss, the carbogen response started after 45 seconds and reached a maximum of 20.7 mmHg (an increase of 215%) 15 minutes after the onset of inhalation. The mean initial values of perilymphatic oxygenation were below the normal range obtained in cats, and in otosclerotic patients. In patients with sudden cochleovestibular loss, a significant correlation
was found between the initial value of perilymphatic oxygenation and the duration of the disease.

Fisch, Nagahara and Pollak (1984) have emphasized that the arterial PCO₂ has a stronger effect on the oxygenation of the perilymph than the arterial PO₂. Similarly hypoventilation induces an increase of the perilymphatic oxygen, while hyperventilation is followed by the opposite effect. Hypoventilation causes the arterial PO₂ to drop, while the PaCO₂ increases. The combination of 5% CO₂ and 95% O₂ gives a fourfold increase in perilymphatic oxygen compared with pure oxygen alone or the inhalation of CO₂ in air. The recommended regimen, therefore, is the inhalation by mask of 95% O₂ and 5% CO₂ for 30 minutes eight times per day at intervals of one hour. Baghat and Shenoi (1982), using this regimen in four patients who were carefully monitored, achieved a good hearing improvement in three who received the treatment within a fortnight of the onset of deafness, but in the remaining patient, after an interval of 4 months, there was no change. It was originally Shea and Kitabchi (1971, 1973) who advocated inhalations of 5% CO₂ and 95% O₂ for 30 minutes four times a day, but this earlier work seems to have been largely overlooked.

**Hyperbaric oxygen**

Pilgramm, Lenders and Schumann (1985) reported the use of this treatment for one hour at 250 kPa (2.5 bar) in 37 patients with sudden deafness of acute onset and a further 51 non-acute cases. In a controlled trial, they concluded that patients with sudden deafness of acute onset fared better in terms of hearing gain and tinnitus reduction and that hyperbaric oxygen therapy was therefore an effective adjunct where it was available.

**Anticoagulants**

There no longer seems any indication to give these unless indicated by the haematological investigations or other disease within the cardiovascular system. Heparin may be chosen in the initial stages and has an effect in reducing the serum lipid level and by stimulating lipoprotein lipase formation; it also binds with histamine.

**Steroid therapy**

Treatment of a vascular cause by trying to improve the local circulation within the cochlea appears entirely reasonable, as has been outlined above. In all other branches of otology great stress is placed upon the tests designed to diagnose the site of the lesion. In our present state of knowledge therefore it appears illogical, having carried out such tests, to jettison the results in favour of a single treatment modality particularly when it involves the use of a group of potent drugs - steroids. It has been the experience of Morrison and Booth (1970), and remains so, that steroids are the treatment of choice when the loss is retrocochlear, and are the only effective treatment in the severe case of this type. It should be remembered that some two-thirds of cases with idiopathic sudden hearing loss may be expected to recover completely, or partially, particularly if the loss is moderate. Wilson, Byl and Laird (1980) carried out a double-blind clinical trial on the efficacy of steroids and concluded that they had a statistically significant effect on the recovery of hearing in patients with moderate hearing losses. However, in so doing, they assumed that a substantial proportion were of viral origin, but made no attempt to correlate this with the probable site
of the lesion. It cannot be emphasized enough that such tests are required and may well need to be repeated as more hearing is recovered, thereby allowing more detailed testing (Kumar, Maudelonde and Mafee, 1986).

All forms of steroids have been used and selection should probably depend on personal experience. Patients receiving these drugs should be examined at regular intervals for side-effects including checks on blood pressure, serum electrolytes and if appropriate, electrocardiography. For clinicians without an established or familiar scheme, prednisone may be recommended, 60 mg on the first day in divided doses (every 6 hours), 50 mg on the second day, 40 mg daily for 3 days, 30 mg daily for 3 days and then the regimen may be tailed off, so that the patient ends medication after approximately 3 weeks.

**Bed rest**

If there is the possibility of a membrane rupture, rest in bed may be indicated. Certainly, strenuous exertion should be avoided.
Chapter 18: Vertigo

A. G. Kerr

Vestibular disorders have been considered in depth in Volume 2. However, every day the otolaryngologist is actively involved in the management of patients with vestibular problems and this volume would be incomplete without a chapter on vertigo. This chapter differs from those in Volume 2 in that it takes a more practical, day-to-day look at the problem omitting much of the detail.

Vertigo tends to be a subject which depresses both patient and doctor. Generally, the patient has difficulty in describing his symptoms and, in the time he has available, the doctor may have difficulty in grasping the picture which the patient is trying to convey.

The patient often feels foolish and thinks that the doctor may be secretly smiling at his naivety in producing these bizarre complaints. On the other hand, the doctor, in approaching this difficult symptom complex, may have a haphazard system, or none at all, and try to make a diagnosis with inadequate information.

Unfortunately, when the conscientious doctor turns to the standard textbooks he may find that he does not get much help. This is not because the information is not available. There are many excellent and comprehensive books on this subject. The problem is that, with few exceptions, the textbooks tend to start with the diagnosis and then give the clinical features. For example, having made a diagnosis of dizziness secondary to vestibulotoxic drugs, there is little difficulty in finding a description of this condition and its management. However, if one starts with the symptoms, but not the diagnosis, it may be necessary to read through most of the textbook to find the appropriate section.

There is only one straightforward way of overcoming this difficulty. That is to start with the detailed symptoms and work backwards, through the differential diagnosis to the identification of the underlying problem.

Despite the bizarre histories which one frequently obtains from patients complaining of vertigo, there are certain characteristic patterns. Many of these are consistent with a specific underlying pathology and, obviously, this pathology should be considered in the management of the patient.

**Definition of vertigo**

The definitions of vertigo which have been given are often as bizarre as the histories given by the patient. Although the Latin root of the word implies a sensation of turning, in general clinical usage of this term a sensation of spinning or turning need not necessarily be implied. Probably the most effective definition is 'a subjective sense of imbalance'. If this contains a sensation of spinning then one can add the adjective 'rotatory' when describing the symptom.
Types of vertigo

The diagnosis of vertigo is usually made on the basis of the history. Subsequent examination and investigations are normally used to confirm the diagnosis and it is likely that, in 80% of cases, if one does not have an idea of the diagnosis at the end of the history, one is unlikely to have it at the end of the examination and investigations.

Basically, vertigo can be described in one of two ways; either it is rotatory or it is not. If it is rotatory, patients usually have little difficulty in saying so. Where there is no obvious sense of rotation patients have more difficulty in giving a good description. They use various terms but, in essence, the complaint is that they are unsteady. Many will have associated symptoms such as deafness, tinnitus, vomiting or nausea.

Generally speaking, each of the two groups (rotatory or unsteady) can be further subdivided into those where the symptom is episodic and those where it is more or less continuous. When it is episodic it may be very short-lived, that is less than a minute, or very much longer, such as hours or days. Consequently, the vast majority of patients with vertigo can be classified as in Table 18.1. It would be naive to expect every patient to fit neatly into any classification but, remarkably, most do. Broadly speaking, each group has a basic underlying pathological correlate which is discussed later in the chapter.

Table 18.1. Classification of vertigo

Rotation

(1) Episodic
   (a) seconds
   (b) hours
(2) Prolonged
   weeks

Unsteadiness

(1) Episodic
   (a) seconds
   (b) hours to days
(2) Prolonged
   weeks to months

A certain degree of licence has been taken in that 15 minutes are equivalent to hours.

History

Certain precautions must be observed when taking a history. The first is to ensure that the story given by the patient starts at the onset of the complaint. There is a tendency in any condition which has been going on for some years, for the patient to start the history somewhere other than at the beginning. It is important to establish when the patient was last perfectly steady.
The doctor must control the history-taking. It is through this that he develops a picture of the condition. If he does not have a systematic way of covering all aspects, he will get an incomplete picture. If left to their own devices, patients rarely give the complete story because they will emphasize the aspects which have impressed them most. For example, the periods of freedom from vertigo are as important as those with vertigo, but most patients do not talk about these without prompting.

When seeking a description of the symptoms the patients may need some guidance. One must be careful about leading questions but many find it impossible to describe symptoms without help. It is necessary to know the speed of both onset and resolution.

Throughout the history one must ensure that both the patient and the doctor are on the same wavelength. For example, many patients will say that they are dizzy 'all the time' when they mean 'frequently', but some are, in truth, dizzy 'all the time'. One can ensure that one has an accurate history by asking the same question in two different ways and confirming that consistent answers come back. If not, one must identify where the misunderstanding has arisen and resolve it.

Finally, the patient may well try to interpret the symptoms himself and the doctor must check that both he and the patient are using the same interpretation.

By and large, the history is best taken chronologically with specific details being sought of the first and of a typical recent attack.

Details must be sought of associated symptoms such as deafness, tinnitus, nausea, vomiting, diplopia, blurring of vision, anaesthesia of the face, headaches and loss of consciousness.

**Examination**

In an ideal world, every patient complaining of vertigo would have a detailed neurological examination. Clearly, this is not possible in the average busy otolaryngological outpatient department. Even in vertigo clinics, which are desirable in all sizeable units, this is difficult. However, it is usually possible, within a few minutes, to determine those patients who require a detailed neurological examination.

Following a routine ear, nose and throat examination it is usually possible to make a rapid assessment of cranial nerves III to XII, of cerebellar function and the ability to perform balance tests. It is extremely unusual that the need for a detailed neurological assessment will be overlooked if these are all normal and the history does not point to a central lesion. Although olfactory and ophthalmic symptoms may occur in association with vestibular problems, routine examination of these systems is not required unless some aspect of the history points to them. However, every patient with vertigo should be examined for nystagmus (see below, section on nystagmus). During this examination cranial nerves III, IV and VI will automatically be checked. If there is direction changing or vertical nystagmus, a neurological lesion is usually present and a detailed neurological examination is required. Usually a test of the corneal reflex is sufficient for the assessment of the fifth cranial nerve. Weakness of the seventh cranial nerve will often become apparent simply by looking at the patient while
taking a history. A slower blink on the affected side is usually obvious. Very minor weakness of the facial nerve can be detected by the inability of the patient to bury the eyelashes in tight closing of the eyes.

The auditory part of the eighth cranial nerve will be tested during the routine examination and subsequent audiogram. The ninth and tenth cranial nerves can be rapidly checked by the gag reflex, the eleventh by shrugging the shoulders and, theoretically, the twelfth by having the patient protrude the tongue. Twelfth cranial nerve involvement is uncommon in vertiginous problems which is fortunate as early lesions of this cranial nerve are difficult to detect.

The assessment of balance should have begun when the patient walked into the room. If he walked in steadily there will be no further need to check his walking. A positive Romberg test usually means considerable impairment of function. An extended or tandem Romberg test is more refined. In this the patient is asked to stand in a heel to toe position, first with the eyes open and then closed. One-leg standing, with eyes open or closed, is a further clarification of balance.

Nystagmus

Nystagmus is a disturbance of ocular posture, characterized by a more or less rhythmical oscillation of the eyes. The speed of the eye movements may be the same in both directions or one may be quicker than the other. There is little or no interval between consecutive movements which may be horizontal, vertical or rotatory.

The posture of the eyes, and consequently nystagmus, depends on two sets of afferent impulses, visual and vestibular. The visual impulses are concerned with regulation of the position of the eyes in relation to the object of visual interest. It is by means of the vestibular impulses that the position of the eyes is regulated in relation to the position and movements of the head and the remainder of the body. Eye posture is coordinated by a central mechanism that receives these afferent impulses and controls the efferent impulses to the ocular muscles. Nystagmus may result from any lesion involving these afferent pathways, their central connections or, less frequently, the efferent pathways.

There are two broad categories of nystagmus depending upon the appearance of the movements. Pendular nystagmus is characterized by ocular oscillations that are approximately equal in velocity in both directions. These are almost always horizontal. There may be a jerk component on extreme lateral gaze. Phasic, or jerk, nystagmus is characterized by rhythmic oscillations in which the movement in one direction is significantly faster than in the other direction. Although the slow movement is pathological, the fast, or corrective, movement is used to denote the direction of the nystagmus.

The position in which the nystagmus is least marked is called the null point.

Examination for nystagmus

Nystagmus found at examination may be either spontaneous or induced. Spontaneous nystagmus is said to be present when there are rhythmical eye movements on forward gaze.
Induced nystagmus is said to be present when rhythmical movements are brought about by some specific test. There is an intermediate nystagmus, or gaze nystagmus, which is demonstrated by altering the gaze to the right or left, or up or down. For the purposes of this discussion intermediate or gaze nystagmus will be considered under the heading of spontaneous nystagmus.

When examining the nystagmus it is essential that the patient is in good light. The object at which the patient is asked to look must be within a comfortable range. Ideally, it should be at infinity but a few feet away will suffice, so that excessive accommodation is not required. Care must be taken that, on looking laterally, the nose does not impinge on the field of vision and on looking upwards, that the object remains comfortably in view. Otherwise, searching or nystagmoid movements may be mistakenly interpreted as nystagmus.

Causes of spontaneous nystagmus

Labyrinthine

Labyrinthine nystagmus, which is phasic, has four main characteristics. First, it is usually associated with a sensation of vertigo. Second, the nystagmus is always unidirectional. Third, it is more marked when looking in the direction of the fast phase. Fourth, it is enhanced by removal of fixation by eye closure, Frenzel's glasses or darkness. Following a labyrinthine destructive lesion, the nystagmus decreases with time and clinically has usually disappeared entirely within 4 weeks. However, even then it may still be detected by removal of visual fixation.

Mechanism of vestibular nystagmus

In the normal subject, the tone of the extraocular muscles is to some extent controlled by the vestibular nuclei. The vestibular nuclei drive the eyes to the opposite side. Hence, the vestibular nuclei on the right side influence the left lateral and the right medial recti muscles, moving the eyes to the left side. Normal ocular posture is maintained by a correct balance between the vestibular nuclei on the two sides.

If there is an abnormality of function of the vestibular nuclei on one side there will be a change in the tone in the corresponding muscles. Consequently, stimulation of the vestibular nuclei on one side will result in movement of the eyes to the opposite side. Unilateral inhibition of the vestibular nuclei will result in movement of the eyes towards that side. The effect is to remove the eyes from the point of visual interest. Consequently, there is a correcting movement to restore the eyes to the original position. Repeated deviation of the eyes, and repeated correction, produce nystagmus.

A paralytic lesion involving the right labyrinth, and hence the right vestibular nuclei, will result in slow deviation of the eyes to the right side with the quick correcting movement being to the left side resulting in so-called left beating nystagmus.

In describing unidirectional phasic nystagmus one should state, not only the direction, but also the degree. First degree nystagmus is said to be present when phasic eye movements are detected when looking in the direction of the quick phase. Second degree nystagmus is
present when the phasic movements are seen on looking straight ahead, and third degree when looking in the direction away from the nystagmus.

The logical nature of this is easy to understand when one considers a specific example. A major lesion resulting in reduced function in the right vestibular nuclei will cause grossly reduced tone in the left lateral and right medial recti muscles. Consequently, the opposing recti muscles moving the eyes to the right, will, in comparison, be so hyperactive that there is further drift of the eyes to the right, even when already looking to the right side. As the disproportion between the two groups of vestibular nuclei diminishes as a result of central nervous system compensation, the nystagmus will slowly reduce to second degree, then first degree, and finally nystagmus only when fixation is removed.

Alexander's law states that, in general, if vestibular nystagmus is present it can be enhanced by moving the eyes in the direction of the fast phase and diminished by moving the eyes in the direction away from the fast phase.

Central nervous system lesions

Nystagmus due to central nervous system lesions presents in a multitude of different forms, some of which are not clearly understood. However, most neurological lesions causing nystagmus produce a bidirectional (direction changing) form. Labyrinthine lesions never do this. Similarly, it has been said that labyrinthine lesions never produce a vertical nystagmus which is therefore always indicative of a central lesion. This is not quite true as excitation of the posterior canal crista, as in cupulolithiasis (benign paroxysmal positional vertigo) may cause an upbeat nystagmus and transection of the posterior ampullary nerve may cause a downbeat nystagmus (Gacek, 1985).

Unidirectional nystagmus which is diminished by removal of fixation or which does not vary in amplitude or velocity in different directions of gaze, is almost certainly of central origin.

Textbooks of neurology and ophthalmology describe rare and bizarre forms of nystagmus, for example, monocular, involving only one eye or see-saw, where one eye moves up and the other down. In these and in other central types of nystagmus, most otolaryngologists will wish to seek the opinion of a neurologist!

Toxic

Many drugs including alcohol, barbiturates, tranquilizers and anticonvulsants, are potential causes of nystagmus. It is likely that, in most instances, the effects of the drug are on the central nervous system. Indeed, it has been suggested that drugs are the most common cause of vertical nystagmus. However, the positional nystagmus which is associated with alcohol, may well be peripheral in its action. Positional alcoholic nystagmus has two phases, in opposite directions. The first phase occurs shortly after the ingestion of alcohol and passes off after a few hours. The second phase occurs about 8 hours later. It has been suggested that the nystagmus is due to partial replacement by alcohol of water-containing components of the semicircular canal ampullae, followed by later metabolism, each phase resulting in abnormal but opposite impulses.
Ocular

Any lesion affecting the macula, especially where peripheral vision is still maintained, may result in nystagmus which is usually pendular. This may occur in amblyopia. In the past, miners' nystagmus also fell into this category although it has been suggested that neurosis played a part in maintaining the disorder.

Central nervous system lesions affecting the ocular pathways may also result in ocular nystagmus.

Congenital

Congenital nystagmus, which is often familial, is usually horizontal and pendular although it may be phasic (jerk). The null point is close to the position of forward gaze. Unlike that in any other condition, horizontal nystagmus continues even when the eyes are turned upwards. Closure of the eyes results in a marked reduction in the nystagmus but the effects of darkness, with eyes open, are variable and in some instances the nystagmus increases.

In the everyday life of the otolaryngologist, the diagnosis is usually verified by the patient confirming that the nystagmus has been present since as long as he can remember.

Causes of induced nystagmus

Nystagmus may be induced by clinical testing or by certain investigations. The most common clinical test inducing nystagmus is the positional test. This is useful in diagnosing positional vertigo and differentiating between the common benign paroxysmal positional type and the uncommon positional vertigo of central origin (Table 18.2).

In the fistula test, nystagmus is induced by altering the pressure in the external auditory meatus, producing both nystagmus and a sensation of dizziness. The Tullio phenomenon is a variation of this cause of nystagmus and is induced by acoustic stimuli of high intensity.

Inducted nystagmus in clinical investigations is produced by the optokinetic drum, pendulum tracking and caloric and rotational tests.

Investigations

The only investigation that is required routinely is an audiogram. By and large, if an air conduction audiogram is normal, no further audiometric tests need be done. However, it is the author's routine to do an air and bone conduction audiogram and in addition, a simple speech discrimination assessment (PBmax). There is a danger of over-investigation of patients with vertigo in an attempt to replace ignorance by biochemical screening.

Electronystagmography and caloric testing are not routine. Indeed, there are many who claim that the caloric test is of no practical value. The author disagrees with this conclusion.
but does not feel that it needs to be carried out in the majority of vertiginous patients and especially in the elderly.

Radiological investigations and blood examinations are not required routinely. However, in the light of the clinical features, it may be desirable to exclude an acoustic neuroma or syphilis.

**Table 18.2. Comparison of the positional nystagmus of benign paroxysmal positional vertigo (BPPV) with that of certain lesions of the central nervous system (CNS)**

<table>
<thead>
<tr>
<th></th>
<th>BPPV</th>
<th>CNS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Latent period</strong></td>
<td>A few seconds</td>
<td>Nil</td>
</tr>
<tr>
<td><strong>Distress</strong></td>
<td>Present: may be severe with patient clutching at couch or examiner</td>
<td>Nil</td>
</tr>
<tr>
<td><strong>Direction of nystagmus</strong></td>
<td>This is usually rotatory and is anticlockwise with the right ear down and clockwise with the left ear down. (When the nystagmus is horizontal it is towards the undermost ear.)</td>
<td>Variable</td>
</tr>
<tr>
<td><strong>Duration of nystagmus</strong></td>
<td>Less than 30 seconds</td>
<td>Persists while position maintained</td>
</tr>
<tr>
<td><strong>On sitting up again</strong></td>
<td>Similar events with nystagmus in opposite direction</td>
<td>Nystagmus stops</td>
</tr>
<tr>
<td><strong>Fatiguability</strong></td>
<td>Nystagmus and dizziness stop with repeated testing</td>
<td>Nystagmus persists with repeated testing.</td>
</tr>
</tbody>
</table>

**Pathological correlates**

*Table 18.3* shows the suggested pathologic correlates for the different types of vertigo.

**Table 17.3. Suggested pathological correlates for the different types of vertigo**

*Rotation*

1. Episodic
   a. seconds: short-lived stimulation or depression of the labyrinth
   b. hours; physiological failure of the labyrinth or central connections
2. Prolonged
   weeks: destructive lesion of the labyrinth or central connections

*Unsteadiness*

1. Episodic
   a. seconds: physiological overload of the vestibular system
   b. hours to days: temporary impairment of the central connections or decompensation of the vestibular system
2. Prolonged
   weeks to months: vestibular inadequacy.
Rotatory

(1a) Episodic rotatory vertigo, lasting for only seconds, would be expected from short-lived depression or stimulation of one of the labyrinths or its central connections. The main causes of such vertigo are benign paroxysmal positional vertigo, labyrinthine fistula, the caloric effect and alternobaric vertigo (Table 18.4). Also included in this group, although not in such pure form, are the post-concussional syndrome, vertebrobasilar insufficiency and cervical vertigo.

Table 18.4. Short-lived episodic rotatory vertigo

- Benign paroxysmal positional vertigo
- Labyrinthine fistula
- Caloric effect
- Alternobaric vertigo
- Post-concussional syndrome
- Vertebrobasilar insufficiency
- Cervical vertigo.

These short-lived episodic types of vertigo can recur frequently, many times each day, depending on the frequency of the stimulus.

(1b) The episodic types of vertigo lasting from a few minutes to less than 24 hours, are due to a physiological or metabolic failure of the labyrinth (Table 18.5). They include Ménière’s disease, syphilitic labyrinthitis and other endolymphatic hydrops of immediate or delayed type. Also included in this group are decompensation of a previously compensated lesion and the dizziness which may occur in the first 24 hours after middle ear surgery.

Table 18.5. Physiological failure

- Ménière’s disease
- Syphilitic labyrinthitis
- Delayed endolymphatic hydrops
- Decompensation of previous vestibular lesion
- Following middle ear surgery.

Physiological failure and recovery can recur frequently but not as often as the short-lived attacks.

(2) Prolonged rotatory vertigo, lasting for more than 24 hours and usually for less than 3-4 weeks, can be expected when there is some destruction of the labyrinth or the central connections (Table 18.6). This is a large disparate group where the clinical picture is of severe incapacitating rotatory vertigo associated with nausea and vomiting.

Vestibular neuronitis, bacterial or viral labyrinthitis and vascular lesions of the inner ear fall into this group. Traumatic lesions, either accidental as in head injury or inexpert ear surgery, or planned as in labyrinthectomy or vestibular neurectomy, are also included in this
group. A rare but definite clinical entity is secondary metastatic deposits in the cerebellopontine angle, from primaries in the breast, kidney, lung and prostate gland.

**Table 18.6. Destructive lesions**

<table>
<thead>
<tr>
<th>Vestibular neuronitis</th>
<th>Trauma</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>head injury</td>
</tr>
<tr>
<td></td>
<td>ear surgery</td>
</tr>
<tr>
<td></td>
<td>labyrinthectomy</td>
</tr>
<tr>
<td></td>
<td>vestibular neurectomy</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Labyrinthitis</th>
<th>Viral</th>
</tr>
</thead>
<tbody>
<tr>
<td>bacterial</td>
<td>viral</td>
</tr>
</tbody>
</table>

| Vascular lesions       | Metastatic deposits in cerebellopontine angle. |

In many cases of naturally occurring destructive lesions the damage is incomplete and the vertigo may recur. A destructive lesion cannot recur if it is complete. The central neurological compensation which follows such lesions may, however, break down in the future as a result of stress or some intercurrent illness.

**Unsteadiness**

In those patients with unsteadiness, the picture is usually not quite so clear-cut. However, it still bears some attempt at pathological classification.

(1a) The unsteadiness that lasts for only seconds can be due to a physiological overload of the vestibular or central processing systems (**Table 18.7**). The central processor deals with impulses not only from the labyrinth, but also from the visual and proprioceptive systems. If the central processing system is overloaded, imbalance will be experienced. This may occur for any one of three reasons. First, there may be excessive input, as can happen in a normal person with very rapid movements. Second, it may occur as a result of abnormal input, especially from the visual apparatus. Third, it may result from minor inadequacies in the visual, proprioceptive or labyrinthise systems, when the central processor cannot keep pace with all the signals that are arriving, so that short-lived unsteadiness occurs.

**Table 18.7. Physiological overload of central processor**

<table>
<thead>
<tr>
<th>Rapid movement</th>
<th>Abnormal input - especially visual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor inadequacies</td>
<td>visual</td>
</tr>
<tr>
<td></td>
<td>vestibular</td>
</tr>
<tr>
<td></td>
<td>proprioceptive.</td>
</tr>
</tbody>
</table>

In young people, this is seen in the later stages of recovery from the post-concussional syndrome or benign paroxysmal positional vertigo. It may also be seen in those who have
compensated for a destructive labyrinthine lesion. It is probably seen most often in the elderly, in such activities as rising quickly to the feet or turning rapidly. The dizziness is usually only momentary.

By its nature, this short-lived unsteadiness can occur many times each day.

(1b) The unsteadiness which lasts from hours to days may be due to temporary impairment of the central vestibular connections or decompensation of the vestibular system (Table 18.8). Drugs are a common cause of the temporary impairment. They may be self-inflicted as in drug overdose or alcohol. They may be iatrogenic where drugs such as tranquilizers or anticonvulsants are used, which, even in normal therapeutic dosage, can cause unsteadiness. Travel sickness also produces unsteadiness and is included in this category.

**Table 18.8. Unsteadiness for hours to days**

<table>
<thead>
<tr>
<th>Drugs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>self-inflicted</td>
<td></td>
</tr>
<tr>
<td>iatrogenic</td>
<td></td>
</tr>
<tr>
<td>Travel sickness</td>
<td></td>
</tr>
<tr>
<td>Perilymph fistula</td>
<td></td>
</tr>
<tr>
<td>Active chronic suppurative otitis media</td>
<td></td>
</tr>
<tr>
<td>Decompensation of pre-existing lesion</td>
<td></td>
</tr>
<tr>
<td>Hyperventilation</td>
<td></td>
</tr>
<tr>
<td>Functional</td>
<td></td>
</tr>
</tbody>
</table>

It is difficult to categorize the dizziness due to perilymph fistula, but it can reasonably be inserted here, even though the unsteadiness may persist for weeks or months. Similarly, the unsteadiness sometimes seen in active chronic suppurative otitis media, which resolves with control of the infection, can also be included here. When it is prolonged it falls into the next category.

The unsteadiness due to stress, both in normal subjects and in those where decompensation of a pre-existing lesion occurs, can also be included. This may be precipitated by hyperventilation.

(2) Prolonged unsteadiness, lasting for weeks or months, is usually due to vestibular inadequacy (Table 18.9). This is most often seen in the elderly. It may also be seen in the group who continue to take the offending drugs, usually unaware that they are the cause of any unsteadiness. Vestibulotoxic drugs such as gentamicin or streptomycin, which cause permanent damage to the labyrinth, also produce this problem.

There are many central nervous system lesions producing chronic vestibular inadequacy but, usually, these are accompanied by other neurological symptoms or signs which indicate the nature of the problem and point to the site of the lesion. Large unilateral or smaller bilateral acoustic neuromata fall into this group.

There is a large group of patients whose dizziness is thought to be psychogenic and who have in the past been categorized as 'floating females'. These patients need not
necessarily be female! On examination and caloric testing they are normal so that they are not, technically, suffering from any identifiable vestibular inadequacy. However, the unsteadiness may persist for months. Remarkably, this rarely interferes with everyday activities.

**Table 18.9. Vestibular inadequacy**

The elderly  
Drugs  
- metabolic effect, eg, anticonvulsants  
- destructive effect, eg, gentamicin  
Central nervous system lesions  
'Floating females'  
Toxic products from chronic middle ear infections.

**Head trauma**

Head trauma causes such a diversity of vertigo that it is an aetiological factor in many of the tables. The six different causes of vertigo following head trauma are listed in Table 18.10.

**Table 18.10. Vertigo following head injury**

Post-concussional syndrome  
Benign paroxysmal positional vertigo  
Destructive labyrinthine lesion  
Perilymph fistula  
Delayed endolymphatic hydrops  
Functional.

**The principles of treatment**

In the management of vertigo there are certain basic principles which can be applied to most conditions. Once enumerated they appear to be basic common sense, but then that applies to much of medicine.

*Treat or eliminate the cause*

Treating or eliminating the cause is a perfectly obvious way of dealing with any problem. John Masefield knew as well as anyone that those who do not go out on the sea do not suffer from seasickness, and those who stay at home and do not go down to the sea, do not suffer from car sickness!

Unfortunately, many of the causes of vertigo are either untreatable with our present knowledge or irreversible by the time the patient presents and consequently this mode of management is not always applicable.
** Suppress the vestibular system **

In labyrinthine vertigo, the sensation of dizziness is due to a disproportion between the activity in the two sets of vestibular nuclei. In an acute labyrinthine destructive lesion, the equal and opposite activity in the vestibular nuclei is lost. In an effort to correct this, the cerebellum imposes an attempt at a shut down of electrical activity in the vestibular nuclei, the so-called 'cerebellar clamp'. This reduces the disproportion between the two sides. This can be augmented by the use of labyrinthine sedative drugs including cinnarizine, cyclizine, dimenhydrinate and prochlorperazine. These drugs are of particular value in acute situations, not only reducing dizziness but also exercising an antiemetic effect. Diazepam also is a potent labyrinthine sedative drug and has, in addition, anxiolytic properties. However, if the problem is already due to vestibular inadequacy, as in the elderly, these labyrinthine sedative drugs will simply increase the unsteadiness.

** Suppress the patient's emotional reaction **

Vertigo is a most distressing symptom especially if it is accompanied by vomiting and is occurring in a random and unpredictable manner. There are few patients who do not develop some emotional reaction to severe, episodic labyrinthine vertigo. This may result in aggravation of the symptoms as it may disturb even further the dysequilibrium between the two sets of vestibular nuclei.

These patients need strong reassurance both about the nature of their dizziness and the prognosis. In addition, a short period of suppression of the emotional reaction with a mild tranquilizer may be desirable. However, it is important to be alert to the possibility that the central effects of tranquilizers, especially in high dosage, can aggravate the dizziness.

** Wait for compensation **

Nature has a marvellous way of compensating for any imbalance, not least in the activity of the vestibular nuclei. In the early stages there is the 'cerebellar clamping' of the activity of the vestibular nuclei. In time, spontaneous activity is generated in the affected vestibular nuclei with gradual restoration of comfortable balance. Thus, following a labyrinthectomy in a young person, the simple passage of time may result in a return of balance function which is normal for most everyday activities. In peripheral lesions, time tends to be on our side. Unfortunately, this is not so common with the dizziness due to lesions of the central nervous system. In many instances the process of compensation can be accelerated by the performance of Cawthorne-Cooksey exercises.

** Eliminate the offending labyrinth **

Although nature can compensate readily for the complete loss of function of a labyrinth, it may have some difficulty in compensating for incomplete loss and will have considerable difficulty in compensating for fluctuating loss. Labyrinthectomy, or vestibular nerve section, may be the treatment of choice in any condition where labyrinthine function is fluctuating or where nature has failed to compensate, despite the passage of an adequate length of time. Unfortunately, labyrinthectomy always, and vestibular nerve section occasionally, results in loss of all auditory function in the affected ear.
Acceptance of the problem

There are some conditions where, despite the application of the appropriate methods of management outlined above, there is persisting imbalance. It is desirable that the physician should understand the prognosis and, where appropriate, explain to the patient that some degree of imbalance will have to be accepted. With the explanation, appropriate aids should be recommended. A walking stick is the first and most obvious but it is often overlooked. Very often this is all that is required to restore the patient's confidence and enable the resumption of reasonably normal everyday activity. In severe cases a walking frame and strategically placed hand rails will be needed.

Surgery for vertigo

It is only occasionally that surgery has any part to play in the management of vertigo. Most conditions where surgery is indicated have been discussed elsewhere in this volume.

In Ménière's disease, surgery may be seen as first, correcting the underlying problem, for example saccus decompression or cervical sympathectomy; second, having a metabolic or even placebo effect, for example saccus decompression or 'cortical mastoidectomy'; or third, ablating all vestibular function in an offending labyrinth, such as vestibular neurectomy or labyrinthectomy.

The management of labyrinthine fistulae is discussed in the section on chronic suppurative otitis media (see Chapter 12). Active chronic suppurative otitis media may be associated with vague imbalance, even in the absence of a labyrinthine fistula. It is possibly due to the absorption of toxins. Although the mechanism is obscure, the alleviation of the unsteadiness is often dramatic when the infection is dealt with by either open or closed cavity techniques.

When a labyrinthectomy is carried out in the presence of an open cavity, there may be persisting imbalance, thought to be due to stimulation of vestibular nerve endings. Subsequent vestibular nerve section may be necessary to control this unsteadiness.

Any incomplete destructive lesion of the labyrinth may be followed by persistent vertigo. In some cases this may be due to delayed endolymphatic hydrops. A complete drill-out labyrinthectomy, or even a vestibular nerve section, may be required.

Perilymph fistulae are discussed in Chapter 7.

The surgery of benign paroxysmal positional vertigo deserves special mention as this is not considered elsewhere. This condition tends to be self-limiting and is only rarely sufficiently severe to warrant surgery. However, in the small proportion of patients whose daily life has become crippled by dizziness, or whose symptoms have persisted for some years, surgery may be indicated.

Gacek (1985) reported section of the posterior ampullary nerve and this is now the operation of choice. In this procedure, the posterior ampullary, or singular nerve, is exposed via the middle ear. The bone overhanging the round window membrane is removed. Drilling
of the bone inferior to the round window membrane will expose the nerve at a depth of 1-2 mm. The nerve is divided with a hook and the canal sealed with absorbable gelatin sponge. Unfortunately in a small proportion of patients the nerve is inaccessible under the basal turn of the cochlea.

The main risk of this procedure is sensorineural hearing loss, which occurs in about 10% of patients. There is also the risk of opening into the labyrinth, causing persistent unsteadiness. Very infrequently, a cerebrospinal fluid leak may occur from the singular canal. This is a difficult procedure which is only rarely indicated, but, in competent hands, produces excellent results.
Chapter 19: Ménière's disease

B. H. Colman

In 1861, Prosper Ménière published a description of the clinical entity that was soon designated 'maladie de Ménière'. The account he gave was so complete and accurate that virtually no addition could improve the picture. He described a condition characterized by sudden and recurring episodes of vertigo with nausea and vomiting, together with hearing loss and tinnitus. He stressed that the abnormality was one of the internal ear and was not related to cerebral apoplexy as had previously been thought. Confusion has arisen following Ménière's reference in his famous paper of 1861, to the post-mortem findings of a serosanguineous exudate in the semicircular canals of a young woman who died 5 days after the onset of continuous vertigo, vomiting and deafness. When Ménière first recorded this case as an addendum to the chapter on nerve deafness in his translation of Kramer's textbook of otology in 1848, he did not mention the vertigo and described the exudate as filling the labyrinth. In fact, Ménière quoted this case some 13 years after the event, merely to illustrate that the symptoms could arise from a labyrinthine lesion and his intention was not to identify such a haemorrhagic lesion as the cause of the non-fatal syndrome. Lack of appreciation of Ménière's objective in presenting this evidence, together with misquotation, has led to the long-lasting misbelief that he had ascribed haemorrhage into the labyrinth as the cause of the disease which bears his name.

The spelling of the eponym should be that used by Ménière himself in his publications, although curiously his family gave a second (acute) accent to his name, on his tomb in Paris.

The term Ménière's 'syndrome' could imply that the condition is merely a collection of symptoms without a pathological basis. For this reason, the term 'disease' is generally preferred since the clinical and histological features are sufficiently constant to indicate the presence of a definite abnormality. The expression 'endolymphatic hydrops' is often used and is acceptable because of the outstanding histopathological feature of the disease. Endolymphatic hydrops, however, may also occur in certain congenital malformations of the ear, in syphilitic labyrinthitis, and especially in viral labyrinthitis.

Incidence

Ménière's disease is not a particularly uncommon disorder although the criteria for diagnosis employed by different clinicians vary tremendously and so, accordingly, does its apparent frequency.

Matsunaga (1976) have an average incidence of 0.5% for the disease in patients attending ear, nose and throat clinics in various hospitals in different countries. Drachman and Hart (1972) and Wilmot (1974) both quoted an incidence of 5% of Ménière's disease in a clinic dealing with balance disorders, a figure which is similar to that of the present author.
**Age of onset**

The experience of most otologists is that, in the majority of patients, symptoms generally start before the age of 50 years. *Table 19.1* brings together the age of onset from several authors.

**Table 19.1. Age of onset of Ménière's disease in 1054 patients**

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>0-10</th>
<th>11-20</th>
<th>21-30</th>
<th>31-40</th>
<th>41-50</th>
<th>51-60</th>
<th>61-70</th>
<th>71-80</th>
<th>over 80</th>
</tr>
</thead>
<tbody>
<tr>
<td>No of patients</td>
<td>14</td>
<td>61</td>
<td>204</td>
<td>286</td>
<td>246</td>
<td>163</td>
<td>64</td>
<td>16</td>
<td>nil</td>
</tr>
</tbody>
</table>

**Bilateral involvement**

The incidence of bilateral involvement is usually put at about 10%, but it appears to depend upon the length of time patients are kept under observation and on the criteria used in diagnosing involvement of the second ear. The author's experience is that second side involvement, when it occurs, is usually seen early, and within 2 years in 50% of cases. Many older patients do show hearing changes in the contralateral ear, although not necessarily associated with dysequilibrium referable to that ear. Nevertheless, Haye and Quist-Hanssen (1976) quoted 37% of their 111 patients as having bilateral involvement.

**Predisposing factors**

No definite predisposing factors are known. Portmann (1980) taking a 60-year retrospective look, observed that 'Ménière's disease is one of the least understood disorders in general and by specialists in particular...'

Although Ménière's disease remains a disorder of unknown origin, it is increasingly regarded as the late result of an insult to the labyrinth which may have passed unnoticed years before the onset of symptoms. Shambaugh and Wiet (1980) made the suggestion that the early damage may be viral in origin. Schuknecht and Gulya (1983) and Schuknecht (1984) in an overview of endolymphatic hydrops generally, and of Ménière's disease in particular, regarded endolymphatic hydrops as a pathological condition which is the final manifestation of a variety of otological insults. In their papers, they presented a classification on the basis of clinical and pathological data which distinguishes symptomatic and asymptomatic forms of hydrops. In symptomatic hydrops, the initiating factor may be congenital, inflammatory, traumatic, or idiopathic. It disrupts those mechanisms responsible for maintaining the proper volume of endolymph so that a progressive situation is reached which becomes symptomatic. Asymptomatic hydrops is clinically silent and found only upon routine histopathological examination of temporal bones, but again may be congenital or acquired, or idiopathic in origin. Schuknecht therefore suggested that Ménière's disease may be redefined as an idiopathic, symptomatic form and as such may be considered to be one member of a family of disorders linked by the common pathology of endolymphatic hydrops.

**Clinical features**

In order to improve the accuracy of the diagnosis and to establish uniform standards, the criteria to be used should be those laid down by the special committee of the American
Academy of Ophthalmology and Otolaryngology (AAOO) chaired by Alford (1972) (see Appendix 19.1). Likewise, especially when comparing results of treatment, it seems sensible to use a system of staging as proposed by Arenberg and Stahle (1979, 1980), Balkany, Sires and Arenberg (1980) and Watanabe (1980). Depending upon the behaviour of the hearing, three phases of the disease can be recognized characterized by early reversible hearing loss, established fluctuant hearing loss, and late non-fluctuant hearing loss.

Various positive and negative criteria should be applied to ensure accurate diagnosis of Ménière's disease as emphasized by Wilmot (1974). Repeated episodes of vestibular failure associated with cochlear and with vestibular symptoms constitute the acute phases of the disease. Between acute attacks, periods of remission of varying duration occur and during these, hearing may return to normal in the earlier stages of the disease. The cycle of activity and remission is characteristically irregular and capricious in Ménière's disease and makes the assessment of treatment difficult.

In the majority of patients, the remission period will be between 3 and 12 months. Remission is seldom less, but occasionally can be very prolonged and may be even of several years' duration. Hearing loss and dysequilibrium most commonly begin together but in about one-third of patients the dysequilibrium occurs first and only after months or sometimes a year or two may the syndrome be complete. Fluctuant hearing is less frequently the first symptom.

**The acute attack**

The dramatic symptom of vertigo dominates the picture in the acute phase. Occasionally the patient is so distressed that the auditory symptoms may go unnoticed, but usually the hearing loss and tinnitus become more obvious to the patient as the vertigo subsides. Unless the attack is minor, it is accompanied by nausea and often vomiting and other symptoms of vagal disturbance, such as sweating and pallor with slowing of the pulse. This may lead to slight transient faintness, but it is emphasized that loss of consciousness is not a feature of Ménière's disease.

Quite often the patient will get warning of an attack by discomfort or aching in the ear, an alteration in the hearing or tinnitus. In other patients, there is just a vague sense of uneasiness. The acute phase may consist of a single attack, although there is often a tendency to cluster formation before a more prolonged remission occurs.

The vertigo occurs in different forms and may be sometimes relatively mild or occasionally extremely severe. It may be rotational in nature, the patient may have a feeling of unsteadiness which causes him to veer to one or other side, sometimes there may be a to and fro, or up-and-down motion 'as on a ship at the mercy of a stormy sea'. On rare occasions the patient is thrown to the ground without warning in what is known as 'a drop attack' or 'utricular crisis'.

The paroxysms can come at any time, or may even waken the patient. The duration of the attack may be from 20 minutes to not more than 24 hours. The patient is fully oriented and conscious throughout the attack and there are no neurological symptoms or sequelae, except those referable to the labyrinth.
Nystagmus is always present during an attack and may change direction during an episode; this disappears as the vertigo subsides.

**Symptoms in the remission phase**

In the early stages the patient will be entirely asymptomatic in the remission phase and will have normal hearing and no tinnitus. As the disease progresses some tinnitus and hearing loss become permanently established.

The vestibular apparatus like the cochlea is also capable of varying degrees of recovery after an acute attack, but nevertheless, with the passage of time some permanent damage is done so that a proportion of patients, even in remission may get brief imbalance, for example on sudden head movement, or they may develop a tendency to motion sickness, positional vertigo, or momentary ataxia when changing direction.

In some patients there appears to be an association with typical migraine attacks with which the Ménière's attacks may 'change places'.

**Clinical variations**

As already mentioned, there is occasionally an interval of several years before all symptoms are present. It is to be noted that the diagnosis of Ménière's disease is not to be made until all symptoms have developed. Cochlear hydrops without vertigo is an undoubted entity. It should be suspected in the patient who has a low frequency sensorineural hearing loss that is fluctuant and in whom other aetiological factors have been excluded. Electrocochleography may be confirmatory. It may be wise to inform the family doctor that such a patient may be a future candidate for Ménière's disease.

Vestibular hydrops without hearing loss probably occurs, but it is more difficult to identify and its pathological basis has not yet been determined. Occasionally, accurate and repeated audiological examination near to an episode of vertigo may demonstrate a hearing change of which the patient was unaware, although more often, the condition can only be diagnosed in retrospect after the complete symptoms of Ménière's disease have eventually shown themselves.

The Lermoyez syndrome is a rare variant in which hearing loss and tinnitus develop over a period of hours; vertigo then occurs, often quite suddenly and with it the hearing and tinnitus improves.

**Ménière's disease in combination with other ear diseases**

Chronic middle ear suppuration may coexist and there may be a diagnosis of erosion of the labyrinthine capsule when in fact no such complication has occurred. Otosclerosis is a disorder in which dysequilibrium sometimes occurs and may lead to some confusion. On occasion otosclerosis and Ménière's disease may coexist. Chronic suppuration, otosclerosis, and Ménière's disease, are not rare disorders in otological practice and will therefore sometimes be seen occurring together.
Investigation

General assessment

An accurate history which includes a detailed description of each relevant symptom can often lead to a correct provisional diagnosis. A search for vertigo, hearing loss and tinnitus, even in the distant past, should be made as these may have been forgotten if recovery has apparently taken place. A past history of exposure to ototoxic drugs, head injury, or ear disease and operations may be relevant to the differential diagnosis.

Obviously the patient's general state must be assessed in detail, the cardiovascular system must be healthy, the carotid pulses equal and normal and the blood pressure within normal limits when taken on both arms. The central nervous system should be healthy and neuro-otological examination negative apart from the findings related to the eighth nerve. Neck movements should be unimpaired. In the course of assessment, the otologist will have taken note of the patient's psychological adjustment to the symptoms. As may be expected from the nature of the condition a significant number of patients develop an overlying anxiety state, but this must not be allowed to mask the organic nature of their basic disorder. Preliminary otological examination is undertaken to exclude any evidence of past or present disease in the middle ear cleft. The fistula test should always be applied, a positive Hennebert sign will be found in approximately 50% of patients according to Schuknecht (1975) who attributed this to the formation of adhesions between the distended saccule and the inner surface of the stapes footplate.

Audiological investigation

Preliminary tuning fork tests will confirm the sensorineural nature of the hearing loss, although a false negative Rinne may be present in patients with severe unilateral deafness. The tuning fork tests may also demonstrate diplacusis. Complete audiometric investigation follows and is an essential step towards diagnosis. The tests involved have been reviewed by Schuknecht (1963) and by Hedgecock (1968).

The various audiometric tests available are described in Volume 2 (Chapters 7 and 8). Characteristically, the results will be those of an end organ lesion, but unusual results are sometimes obtained which may give a mixed pattern of responses. Pure tone audiometry is of fundamental importance and should be repeated at each attendance to try to demonstrate the fluctuant nature of the hearing loss. Three main patterns of pure tone audiogram may be found: a hearing reduction maximal in the low or high tones, or a flat loss. The rising type of curve is generally found in the earlier stage of the disorder, while in older patients a pre-existing high tone loss (as may be shown in the unaffected ear) can be superimposed. As the disease progresses, the curve is seen to flatten out and the hearing loss, although it may halt its progress at any point, becomes increasingly severe.

Further evaluation will include tests for loudness recruitment, loudness discomfort level, stapedius reflex threshold, and possibly tone decay and Békésy testing. Speech audiometry is important and in patients with Ménière's disease, the speech reception threshold very closely matches the pure-tone threshold in over 90% of patients. Discrimination is impaired, although much less severely than in patients with a neural lesion.
Electrocochleography now constitutes a very important part in the diagnosis of endolymphatic hydrops and details of this are given in Volume 2.

Dehydration tests based on the use of glycerol, urea and frusemide (furosemide) have a place in the diagnosis of Ménière's disease. Glycerol was initially used by Klockhoff and Lindblom (1967), and experimental work on guinea-pigs by Angelborg and Agerup (1975) has confirmed that the diuresis after glycerol administration produces a lowering of internal ear pressures. In the presence of an endolymphatic hydrops, a temporary hearing improvement occurs. This may be useful not only in the diagnosis of Ménière's disease, but also in the assessment for the suitability of diuretic treatment and in the selection of patients for operations on the endolymphatic sac. The test, however, is not entirely dependable. Van de Water and Arenberg (1983) compared glycerol and urea and found that they were equally reliable, but that patients preferred urea because of its fewer side-effects. Imoto and Stahle (1983) have also made the same comparison, but concluded that the degree of response depended upon the severity of the hydrops and that an absent response indicated either remission or permanent neural hypofunction.

**Vestibular investigation**

Reference should be made to Volume 2 (Chapter 9). The method used for caloric testing is frequently that described by Fitzgerald and Hallpike (1942) and may show either a simple canal paresis or sometimes a directional preponderance, but a normal response is by no means uncommon and does not rule out the presence of Ménière's disease. A comprehensive account of the clinical, caloric and rotational test findings has been given by Wilmot (1974). A detailed analysis of electronystagmography in the diagnosis of Ménière's disease is provided by Stahle (1976a) who found that 59% of his patients had a reduced caloric response, 40% had a normal response, and 1% an exaggerated response.

Galvanic stimulation, as described by Swaak and Oosterveld (1976) provides an important means of differentiating an end organ from a neural type of vestibular lesion, although the test has not found wide acceptance in the UK.

**X-ray examination**

There has been some debate concerning the relationship of pneumatization to the development of Ménière's disease. Oku, Hasegawa and Watanabe (1980) concluded that there was no difference in the pneumatization of the temporal bone radiologically in Ménière's disease, various types of sensorineural deafness and the normal individual. Conversely, Stahle and Wilbrand (1983) concluded that gross anatomical changes were present in respect of decreased pneumatization, not only in the mastoid generally, but particularly around the periductile region, while Clemis and Valvassori (1968) and Valvassori (1983) found abnormalities of the vestibular aqueduct itself in patients with Ménière's disease. Dreisbach, Seibert and Arenberg (1983) also examined the question of patency and visibility of the vestibular aqueduct in Ménière's disease, but concluded that there was considerable anatomical variation, and that demonstration accordingly was often difficult. Considering the size of the duct it is perhaps hardly surprising that even with the most modern scanning techniques it is not always possible to demonstrate the structure. It has been suggested that operations on the
saccus are futile if the duct cannot be demonstrated radiologically but most otologists remain sceptical and regard the case as not-proven.

**Differential diagnosis**

A vast number of clinical conditions enter into the differential diagnosis of vertigo and it has to be admitted that many patients remain without an exact diagnosis. The typical case of Ménière's disease can usually be diagnosed quite readily; in other cases the diagnosis will depend on how far the otologist is willing to stretch his criteria and this clearly is of great significance in those patients who may be candidates for surgical treatment.

Other disorders which affect the labyrinth include cholesteatoma and fistula formation, dysequilibrium after head injury, viral labyrinthitis, drug toxicity, positional vertigo and perilymph fistula. Syphilis produces an endolymphatic hydrops with symptoms that simulate Mениère's disease. In Cogan's disease, the symptoms are those of Mениère's disease to which are added redness of the eyes and blurring of the vision with interstitial keratitis. Disorders of the vestibular nerve and its central connections always have to be considered and include vestibular schwannoma (neuroma) in its various atypical forms, vestibular neuritis and multiple sclerosis. Cardiovascular disturbances, giddiness of ischaemic or neck origin when coexisting with a sensorineural hearing loss can be confusing (although less so if the sensorineural loss is bilateral and symmetrical). Cranio-cervical dysplasia can produce fluctuant sensorineural hearing loss with tinnitus and dysequilibrium and may mimic Mениère's disease. However, the dysequilibrium has different characteristics, as described by Ellies and Plester (1980). When in doubt, it is sometimes helpful to go back to the basic points and to remind oneself that the condition is usually unilateral, and likewise that the symptoms are unilateral, and consist of fluctuant hearing loss, fluctuant tinnitus and episodes of dysequilibrium separated by characteristic remissions, and that other neurological, cardiovascular, neck problems etc, are absent or separate.

**Pathology**

Although it was long speculated that endolymphatic hydrops was associated with Mениère's disease, this was only confirmed by Hallpike and Cairns in 1938. Many others have since reported similar findings. The most comprehensive description available at present is that of Schuknecht (1974, 1975) based on material in his own collection of temporal bones. The most obvious abnormality is the distension of the endolymphatic spaces. This mainly affects the cochlea and the saccule. The utricle is involved to a lesser degree and the semicircular canals only slightly (in the region of the ampullae). Dilatation of the endolymphatic sac has not been found. The distension of the scala media of the cochlea is seen as a bulging of Reissner's membrane into the scala vestibuli, often leading to obliteration of this part of the perilymphatic compartment. Reissner's membrane is frequently observed to bulge through the helicotrema into the apical part of the scala tympani.

The second feature in Mениère's disease concerns herniation or rupture of the membranous labyrinth. These herniations can occur at any site in Reissner's membrane or in the saccule, utricle or ampullae. That rupture can occur implies that healing can also take place. Accordingly, it has been suggested that these ruptures are vital phenomena, and are related in some way to the exacerbations and remissions which characterize Mениère's disease.
The incidence of these ruptures is variable. Antoli-Candela (1976) observed them to be present in 13 out of 19 temporal bones that were studied, but Fraysee, Alonso and House (1980) observed them in only three out of 23 bones they examined.

A third feature is collapse of the membranous labyrinth which presumably occurs when a break therein fails to heal. It may be that a permanent break of this kind is the situation which occurs in 'burnt-out' Ménière's disease.

The fourth point of interest concerning the membranous labyrinth, is the proliferation of fibrous tissue in the vestibule. Adhesions occur between the footplate and the walls of the utricle and saccule. They are thought to account for the presence of Hennebert's sign in some patients with Ménière's disease.

The fifth feature, concerns the hair-cell and ganglion-cell population of the ear affected by Ménière's disease. Schuknecht, Benitez and Beekhuis (1962) were able to achieve early fixation of the labyrinthine structures in three temporal bones from patients with Ménière's disease and found normal hair-cell populations in the organ of Corti, the maculae of the saccule and the cristae of the three semicircular canals. The neuron population of the spiral and vestibular ganglia were also normal. Schuknecht (1968) confirmed these findings in a further paper and concluded that degenerative changes only occur in exceptional cases. Such exceptions have been presented by Lindsay, Cohurt and Sciarrà (1967) and also by two cases now in the Schuknecht collection. In these cases the loss of hair cells and of ganglion cells is confined to the apical region of the cochlea.

Antoli-Candela (1976) in a further study of material in the Schuknecht collection provided a very detailed account of the appearance on light microscopy and confirmed the normality of the hair-cell population in the organ of Corti. Changes in the hair cells and ganglion cells were the same in both the affected and unaffected ear. He could find no correlation generally between the severity of the sensorineural hearing loss and the histopathological findings in the sensory and neural structures. Fraysee, Alonso and House (1980) also found that the hair-cell population was normal, although considered that there might be some loss of ganglion cells in specimens showing very severe hydrops.

Ylikoski, Collan and Palva (1979) reported on material obtained at operation from the cochlear nerve, vestibular nerve and neuroepithelial areas of the utricle and semicircular canal cristae and found no microscopic evidence of deterioration, even in long-standing advanced disease, only minor variations from normal were found in individual cells. Whatever the nature of the degenerative changes in the receptors, it is evident that they are not gross enough to be shown by light microscopy in the material which has become available for study, and that any structural changes are ultramicroscopic in character.

Electron microscopy has been carried out on material obtained at operation and from experimental material in animals by a number of researchers including Kimura and Schuknecht (1970) and by Calman, Friedmann and Wright (1975) who examined the vestibular nerve and other parts, from patients undergoing vestibular neurectomy, but it is often difficult to know whether the features described are those of Ménière's disease or are the result of ageing and other processes.
Endolymphatic distension

To appreciate the theories of causation of endolymphatic hydrops, an understanding is necessary of the normal anatomy and physiology of the inner ear and its fluids (see Volume 1, Chapters 1 and 2).

Briefly, it may be said that distension of the endolymphatic spaces, as seen in Ménière's disease, could in theory arise in several ways:

1. insufficient production of perilymph, if it is accepted that perilymph production is an active process

2. excess production of endolymph, assuming it is produced by the stria vascularis and other lesser sites

3. by inadequate absorption in the endolymphatic sac, if it is accepted that endolymph moves towards the sac and that the latter has an absorptive function.

The various theories of the cause of endolymphatic hydrops have been reviewed by Lawrence (1968) although he emphasized that he does not necessarily accept the view that over-accumulation of endolymph per se is the cause of clinical symptoms. As he pointed out, the hydrops may be a concomitant and incidental occurrence, along with the other features of the disease, all arising from some basic underlying disturbance such as alteration in ionic concentrations or osmotic pressure relationships. Most otologists, however, accept the hydrops as the basic feature, even though there is difficulty in explaining its cause and in correlating it with the symptomatology.

Generally, the theories of causation of endolymphatic hydrops can be grouped as follows:

1. Those based on disturbance of fluid formation. These are mainly dependent on the principle of radial flow of inner ear fluids, described by Naftalin and Harrison (1958).

2. Those concerned with mechanical blockage and disturbed reabsorption. These are mainly dependent on the theory of longitudinal flow of endolymph as described by Guild (1927), that is with the movement of endolymph towards the endolymphatic sac, or with malfunction of the sac itself.

It should not be thought that these two theories are incompatible or conflicting and, indeed, it is probable that both types of flow occur in the normal ear, a fast radial flow and a slow longitudinal flow.

In the theory of radial flow of endolymph, Naftalin and Harrison (1958) suggested that secretion and absorption occur in the same radial area of the cochlea. Their theory deals with ionic exchanges in the inner ear, and they suggested that fluid in the inner ear passes from perilymph and that the function of the stria is to absorb perilymph. They postulated that the function of Reissner's membrane is to retain potassium ions in the endolymph and to prevent protein from entering endolymph by being impermeable to large molecules. The stria, like the
tubular cell of the kidney, extracts sodium and inserts potassium to maintain a high endolymphatic concentration of the latter. They emphasize that according to the theory, ionic transport against gradients is carried out by the stria vascularis, the only structure capable of doing so. Potassium and sodium exchange across Reissner's membrane is in the direction of concentration gradients and therefore requires no energy. At the present time (1986) it is increasingly accepted that the basic problem in Ménière's disease is one affecting Reissner's membrane (Wersäll, 1986 personal communication).

Naftalin and Harrison further stated that perilymph is formed by ultrafiltration from vascular tissues of the perilymph space but in Ménière's disease there is decreased production and this leads to an apparent increase in endolymph. This is later followed by a true increase of endolymph caused by a gradual increase of potassium as flow through Reissner's membrane diminishes.

The work of Johnstone (1975) should also be noted. He put forward sound evidence which supports the possibility of two fairly independent radial circulations, one mainly in the cochlea and saccule, the other confined to the utricle and canals. Others have also put forward evidence in favour of radial flow (combined with longitudinal flow) and suggested that radial flow provides for the energy metabolism and ion exchange and is the only satisfactory way in which the high energy demands of the organ of Corti can be met. Lawrence (1980) accepted chemical exchange as occurring all along the endolymphatic space, this occurring together with longitudinal flow to the endolymphatic sac.

The work of Kishimoto et al (1983) is of interest. Their experiments showed that the endolymphatic sac and duct can transmit physiological variations of cerebrospinal fluid pressure to the inner ear fluids and submit that this function may be significant in maintaining normal perilymphatic and endolymphatic pressures.

Rauch (1968), like Naftalin and Harrison earlier, saw the primary defect as being in the production of perilymph, but endolymphatic hydrops could equally be from overproduction of endolymph (in the stria vascularis supplemented by the planum semilunaris and dark vestibular cells) or from obstruction to longitudinal flow or malabsorption in the endolymph sac.

Experimental work by Kimura (1967, 1968) indicated that obliteration of the duct and sac can produce a gross endolymphatic hydrops in certain animals, but it must be emphasized that other procedures in experimental animals, even those merely confined to the middle ear, can also produce hydrops. Such experimental hydrops is not usually associated with dysequilibrium. The symptoms of Ménière's disease have yet to be produced in experimental animals. However, the theory that the endolymphatic sac may have a resorptive function finds further support in the work of Lundquist, Kimura and Wersall (1964), Ishii, Silverstein and Balogh (1966), and Adlington (1967).

Radiological evidence, as already mentioned, has also been submitted by Clemis and Valvassori (Clemis and Valvassori, 1968; Valvassori, 1983) to suggest that obstruction to longitudinal flow towards the endolymphatic sac may have a part in the production of Ménière's disease. Support has also been provided by Stahle and Wilbrand (1974). This work, however, has not received general acceptance, and as Dreisbach, Seibert and Arenberg 919830
concluded, the anatomy of the vestibular aqueduct is so variable that even with the best scanning techniques non-visualization readily occurs as a result of the inability to cut in exactly the required plane. It also has to be said that histological studies have failed to demonstrate definite abnormality of the endolymphatic duct in patients with Ménière's disease.

Accordingly, the view that operations designed to drain the endolymphatic sac are futile unless the duct can be shown radiologically is invalid.

**Correlation of pathology with symptoms**

Attempts have been made to explain the symptoms partly on a mechanical and partly on a biochemical basis. It has also been suggested that the early and variable symptoms may be caused by mechanical aspects while the later irreversible symptoms are the result of permanent biochemical factors.

The assumption that early and reversible low frequency hearing loss could be explained on a mechanical basis by the greater distortion of the broad part of the basilar membrane has been supported by the use of cochlear models constructed by Tonndorf (1957). He expanded his original theory as a result of further work (1968) and concluded that several of the auditory changes in Ménière's disease could be explained on the basis of altered responses characteristics of the cochlea.

A mechanical explanation for the sudden onset of vertigo is difficult, but Lindsay (1960) noted the frequency with which out-pouchings of the membranous labyrinth could be found near the canal ampullae and suggested that they could interfere mechanically with the cristae contained therein.

In respect of biochemical factors, it will be recalled that according to classical membrane theory, it would be physiologically impossible for action potentials to be generated in high potassium fluid surroundings, such as endolymph. It was demonstrated by Rauch (1960) that the cortilymph in the spaces of Nuel and the tunnel of Corti, has extracellular properties and closely resembles perilymph. It is poor in potassium and thus provides an appropriate medium for normal neural excitation and transmission. Leakage of potassium into the perilymphatic compartment with consequent contamination of the cortilymph through the canaliculae perforantes might be expected to produce symptoms of cochlear failure. Such contamination could occur from breakage or leakage of the histologically-proven herniations which are frequently present. Experimental alteration of potassium levels by perfusion of the cochlea in animals supports this theory. Dohlmann (1965) described how vestibular function can be affected in a similar biochemical fashion.

It must be emphasized, however, that the significance of the membranous herniations continues to be one of debate. One view is that rupture is responsible for the onset of symptoms and another, to the effect that rupture is responsible for the remissions that occur in Ménière's disease. It is also difficult to explain how multiple herniations can develop; if one area of weakness has been produced it would be expected that the same area would rupture on future occasions rather than a new herniation developing. It is also difficult to accept that potassium contamination occurring, for example, through a rupture of Reissner's membrane can produce almost simultaneous onset of both cochlear and of vestibular
symptoms, such as occurs in the majority of patients in an acute attack. It is equally awkward to image simultaneous ruptures occurring separately in the cochlear and in the vestibular parts of the labyrinth.

For further discussion of this very interesting aspect of Ménière's disease the reader should refer to the previous edition of this volume, and also to Chapter 5.

**Treatment**

Because our knowledge of the basic pathology is so inadequate, it is difficult to design any satisfactory medical or surgical treatment for Ménière's disease. Schuknecht (1976) summed up the situation regarding medical treatment in the following words: 'I think if we sit as a jury of honest judges looking at the results, I doubt that we could approve one single drug in the treatment of Ménière's disease'. The situation seems to have improved very little since Furstenburg, Lashmet and Lathrop (1934) commented on 'The bewildered and futile state of medical therapy in the Ménière's syndrome complex'. Indeed, one might reasonably ask oneself whether medical treatment has improved to any significant extent since Ménière first described the disorder!

The variety of surgical procedures is also bewildering. Any success claimed for different operations, like medical treatment, must always be weighed against the widely varying periods of natural remission. The only surgical exception being total destruction or denervation. Indeed, there is much evidence that suggests that most medical treatment and certain surgical procedures are effective only through a placebo effect. Fortunately, it is becoming a little easier now to compare results since more authors are using a system of staging and analysing their results on the AAOO system previously mentioned.

**General management**

The relief of tension and the anxiety state resulting from the unpredictable nature of the disease is of prime importance and an understanding and sympathetic approach to the patient's problems is equally essential. Strong reassurance stressing the non-fatal nature of the disorder is necessary, coupled with emphasis that it is entirely a disorder of the inner ear. Some explanation of its nature, for example 'an excess of fluid in the balance organ' is of some help. It must be explained that the condition can be ameliorated, even if it cannot be completely cured. It is also wise to tell patients that relapses can occur and, if need be, management may be altered from time to time, otherwise the patient will inevitably suffer loss of confidence sooner or later.

Pulec (1972) emphasized the need to treat any abnormality which can be discovered in thyroid function, pituitary/adrenal insufficiency, glucose tolerance and similar problems. He claimed to find a high proportion of patients in whom some basic disturbance is discovered, but this has not been confirmed by other writers, including Schmidt, Brunsting and Antvelink (1979), although syphilis, of course, must be excluded routinely.
**Medication**

Much medical treatment is on an empirical basis. There is little statistical evidence that medication alters the natural history of the disease or confers any specific benefit. Nevertheless, most otologists provide some kind of medication and such treatment should always be given a substantial trial before recommending surgical management. There is some evidence that regular supervision, special testing and the involvement in the machinery of a big hospital has in itself a significant placebo effect. If the patient is seen regularly it also gives the opportunity of offering suitable surgical treatment at the appropriate time if deterioration occurs.

Dietetic treatment based on low salt and fluid intake was introduced over 50 years ago and is still employed. Boles et al (1975) reported satisfactory results and few operations in a series of 500 consecutive patients treated along these lines, although there is little evidence that labyrinthine or serum electrolyte concentration can be altered by ordinary dietetic measures.

Vasodilators are frequently used, although this seems a curious way to diminish endolymph production by the stria vascularis. The experimental evidence of Snow and Suga (1975) has confirmed that cochlear blood flow was greatly increased by carbon dioxide, amyl nitrite, and betahistine, but no increase occurred after nicotinic acid administration.

Various phenothiazine drugs with antihistamine properties have been reported to be useful; cinnarizine and diphenidol, are frequently used.

Other drugs used in treatment include lithium carbonate, which was introduced in the hope that it might favourably alter the transport of fluid and ions across the membranes of the internal ear, although Thomsen et al (1976) demonstrated no more than a placebo effect. Lemon bioflavonoid derivatives and vitamin therapy seem to have a few supporters. Sedatives and tranquilizers sometimes appear helpful, especially in those patients who are aware that attacks tend to occur during periods of stress. Preparations such as prochlorperazine and thiethylperazine are useful to suppress nausea and vomiting, as well as the unsteadiness which sometimes follows an acute exacerbation.

**Treatment of the acute attack**

Some patients appear to control minor episodes or even prevent a major attack from coming on by retiring to a quiet corner and telling their well-wishers to stop fussing around. Minor episodes can sometimes be managed by sitting down and taking various drugs, such as promethazine, dimenhydrinate, perphenazine, or chlorpromazine but, in a severe and prolonged attack, the patient must retire to bed and be given one or other of these drugs intramuscularly in fairly high dosage.

Gejrot (1976) believed that an acute attack can also be relieved by the intravenous infusion of lignocaine in a dosage of 1 mg/kg body weight to be given at the rate of 6 mg/minutes.
Stellate ganglion block is a simple procedure which should be within the capability of an otologist and can likewise give rapid relief from a severe episode. Stellate block repeated two or three times a week can also promote a remission in those patients who are going through a bad cluster of major attacks.

**Ototoxic therapy**

Streptomycin therapy has been described by Fowler (1948) and by Schuknecht (1957) whose same long-term patients and more recent ones were reviewed by Singleton and Schuknecht (1968). This therapy takes advantage of the vestibulotoxic effect of the drug and may have a place in patients with bilateral disease (see Chapter 5). The treatment, however, is not entirely without some risk of cochlear damage, and bilateral suppression of vestibular function itself constitutes a substantial disability which requires intensive physiotherapy for adaptation. Streptomycin was injected locally into the middle ear of unilateral cases by Lange (1972). Other vestibulotoxic drugs have been similarly employed either by local injection or insertion through a ventilation tube into the middle ear.

**Treatment with hearing aids**

Because of the impaired discrimination and limited tolerance of amplification that is present in most patients with Ménière's disease, the benefit from a hearing aid is often limited. This matter has been discussed by Johnson and House (1979). Most patients with unilateral disease do not find an aid beneficial. There are many exceptions to this rule, and occasionally the benefit to a patient even with bilateral disease and very severe loss of hearing can be substantial.

**Surgical treatment**

Surgical treatment must be considered for those patients in whom disabling symptoms are continuing to occur without evidence of adequate remission. It is customary to provide medical treatment for about 6 months before making any decision, but this will depend upon individual circumstances. If a patient's condition is deteriorating rather than improving, and he is unable to follow his normal activities, then surgical treatment may be indicated. In the past, the severity of the vertigo has been the main criterion used in reaching a decision. However, with increasing realization that even the best medical treatment does little to conserve hearing, combined with the knowledge that the progressive nature of the disorder will almost inevitably lead to increasing hearing damage, there is now a greater tendency to operate earlier in an attempt to conserve hearing (albeit in the knowledge that surgical treatment is also uncertain and unproven from this point of view).

Most surgical procedures can be considered under the following main headings.

1. Procedures designed to influence endolymph production (for example sympathectomy).

2. Procedures designed to influence endolymph absorption (for example operations on the endolymphatic sac).
(3) Selective denervation of the vestibular labyrinth (vestibular nerve resection).

(4) Labyrinth destruction
   (a) selective destruction of the vestibular labyrinth (by ultrasound or cryosurgery)
   (b) total destruction of the labyrinth (labyrinthectomy) combined perhaps with total denervation (translabyrinthine cochleovestibular neurectomy).

The exact procedure will mainly depend on the level of the hearing present and whether the disease is unilateral or bilateral. All of the operations except the last in the list, aim to preserve hearing. Operations in the last group offer no possibility of retention of hearing after operation and accordingly are only suitable if it is felt that the residual hearing in the affected ear can safely be sacrificed and that the other ear is healthy.

Conservation operations

Cervical sympathectomy

This has been suggested on the basis that in some way, as yet undetermined, it helps to correct the microcirculatory fault in the stria vascularis. Golding-Wood (1973) reported satisfactory results from the operation and gave long-term follow-up in 247 patients. An important point to remember about sympathectomy is that it is an operation which is remove from the ear and therefore totally free from any risk to the hearing. Accordingly, it may be especially suitable for those patients having Ménière's disease in an only remaining ear. The resection must be from C3 to T3 inclusive. However, it has to be said that sympathectomy has not been widely used in the treatment of Ménière's disease.

Operations on the endolymphatic sac

There has been much interest in these operations since the sac was first opened by Georges Portmann (1927). The particular patient was still living at the age of 75 never having experienced a return of vertigo (Michel Portmann, personal communication).

Although operations on the endolymphatic sac have an important place in the surgical management of Ménière's disease it has been suggested that the results are no different from those one might expect from the natural history of the disease. This view finds some support in the controlled double-blind study reported by Thomsen et al (1981) and by Bretlau et al (1984). Some of their patients had a simple mastoidectomy carried out, in others the sac was opened. Their statistical analyses revealed no significant difference between the two groups of patients, and they concluded that the effect of surgery was purely as a placebo. However, a separate statistical analysis on the same patients made by Pillsbury et al (1983) produced the opposite conclusions.

Experience at the Radcliffe Infirmary, Oxford, shows a very substantial difference in results between patients in whom the surgeon had been unable to identify the sac with a high degree of certainty, or in whom the operation consisted of merely 'decompressing' the posterior fossa dura without a search being made for the sac, compared with a group of patients in whom the sac had been identified with a very high degree of certainty and a
Silastic strip inserted into its lumen. The remission rate was much better and more prolonged in the latter group.

The author's experience has been that the insertion of a saccus-subarachnoid shunt gave no advantage over simply inserting a Silastic drain into the sac. There is, however, renewed interest in the use of valved subarachnoid shunts. Superior results have been reported by Arenberg (1980) and by Brachmann and Anderson (1980); but it is yet another aspect of Ménière's disease which remains controversial.

The use of the glycerol test and urea test has been discussed previously in respect to diagnosis. It is also suggested by Wiet (1983) and by other authors that the test may be useful in a selection of patients for saccus surgery and for judging the prognosis (see also Chapter 17). Arenberg (1980) stated that a good hearing improvement after saccus surgery may be expected in the presence of a strong response to the glycerol test (although a negative test is not a contraindication for attempting relief of vertigo by the operation). Reference has already been made concerning radiological studies of the endolymphatic duct in a selection of patients for saccus surgery. Shea, Emmett and Moore (1979) indicated that superior results could be obtained if the vestibular aqueduct was readily demonstrated, but Wiet (1983), probably representing the majority view, came to the conclusion that radiological studies were interesting for demonstrating the anatomy and the extent of pneumatization, but that there was no relationship between the results of operation and of the ability or inability to demonstrate the aqueduct.

The surgical anatomy of the endolymphatic sac has been described in detail in a beautifully illustrated paper by Arenberg et al (1977) to which reference should be made. Further detailed information for the surgeon concerning the anatomy in 20 normal ears is provided by Shea, Emmett and Moore (1979).

Although operations on the endolymphatic sac are relatively straightforward and without any great risk of complications, it is important to remember that severe sensorineural hearing loss can occasionally occur. Fisch (1976) has quoted a risk of 4% of partial sensorineural hearing loss. This complication is often said to be the result of an accidental injury of the posterior semicircular canal, but the author's experience is that the complication can occur in the undoubted absence of such an injury.

The results of saccus surgery reported by various surgeons employing different techniques have been reported on many occasions and reference should be made to the current literature. Palva, Karja and Palva (1976) found their results were somewhat less satisfactory than in most published series but, nevertheless, were in accordance with the experience of many others. Many otologists with interest and experience in this field will find themselves in sympathy with Palva's observations.

Endolymph-perilymph shunts

Various ways have been suggested by which the endolymphatic space might be decompressed with consequent relief of vertigo and preservation of hearing. Decompression of the saccule was first described by Fick (1964), but the experience of nearly all otologists has been that the operation carries a dangerously high risk of profound sensorineural hearing
loss. Accordingly, the operation must be regarded as destructive, but it may have a place in the management of the older patient, who could be expected to have difficulty in adaptation after a formal labyrinthectomy. Cody (1968) inserted a stainless steel tack which was left permanently in position in the stapes footplate so that the distending saccule could be automatically and repetitively decompressed by contact against it. In a long-term follow-up (Cody, 1974) he reported on 140 such patients, but in spite of his encouraging results, the operation has not become generally accepted because of the high risk to hearing.

House (1968a) used a cryosurgical probe onto the promontory in order to try to create a small fistula while Pulec (1968) inserted a small tube through the basilar membrane using a round window approach. A further refinement is that of Schuknecht (1982), who described the creation of a cochlear endolymphatic shunt. His results were analysed using the AAOO criteria (Schuknecht, 1986, personal communication). With an average follow-up of 22 months, the severe episodes of vertigo were relieved in 72% of patients, 45% of patients had some worsening of hearing at the time of their most recent audiogram, but only 12% suffered a profound sensorineural hearing loss. The author's personal experience of the operation has been much better in respect of vertigo relief, but much worse in respect of hearing conservation.

**Vestibular neurectomy**

Division of the vestibular nerve for persistent aural vertigo was achieved by Frazier (1912), McKenzie (1932) and by Cairns and Brain (1933). Dandy (1941) was able to report a series of 401 operations with only one death, utilizing a posterior fossa approach. The middle fossa microsurgical technique of House (1968b) is now well known and has been further modified and described by Fisch (1970, 1976). The operation demands a high degree of surgical skill and it potentially carries the various complications and risks of morbidity that are associated with intracranial procedures in the middle fossa.

There has now been considerable experience with the middle fossa procedure and, in experienced hands, it has shown itself to be highly predictable in the relief of vertigo and preservation of hearing with minimal complications. However, the operation is not one for the occasional surgeon. The results obtained by Fisch (1976) and by Palva, Ylikoski and Paavolainen (1979) are probably representative. They quoted 90% of patients relieved of their vertigo, and 80% with preservation of hearing; 3% of their patients had temporary partial facial weakness. Vestibular neurectomy is followed by a powerful bilateral suppression of vestibular activity which was investigated by Fisch (1973) and which makes for a more rapid compensation compared to that after labyrinthectomy. This is probably a result of the divisions of the efferent fibres to the labyrinth.

It has been suggested that the natural history of the disease may be altered by this operation with consequent control of any further hearing deterioration. This too, has been attributed to the division of the efferent fibres to the labyrinth. The author's experience, however, is that with prolonged follow-up the hearing gradually continues to deteriorate, probably because the disease is still continuing, albeit in a fairly asymptomatic fashion.

At the present time, attention is again being given to the posterior fossa approach. Indeed, Bryan and Bucy as long ago as 1973 reported on 17 such patients, although with
substantially less satisfactory results than those obtained with the middle fossa approach. The method used can be either neurosurgical and retro-sinus or alternatively trans-mastoid retrolabyrinthine. House et al (1983) using the latter approach, obtained complete relief of vertigo for 83% of their patients.

**Selective destruction of the labyrinth**

Ultrasonic energy was first employed to destroy the human labyrinth by Krejci (1951) and was soon followed by Arslan (1953) and by Angell-James (1973) in England. Experimentally the effectiveness of ultrasound in the destruction of the vestibular end organs in animals was demonstrated by Brain et al (1960).

The technique employed is essentially that described by Angell-James (1969a, b) who reported his results from 232 patients several years after first employing the method. Stahle (1976b) reported his experience with 356 patients over a 12-year period using fairly similar methods. Barnett and Kossoff (1977) described a special applicator for use at the round window.

Although ultrasound treatment still has its advocates and can undoubtedly obtain satisfactory results, most otologists have abandoned its use. The reason for this has probably been similar to those of the author, namely the difficulties in obtaining and maintaining a generator and applicator whose output of energy can be depended upon. It has also been his experience that in the very long term the hearing continues to deteriorate even though the patient may remain free of vertigo.

The author's view is that ultrasound treatment, like the saccus operation, is best regarded as a time-borrowing procedure; the amount of time gained can be very variable, but a substantial number of patients remain free of vertigo for 10 years or more.

**Destruction operations**

**Labyrinthectomy**

If it is decided that the residual hearing in the ear is permanently at a very low level, that dysequilibrium continues to be disabling, and that the opposite ear is undoubtedly asymptomatic, then the labyrinth can be destroyed by various methods:

1. the postaural lateral semicircular canal approach

2. an extension of this with complete exenteration of all three canals and of the vestibule (and perhaps with neurectomy)

3. a permeatal transtympanic window approach (which can also include a neurectomy).

All methods of labyrinthectomy provide a high likelihood of relieving the major attacks of vertigo, but it has to be emphasized to the patient that this is at the expense of total hearing loss in the operated ear and consideration must always be given to the possibility of
disease affecting the only surviving ear. Labyrinthectomy, therefore is not a decision to be taken lightly, especially in the younger patient who has many years ahead during which second side involvement may occur. Likewise, careful consideration has to be given in the case of the older patient because the older the patient the greater the difficulty with adaptation; for this group, there is much to be said for performing either a Fick procedure or a cochleotomy in the first instance (see above). Sacculotomy and cochleotomy are very much less disturbing to the patient and if they fail a formal labyrinthectomy can still be considered.

Appropriate exercises help to establish full adaptation. Results are generally excellent and the loss of distorted hearing in the ear is a benefit. Labyrinthectomy through a lateral semicircular canal approach is probably the simplest operation available. It is highly reliable, although not completely so. Sometimes the destruction is incomplete and there is later a return of symptoms. It is for this reason that complete exenteration of all three semicircular canals and of the vestibule, is to be preferred. Translabyrinthine neurectomy, as described by Pulcer (1968) enables the otologist to check that no abnormality of the internal meatus has been missed, provides the patient with more complete and more rapid adaptation, and if the cochlear nerve is resected some patients obtain relief from their tinnitus. However, extension of the operation in this way makes it a more major procedure and calls for considerable skill and the possible advantages have to be balanced against the extra danger to the facial nerve, as well as to the occasional possibility of a cerebrospinal fluid leak and consequent meningitis. The permeatal transtympanic window labyrinthectomy was described by Schuknecht in 1956. The stapes is extracted, and the round window is opened. It is absolutely essential that, using a suitable pick, every attempt is made to extract each individual area of sensory epithelium. If this is not done, there is a possibility of return of some function and of symptoms. Extension of the operation has been described by Silverstein (1976) to include a cochleovestibular neurectomy by drilling away the promontory for increased access. It may be considered, however, that the access is somewhat awkward, the hazard to the facial nerve too great, and that if one wishes to undertake a neurectomy a translabyrinthine route gives better exposure and greater safety.

The question of incomplete compensation (especially in older patients) has been discussed by Palva, Karja and Palva (1976). They found that a high proportion of older patients, although relieved of their major episodes of vertigo had a fairly constant, but ill-defined mild unsteadiness. The patients of Pedersen and Sørensen (1970) were perhaps less well motivated. Half of their 32 patients, who they were able to trace with an average follow-up of 7 years, still complained of persistent imbalance that was sufficiently severe to incapacitate them and prevent their return to full-time work. Fortunately, most patients achieve much better results than this.

**Other procedures**

For completeness the following two modalities of treatment require a mention.

(1) Insertion of a ventilation tube through the tympanic membrane has been advocated on the assumption that, in Ménière's disease, the internal ear disturbance is a manifestation of abnormal middle ear pressures. Scientific support for this assumption is somewhat lacking, but nevertheless dramatic improvements in symptoms have been reported following this minor
operation. It is difficult to see any scientific basis for it and it seems that the effect is purely that of a placebo.

(2) Treatment in the hypobaric chamber of patients with acute attacks of symptoms has been described by Tjernström et al (1980), but is of interest from the scientific aspect rather than from the treatment point of view.

**Choice of operation**

Operation is to be considered when there is failure to control symptoms by so-called medical treatment, or if there is absence of prolonged spontaneous remission. It is always an individual decision and depends mainly on the degree to which attacks of vertigo are interfering with the patient's normal life. If the symptoms are disabling then operation should be offered. Usually, the severity of the vertigo has been the main factor in reaching a decision. In recent years, and in spite of the unpredictability in hearing conservation operations, there has been a tendency to operate earlier in the disease in the hope of controlling progressive hearing loss. However, the relief of tinnitus and improvement of hearing by surgery although sometimes obtained, cannot be relied upon. It seems that the best results in this last respect, occur probably in younger patients and in early cases where the degree of permanent cochlear damage is not too great.

The type of operation is generally determined by the level of hearing in the affected ear. If hearing in the affected ear is useless and the other ear is healthy then a destructive operation can be carried out. The surgeon will generally be less willing to undertake a destructive procedure in a younger patient who has many years ahead of him in which he may develop bilateral disease. If hearing in the affected ear is still at a useful level, if the patient has only one hearing ear, if the patient has bilateral disease, or if he shows any evidence whatever that might suggest early signs of trouble in the apparently healthy ear, then any operation to be offered must clearly be of the hearing conservation type.

Generally speaking, the 'hearing-destructive' operations are straightforward and give a very high probability of relief from the acute attacks. Although they may leave some imbalance they are probably the best method available to restore full working capability to the patient. The hearing-destructive operations include the various types of labyrinthectomy and translabyrinthine neurectomy, and must also include the Fick and Cody operations on the saccule.

The 'hearing-conservation' operations are generally more complex procedures. They have a high probability of doing no damage to hearing, but offer less certain relief of the vertigo compared to destructive operations (except for middle fossa vestibular neurectomy). These operations include the various procedures on the endolymphatic sac, as well as ultrasound and cryosurgical methods, and sympathectomy. Middle fossa vestibular neurectomy is also to be included in this category, as may posterior fossa neurectomy and perhaps the insertion of a ventilation (pressure-equalizing) tube.

Labyrinthectomy, in some form, will be the operation of choice when disease is clearly unilateral and the hearing is so diminished and distorted as to be useless, but it is again emphasized that apparently minor transient symptoms in the opposite ear, are sometimes the
first indication of major involvement which may only become manifest after a prolonged interval and, particularly, in the younger patient are to be regarded with apprehension. Labyrinthectomy, by either a permeatal or mastoid approach, is highly effective in the unilateral case and in younger, well-motivated patients is followed by rapid vestibular compensation. Furthermore, the patient is often relieved of hearing which is so distorted as to interfere with reception on the normal side. The advantage of proceeding to a translabyrinthine resection of the vestibular nerve and may be the cochlear nerve also must be weighed against its potential further difficulties and complications and should perhaps only be undertaken by a surgeon who is familiar with the internal auditory meatus.

The Fick and Cody transfootplate operations on the saccule must be regarded as destructive procedures; even their main protagonists have failed to demonstrate that hearing can be stabilized or improved. The majority of surgeons who have performed these operations have reported an extremely high incidence of total hearing loss in the ear. Nevertheless, they can be useful operations for the elderly, fragile, or ill patients who can only tolerate a minor operation, performed if necessary under local anaesthesia.

The author's experience with cochleotomy, as already mentioned, places it in this group of operative procedures, it carries a high risk of severe sensorineural hearing loss, but is extremely undisturbing and makes for easier adaptation for the older patient in whom a conventional labyrinthectomy would be the only alternative.

Of the operations designed for hearing conservation there has been increasing interest in operations involving the saccus endolymphaticus, but there is no satisfactory evidence to indicate that any one type of operation is superior. The best results seem to be obtained in the earlier (and therefore potentially reversible) stages of Ménière's disease in which hearing is normal or near-normal during remission. A positive test with glycerol or frusemide may be helpful in making a decision. The radiological demonstration the patency of the vestibular aqueduct is of doubtful value.

A saccus procedure can, nevertheless, sometimes give a good result in the later stages of the disease in spite of a negative glycerol test. Ultrasound treatment offers a satisfactory alternative in those departments where the necessary equipment and skills are available and the same may apply to cryosurgery, although there have been far fewer reports relating to the results. Sympathectomy, as mentioned, is an operation away from the ear and therefore is the only procedure available which carries no risk to hearing. It should be considered especially in those patients with either bilateral disease or only one functioning ear. Its exact mode of action is likely to remain uncertain until the efferent innervation to the ear is clarified.

Selective resection of the eighth nerve through a middle fossa approach, although a major procedure, has now established itself as highly predictable for the relief of vertigo. It is associated with an acceptably low risk of damage to hearing in skilled and experienced hands. Its long-term effect upon the natural history of the disease remains to be proven. The precise indications for the operation are still debated. Fisch (1976) regards it as the surgical treatment of choice in those patients with irreversible Ménière's disease, that is those who have a hearing loss which is stable or a hearing loss which fluctuates but is never normal. Palva, Karja and Palva (1976) use the operation if hearing is at a level of 70 dB or better on pure-tone testing with a discrimination score of at least 50%. They also regard it as the
treatment of choice if there is a possibility of bilateral disease. It is a major operation, which should perhaps be regarded not as a primary procedure, but one which should be utilized when an earlier operation such as the saccus operation, has failed in a particular patient. Like translabyrinthine neurectomy it is an operation which calls for an advanced degree of surgical skill.

The choice of operations for Ménière's disease remains somewhat bewildering and to some extent the choice will depend upon the experience and personal preference of the otologist concerned. Useful reviews have been provided by Snow and Kimmelman (1979) and by Kinney (1980). It is to be hoped that the criteria set down in the AAOO system will help to clarify the situation. Until these or some similar criteria for assessing results are more widely employed, it will continue to be impossible to compare directly the effects of one treatment with those of another and the management of Ménière's disease will remain somewhat haphazard. Until better understanding of the pathogenesis of Ménière's disease becomes available and provides some basis for improved medical treatment or preventative measures, future progress seems to lie along the lines of early conservation surgery before irreversible damage occurs to the inner ear.
Appendix 19.1 (From Committee on Hearing and Equilibrium, 1972, with permission)

Definitions

The deafness is sensorineural in type, fluctuating, usually unilateral and progressive. The deafness may recover in large measure between episodes early in the disease but each episode tends to cause some additional permanent impairment.

The vertigo occurs in well-defined episodes. The definitive spell is often prostrating, frequently accompanied by nausea and sometimes vomiting, and persists for a prolonged period of time (20 minutes to no more than 24 hours). The patient is fully oriented and conscious throughout the spell and there are no neurologic accompaniments or sequelae to the spell except those referable to the end-organ. Vestibular nystagmus is always present (of the end-organ variety: fine, rapid, quick-slow, in a single definite direction, and horizontal or horizontal-rotatory). Between definitive spells there may be various kinds of adjunctive spells, such as motion intolerance, positional vertigo, falling attacks, and momentary ataxia on cornering, but the diagnosis is not tenable unless definitive spells are present with good health between them. During and briefly before a definitive spell hearing in the affected ear may decrease and tinnitus increase, remaining so for a variable time after the spell. It is accepted that many patients notice no subjective change in hearing during a spell, and it may rarely occur that hearing increases after a spell.

The tinnitus is quite variable and always subjective. It generally varies directly with the magnitude of the deafness.

Subvarieties of Ménière's disease

There are two subvarieties:

Cochlear Ménière's disease, or Ménière's disease without vertigo, is characterized solely by a fluctuating and progressive sensorineural deafness;

Vestibular Ménière's disease, or Ménière's disease without deafness is characterized solely by the definitive spells of vertigo.

Reporting results of treatment

The following criteria are offered reporting success or failure of therapy.

Vertigo

Control means absence of definitive spells for ten times the average interval between spells before treatment. In this group, a subgroup may be defined in which both definitive and adjunctive dizzy spells have been absent for ten times the average interval between definitive spells before treatment. If unindicated, it is assumed that some or all patients continue with adjunctive spells. A statistical analysis of the data reported is desirable.
Deafness

(1) *Hearing improved and serviceable* means a sustained pure tone threshold or SRT of 30 dB or better and a discrimination score of 80% better where one (or both) was not so before.

(2) *Hearing improved but nonserviceable* means either
   (a) a sustained increase in the speech frequencies of an average of 15 dB or more (but an SRT of greater than 30 dB) together with a discrimination score of at least 80% or an improvement of 15%, or
   (b) a discrimination score improvement of 20% or better
(3) *Hearing worse* means a 15 dB or greater loss in the average of the speech frequencies or a 15% or greater decrease in a discrimination score that was 80% or less
(4) *Hearing unchanged* means less than 15 dB change in the average of the speech frequencies, and less than a 15% change in discrimination score.

Reporting according to overall level of result

There is some value in uniformity of reporting according to overall result. It would seem to be useful if all authors and their readers could immediately know, by a simple letter designation for example, that the patients under discussion were relieved of all spells as well as the definitive or major spells, or that the patient under discussion received both improvement in hearing and relief of spells, etc. The following classified levels are suggested.

**Class A**

(1) Absence of definitive spells for described period (in addition, absence of adjunctive spells as well could be noted)
(2) Hearing improved (in addition, hearing improved as well as serviceable could be noted).

**Class B**

(1) Absence of definitive spells for described period
(2) Hearing unchanged.

**Class C**

(1) Absence of definitive spells for described period
(2) Hearing worse.

**Class D**

Failure of control of definitive spells.
Chapter 20: Ototoxicity

David A. Moffat

The sensitivity of the inner ear to the toxic effects of various therapeutic agents has been recognized for centuries, but our awareness of ototoxicity has been made more acute by the advent of the powerful aminoglycoside group of antibiotics. Hawkins (1976) has defined ototoxicity as:

'The tendency of certain therapeutic agents and other chemical substances to cause functional impairment and cellular degeneration of the tissues of the inner ear, and especially of the end-organs and neurons of the cochlear and vestibular divisions of the eighth cranial nerve.'

Synchronous with the exciting advances in medicine and surgery, there has been an explosive expansion of the modern pharmacopoeia and with it a proportional increase in the number of potentially ototoxic medicines. The list is now a long one and is continually expanding and the *Index-Handbook of Ototoxic Agents 1966-1971* (Worthington et al, 1973) needs to be updated. Aminoglycosides followed by salicylates, antiprotozoal agents and loop diuretics are the most important groups but apart from these are other antibiotics and analgesics, cytotoxics, anticoagulants, topical anaesthetics, antidepressants, antihistamines, anti-inflammatory preparations, antituberculous drugs, insulin and hypoglycaemic medications, sedatives and tranquilizers (including thalidomide), analeptics (including caffeine), cardiovascular agents, oral contraceptives and substances such as tobacco and marihuana. Groups including heavy metals and chemicals are of increasing importance since some of them are used as antiseptic agents and can produce a topical ototoxic effect when applied to the mucosa of the middle ear cleft. The number of drugs producing definite ototoxicity may be considerably less than this, however, since in the detection of ototoxicity reliance is often placed on subjective symptoms and tests and it is known that vertigo comprises 30% of the side-effects noted by patients taking a placebo!

Otolaryngologists must have a knowledge of these potentially ototoxic drugs, their proposed mechanism of action, and the factors predisposing to ototoxicity, not only because they will encounter cases within their own professional compass, but especially because they should be able to advise medical and surgical colleagues in other disciplines, particularly transplantation, where unforeseen ototoxic complications are more frequently encountered.

**Historical aspects**

It is not possible, with any degree of certainty, to determine the first description of the ototoxic effect of a medication. The early literature is difficult to appraise because the diseases being treated often produced a vestibulocochlear disturbance themselves and were often generally of such severity that an additional minor iatrogenic ototoxic effect could well have passed unreported. This is still the case today and makes the objective assessment of the adverse effects of drugs on the human ear a challenging problem which, even with the use of animal models, has not been completely resolved.
Arabic physicians used mercurial preparations to treat lice and skin rashes. Avicenna (980-1037) appears to have been the first to mention the untoward effect of mercury vapour inhalations on the ear: 'Fumus tollit auditem' (Avicenna, 1658). Hutten (1519) also ascribed possible ear disturbances to the use of mercurial preparations:

>'For the use of these ointments destroys the appetite, produces vertigos, madness, tremors, sometimes partial, sometimes universal and incurable ones.'

Petronius (1565) who had previously described tinnitus and deafness in syphilitic patients also noted that:

>'Many became blind and deaf under the use of the guaicum, sarsa and china.'

Long before the Spanish invasion, the Peruvian Indians used cinchona bark which contains quinine to treat various fevers, including malaria. Richard Morton, Physician-in-Ordinary to King William III was the first person to describe its ototoxic effect, in 1692, in the second of his two well-known books, *Pyretologica - A Book of Fevers*:

>'As for myself I can honestly declare, and after 25 years of daily use, I am experienced at putting its powers to the test, that I have never known anyone suffer a misfortune as a result of using the Bark, other than to experience a distressing type of hearing loss at the time of use, certainly the result of the disordered agitation of the spirit and the struggle between poison and counterpoison.'

In 1880, Charles Maillard used an audiometer which he constructed himself to record the reversible changes in hearing threshold following the administration of quinine sulphate. The first modern audiometric study of the effects of quinine on hearing threshold was by Pohlman and Kranz in 1922. The same authors were the first to document audiometrically the phenomenon of recruitment (Pohlman and Kranz, 1924).

As the culmination of many years of Ehrlich's work devoted to the production of an effective antibacterial agent, Salvarsan (sometimes known as arsphenamine or '606') was introduced by Ehrlich and Hata in 1910. It replaced mercury as the main treatment of syphilis, and by 1911 Ehrlich and McDonagh had reported eight cases of hearing impairment produced by the drug in a population of 7000 patients.

Along with the unfortunate ototoxic sequelae of the early medications, came the realization that the effective drug treatment of the disease may be achieved at the price of side-effects which were variable in severity but which could profoundly affect the patient's future quality of life. No drugs were to bring this more to light than the powerful aminoglycoside antibiotics.

**The aminoglycosides**

The 'unruly family of basic streptomycetes antibiotics' (Hawkins, 1959), which are closely related to one another in their microbiology, pharmacology and toxicity, have proved to be vital therapeutic tools in the treatment of serious infectious disease. They also represent
by far the most important group of ototoxic drugs and, in so doing, highlight one of the modern dilemmas of clinical practice. The justified concern about their toxic effects on the auditory and vestibular functions of the inner ear as well as the kidney, has complicated their effective use and compromised their therapeutic value.

In 1944 Waksman and his associates isolated streptomycin from *Actinomyces griseus* following a period of research directed towards extracting antimicrobial agents from various soil microorganisms (Waksman, Bugie and Schatz, 1944). Streptomycin proved to be the first effective chemotherapeutic agent against tuberculosis but, from the first report of its use in humans (Hinshaw and Feldman, 1945), it became evident that it could produce deafness and disturbances of balance. The former tended to occur when the dosage was high, for example 3 g daily (Bignall, Crofton and Thomas, 1951). This deafness rarely occurred if the dose did not exceed 0.5 g daily (Cawthorne and Ranger, 19570, or 24 mg/kg body weight (Meyler, 1963). Many of the patients who suffered from hearing impairment were being treated for tuberculous meningitis and the deafness may have resulted from tuberculous involvement of the eighth nerve rather than from the streptomycin (Jamieson, 1952). In Brown and Hinshaw's (1946) series, some of the patients suffering from hearing losses noted an improvement in hearing when the dose of streptomycin was lowered enabling the authors to conclude that the drug probably exerted a toxic action on the cochlea.

Caussé and colleagues (Caussé, Gondet and Vallancien, 1948; Caussé and Vallancien, 1949) demonstrated unequivocally from a well-designed series of experiments that the toxic vestibular effects of streptomycin were on the labyrinth rather than acting centrally. Although in adults streptomycin is mainly vestibulotoxic, its cochleotoxic effect is much more pronounced in infants (Šzékely and Draskovich, 1965; Pražić and Salaj, 1972). In view of the unpleasant vestibulotoxic symptoms produced by streptomycin, a search was made for a less toxic derivative. Dihydrostreptomycin, formed by the catalytic hydrogenation of streptomycin, was the result (Edison et al, 1948; Feldman, Karlson and Hinshaw, 1948). The drug had an equivalent antituberculous effect to streptomycin and the vestibular toxicity was less and later in onset, but it soon became apparent that it was much more cochleotoxic (Allison, Volk and Vitagliano, 1949; Glorig, 1951) and that its effect on hearing was unpredictable, sometimes delayed and frequently progressive. Subsequently dihydrostreptomycin was withdrawn from use. Early histopathological studies, in the cat, showed a loss of outer and inner hair cells in the second and third turns of the cochlea (Hawkins and Lurie, 1953).

Waksman had been continuing his work with various soil micro-organisms and, in 1949, he isolated from *Streptomyces fradiae* a group of antifungal compounds (Fradicin) and a new group of antibacterial substances that he called 'neomycin'. The structure of neomycin and of the aminoglycosides developed subsequently was quite distinct from that of the streptomycins. All the aminoglycosides consist of two or more amino sugars joined in a glycosidic linkage to a hexose nucleus. This hexose nucleus (an aminocyclitol) is streptidine in streptomycin and dihydrostreptomycin, and 2-deoxystreptamine in all the other aminoglycosides. The aminocyclitol is in a terminal position in the streptomycins, while it is central in all the other aminoglycosides.

Many other aminoglycosides have been produced and framycetin followed after neomycin. Kanamycin was discovered by Ūmezawa and colleagues, in 1957, and, in 1962,
Leach listed nine antibiotics, most of the aminoglycosides, which were 'known or suspected to be toxic to the labyrinth to a greater or lesser degree when administered parenterally'.

The gentamicins, introduced in the late 1960s, were unique in that they were the first aminoglycosides to be isolated from a source other than *Streptomyces* *spp*; in this case *Micromonospora purpurea* and *Micromonospora echinospora*, hence the difference in the spelling of the terminal -micin (Weinstein et al, 1963). Tobramycin (Higgins and Kastners, 1967) and sisomycin (Weinstein et al, 1970) followed and, in 1972, amikacin a derivative of kanamycin - the first semisynthetic aminoglycoside - was developed by Kawaguchi et al. Subsequently netilmicin (the 1-N-ethyl derivative of sisomycin) was produced by Wright in 1976. Continued clinical and commercial pressure to produce powerful broad-spectrum antibiotics especially active against Gram-negative organisms, and resistant to inactivation by bacterial enzymes, has resulted in the production of large numbers of new aminoglycosides, some of which will enter the clinical field.

All of the aminoglycoside antibiotics share the peculiar tendency to damage the inner ear to a greater or lesser degree. Some are predominantly cochleotoxic while others are vestibulotoxic. The toxicity which the different aminoglycosides manifest to the cochlea relates to the number of free amino groups (-NH₂) attached to the glycoside portion of the molecule, while a predominance of the methylamine groups (-NHCH₃) affects the vestibular apparatus (Hawkins, 1976).

Neomycin and kanamycin are particularly cochleotoxic, rarely affecting the vestibular system. On the other hand, gentamicin and tobramycin are mainly vestibulotoxic, but can exhibit both types. These drugs are also nephrotoxic. The early recognition of the ototoxicity of the aminoglycosides when administered parenterally tended to restrict their use to oral and topical preparations. This did not prevent the cochleotoxic effects, however, and there were numerous reports of sensorineural deafness following the oral administration of neomycin for bowel sterilization (Carr, Brown and Pfuetze, 1950; Last and Sherlock, 1960; Ballantyne, 1970). The belief that neomycin could be absorbed through the gut wall in the seriously ill was confirmed by Berk and Chalmers (1970) and Ward and Rounthwaite (1978) who made similar reports of deafness following oral administration.

It should not be forgotten that profound ototoxic deafness may occur following the use of topical creams, ointments and sprays containing aminoglycosides. Of particular importance in this respect is neomycin which is often applied to extensive areas of denuded skin following severe burns (Sugarbaker, Sabath and Morgan, 1974; Little and Lynn, 1975; Masur, Whelton and Whelton, 1976; Bamford and Jones, 1978). By the same token ototoxicity has been produced by intrabronchial (Loran, 1962), intrapleural (Leach, 1962) and intraperitoneal administration (Halpern and Heller, 1961), colonic irrigations (Fields, 1964), aerosols (Fuller, 1960; Morrell et al, 1985) and topical irrigation of wounds and draining sinuses (Campanelli, Grimes and West, 1966; Kelly, Nilo and Berggren, 1969). It may also be a sequel to the topical application of ear drops many of which contain aminoglycosides (see Ototopical ototoxicity).
Modes of access to the inner ear

Ototoxic antibiotics gain access to the fluids of the inner ear by way of the bloodstream either directly by intravenous administration or secondarily following intramuscular injection, absorption from the gut or topical application to denuded skin and mucosa. The toxic effect is greatly enhanced if they are given intrathecally (Ranta, 1958) and they may reach the labyrinth fluids by way of the cerebrospinal fluid and perilymph. Alternatively, they may be secreted into the perilymph from the vessels of the spiral ligament or into the endolymph from the stria vascularis (Hawkins, Beger and Aran, 1967).

Following topical application of the aminoglycosides to the mucosa of the middle ear cleft, the drug may reach the organ of Corti by passing through the round window membrane or annular ligament to the perilymph in the scala vestibuli and through Reissner's membrane into the endolymphatic space in the scala media.

Resorption in the stria vascularis is the probable mechanism by which the aminoglycosides are eradicated from the fluids of the inner ear (Osteyn and Tyberghien, 1968). The stria itself may be damaged by the ototoxicity thus slowing the rate of resorption of the drugs which are, therefore, removed from the inner ear more slowly than the blood. The hair cells are therefore exposed to high levels for a long time (Voldrich, 1965).

Incidence of aminoglycoside ototoxicity

This varies enormously depending on the number of cases studied, the specific drug and the criteria used. Reports in the literature relating to gentamicin vary from 3% (Jackson and Arcieri, 19710 to 25% (Myers, 1970). Impaired renal function was the dominant feature of patients who developed auditory or vestibular damage and, in this group, previous courses of ototoxic antibiotics and the total dose of gentamicin were also predisposing factors. The size of the daily dose of gentamicin was the only significant factor in those patients with normal renal function. Smith et al (1980) carried out a prospective double-blind comparison of the nephrotoxicity and auditory toxicity of gentamicin and tobramycin in which cochleotoxicity was noted in 10% of patients given gentamicin and 11% given tobramycin. A similar study by Fee (1980) revealed an overall incidence of 26%. Vestibular toxicity was associated with 15% of gentamicin and 5% of tobramycin courses. Factors predisposing to ototoxicity in this series were pyrexia, total dosage of drug, raised creatinine clearance, and therapy for more than 10 days. Daily dosage, serum levels, prior treatment with aminoglycosides, age, noise exposure, and the administration of other potentially ototoxic drugs did not appear to be significant.

Jackson (1967a) has defined the factors which predispose to aminoglycoside ototoxicity and they include: renal failure, high serum antibiotic levels (peak > 12 microg/mL), total antibiotic dosage (> 1 g in the case of gentamicin), patients aged over 60 years, and previous treatment with another ototoxic drug, either another aminoglycoside or a loop diuretic such as frusemide or ethacrynic acid. In patients treated by peritoneal dialysis, it is not possible to calculate the total dose of the antibiotic.

A more recent analysis of risk factors by Moore and Smith (19840 has incriminated a long period of therapy, bacteraemia, and a raised temperature in the development of
auditory toxicity. Kennet, Guess and Chole (1983) have also shown that hyperthermia increases aminoglycoside ototoxicity. Studies in mice have shown that susceptibility to ototoxic hearing loss may be age dependent (Prieve and Yantz, 1984).

Certain families show an unusual predisposition to aminoglycoside ototoxicity (Podvinec and Stefanovic, 1966; Miszke, 1972) and, in the very young and in the elderly, very high concentrations of aminoglycosides may appear in the blood even after ordinary doses.

**Clinical features of ototoxicity**

**Tinnitus**

This symptom often represents the initial manifestation of toxic damage to the cochlea and is usually high frequency and continuous. The tinnitus may only become apparent after the drug has been withdrawn due either to delay in onset or initial failure of the patient to notice it. It is clinically important to realize that the symptoms of ototoxicity may progress after completion of therapy.

**Deafness**

A high frequency sensorineural hearing loss is seen initially and may be marked before the patient is aware of the hearing defect, especially if the threshold is maintained in the speech range of frequencies. A z-shaped audiogram may be seen at a certain stage of gentamicin toxicity (Huizing, 1972) and recruitment can be demonstrated (Lidén, 1953). Deafness often appears after a latent period and may become progressively worse as treatment is continued. Eventually the hearing loss progresses to involve the speech frequencies and below, and the patient may become profoundly deaf. If the antibiotic is stopped further deterioration in hearing may be prevented in some patients, at least so long as renal function remains normal. Dihydrostreptomycin is an exception in this regard and an insignificant hearing loss during treatment may progress to a severe deafness after the antibiotic has been discontinued (Šupáček, 1972).

Gentamicin and streptomycin, while displaying a predilection for the vestibular neuroepithelium, can cause deafness (Arcieri et al, 1970; Jackson, 1967b). Stephens (1968) described the development of a profound bilateral sensorineural hearing loss in a uraemic patient treated with gentamicin which was felt to have accentuated previous damage caused by streptomycin. Moffat and Ramsden (1977) have described sudden profound bilateral sensorineural hearing loss caused by gentamicin and considerable recovery of hearing eventually occurred within one year.

Clearly, concomitant nephrotoxicity will increase the rapidity of onset of ototoxic symptoms and, in patients with renal insufficiency, the blood levels of any aminoglycoside must be carefully monitored and the dose adjusted to avoid damage to the inner ear.
**Dysequilibrium**

The vestibular toxicity of the aminoglycosides is mainly directed to the vestibular end-organs. In addition to streptomycin, gentamicin, tobramycin and the polycationic non-aminoglycoside viomycin also exhibit this feature. The pattern of the dysequilibrium is characteristic (Wallner, 1949) and there is an inability to focus sharply; distant objects appear to jump about on sudden head and body movements. No nystagmus is observable and the caloric and rotational tests show a bilateral loss of labyrinthine function. This is known as bobbing oscillopsia, a term first coined by Brickner in 1936 to describe a visual illusion of oscillating movement of stationary objects caused by concurrent nystagmus. Maw (1971) is one of the most recent authors to emphasize that this symptom can arise from lesions to the peripheral vestibular system. Ramsden and Akrill (1982) have pointed out that gentamicin toxicity by producing hypofunction of the labyrinth would reduce or obliterate vestibulo-ocular tonus and that at head movement frequencies of greater than 1-5 Hz, bobbing oscillopsia would occur. Patients may also experience vertigo and a sense of continued rotation after turning the head or turning over in bed, but true rotatory vertigo is rare. The acute bilateral loss of labyrinthine function produces difficulty for ambulatory patients in the dark or walking on uneven ground. The vestibulotoxicity of the aminoglycosides may not become apparent immediately, since the patients are often ill and confined to bed. Even on mobilization, their unsteadiness may be ascribed to the debility of their illness and diagnosis may be delayed or even overlooked.

**Pharmacokinetics**

The half-life of aminoglycosides in the perilymph and endolymph appears to be much greater than in the blood, and it has been suggested that the concentration of the aminoglycosides in the endolymph probably plays a prominent part in the development of their ototoxic action (Tran Ba Huy, Manuel and Meulemans, 1981).

The long half-life of the aminoglycosides in the inner ear fluids has also been demonstrated in the cat by Vrabec, Cody and Ulrich (1965). The cochleotoxicity of neomycin may be related to the observation that a dose of 150 mg/kg produced detectable levels in perilymph 55 hours later (Voldrich, 1965). More recently studies of the pharmacokinetics of gentamicin and tobramycin (Federspil, Schatzle and Tiesler, 1977; Brummett et al, 1978) have shown a slow and high rise in drug concentration in the perilymph and endolymph after parenteral administration with therapeutic levels occurring only after 2-5 hours.

Stupp (1972) found that the more toxic the substance, the higher its concentration in the inner ear, whether it was applied topically or given systemically by intramuscular injection. Other non-aminoglycoside antibiotics such as polymyxin, tetracyclines, chloramphenicol and erythromycin caused no damage when given intramuscularly because of their inability to penetrate the inner ear through the blood-lymph barrier. When applied topically to the middle ear, however, damage to the sensory cells occurred. Only penicillin, independent of its mode of administration, failed to produce any harmful effects on the inner ear.

Portmann and Darrouzet (1974) studied the distribution of tritiated dihydrostreptomycin in the guinea-pig cochlea. The drug spread by way of the perilymph across Reissner's and the
basilar membrane to concentrate in the supporting Deiters' cells after one hour. At 4 hours, a predilection for the ribosomal fraction of the outer hair cells was noted with much less radioactivity over the inner hair cells. From a series of experiments on guinea-pigs, in which the relative concentrations of kanamycin in the blood, heart muscle and perilymph were measured following subcutaneous injections of varying doses (25, 50, 250 mg/kg body weight) of kanamycin, Stupp et al (1967) came to the conclusion that the drug actively accumulated in the perilymph and endolymph. When the dose of kanamycin was doubled from 25 to 50 mg/kg body weight, there was a 10-fold increase in the concentration of kanamycin in the perilymph but at higher doses (250 mg/kg body weight) it did not increase. This disproportionate increase in kanamycin concentration was explained by enlargement of the cells of the inner ear and swelling of the nuclei (Müsebeck, 1964; Kohonen, 1965) as the first manifestation of intoxication leading to compression and occlusion of the intercellular gaps reducing the extracellular space. Kanamycin, it was proposed, blocked its own way out of the inner ear by impeding diffusion.

In the second phase of kanamycin intoxication, there was an increasing blockage of the active resorptive processes in the membrane causing a limitation of lymph circulation and ion and water transport. This was thought to account for the apparent arrest of the accumulation process of kanamycin. At that time, it was thought strange that the inhibition of the active resorption of the membrane did not affect the kanamycin elimination which was dependent on the concentration gradient.

Recently the meticulous work of Tran Ban Huy et al (Tran Ba Huy, Manuel and Meulemans, 1981; Tran Ba Huy et al, 1981, 1983a, b), on rats, has cast doubt on Stupp's original theories. These workers ensured that the plasma levels of gentamicin stayed within a narrow range, by using a continuous intravenous infusion (pumps delivering 10 microg/minute), and carefully checked that there was no evidence of renal failure. Gentamicin entered the perilymph first and only very slowly entered the endolymph. The half-life ($t_{1/2}$) of gentamicin in the plasma was rapid as in previous studies ($t_{1/2}$ of 40 minutes). The disappearance from perilymph was slow (it was still detectable at 15 days), and even slower from the endolymph. It was concluded that the aminoglycosides do not actively 'accumulate' in the perilymph or endolymph, the levels in these two compartments being dependent on plasma levels, and that there does not appear to be a threshold for entry into these compartments as proposed by Stupp et al (1973). The slow removal of the aminoglycosides from the cochlea suggests that either they were bound to tissues within the inner ear and only released slowly, or that the aminoglycosides altered the boundary membranes making them less permeable. Although the first suggestion is attractive, Desrochers and Schacht (1982) were unable to find any accumulation of neomycin in the dissected tissues of the stria vascularis or organ of Corti after chronic administration to guinea-pigs. The second possibility is unlikely, since the aminoglycosides are thought to increase membrane permeability (Lodhi, Weiner and Schacht, 1979; Schacht, 1979). The mechanism of the distribution of the aminoglycosides within the cochlea is far from established.

The importance of the concentration of aminoglycoside in the endolymph was highlighted by Konishi (1979) and Lodhi et al (1980) who have shown that when the aminoglycosides are administered directly into either peri- or endolymph, then the concentration needed to alter the cochlear microphonic is lower when the endolymphatic route is used.
Schacht (1979) has also shown that the aminoglycosides interact with the polyphosphoinositides, which are a small fraction of the phospholipids in the cell membrane and are found in high concentration in the brain, kidney and cochlea and which are strongly implicated in the control of membrane permeability. Wiener and Schacht (1981) have suggested that the avid binding of aminoglycosides to the polyphosphoinositides located in the cell membrane of the stria and organ of Corti lead to increased permeability and, by allowing more aminoglycoside into the cell, this may well be the first stage in the mechanism of the ototoxic action of these drugs. The formation of an aminoglycoside-lipid complex may occupy the binding site for calcium ions blocking the phosphorylation-dephosphorylation cycle, and thus disturb the normal function of the membrane leading to cell death.

The cell bodies of the inner and outer hair cells lie in the organ of Corti which is isolated from the endolymph by a series of tight intercellular junctions or zona occludentes. This would account for the very long equilibration times and low levels of aminoglycoside in the endolymph. There is continuity between the scala tympani and the extracellular spaces of the spiral ligament, spiral limbus and organ of Corti, and the bodies of the sensory cells are not therefore isolated from perilymph or cortilymph. In this case, the concentration of drug in the perilymph is more relevant to the expression of ototoxicity than its concentration in endolymph and this would explain the direct relationship between the level of drug in the perilymph and the degree of ototoxicity (Federspil, Schatzle and Tielsr, 1977; Brummett et al, 1978).

The measurement of perilymph concentrations of gentamicin in early post-mortem human material was carried out by Lerner et al (1981). The mean perilymph levels were significantly higher in those patients with abnormal renal function, supporting the findings of Jackson and Arcieri (1971) which suggested that impaired renal function was the most important factor in the development of aminoglycoside ototoxicity.

Other metabolic studies

The action of enzymes is responsible for maintaining the active transport of ions across cell membranes and ATPase, which is involved in sodium and potassium transport, has been found in the stria vascularis and spiral ligament of the guinea-pig (Inuma, Mizukoshi and Daly, 1967). Ototoxic drugs can reduce the membrane ATPase and thus interfere with intracellular metabolic processes changing the ionic content of the endolymph (Mendelsohn and Konishi, 1969; Konishi and Mendelsohn, 1970) leading to a fall in the potassium (normally high in endolymph) and a rise in sodium ions. Kanamycin can lead to a loss of membrane ATPase in the stria vascularis and spiral ligament and thus cause damage (Matz, Wallace and Ward, 1965; Koide et al, 1966; Osteyn and Tyberghein, 1968).

Intraperitoneal injection of high doses of kanamycin sulphate in guinea-pigs can produce highly significant changes in the cation content of the endolymph with a considerable fall in potassium and a huge rise in sodium (Mendelsohn and Katzenberg, 1972). They also found a fall in the endocochlear potential, corresponding to a reduction of the endolympathic potassium level.

The intracellular glycogen level is a sensitive indicator of cell damage and permanent damage to the outer cells in the cochlea produced by tobramycin sulphate is most prevalent
in areas that normally have the least amount and the smallest granule size of glycogen (Postma et al, 1976).

In recent experiments *in vitro* by Sitaras et al (1985), it was shown that aminoglycosides, in contrast to other antibiotics inhibited the metachromatic reaction using o-toluidine blue as a basic dye and heparin-sodium as a polysulphate-polysaccharide substrate. The inhibitory concentrations were inversely proportional to the free amino groups of the aminoglycosides tested. Since the aminoglycosides antagonize the presence of Ca$$^{++}$$, and mechanisms of ototoxicity involve ionic alterations in endolymph, it was suggested that aminoglycoside ototoxicity could be the result of the reaction between these drugs and ionic polyelectrolytes of the group of polysulphated polysaccharides in a metachromic process.

As a result of multiple animal experiments, a great number of scientific papers have appeared in the literature concerning the pharmacokinetics of the aminoglycosides in the inner ear. Clinicians must be very critical in their appraisal of this work and, in particular, great care must be taken not to extrapolate the observed biochemical, physiological and anatomical changes to the human inner ear. There are a number of reasons for this. The analysis of the distribution of the aminoglycosides within the cochlea is made difficult because, until recently, the assays available for aminoglycoside determination have been relatively insensitive so that very large non-therapeutic doses have had to be administered to allow their subsequent reaction in perilymph and these cause unequivocal evidence of histological damage. Aminoglycosides can bind to ionized calcium in the blood to form a complex (Kubikowski and Szrenawski, 1963; Crawford and Bowen, 1971) producing neuromuscular blockade with respiratory depression and acidosis. This effect, as well as nephrotoxicity, can alter the clearance of the drug from the plasma and increase the possibility of cochlear damage. Repeated intramuscular doses do not yield reproducible peak plasma levels (Tran Ba Huy, Manuel and Meulemans, 1981; Tran Ba Huy et al, 1981) and different species distribute an equivalent dose of aminoglycoside in different ways so that maximum plasma concentrations are extremely variable. Experimental animals are given large single doses which bear no relation to those used in clinical practice and large swings in plasma levels are seen. Despite this there is no doubt of the great value of the animal model and carefully controlled, scientifically valid studies, notably on the inner ear of the guinea-pig and cat, but also others, have led to a greater understanding of aminoglycoside ototoxicity.

**Electrophysiological measurements**

Since the ototoxic effects of the aminoglycosides are directed at the inner ear, electrophysiological measurements may be obtained by electrocochleography, recording of the endocochlear potential and of single units.

**Electrocochleography**

The demonstration that the cochlear microphonic is produced by vibration of the hair cells of the organ of Corti (Davis et al, 1934) was accompanied by the observation that no cochlear microphonic could be recorded when the hair cells were profoundly altered. In 1950, Hawkins noticed that the cochlear microphonic was markedly reduced in cats treated with streptomycin and this allowed Davis et al (1958) to conclude that the cochlear microphonic is essentially produced by the outer hair cells, since streptomycin damages these cells. By
recording both the cochlear microphonic and summating potential in kanamycin-treated guinea-pigs, Dallos and Cheatham (1976) were able to map areas of outer hair cell loss in the cochlea since a marked reduction in the amplitude of both was seen. In the study of the cochlear microphonic, a differential recording procedure (scala tympani versus scala vestibuli) is the method of choice since responses from restricted portions along the basilar membrane can be registered. Recording the cochlear microphonic from the round window membrane is less specific and the basal coil produced a cochlear microphonic to all frequencies. In the evaluation of the damage caused by ototoxic drugs, cochlear microphonic measurements (Brummett, Meikle and Vernon, 1971) together with observations on the Preyer pinna reflex and histopathological counts of the hair cells, have commonly been used but little information about the inner hair cell can be obtained from the cochlear microphonic.

The compound auditory nerve action potential is a useful measurement in studies in ototoxicity. It is easy to plot frequency/threshold and latency/frequency curves using the action potential evoked by clicks, tone pips or tone bursts since its presence or absence is obvious, whereas the cochlear microphonic only measures isopotential curves. Place information can be inferred from the latency of neural responses through the use of input/output functions for amplitude and latency of the action potential at various sound intensities; thus information relating to the functioning of the outer and inner hair fells can be obtained. Chronically implanted electrodes allow these electrophysiological recordings to be made in long-term studies of ototoxicity (Aran, 1981).

Logan and his colleagues (1974) demonstrated in guinea-pigs a dose-related decrease in both the action potential and the cochlear microphonic within 5 minutes of tobramycin infusion. Furthermore, they were able to record, from an intracochlear electrode, an immediate and profound decrease in the magnitude of the endolymphatic potential. Wilson and Ramsden (1977) obtained similar results using continuous trans-tympanic electrocochleographic recordings following intravenous tobramycin administration. No changes in the action potential or cochlear microphonic were observed following gentamicin. Contrary to this, a reduction in the action potential and cochlear microphonic following intravenous gentamicin was observed by Keene and Graham (1984). The rapidity of onset of the changes observed both in the guinea-pig, and in humans, suggest a metabolic block at one or more sites in the cochlea, possibly the organ of Corti or the stria vascularis. Blocking of cation transport (Crawford and Bowen, 1971), interruption of cell respiration and interference with phosphoinositide metabolism (Schacht, 1974; Tachibana, Anniko and Schacht, 1984) are the most probable modes of action of the drug.

The slower structural damage to hair cells that leads to permanent deafness is more likely to come from the later direct toxic effect of a high aminoglycoside level in perilymph and endolymph and may be due to changes in protein synthesis and RNA (Beck, 1965).

**Endocochlear resting potential**

The maintenance of this positive potential is dependent on the metabolic mechanisms inside the cochlear compartments. A decline in this potential is seen when the aminoglycosides exert a toxic effect on the inner ear and the endocochlear resting potential is a sensitive indicator of early metabolic changes. The endocochlear resting potential has also been analysed extensively in experiments on the combined effects of aminoglycoside
antibiotics and loop diuretics. The endocochlear resting potential is not dependent on the presence of hair cells.

**Single-unit recordings**

The effects of aminoglycoside treatment have been studied at the basic functional level, that is the single cell. Investigators have used the effects of these drugs in order to demonstrate fundamental properties of the cochlea and, in particular, the changes in threshold and tuning of single fibres associated with outer hair cell loss (Harrison and Evans, 1977). Recordings of single cochlear nerve fibres in the cat, following high doses of salicylate, have been used as an animal model for tinnitus (Evans, Wilson and Borerwe, 1981).

**Histopathology in animals**

The major changes that occur in the tissues of the inner ear in response to the ototoxic action of the aminoglycoside antibiotics are found in the organ of Corti, the ampullary cristae, and in the maculae of the utricle and saccule. The destruction and disappearance of sensory cells and other structures of these neuroepithelia can easily be observed by light microscopy, as first demonstrated in conventional serial sections of celloidin-embedded temporal bones from experimental animals treated with streptomycin (Berg, 1949; Jarlstedt and Bagger-Sjöbäck, 1977). The method of microdissection and surface preparation of inner tissues stained with osmium tetroxide (Caussé and Vallancien, 1949; Christensen et al, 1951; Engström, 1951) avoids the delays which are inherent in the processes of decalcification and celloidin embedding and has formed the basis of many studies on the histopathological changes in the sensory epithelia of animals treated with aminoglycoside antibiotics. It makes possible a detailed, quantitative assessment of the extent and severity of hair cell loss in the form of a cytocochleogram, which is based on a count of hair cells over the whole length of the basilar membrane. The use of quantitative techniques for the determination of hair cell degeneration has facilitated studies of localization and progression of cochlear hair cell damage after antibiotic intoxication. The introduction of transmission (Wersäll and Hawkins, 1962; Duvall and Wersäll, 1964) and scanning electron microscopy (Wersäll et al 1971) for the analysis of fine structural damage of the inner ear after antibiotic intoxication, has provided abundant data on the detailed histopathology.

**Cochleotoxicity**

The pattern of degeneration of sensory cells in the organ of Corti is similar, but not identical, for the various aminoglycoside antibiotics. The outer hair cells are generally more sensitive to damage than the inner and the first row of outer hair cells (closest to the tunnel of Corti) are more severely damaged than the others (Hawkins and Engström, 1964; Kohonen, 1965; Ylikoski, Wersäll and Björkroth, 1974). One of the earliest changes is a distortion of the normal W-pattern of the stereocilia on the outer hair cells. With increasing damage, the hairs of some cells are entirely lost and the whole cell may disappear leaving a 'phalangeal scar'. The greatest degeneration occurs in the basal turn of the cochlea, with progressive involvement of hair cells along the basilar membrane towards the apex when the dosage level and duration of treatment are increased (Hawkins and Engström, 1964; Kohonen, 1965). Damage is confined to the basal turn in short-term high dose treatment and is scattered over large areas of the cochlea in long-term low dose treatment. There is, however, considerable
variation at the same dose schedule (Ylikoski, 1974) and neomycin is exceptional in producing more severe early damage to the apical part of the cochlea. The sensory cells are much more sensitive to damage than the supporting cells and this may be because they have more reactive sites in the plasma membrane from which calcium can be displaced by the aminoglycosides (Weiner and Schacht, 1981). The order of degeneration is first, second and third rows of outer hair cells, pillar cells, Deiters’ cells and Hensen cells. Degeneration of the inner hair cells, which are affected much later than the outer, begins at the apex and progresses towards the base.

It may be that the sensory cells, which have the greatest metabolic activity, are the first to be affected by ototoxic antibiotics and there is now evidence that these are the outer hair cells. Innervation of the outer hair cells in the basal coil of the cochlea is denser than in the apical (Smith, 1961; Engström and Kohonen, 1965) and this may reflect the higher metabolic activity. Oxygen consumption of the stria vascularis is higher in the basal than in the apical areas and Osteyn and Tyberghein (1968) found that the stria was always affected when the outer hair cells were damaged and the impairment in these two structures developed in parallel from base to apex.

**Fine structural damage of cochlear hair cells**

The stereocilia of the outer hair cells may lose their integrity and collapse, the surface of the organ of Corti becoming covered with debris, the origin of which is apparent. Where all the outer hair cells are lost, there may also be a loss of inner hair cells and the stereocilia of the inner hair cells close to the region of damage may be fused or collapsed. The supporting cells have a profusion of microvilli on their endolymphatic surface and stereocilia may be buckled or fused. The fusion tends to be limited to the tips of the stereocilia.

Transmission electron microscopy reveals early cellular changes. A typical sign of early damage is an accumulation of dense bodies, some of which are lysosomes or phospholysosomes in the subcuticular region and along the sides of the hair cells. This indicates a high enzymatic degradation activity during the early phases of ototoxic damage and an increased acid phosphatase activity demonstrating a considerable capacity of the sensory cells to digest the degenerating cell structures (Wersäll, 1956; Lindeman, 1969; Wersäll et al, 1971). The interspaces between pairs of membranes located on the inside of the hair cells become irregular. This indicates degeneration of the membrane substance of the Hensen body with formation of new phospholipid membranes.

As the degeneration of the cell progresses, the mitochondria begin to disintegrate due to the toxic effect on the membrane components and the permeability barrier of the cell. Some accumulate dark substances and form lamellated bodies while others swell. The ribosomes decrease in number demonstrating that RNA metabolism might be affected by the antibiotics (Jarlstedt and Bagger-Sjöbäck, 1977) and the cells become watery in appearance with large clear areas lacking cellular content. Vacuoles are formed within the cells and finally the plasma membrane disintegrates. Cell debris is often found between remaining sensory hairs in the vicinity of degenerating hair cells.

Nuclear swelling is an early sign of degeneration and can be observed in otherwise intact sensory cells. When the inner hair cells degenerate, collapse and degeneration of the
pillar cells soon follow and then Deiters' and pillar cells degenerate and are absorbed. Finally, the whole organ of Corti disappears, leaving behind a single layer of cells on the basilar membrane.

Retrograde degeneration (Ylikoski, Wersäll and Björkroth, 1974) and disintegration of the afferent nerve endings occur very soon after hair cell degeneration, but efferent nerve endings take much longer, although degeneration eventually occurs; 80-90% of the nerve fibres and ganglion cells are preserved when only the outer hair cells have degenerated.

Marked blistering of the stria vascularis is often observed by scanning electron microscopy and the endolymphatic surface of the cells has relatively few microvilli (Wright, 1986). The changes in the stria are marked in the basal and middle turns. Transmission electron microscopy shows blistering of the endolymphatic surface of the strial cells, with widened intercellular spaces the plasma membrane and possibly in other. The surface blisters have a limiting bilaminar membrane and are usually filled with a homogeneous matrix, although occasionally organelles are present. The rest of the marginal cell is indistinguishable from other marginal cells. The tight junctions between neighbouring marginal cells remain intact, but wide intercellular spaces between marginal and intermediate cells appear to be the result of shrinkage of the processes of the intermediate cells. The basal cells are unaffected but the capillaries tend to have only sparse cellular content.

Vestibulotoxicity

The pattern of degeneration in the vestibular part of the labyrinth seems to vary, depending on the antibiotic used, the frequency and route of administration, and the total dose. Concentrated solutions of streptomycin or gentamicin (25-50%) applied directly to the round window cause nuclear pyknosis and rapid disintegration of the sensory cells. On the other hand, a drop of streptomycin or gentamicin containing 3-5 mg/mL, when applied to the round window of guinea-pigs once a day for 7 days, produces structural changes similar to those found after parenteral antibiotic treatment in low dosage for 3-5 weeks. Fusion of the sensory hair takes place and, if this becomes complete, the surface plasma membrane forms a large, balloon-shaped protrusion from the sensory cell surface which is filled with organelles. The sensory hair fusion in the vestibular system indicates that an early action of aminoglycosides on the sensory cells affects the plasma membrane. Demonstration of interactions of neomycin with molecular films of polyphosphoinositides and other lipids indicates that aminoglycoside antibiotics can interfere with phospholipid function in the plasma membrane and possibly in other organelles in the cells, such as the membranes of the mitochondria and the endoplasmic reticulum (Lodhi, Weiner and Schacht, 1979). Disintegration of the cell in situ may occur or it may disappear into the endolymph. Intracellular dark bodies, some of which are lysosomes and others degenerated mitochondria, seem to increase in number. The density of the nucleus increases and in some cases it swells and disintegrates. During the later stages of degeneration, vesicles form within the cytoplasm, the plasma membrane breaks down, and cellular debris is either pushed out into the endolymph between the supporting cells or taken up by the phagocytic activity of the neighbouring cells.

Type I sensory cells are more sensitive to degeneration than type II in the crista ampullaris, and degeneration begins in the central part and spreads peripherally. Degeneration
of the crista ampullaris precedes that of the utricle and saccule. The afferent nerve endings degenerate in parallel with the sensory cells, whereas the efferent fibres may remain between the supporting cells for some time, even after most of the sensory cells have disappeared.

The supporting cells remain intact long after the degeneration of most of the sensory cells and nerve endings and flattening of the epithelium occurs. Signs of degeneration in the ganglion cells appear during the later stages of degeneration.

**Histopathology in humans**

In an attempt to validate the use of the animal model in studies in ototoxicity and in evaluating new drugs, Wright (1986) has studied post-mortem human temporal bone histopathology in patients who had received aminoglycoside antibiotics immediately prior to their death. Three forms of preservation of inner ear tissues were evaluated, and only perfusion of the cochlea with fixative within one hour of death gave results that were free from artefact and therefore allowed any change to be confidently ascribed to pathology rather than post-mortem autolysis.

The observed structural findings in the human closely resembled those found in previous animal studies, although the site of early hair cell loss was different from that found in guinea-pigs. The results of this work have validated the use of animal models to predict a clinical effect in humans bearing in mind inter species variability and, even though the animals are healthy, they are given dosage schedules that do not resemble those given to patients who are unwell and may be in renal failure.

**Ototoxicity and renal status**

The excretion of the aminoglycoside antibiotics occurs by glomerular filtration in the kidney and, therefore, impairment of renal function may allow excessively high plasma levels to develop and enhance their ototoxic effects (Waisbren and Spink, 1950; Goldner, 1958; Greenwood, 1959; Ballantyne, 1970; Miszke, 1972). Many of the aminoglycosides are themselves nephrotoxic and the ability of the kidney to eliminate them may in part determine individual susceptibility to these drugs. It should be carefully noted, however, that it may be the renal failure itself, with its metabolic, electrolyte and osmotic changes, which is responsible for the hearing impairment rather than the aminoglycosides and there is certainly a strong association between hereditary renal disease and deafness (Bergstrom et al, 1973).

Many papers have shown that renal failure or its treatment by repeated dialysis or transplantation may result in sensorineural deafness and other auditory symptoms (Bergstrom et al, 1973; Oda et al, 1974), but it is not easy to prove (Quick, 1976). Hyponatraemia and hearing loss in renal failure have been described by Yassin, Badry and Fatt-Hi (1970) and the hearing improved when the serum sodium was restored to normal. This could account for the fluctuant hearing loss sometimes observed in patients undergoing dialysis. A number of patients do not improve following correction of the serum electrolytes and blood urea (Mitschke et al, 1975).

There are certain resemblances between the structure of the stria vascularis and the glomerular tufts of the kidney and, in cases of hereditary nephritis with documented hearing
loss, the strial changes are similar to those seen in the glomerular basement membrane from renal biopsies of the same patients. Merck, Hoppe-Seyler and Curten (1976) have shown marked changes in the intermediate and marginal cells of the stria vascularis of uraemic rats. The relationship between altered renal function and the ototoxicity of the aminoglycosides is too strong to deny (Jackson and Arcieri, 1971) and this is presumably due to altered renal clearance and toxic levels of drug in the endo- and perilymph. However, even if the serum level of the aminoglycosides is monitored and kept within conventionally safe limits, there is still a risk of ototoxicity which appears to be independent of renal damage.

**Ototoxic mechanisms**

From the foregoing, it is clear that, although a great deal of important electrophysiological, biochemical and histopathological information concerning the ototoxic effects of drugs has emerged in recent years, the precise mechanism by which the drugs act on the inner ear has yet to be elucidated. It seems likely that the aminoglycosides have immediate, delayed and long-term ototoxic effects. The immediate effects are seen as a decrease in the resting endolymphatic potential, cochlear microphonic and action potential and may not be associated with any subjective change in the patient's hearing threshold and are often reversible, returning rapidly to normal. These changes cast doubt on the haematolabyrinthine barrier proposed by Hawkins (1973) and support the theory of a metabolic block in the cochlea; a reduction of ATPase with blocking of cation transport, interruption of cell respiration and interference with phosphoinositide metabolism are the most probable modes of action.

Intermediate effects produce a clinical deafness which may be partially reversible and some recovery in hearing can occur (Moffat and Ramsden, 1977). This may reflect toxic effects on cell metabolism with increased membrane permeability and histopathological changes in the hair cells are observed, some of which may be reversible.

Long-term effects are associated with permanent, often profound, deafness with dramatic histopathological changes in the organ of Corti and vestibular neuroepithelium. Irreversible changes in DNA and protein synthesis may occur.

**Other antibiotics**

While the aminoglycoside group of antibiotics is the most important in exhibiting ototoxicity, it is not peculiar to it and other antibiotics can behave in a similar fashion. Vancomycin is used occasionally to treat penicillin-resistant staphylococcal infections, and excessive blood levels (80-100 microg/mL) may produce irreversible sensorineural hearing loss which progresses after the drug is discontinued (Geraci et al, 1958). Viomycin, a basic polypeptide antibiotic derived from *Actinomyces spp*, is an effective antituberculous drug known to produce cochleovestibular damage (Leach, 1962). The polymyxin group also consists of polypeptides normally used topically, but occasionally systemically, and which have ototoxic potential. Chloramphenicol is known to be ototoxic when used topically in the ear (D'Angelo, Patterson and Morrow, 1967), but its systemic use has only produced a small number of reports of sensorineural hearing loss (Gargye and Dutta, 1959; Svenungsson et al, 1976; Iqbal and Srivatsav, 1984). An immunological basis has been postulated for the serious toxic effect of chloramphenicol on the bone marrow and optic nerve, and the idiosyncratic
response, in which previous exposure to the drug is an important factor, may be responsible for the ototoxicity.

Transient sensorineural deafness after the administration of erythromycin has been reported in the literature and five of the six patients received the drug intravenously as erythromycin lactobionate. All those developing the deafness were female and the significant change of the acid radical in the intravenous form of the drug and the mechanism of the temporary cochlear dysfunction remains unclear (Karmody and Weinstein, 1977). One report of ototoxicity from erythromycin administered orally was in a diabetic where nephropathy may have contributed significantly to the ototoxicity with oral medication (Eckman, Johnson and Reiss, 1975).

Minocycline, one of the more recently evolved tetracyclines, may be responsible for transient reversible vertigo, but its effects have not been fully evaluated.

**Loop diuretics**

It has been known for many years that the 'loop-inhibiting' diuretics have ototoxic effects, namely deafness and sometimes vertigo, and the two most potent drugs in general use are ethacrynic acid and frusemide (furosemide). The ototoxic effects are usually seen when the drugs are administered *intravenously*. Their principal mode of action is on the ascending loop of Henle where they inhibit reabsorption of sodium and water (Hawkins, 1976).

**Ethacrynic acid**

Maher and Schreiner (1965) were the first to describe immediate and reversible sensorineural hearing loss and vertigo following the oral or intravenous administration of ethacrynic acid to patients with renal failure. Schneider and Becker (1966), Schmidt and Friedman (1967) and Ballantyne (1970) also reported the ototoxic effects of this drug which may last a few hours to several days even in patients with normal renal function. Although Pillay et al (1969) claimed that permanent losses could occur, this was not generally agreed and it was the studies of Brummett, Traynor and Brown (1975) which clarified the situation by demonstrating the conditions under which ethacrynic acid could produce temporary and permanent effects. Ethacrynic acid used alone produced a reversible depression of cochlear activity and no damage to the organ of Corti. Permanent depression of cochlear activity and severe damage to the organ of Corti was seen when ethacrynic acid was used in combination with any ototoxic aminoglycoside. The same applies to frusemide or any loop-inhibiting diuretic.

**Frusemide**

Transient cochleotoxic effects, occasionally with vertigo, have been observed after rapid infusion of high doses of frusemide by Schwartz et al (1970) and Venkateswaran (1971). Permanent hearing losses have also been reported by Llloyd-Mostyn and Lord (1971) and Quick and Hoppe (1975), but the latter authors realized the problem of ascribing the hearing loss to the drug when 5% of their renal transplant and dialysis patients became deaf anyway during the course of their disease. The great difficulty in separating the causes of
deafness in patients with renal failure who may have received loop-inhibiting diuretics and/or aminoglycoside antibiotics remains to this day.

**Bumetanide**

This benzoic acid derivative is one of the most recent loop diuretics to be introduced and was synthesized by Feil in 1971. It appears to have a lower ototoxic potential than frusemide (Bourke, 1976; Tuzel, 1981).

**Mechanism of diuretic ototoxicity**

Correlation of the available neurophysiological and histopathological evidence points to mediation of the toxic effect in the stria vascularis. Within a few seconds of the intravenous administration of ethacrynic acid or frusemide, there is a depression of the cochlear microphonic and eighth nerve action potential (Mathog et al, 1970), as well as a decrease in vestibular nystagmus in response to caloric irrigation (Levinson, Capps and Mathog, 1974). These functions usually return to normal within one hour, although the cochlear microphonic may recover slowly over a period of days (Kohonen, Jauhainen and Tarkkanen, 1970). A rapid decline in the normally positive endolymphatic potential with a return to normal within a few hours has also been observed. It was thought that these neurophysiological changes resulted from changes in the electrolyte composition of the endolymph and 'cortilymph', the perilymph being remarkably stable in its composition during intoxication. Alterations in the active transport systems that maintain the electrolytic composition of the endolymph and which are located in the stria vascularis change the endolymphatic potential (Bosher, 1981) and may be responsible for these observations.

Morphological assessment of the cochlea after treatment with large doses of loop diuretics have shown extensive oedematous changes primarily in the stria vascularis occurring within minutes of intravenous injection (Quick and Duvall, 1970; Johnsson and Hawkins, 1972; Bosher, Smith and Warren, 1973; Quick and Hoppe, 1975; Brummett et al, 1977; Bosher, 1980a, b). The decline and recovery of the endolymphatic potential can be correlated with the ultrastructural changes in the stria vascularis. Initially, as the endolymphatic potential becomes less positive, the marginal and the intermediate cells swell and vacuolation occurs. The intermediate cells subsequently shrink, an unusual response to injury and quite unlike that seen in experimentally produced renal failure, and the intracellular spaces fill with large quantities of oedema fluid (Arnold, Nadol and Weidauer, 1981) so that the whole stria appears swollen. The basal lamina of the capillaries is disrupted. As the endolymphatic potential starts to recover the marginal and intermediate cells mostly return to their normal appearance, although minor structural changes may persist (Brummett et al, 1977). The basal lamina regains its normal appearance by the time of complete recovery of the endolymphatic potential. Scanning electronic microscopic studies have also demonstrated these changes with gross swelling of the marginal cells and loss of microvilli (Forge, 1981).

Although some groups have found changes in the organ of Corti characterized by loss of outer hair cells in the basal turn induced by loop diuretics (Mathog et al, 1970; Matz, Beal and Krames, 1970; Crifo, 1973), others have found little or no change in them (Kohonen, Jauhainen and Tarkkanen, 1970; Federspil and Mausen, 1973). However, where an aminoglycoside antibiotic and loop-inhibiting diuretic are administered, ototoxic synergism
occurs producing an extensive destruction of the cochlear hair cells and permanent deafness (West, Brummett and Himes, 1973; Johnson and Hamilton, 1970).

**Ototoxic synergism**

If several ototoxic agents are administered serially or concurrently, potentiation may occur producing severe damage to the cochlea, even when the dose of either drug is within the recommended limits (Mathog and Klein, 1969; Johnson and Hamilton, 1970).

**Aminoglycoside-loop diuretic interaction**

The damage observed in the organ of Corti when an aminoglycoside is given followed by a loop diuretic is essentially the same as that produced when the aminoglycoside is used alone, but occurs at a lower overall dosage and usually much more rapidly (Nakai, 1977; Russell, Fox and Brummett, 1979). Changes in the stria vascularis resemble those seen when loop diuretics are used alone but the swelling is often greater.

The mechanisms behind this extensive damage to the organ of Corti are not clearly understood and the evidence is conflicting (Ohtani et al, 1978; Russell, Fox and Brummett, 1979), but the concentration of aminoglycosides in endolymph, but not perilymph, seems to be increased by the loop diuretics (Tran Ba Huy et al, 1983a).

Brummett et al (1974) demonstrated that the interaction did not occur with the non-loop inhibiting diuretics and kanamycin. The ototoxic interaction appears to be specific to the loop-inhibiting diuretics but not specific to the aminoglycosides, since the interaction of ethacrynic acid with viomycin, capreomycin and polymyxin B produces cochlear hair cell damage similar to that produced by aminoglycoside antibiotics administered with ethacrynic acid (Davis et al, 1982).

**Other ototoxic drug interactions**

Previous treatment with one ototoxic antibiotic may also render the spiral organ more susceptible to damage during subsequent treatment with another (Frost, Hawkins and Daly, 1960). Nilges and Northern (1971) have described a case of kanamycin ototoxicity in which synergism occurred in a cochlea which had been 'primed' by antimalarial drugs taken 3 weeks earlier.

**Ototoxic drugs and noise interaction**

There is conflicting experimental evidence that noise exposure may predispose the inner ear to the ototoxic effects of antibiotics and that acoustic and cochleotoxic damage may be additive (Darrouzet and De Lima Sobrinho, 1962). On the other hand, Vernon and Brummett (1977) found no interaction between kanamycin and acoustic overloads, nor between loop-inhibiting diuretics and noise trauma. Hawkins, Marques and Clark (1975) found a slight interaction between neomycin and acoustic overload.
Salicylates

The medicinal use of the naturally occurring salicylates dates back to at least the fourth century BC and Hippocrates, Pliny, Celsius, Galen and many other early physicians were aware of the therapeutic benefit of these drugs. They are now widely used as analgesics both on their own and as part of compound proprietary brands. Aspirin was one of the first drugs to be recognized as having an ototoxic effect in overdose (Müller, 1877) and Schwabach (1884) reported deafness from therapeutic doses of salicylates. The occurrence of a bilateral usually flat, cochlear hearing loss of up to 40 dB (Myers and Bernstein, 1965) or even 60 dB (Waltner, 1955; McCabe and Dey, 1965) is frequently preceded by tinnitus at blood concentrations in the range of 200-450 mg/L (Mongan et al, 1973). These symptoms are characteristically reversible within 24-72 hours after the drug is discontinued (Falbe-Hansen, 1941), but can be permanent (Gignoux, Martin and Cajgfinger, 1966). In patients with pre-existing sensorineural hearing loss, the thresholds of near normal sensitivity become elevated to a greater degree than the frequencies already affected (Myers and Bernstein, 1965) tending to flatten the hearing curve. Ototoxicity has also been observed following application of salicylates to the skin for psoriasis (Perlman, 19660. Imbalance has rarely been reported.

Histology

As long ago as 1881, Kirchner detected haemorrhage into the organ of Corti and labyrinth in human temporal bones and Mosher (1938) noted similar findings in guinea-pigs following salicylate intoxication. Wittmaack (1903) found changes in the spiral ganglion cells in the form of disappearance of Nissl's bodies and changes in the nucleus. Histopathological studies in animals have shown various minor usually reversible microscopic changes in cochlear structure and, while some of these have been contradictory, they may be the basis of at least some of the reported clinical and electrophysiological findings.

Covell (1936) found dilatation of the blood vessels of the stria vascularis and mitochondrial changes in the strial cells and outer hair cells in guinea-pigs, but the spiral ganglia were unaffected, Gotlib (1957), on the other hand, failed to find any strial or spiral organ abnormalities, although he did report alterations in the spiral ganglion similar to those previously noted by Lurie (1935). Loss of outer hair cells was noted by Falbe-Hansen (1941), but Myers and Bernstein (1965) failed to find any significant light or electron microscopic changes in cochlear structure compared with a control group.

Silverstein, Bernstein and Davies (1967) and Ishii, Bernstein and Balogh (1967) have shown that isotopically labelled salicylate accumulates in the cochlea, mainly the stria vascularis and spiral ligament. These observations have been contradicted, however, by a recent electron microscopy study in guinea-pigs by Douek, Dodson and Bannister 1983) in which the stria and the hair cell/neuron were largely unaffected. Salicylate overdosage produced extensive vacuolation of the lateral smooth endoplasmic reticulum of the outer hair cells to a greater extent than the inner, and this suggested that the cells had suffered an osmotic disturbance soon after only a single high level dose. The onset of flaccidity in the stereocilia of the outermost row of outer hair cells of the apical two turns also pointed to an ionic change within the hair cells. As the stria was not altered, this probably represented the direct action of salicylate on the outer hair cells rather than an indirect one via the endolymph. This recent work has cast doubt on the previously held belief that the toxic
effects of salicylates may be caused by vasoconstriction of the small vessels of the cochlear microvasculature (Hawkins, Beger and Aran, 1967).

The fact that no consistent morphological or ultrastructural changes have been observed in animals or humans has led to the presumption that the mechanism of ototoxicity is related to a reversible biochemical or enzymatic function in the cochlea.

**Biochemistry**

Salicylates influence three important groups of enzyme systems involved in intermediary metabolism. They exert an uncoupling action on oxidative phosphorylation, inhibit various transaminase and dehydrogenase systems, and competitively inhibit nicotinamide adenine dinucleotide (NAD) which in turn inhibits various enzymes dependent upon this coenzyme for hydrogen transfer (Silverstein, Bernstein and Davies, 1967).

In cats with acute salicylate intoxication, malic dehydrogenase levels in perilymph and endolymph are decreased and there is decreased electrical activity in the cochlea. This could reflect a decrease in metabolic activity of the stria vascularis and organ of Corti.

Glucose levels are increased, reflecting a rise in blood glucose, but sodium, potassium and total protein concentrations remain unchanged. These biochemical changes produced by salicylates are of particular interest in view of the more recent electrophysiological work and it is possible to postulate that cellular metabolic alterations are responsible for the changes in the recordings of the intracochlear and eighth nerve potentials.

**Electrophysiological studies**

Mitchell et al (1973) demonstrated that a single subcutaneous dose of sodium salicylate interferes with the cochlea's ability to generate a neural action potential whereas the cochlear microphonic is unchanged or if anything enhanced. The reversible effect on the action potential is greater in the higher frequencies and if, as is likely, this reflects a change in the threshold of hearing it would be greater in the higher frequencies as reported by McCabe and Dey (1965). These findings are in agreement with those of Wilpizeski and Tanaka (1967) (who also found no effect on the cochlear microphonic), but not with Silverstein, Bernstein and Davies (1967) who found a decrease in the ability of the cat's cochlea to generate a cochlear microphonic. Mitchell et al (1973) interpreted their findings as indicating that salicylates have no appreciable effect on the hair cells, but do affect the afferent fibres of the cochlear nerve or perhaps synaptic transmission. Evans, Wilson and Borerwe (1981) also demonstrated a rapid elevation in the threshold of all eighth nerve fibres in the cat regardless of the specific frequency. There was also a reduction in the tuning and dynamic range of the cochlear fibre responses and an unexpected increase in the spontaneous discharge rate in most of the fibres. These changes were related to hearing levels and were rapidly reversible.

Ramsden, Latif and O'Malley (1985) carried out serum salicylate estimation, pure-tone audiometry and transtympanic electrocochleography before, during and after gastric lavage and forced alkaline diuresis in two patients who had taken a large salicylate overdose. They demonstrated a fully reversible 40 dB sensorineural hearing loss which was slightly more
marked in the higher frequencies. A recruiting biphasic action potential of the pattern associated with cochlear hair cell damage was noted. Widening of the action potential due to an enhanced negative summating potential of the pattern seen in endolymphatic hydrops was not observed (Moffat et al, 1978), thus contradicting the theory of Falbe-Hansen (1941) that salicylates caused increased intralabyrinthine pressure. The input/output curves demonstrated a progressive recovery from the unimodal type reported as typical of outer hair cell damage to the neural bimodal type as recovery continued. This was interpreted as a reversible physiological blockage of outer hair cell function. Since the cochlear microphonic measurements were unchanged, these findings were in agreement with those of Mitchell et al (1973) in guinea-pigs. As the cochlear microphonic is believed to be a mechanoreceptor potential originating from the hair cell itself, it is possible that salicylate produces its ototoxic effect by a temporary metabolic blockade at the synapse between hair cell and neuron where the chemical transmitter remains unidentified.

It has, therefore, not been possible as yet to correlate definitely the histological, biochemical and electrophysiological changes in salicylate ototoxicity. While the research continues, it is prudent to be aware of the ready availability of aspirin and its widespread uncontrolled self-medication, especially for arthritic conditions, which may produce increased sensorineural hearing losses and tinnitus in the elderly.

**Quinine and derivatives**

The quinine derivatives have long been used as antiprotozoal agents in the treatment of malaria and as abortifacients. The active alkaloid quinine was isolated from cinchona bark in 1820 by Pierre-Joseph Pelletier and Joseph-Bienaime Caventou, but the ototoxic effect of Cinchona bark was first described by Richard Morton in 1692. Laveran (1898) noted that tinnitus and hearing impairment could develop at a relatively early stage in the treatment of malaria with quinine. The toxicity is similar to that produced by salicylates, reversible tinnitus and sensorineural hearing loss being the principal symptoms. Permanent sensorineural loss may occur, however, and may be progressive after discontinuance of the drug. Imbalance on rapid head movement has been described by Scherbel, Harrison and Atdjian (1958) and by Hart and Naunton (1964). Quinine administered to pregnant women during the first trimester has produced congenital deafness, even anacusis, and marked vestibular paresis as well as other associated abnormalities (Matz and Naunton, 1964).

These ototoxic effects may be induced by vasoconstriction in the microvasculature of the cochlea and strial changes (Covell, 1936) and narrowed capillaries in the spiral ligament and basilar membrane have been described. There is possibly an inhibitory effect on local prostaglandin synthesis (Ferreira and Vane, 1974). Covell (1936) injected pregnant guinea-pigs with quinine bisulphate and noted loss of outer hair cells in the organ of Corti. Hennebert and Fernández (1959) confirmed this work using the synthetic antimalarial, chloroquine.

Some patients have an idiopathic sensitivity to the drug and toxic manifestations are present at therapeutic plasma levels. Seventy per cent of quinine is bound to plasma protein and treatment for overdosage can be effective by exchange transfusion, particularly in children (Burrows et al, 1972).
Cytotoxic agents

Sensorineural hearing loss following the regional perfusion of nitrogen mustard (2,2-dichloro-N-methyl-diethylamine hydrochloride) has been reported by Conrad and Crosby in 1960 and subsequently in several reports (Lawrence et al, 1961; Schuknecht, 1964; Cummings, 1968).

Histopathological changes in the organ of Corti were demonstrated by Schuknecht in 1964, and, in 1968, by Cummings; more recent work has shown greater degeneration in the outer hair cells than the inner in the basal turn of the cochlea in animals. There was no effect on the stria vascularis, spiral ganglion, cochlear nerve or vestibular neuroepithelia.

The decrease in the normally stable +85 mV endocochlear potential following the administration of nitrogen mustard to guinea-pigs was first reported by Asakuma and Snow in 1978. It is generally thought that the stria vascularis is the source of the endocochlear potential, yet electron microscopic ultrastructural changes in the stria were not observed in a more recent study by the same author (Asakuma et al, 1984). The electrophysiological findings did not correlate well with the histopathology and it was, therefore, postulated that either nitrogen mustard damaged the hair cells so rapidly that the electrical insulation of the basilar membrane may be lost in the face of a normal functioning endocochlear potential generating system in the stria, or there may be some unknown functional derangements in the stria vascularis which cause the decrease in the magnitude of the endocochlear potential. Both of these speculations were found to be inadequate in explaining the reduction of the endocochlear potential on the basis of the findings of further experiments, and another possibility is that there is a leakage of negative intracellular potential from the injured cells, the so-called 'injury potential', due to the damage to the organ of Corti.

Cisplatin (cis-diaminedichloroplatinum (II), Cl₂H₆N₂Pt), a complex with ammonium and chloride ions arranged in a cis form with a platinum atom at its centre, is known to be effective against cancers of the urinary and genital organs and for cancer of the head and neck. Ototoxicity has been reported as a toxic effect of this drug (Helson et al, 1978) and it has been reported to cause cochlear damage in animals (Fleischman et al, 1978; Stadnicki et al, 1975). The ototoxicity of cisplatin resembles the aminoglycosides and nitrogen mustard in causing greatest injury to the first row of outer hairs in the basal turn of the cochlea. This was demonstrated in a study by Nakai et al (1982) in guinea-pigs when hearing function was tested using auditory brainstem responses, and morphological investigation conducted by scanning and transmission electron microscopy. The observed high frequency hearing loss correlated with the observed histological changes and was dose dependent.

Anticonvulsant agents

Vestibular disorders have been described following overdosage with certain anticonvulsant drugs, especially phenytoin (Nozue, Mizuno and Kaga, 1973). The dysequilibrium may be acute and reversible on cessation of the treatment or more commonly chronic and persisting with repeated doses of drug over a long period which are clearly necessary in young epileptics. Careful control of dosage by close monitoring of the serum phenytoin levels may be necessary.
Detailed studies of the spontaneous 'rebound nystagmus' which may occur in such patients have shown it to be associated with chronic cerebellar degeneration (Hood, Kayan and Leech, 1973), with loss of Purkinje cells in the cerebellar cortex (Hofman, 1958). Ethosuximide and other anticonvulsants may have similar vestibulotoxic properties.

**Barbiturates**

There is now some evidence to show that barbiturates may have an ototoxic effect and Hall (1985) has recently demonstrated an abnormally large amplitude of wave I in the auditory brainstem responses in patients recovering from therapeutic barbiturate coma. Auditory brainstem response latency remained within normal limits, but the acoustic reflex and the second positive peak usually occurring at 30-45 ms (Pa component) of the middle latency responses were absent and reappeared with the patients' recovery.

**Sedatives and tranquilizers**

These drugs may have vestibular side-effects but, apart from thalidomide, direct evidence is lacking to classify them as directly ototoxic.

**Beta-adrenoceptor blocking drugs**

This group of drugs blocks the beta-adrenoceptors in the heart, peripheral vasculature, bronchi, pancreas and liver. They have been used now for many years and are of great importance in the treatment of hypertension, angina and in the prevention of myocardial infarction and the control of cardiac dysrhythmias. There are many preparations now available including propranolol, atenolol, metoprolol, oxprenolol and labetalol which combine alpha- and beta-receptor blocking activity.

These drugs may produce adverse reactions but the side-effects are generally mild and reversible. Practolol, however, is unique in producing deafness and has now been withdrawn in view of this and its other effects, namely psoriasiform skin rashes, dryness of the eyes, bronchitis and pleurisy, 'plastic' peritonitis and recurrent ulceration of the mouth and nose (McNab Jones et al, 1977). Characteristically, the deafness has been noted only months and sometimes years after the other effects and, in a significant proportion of patients, a mixed sensorineural and conductive deafness has been observed, the latter due to serous otitis media. The pathogenesis of this unusual mixed deafness is not known and there have been no long-term animal studies.

**Antiheparinizing preparations**

Hexadimethrine bromide was formerly used as an antiheparinizing drug and was given after dialysis to counteract the effects of heparin given prior to the haemodialysis in patients with renal failure. Ransome et al (1966) reported that six out of 14 patients treated with this drug developed various degrees of sensorineural deafness.

The histopathological changes in the temporal bones of one patient treated with this drug included gross degeneration of the spiral organ, degeneration of the stria vascularis, slight degeneration of the spiral ganglion, thickening of Reissner's membrane, rupture and
disorganization of the endolymphatic sac and a fibrin-free exudate in the subepithelial connective tissues of the otolithic maculae and the cupulae.

**Bromocriptine**

Bromocriptine (2-bromo-alpha-ergocryptine) is a dopamine agonist which has been used successfully to treat parkinsonism, acromegaly, prolactinomata and other 'non-functioning' pituitary tumours, mastodynia and chronic hepatic encephalopathy. Lanthier, Morgan and Ballantyne (1984) have reported the occurrence of a reversible ototoxic effect in three patients treated with this drug for chronic hepatic encephalopathy. The bilateral high frequency sensorineural hearing loss improved when the dose of bromocriptine was reduced and a vascular origin for the deafness has been proposed.

**Oral contraceptives**

There have been several cases reported of bilateral sensorineural hearing loss thought to be attributable to the use of the oral contraceptive pill. In one case, the patient was one month pregnant before she began taking mestranol and norethisterone and her child was born deaf.

**Muscle relaxants**

A recent case of sudden sensorineural hearing loss following the use of the skeletal muscle relaxant dantrolene sodium has been described (Ramsden, 1986, personal communication).

**Other chemical substances**

These include nicotine, tobacco and marihuana, but again, definite evidence of ototoxicity is lacking (see Chapter 17).

**Ototopical ototoxicity**

There is a rather worrying dichotomy of opinion concerning the potential ototoxicity of drugs applied topically to the middle ear cavity through tympanic membrane perforations and at surgery. Animal experiments indicate unequivocally that ototoxic antibiotics and chemicals, when applied as ear drops to the tympanic mucosa, gain access through the round window membrane and damage the inner ear, yet many topical otological preparations containing ototoxic drugs are still used worldwide in huge quantities in acute and chronic suppurative ear disease (British Medical Journal, 1969). Although conclusive evidence of ototopical ototoxicity is lacking in man (McKelvie et al, 1975; Smith and Myers, 1970; Fee, 1980), it seems unlikely that he should differ so dramatically from animals in this regard. It may be that increased hearing loss formally attributable to a decrease in cochlear reserve produced by chronic infection and osteitis of the otic capsule is, in fact, a manifestation of the ototoxic effect of the ear drops. Also the high frequency auditory function that these drugs would be most likely to affect first is not measurable by conventional audiometry (Brummett, Harris and Lindgren, 1976).
When the aminoglycoside antibiotics are applied topically to the middle ear (Spoendlin, 1966; Kohonen and Tarkkanen, 1969), they may reach the perilymph by permeating either the round window membrane or the annular ligament of the stapes and thence to the spiral organ by penetrating into the endolymphatic space from the scala vestibuli, through the vestibular membrane. Streptomycin injected into the middle ear produces marked vestibular symptoms which occur within 3-6 hours and changes are observed in the type I hair cells (Schuknuecht, 1957; Spoendlin, 1966). Gentamicin applied topically also produces cochlear hair cell damage (Dayal and Smith, 1974).

Brummett, Harris and Lindgren (1976) have shown that both neomycin and polymyxin B can, in concentrations similar to those found in commercially available otic drops, induce dose-related cochlear damage when applied to the middle ear cavity of guinea-pigs. The ototoxic effects were detected as a reduction in the cochlear microphonic and a loss of hair cells.

Other antibiotics such as chloramphenicol, tetracycline and erythromycin can have similar effects (Proud, Mittelman and Seiden, 1968; Küpper et al, 1970). Chloramphenicol, when applied directly to the round window membrane of guinea-pigs for 30 minutes produces a depression of the cochlear microphonic that progresses for several hours and recovers only slightly (Gulick and Patterson, 1964). Proud, Mittelman and Seiden (1968) also demonstrated the ototoxicity of chloramphenicol by applying it in the form of sodium succinate powder to the round window membrane of guinea-pigs in amounts that were predicted to be the same as those insufflated into human ears.

The ototoxic effects of some of these drugs may increase as a function of duration of administration. This has been shown for neomycin in guinea-pigs (Brummett, Harris and Lindgren, 1976) and framycetin in the human (Tommerup and Møller, 1984).

Ototopical ototoxicity is not confined to antibiotics; ethacrynic acid and frusemide may cause dramatic strial oedema and widespread destruction of the spiral ganglion when given intratympanically (Hawkins, 1976).

The potentially harmful effects of absorbable gelatin sponge (Gel-foam) upon the inner ear were noted by Belluci and Wolff (1960) and the damage produced by a similar preparation (Sterispon) when placed in close proximity to an open oval window was described by Shenoi (1973). Sterispon used to contain small quantities of free formaldehyde, but new manufacturing processes are claimed to have overcome the problem. The application of chromic acid to a small posterior perforation of the tympanic membrane was reported by Taylor (1975) to have produced a profound sensorineural deafness.

In recent years, attention has been drawn to the possible ototoxic effects of disinfectants used for preoperative skin sterilization, which may gain access to the middle ear cleft. Bicknell (1971) found, in a retrospective study on simple myringoplasties, that more than 14% of these ears ended up with total deafness 3-6 months postoperatively and the only common factor was the use of chlorhexidine in spirit. Subsequent studies on guinea-pigs by Aursnes (1981a) have shown that chlorhexidine, when applied to the middle ear, produced mucosal changes and outermost outer hair cell damage which was most extensive in the basal turn. This is unlike the aminoglycosides which tend to damage the innermost row of outer
hair cells more severely than the outermost rows (Hawkins and Engström, 1964; Ylikoski, 1974) and thus the mode of action is likely to be different and may be related to thrombosis in the microvasculature of the cochlea. Chlorhexidine also damages the vestibular neuroepithelium (Aursnes, 1981b) and, like the cochleotoxicity, the extent of the damage is related to the concentration of chlorhexidine, to the duration of exposure and to the time lapse after exposure. The quaternary ammonium compounds, benzethonium chloride and benzalkonium chloride also used as skin disinfectants have a similar effect on the inner ear (Aursnes, 1982a).

It has been proposed that the spirit base of these preparations may be a factor in their ototoxicity and Morizono and Sikora (1981) have noted an irreversible reduction in the endocochlear potential following the application of 70% ethanol to the round window of the chinchilla. Thirty-five per cent ethanol produced a reversible decline in the endocochlear potential. Further studies of skin disinfectants in the guinea-pig by Aursnes (1982b) have demonstrated that the application of iodine in 70% alcohol in the middle ear cavity can produce damage to the cochlear and vestibular neuroepithelium which is similar to that produced by chlorhexidine. In ears exposed to aqueous iodine, no damage to the inner ear sensory epithelia was revealed.

**Congenital ototoxic hearing loss**

It is now known that many drugs cross the placental barrier and may have profound effects on the developing fetus. No drug should be administered to a pregnant woman without great caution and only when it is absolutely necessary. Many ototoxic drugs have been shown to produce severe fetal deformities such as, cleft lip and palate, dental deformities, skeletal malformations, ocular defects, anomalies and abnormalities of the cardiovascular, genitourinary and gastrointestinal systems as well as otological defects (Northern and Down, 1974). The first trimester (especially the sixth to the eighth weeks) appears to be the most vulnerable period for the developing ear and quinine, salicylates, streptomycin, dihydrostreptomycin and thalidomide have been the most strongly implicated. In one series, streptomycin was found to pass into the fetus and amniotic fluid in concentrations of up to 50% of the maternal levels (Moya and Thorndike, 1963). Variable factors such as the dose of drug, the effectiveness of the 'placental barrier', the duration of treatment and the stage of development may explain the different incidence of eighth nerve abnormalities in the literature. Conway and Birt (1965) found that almost 50% of children were affected, whereas Robinson and Cambdon (1964) thought that it was rare. Kanamycin, on the other hand, does not appear in the amniotic fluid after injection. Recently, Dumas and Charachon (1982) have demonstrated the transplacental ototoxicity of kanamycin in developing guinea-pigs.

The brief but tragic experience with thalidomide has been well documented and it is a reflection of its teratogenicity that as little as a single dose of 100 mg could produce marked congenital abnormalities, the severity of which is not dose related (Livingstone, 1965). Ear defects and limb deformities were commonly observed but there is no estimate of how many children had only hearing loss (D'Avignon and Barr, 1964; Jorgensen, Kristensen and Buch, 1964). Labyrinthine abnormalities and aplasia, multiple cranial nerve palsies with absence of seventh and eighth nerves, middle ear and inner ear defects with dysplasia of the organ of Corti have been observed in histopathological studies (D'Avignon and Barr, 1964; Northern and Downs, 1974).
Clinical monitoring and prevention of ototoxicity

The wide variation in the incidence of ototoxicity reported in the literature is a reflection of the difficulty in monitoring early significant change in cochlear and vestibular function in patients who are very often ill and confined to bed. Nevertheless, if this is to be accurately determined for each aminoglycoside, regular assessment of these functions must be carried out. Clearly, since there is no effective treatment for the established case, it is important to identify the predisposing factors to prevent the development of auditory and vestibular damage. Ototoxic drugs should not be used unless it is absolutely essential, especially in cases of renal or hepatic failure, in the very old or very young, in pregnant women and in those previously treated with ototoxic agents, those previously exposed to noise and in those with a known familial history of ototoxicity (Ballantyne, 1973).

Serum aminoglycoside levels

It was hoped that by careful assay of serum aminoglycoside levels during treatment, an adequate antibacterial dosage could be achieved while minimizing the rise of ototoxic side-effects. Pharmacological studies in humans indicated that the concentration of the aminoglycosides in the blood is representative of the tissue level throughout the body and this value may be used for therapeutic purposes (Chisholm, Calnan and Waterworth, 1968). In the case of gentamicin, it has been recommended that peak serum concentrations (15 minutes after intravenous injection and one hour after intramuscular injection) should be measured from the first day of treatment and the dosage modified accordingly until values of at least 5 μg/mL or preferably 8-12 μg/mL are achieved (Noone et al, 1974). These serum concentrations can be achieved only by starting with a regimen of 5 mg/kg per day in three divided doses in all adult patients, subsequent dosage being determined by the results of rapid serum assay. In urinary infections, it may be possible to use a reduced dosage (1-2 mg/kg per day) since gentamicin is concentrated in the urine. The concept of a fixed dosage adequate in all patients should be abandoned since there is considerable individual variation in the peak serum levels in response to a standard dose. When gentamicin might accumulate (because of renal failure or prolonged high dosage) monitoring should include measuring residual gentamicin (‘trough’ concentration) in sera taken just before the next dose is given and should be less than 1 μg/mL. Similar values are recommended for tobramycin therapy. The ideal assay should be accurate and rapid since doses are usually administered every 8 hours. A new quenching fluoroimmunoassay has been reported which appears to be a satisfactory alternative to acetyl transferase assay, radioimmuneassay, and the slow microbiological assays (White, Scammell and Reeves, 1980). Despite the well documented delay in the rise of perilymph aminoglycoside concentration following drug administration, it would seem sensible to adhere closely to body weight, age- and sex-related dosage schedules and to monitor regularly and closely peak and trough serum levels. Since the aminoglycosides are excreted by the kidneys and are themselves nephrotoxic in high doses, renal function should also be assessed by regular estimations of serum creatinine after determining a baseline creatinine clearance. In patients with total renal failure undergoing dialysis, aminoglycosides can only be eliminated in the dialysate and pre- and postdialysis antibiotic levels should be carried out to help minimize the risk of ototoxicity. In the case of gentamicin, adequate levels can often be maintained by a single dose of 1 mg/kg after each dialysis.
Mawer and his colleagues (1972) have developed a digital computer program for calculating safe and effective doses of kanamycin for individual patients with renal insufficiency. In a later communication (Mawer, Lucas and McGough, 1972), a nomogram has been constructed from which a suitable dosage schedule may be obtained for any individual patient provided that the serum creatinine, age, sex and body weight are known. This nomogram is designed to produce serum concentrations of kanamycin within the accepted therapeutic range (10-30 mg/L) 2 hours after each dose and a similar one has been devised for gentamicin. Despite this, a combination of calculated doses and monitoring of peak and trough serum levels at regular intervals throughout therapy is the safest approach in view of the marked individual variation in these levels (Gyselynck, Forrey and Cutler, 1971) and the possibility of a genetic predisposition for ototoxicity (Jackson and Arcieri, 1971; Ballantyne, 1973).

Noone et al (1978) in a study of aminoglycoside monitoring of patients in renal failure felt that nomograms based on serum creatinine concentration were of little value in adjusting aminoglycoside dosage since the maintenance doses required varied greatly between patients and were unrelated to serum creatinine concentration, which fluctuated widely in recently transplanted patients and appeared to lag further behind current renal function than did serum aminoglycoside concentrations. Serum aminoglycoside levels were directly affected by concurrent administration of carbenicillin, by flucytosine and the administration of cephradine and cephalixin with gentamicin may have produced nephrotoxicity. They considered that aminoglycosides, when carefully monitored, were effective and safe in patients with severely impaired renal function. Serum levels ought also to be measured during treatment by topical application of these drugs in view of the reported increase of ototoxicity.

It is perhaps not surprising that the peak level at which ototoxicity occurs cannot be readily defined since this may not be the crucial parameter producing this complication (Jackson and Arcieri, 1971; Hewitt, 1973).

The suggestion that serum trough levels seemed to be better related to the occurrence of ototoxicity than peak levels was noted by Line, Poole and Waterworth (1970). A correlation between ototoxicity and the 'baseline' area (a function of trough levels and the length of administration), but no correlation with peak levels was found by other investigators. Since the drug is excreted more slowly in patients with renal impairment, the regular achievement of peak serum levels of over 5 μg/mL inevitably leads to higher trough levels and larger baseline areas than in patients with normal renal function, if the dose frequency is the same. Decreasing the dose frequency will give lower trough levels, although their reduction will be proportionally less because of the exponential nature of the gentamicin blood level curve. The concept of 'the area under the curve', rather than transient peaks associated with ototoxicity, is supported by the animal experiments which have shown the delay in the rise of the aminoglycoside concentration in the inner ear following administration. This would explain the close relationship between renal impairment and ototoxicity.

In a large prospective study of patients receiving gentamicin and tobramycin, Fee (1980) demonstrated a higher than expected increase of ototoxicity, but it was largely reversible. Tobramycin had significantly less vestibulotoxicity than gentamicin. Interestingly, dose, serum levels, area under the curve, age, prior noise exposure, previous aminoglycoside treatment and other ototoxic drugs, were not statistically associated with toxicity. Factors
significantly associated with toxicity were high temperature, initial haematocrit and critical illness. If the total dose was limited to less than 2 g and duration of therapy less than 10 days, a very low incidence of ototoxicity was expected. Recent studies on the newer aminoglycosides have shown that although amikacin, a derivative of kanamycin, is markedly cochleotoxic (24%), monitoring of serum levels and limitation of duration of therapy helped to prevent the development of ototoxicity (Black et al, 1976). Netilmicin may be less ototoxic than gentamicin (Tjernström et al, 1982).

**Audiometry and tests of vestibular function**

The aminoglycosides exert their initial effects on the outer hair cells of the basal turn of the cochlea producing a high frequency sensorineural hearing loss. High frequency audiometry has been used to detect early changes in patients receiving ototoxic drugs (Jacobson, Downs and Fletcher, 1969). There are, however, considerable technical difficulties in the clinical use and calibration of audiometers capable of operating in the frequency range 10-20 kHz. Furthermore, many patients receiving aminoglycosides have high frequency losses due to presbyacusis, or environmental factors and cannot be screened accurately with the currently available instrumentation.

It has been suggested that routine assessment of auditory and vestibular function cannot be justified on the grounds of cost, time and effort in view of the large number of patients receiving potentially ototoxic drugs. Monitoring of these functions has only been recommended for those patients who require a high level of auditory acuity (for example a musician or piano tuner) and those patients with a history of previous ototoxicity, raised serum levels, those in renal failure or receiving treatment for more than 14 days (Lerner and Matz, 1979). A baseline pure-tone audiogram ought to be carried out on all patients and clinical judgement should be exercised in determining the degree of monitoring. Criticism has been levelled at the use of electronystagmography (ENG) in the assessment of vestibular function since it is even more susceptible to extraneous influences than the pure-tone audiogram. Vagaries in performance and interpretation limit its clinical usefulness particularly in patients who are critically ill.

**Electrocochleography**

Transtympanic electrocochleography is a reliable and safe procedure but the test is expensive and time consuming and is clearly not applicable to large screening programmes. It can only be used with great difficulty in patients who are ill, since the patients have to be moved to the test area and this may be difficult to justify. Nevertheless, the immediate electrophysiological changes observed in the cochlea after intravenous administration of the aminoglycoside antibiotics have been an important advance and have shed considerable light on the possible ototoxic mechanisms at a cellular level. This test may prove to be of value in the future for selecting those patients who are particularly susceptible to the effects of ototoxicity. The effects of kanamycin on wave I of the auditory brainstem response (the eighth nerve action potential) have been recently determined in guinea-pigs (Schwent, Williston and Jewett, 1980). Persistent changes in latency may be an early indicator of cochleotoxicity and could herald the use of a surface electrode technique in the clinical monitoring of patients receiving aminoglycosides.
There is little doubt that the current inadequacies in clinical monitoring of patients receiving potentially ototoxic drugs has been responsible for our lack of precise scientific information on the incidence of ototoxicity and the influence of predisposing factors, drug dosage and serum concentration levels on its development.

Management of ototoxicity

Early recognition by careful monitoring is particularly important since many drugs produce a temporary loss in hearing acuity, for example quinine, salicylates and the loop diuretics. Even drugs such as the aminoglycosides which are known to produce permanent cochlear and/or vestibular damage may initially exert reversible changes on the inner ear. Cessation of treatment and the substitution of a different antibiotic regimen is all that may be necessary in these cases. Delayed recovery has been reported in a case of profound sensory hearing loss caused by gentamicin (Moffat and Ramsden, 1977), but it is unreasonable to offer high expectations of improvement to patients with established ototoxicity.

Drug treatment with vasodilators or other therapy is ineffective but amplification in the form of a hearing aid with auditory rehabilitation and retraining is only of value if good speech discrimination is retained. Since the initial damage is sensory in nature and only at a later stage does neural degeneration occur, some of these patients may be suitable for cochlear implantation.

Tinnitus, if mild, should be treated by simple reassurance. In those patients who have difficulty sleeping, a mild hypnotic and advice on pillow maskers is often helpful. Tinnitus masking can help some patients and should be tried, particularly in cases where a hearing aid is of little value. Patients with tinnitus and normal hearing will rarely tolerate masking.

Prolonged dysequilibrium and bibbing oscillopsia may severely impair the patients' quality of life and prevent them from working. Advanced age, debilitating illness and loss of proprioception due to uraemic polyneuropathy may exacerbate these symptoms (Dayal, Chait and Fenton, 1979). The management of these patients is difficult and vestibular sedatives are not helpful. Realistic reassurance and regular physiotherapy with Cooksey Cawthorne vestibular rehabilitation exercises not only produces an improvement in some patients, but serves as a morale-booster to others who would otherwise be distraught at the prospect of no treatment. The wearing of thick, soft, rubber-soled shoes and the avoidance of pitch darkness and sudden head movements should be recommended (Maw, 1971).

Ototoxic drugs in general, and the aminoglycoside drugs in particular, should be avoided unless they are essential to the survival and future well-being of the patient. The third generation cephalosporins, cefotaxime, cefsulodin soon to be replaced by the forth generation, and the newer synthetic penicillins such as mecillinam, azlocillin and ticarcillin are effective against Gram-negative bacteria and it is to be hoped that these and similar non-ototoxic drugs will replace the aminoglycosides in the near future. Until that time an acute awareness of the ototoxic potential of certain drugs and the importance of early detection of the disabling symptoms which may ensue as a result of auditory and vestibular damage should be firmly instilled in the minds of those physicians who prescribe them.
Chapter 21: Acoustic tumours

Richard T. Ramsden

History

The fascination that acoustic neuromata have always held for the otolaryngologist originates not only from his conviction that the early diagnosis of the condition at the 'otological' stage is his prerogative, but also that their expeditious surgical removal is greatly enhanced by his traditional knowledge of temporal bone and facial nerve anatomy, and of microsurgical technique. In a sense, the internal auditory meatus is a meeting point between the territories of the neurosurgeon and the otologist, and like other such disputed zones is fraught with danger and pitfalls for the unwary. Where surgical disciplines do abut, there has tended to be a danger in the past for both to deal less than adequately with problems of management, and certainly in the case of lesions of the cerebellopontine angle, it has become increasingly apparent over the past two decades that the high ideals of early diagnosis, total tumour removal, low mortality and morbidity, preservation of the facial nerve and occasionally useful hearing, can only come about if otologist and neurosurgeon work together for the good of the patient.

It would appear that the first case of acoustic neuroma to be fully documented was that described by Sandifort of Leyden, in 1777, in an article entitled 'De duro quodam corpusculo, nerve auditorio adhaerente' in which he described the post-mortem finding of a small firm tumour of the auditory nerve, emerging from the internal auditory meatus and compressing the medulla in a patient who had complained of deafness. Sir Charles Bell, in 1830, provided one of the earliest clinical descriptions of the progressive symptomatology of a patient who was referred to him as a case of tic douloureux, and went on to develop deafness, dizziness and facial paralysis before dying of apparent brainstem compression and raised intracranial pressure. At post-mortem, a semicystic tumour, the size of a pigeon's egg, was found in the cerebellopontine angle, indenting the pons, extending into the internal meatus and involving the fifth and seventh cranial nerves. This description is of particular interest for Bell's own excellent illustration of the post-mortem specimen.

Throughout the nineteenth century there appeared an increasing number of clinicopathological descriptions of what, despite somewhat ambiguous histopathology, were certainly acoustic neuromata, (for example Cruveilhier, 1835; Toynbee, 1853; Stevens, 1879; Oppenheim, 1890) and the reader is referred to the review by Harvey Cushing (1917) for further details of this fascinating period. Ballance is usually credited with the first successful removal of an acoustic neuroma in 1892, but Cushing felt that his case was more likely to have been a meningioma and attributed the honour to a Scot, Annandale of Edinburgh in 1895 - 'a brilliant surgical result, the first recorded'. Generally, however, the mortality and morbidity of early surgical series were dauntingly high, due to late presentation, poor anaesthesia and instrumentation, haemorrhage, and above all the feeling that these tumours could be enucleated rapidly with the finger, a manoeuvre that inevitably resulted in serious bleeding from the anterior inferior cerebellar artery, the importance of which vessel was not appreciated. Indeed, it is significant that Ballance, in 1908, expressed the view that the surgical results might be improved if that artery could be ligated prior to removal of the tumour.
The first attempts at surgical removal were by way of the unilateral suboccipital approach of Krause (1903), that particular writer reporting an operative mortality of 83.8%. In a visionary article in 1904, Panse proposed that an approach through the labyrinth might allow removal of an acoustic neuroma as large as a hen's egg. He defined the anatomical limits of that exposure, the lateral sinus, the jugular bulb, the carotid artery and the temporal lobe but felt that the facial nerve must inevitably be sacrificed. However, he suggested that in certain tumours of this region the facial nerve could be re-routed after being mobilized from the geniculate ganglion to the stylomastoid foramen, thus anticipating Fisch by three-quarters of a century. The translabyrinthine approach appears to have been first employed, in 1911, by Kummel in Heidelberg (Marx, 1913) and Quix (1912) in Utrecht, but failed to find widespread acceptance, Ballance dismissing it as 'objectionable for obvious reasons'. In 1917, Harvey Cushing, in his monograph 'Tumours of the nervus acusticus and the syndrome of the cerebellopontine angle', described his bilateral suboccipital approach to the posterior fossa which allowed not only a wide decompression, but also the possibility of exploring both sides in cases in which there was doubt as to the side of the lesion. He recommended a subtotal intracapsular removal, and was able to reduce the operative mortality by 1931 to 4%, this despite the fact that the tumours were almost always very large with hydrocephalus, brainstem compression and failing vision. Dandy (1925), however, was strongly in favour of a total removal via a unilateral suboccipital approach.

The surgical results of these two great American neurosurgeons were certainly an encouraging improvement on those of their predecessors, but despite that and the invaluable contribution of Atkinson (1949) in clarifying the importance of the anterior inferior cerebellar artery, there remained a certain reluctance on the part of neurosurgeons to embark on this type of surgery unless the tumour was so large as to be causing pressure effects on the brainstem, or raised intracranial pressure. Many patients were in effect told that their tumours were too small for surgery and to return when they had grown larger! It was to this unique surgical anomaly that William House directed his attention in the early 1960s, developing first the middle fossa, and shortly afterwards the translabyrinthine approach to the internal auditory meatus. The great improvement in results achieved by his group, in terms of both mortality and morbidity, particularly to the facial nerve, is largely the consequence of the policy of early diagnosis and surgery and owes much to advances in diagnostic techniques in the fields of both radiology and audiology and to the evolution of microsurgery as an essential skill for both otologist and neurosurgeon. Rand and Kurze (1965) were among the first neurosurgeons to apply microsurgical techniques to acoustic neuroma removal via the suboccipital transmeatal route, an approach which is now enjoying renewed popularity as surgeons seek to preserve hearing in selected cases. In recent years, there have been rapid changes in the audiological and radiological assessment of acoustic neuroma suspects with the emergence of brainstem electric response audiometry, and computerized tomography (CT) and magnetic resonance (MR) promising to bring the ideal of early diagnosis close to reality.

Anatomy

The cerebellopontine angle is a triangular area bounded laterally by the medial portion of the posterior surface of the temporal bone, medially by the edge of the pons and posteriorly by the anterior surface of the cerebellar hemisphere and the flocculus, and is part of the lateral medullary cistern. Superiorly it is limited by the trigeminal nerve as it crosses the petrous apex and by the edge of the tentorium. Its inferior limit is formed by the lower cranial nerves.
(IX, X, XI) as they enter the jugular foramen, and by the hypoglossal nerve. It contains one important artery, the anterior inferior cerebellar, and two cranial nerves, the facial and vestibulocochlear, as they pass from their points of origin at the pontomedullary junction towards the internal auditory meatus.

The internal meatus (Latin meatus, a coming together) is a passage through the petrous bone leading from the posterior surface of the temporal bone to the medial wall of the vestibule. It has a porus, or inlet, medially with a sharply defined crescentic posterior lip and a rather poorly demarcated anterior edge, a canal proper which is roughly cylindrical and a fundus laterally which abuts the medial wall of the vestibule. The lateral wall of the meatus presents several features of great surgical importance. It is divided into superior and inferior halves by the falciform crest. The upper compartment is further separated into an anterior area for the facial nerve and a posterior area for the superior vestibular nerve, by a sharp vertical ridge of bone known as 'Bill's bar' after William House. The lower half also comprises two areas, anteriorly the tractus spiralis foraminosus through which the spiralling fibres of the cochlear nerve pass, and posteriorly the rather smaller area for the inferior vestibular nerve supplying the saccule. The singular nerve, a branch of the inferior vestibular nerve supplying the ampulla of the posterior semicircular canal, passes through a small canal on the floor of the meatus, about 1 mm from the fundus.

The seventh and eighth nerves leave the brainstem at the region of the pontomedullary junction, at which point they are closely related to each other and here it is impossible to make out the individual components of the vestibulocochlear nerve. As they pass laterally separation between them becomes more apparent, and at the level of the porus, four individual nerves can be identified, the facial and nervus intermedius anterosuperiorly, the superior vestibular posterosuperiorly, the cochlear anteroinferiorly, and the inferior vestibular posteroinferiorly. The anastomosis between the facial and vestibulocochlear nerves is referred to in Chapter 19.

The anterior inferior cerebellar artery usually arises from the basilar artery as a single trunk, and in the cerebellopontine angle forms a loop which has an intimate, but somewhat variable, relationship with the facial and audiovestibular nerves and with the internal auditory meatus; on occasion the artery may in fact loop right into the meatus. The main branches of the anterior inferior cerebellar artery are the internal auditory and subarcuate arteries, and these tend to tether the anterior inferior cerebellar artery to the posterior surface of the temporal bone. It is important to realize that this is a region of considerable anatomical variation, and for further details the reader is referred to the excellent post-mortem studies of Mazzoni and Hansen (1970) and of Rhonot et al (1982).

The most important venous channels in this region are the jugular bulb which sweeps up below the internal meatus, but which may if high be a posterior relation of the meatus, and the superior petrosal sinus running in the line of attachment of the tentorium to the petrous ridge, and draining the petrosal vein anteriorly.

The relationship of the meninges to the internal meatus and its contents is of considerable surgical importance. The dura of the posterior surface of the temporal bone is firmly adherent round the porus where it merges with the periosteal lining of the meatus. The pia-arachnoid, on the other hand, continues into the meatus investing the nerves in individual
or common sheaths, and blending with the neurilemma. The subarachnoid space therefore extends laterally to the fundus of the meatus.

**Pathology**

**Site of origin**

The term acoustic neuroma seems to be fixed indelibly in the English literature, and yet on semantic as well as pathological grounds this is clearly inappropriate. As Schuknecht (1974) has pointed out these tumours have, over the years, been variously described as neuromata, neurilemmomata, neurofibromata, and perineural fibroblastomata, and yet none of these terms accurately describes their histological origin. It would seem that they arise from the Schwann cells which envelop the distal portion of the eighth nerve from the point at which the neuroglial elements cease. This zone, the glial-neurilemmal junction, may be a zone of cellular instability and is thought by some authorities to be the likely site at which neoplastic change occurs. This view does not find favour with Schuknecht (1974) who stated that schwannomata may arise at any point between the glial-Schwann cell junction and the cribrose area. It is, however, clear that, because this junctional area usually lies within the internal auditory meatus, most tumours take origin within that canal, an observation first made by Henschen in 1912. In an important minority of instances the glial-neurilemmal junction is situated more medially, in the cerebellopontine angle and tumours arising here may reach considerable size before presenting, a fact which may be partly explained by Schuknecht's observation that the glial-Schwann cell junction of the cochlear nerve is situated more medially than that of the vestibular. Furthermore, it appears to be the experience of most surgeons in this field that the superior vestibular is the most common nerve of origin of these neoplasms, with only rare involvement of the cochlear (Nager, 1964). It would appear, however, that for the foreseeable future, common usage will decree that the term 'acoustic neuroma' will take precedence over vestibular schwannoma'.

The different pathological features of von Recklinghausen's disease are considered later in this chapter, together with the unique problems of management of that condition.

**Pattern of growth**

As the tumour grows within the internal meatus, it causes progressive but slow destruction of the vestibular nerve and produces pressure effects on the adjacent cochlear and facial nerves. Because the tumour arises in the nerve sheath, it tends to compress the neurons rather than to infiltrate them, and thus creates a possible plane of surgical dissection between tumour and nerve, although Neely (1981) and Luetje et al (1983) have drawn attention to the fact that this plane may be more apparent than real, and that histological involvement of the facial and cochlear nerves may occur. The tumour is invested in a layer of arachnoid, and as it expands, a double layer is created, which covers the whole tumour and separates it from adjacent structures (Di Tullio, Malkasian and Rand, 1978). At a fairly early stage of growth, the tumour causes an increase in cerebrospinal fluid protein, which in turn may cause some degree of arachnoiditis, often leading to the development of an arachnoid cyst in association with the tumour. The tumour may be small with a large arachnoid cyst and vice versa. Erosion of the bony walls of the internal meatus occurs, particularly at the porus; occasionally tumour can break through the roof of the meatus into a suprameatal air cell system and
continue to grow within the petrous bone, and this may make surgical identification of the facial nerve difficult.

As expansion continues in a medial direction, the cerebellopontine angle is entered, and because this is a large relatively empty space, growth proceeds quite silently. During this time, the facial nerve is becoming increasingly attenuated over the surface of the tumour, and displaced by it, usually in a sharply anterior direction at the porus, but occasionally posteriorly. The tumour also displaces the anterior inferior cerebellar artery, and develops a blood supply from it, although Perneczky (1981) maintains that most of the tumour blood supply is from meningeal vessels. Lye, Elstow and Weiss (1984) and Lye (personal communication, 1986), described an endothelial cell stimulating angiogenic factor (ESAF) which is responsible for new blood vessel formation in a variety of intracranial neoplasms, including acoustic neuromata.

The anterior inferior cerebellar artery and the facial nerve, although often considerably displaced by the tumour, remain separated from it by the double arachnoid layer referred to above. Rarely, an inframeatal loop of anterior inferior cerebellar artery may become compressed within the meatus by a relatively small tumour with resultant ischaemic effects on the cerebellum. When the tumour is about 2 cm in diameter, its upper pole makes contact with the trigeminal nerve as it crosses the petrous apex to enter the cave of Meckel, and compresses it against the pons and midbrain. The lower pole of the tumour displaces the ninth, tenth and eleventh nerves, but these seem relatively resistant to pressure and stretching. Brainstem and cerebellar involvement follow, and quite marked degrees of brainstem shift may occur, to the extent that ultimately, contralateral false localizing signs may be seen. (Cushing's bilateral suboccipital approach was developed partly because of the problems of correct lateralization.) In addition, the tumour may pass ventral to the brainstem and may ultimately reach almost to the opposite temporal bone. Because of the size of the cerebellopontine angle, the slow rate of growth of the tumour, and the capacity of the brain to tolerate quite a striking degree of shift, if slowly applied, the posterior fossa can accommodate a surprisingly large mass before serious changes in cerebrospinal fluid hydrodynamics occur, but a stage is reached when all the 'slack' in the system has been taken up, and hydrocephalus with papilloedema, and brainstem embarrassment may follow quite rapidly, especially if there is a sudden bleed into the tumour. Hydrocephalus may be either internal, from distortion of the aqueduct, or external from obstruction to flow in the lateral medullary cisterns.

Effects on the inner ear

Degenerative changes in the cellular structures of the inner ear, and biochemical alterations in the inner ear fluids secondary to the presence of an acoustic neuroma in the internal meatus have been frequently described (De Moura, Hayden and Connor, 1969a; Schuknecht, 1974), and may account for the fact that in many cases of acoustic neuroma the audiological picture may appear to be cochlear, or exhibit mixed cochlear and retrocochlear features. Suga and Lindsay (1976) postulated that cochlear changes may result from interference with the arterial blood supply of the inner ear from pressure of tumour on branches of the internal auditory artery. They pointed out, however, that the venous drainage of the inner ear is mainly by way of the canals of the cochlear and vestibular aqueducts, rather than via the internal meatus, and that venous backpressure on the cochlea from meatal
obstruction is unlikely to be responsible for inner ear changes as suggested by Brunner (1925) and Watkyn-Thompson (1939). Degeneration is more commonly seen in the cochlea than in the otolith organs or in the semicircular canals. There may be atrophy of the organ of Corti, most frequently seen in the basal turn, but occasionally widespread or complete. Vacuolization of the stria vascularis has been frequently reported, notably by Suga and Lindsay (1976), who observed that quite extensive strial damage could be associated with surprisingly good preservation of the organ of Corti, and of the endolymphatic spaces of the cochlea and vestibule, leading them to conclude that only a small amount of normal stria is necessary for the maintenance of the normal volume of endolymph in the inner ear. The other notable change reported has been in the spiral ganglion, the cells of which may be extensively or totally lost.

The occurrence of high protein levels in the endolymph was first described by Dix and Hallpike (1950) and has been the subject of many subsequent studies (Silverstein and Schuknecht, 1966). An exudate may even be seen in the perilymphatic spaces of the cochlea. Several attempts have been made to identify the protein by electrophoresis, in samples of perilymph taken at the time of translabyrinthine surgery, but the main problem appears to be in obtaining a sample free from contamination with blood. O'Connor et al (1982) were unable to identify a protein pattern specific to acoustic neuroma. Palva and Raumio (1982) carried out immunodiffusion tests using anti-cerebrospinal fluid, anti-tumour antiserum pooled from five patients with acoustic neuromata and were able to demonstrate cerebrospinal fluid and tumour specific proteins in the perilymph. They suggested that cerebrospinal fluid proteins could enter through the cochlear aqueduct, and tumour protein through small channels in the cribriform area. The search to identify an immunological marker in the bloodstream has, as yet, met with little success, although Rasmussen, Thomsen and Tos (1981) were able to demonstrate cell-mediated immunity against acoustic neuroma in four out of 11 patients before surgery, as well as in one normal control (out of 16), using the leucocyte inhibition capillary tube technique. Anniko, Arndt and Noren (1981) grew acoustic neuroma cells in organ culture and demonstrated that they were highly radioresistant.

Rare instances are reported of tiny unsuspected and asymptomatic neuromata wholly confined within the cochlea or vestibule, and found by chance at post-mortem, as in the case of Johnsson and Kingsley (1981) who described a small tumour of 1.5 mm diameter within the scala tympani seeming to have originated in the distal process of the cochlear neuron. Such a tumour could well have given rise to a Ménière-like syndrome. Thomsen and Jorgensen (1973) reported a case of an intracochlear neuroma which was seen to originate in the spiral ganglion. Storrs (1974) presented two cases in which an acoustic neuroma presented as a middle ear tumour. Intracochlear neurofibromatosis is a well recognized feature of von Recklinghausen's disease (Linthicum, 1972).

**Gross appearance of the tumour**

The typical acoustic neuroma is a firm, well encapsulated tumour with a somewhat nodular surface which tends to mould itself to the contours of the cerebellopontine angle. There is a relatively well-defined plane of separation between the tumour and the arachnoid, but in places it may be rather firmly adherent to its surroundings, particularly in the proximity of branches of the anterior inferior cerebellar artery, making safe removal at times difficult or occasionally impossible. The medial pole of the tumour usually displaces the brainstem
before it, but on occasion may almost appear to infiltrate into the brainstem, and may enter
the fourth ventricle through the foramen of Luschka. The interior of the tumour is usually
rather softer than the capsule and, although there is considerable variation from one tumour
to another and in different parts of the same tumour, the consistency generally resembles that
of a grape. The cut surface is rather variegated, with grey, yellow and purplish areas. Cyst
formation within the substance of the tumour is common, and in some instances these cysts
may constitute the main bulk of the tumour (Hitselberger and House, 1968). They contain
serous yellow or haemorrhagic fluid which may be cerebrospinal fluid. Spontaneous
haemorrhage into the tumour is not uncommon and in a large tumour may cause a sudden
dangerous increase in intracranial pressure. Calcification is seen occasionally, usually in quite
small patches, but Thomsen, Klinken and Tos (1984) described an acoustic neuroma which
was almost totally calcified.

**Histological appearance**

Microscopically the neoplastic cells show two characteristic patterns, the Antoni types
A and B, thoroughly described by Antoni in 1920. In the Antoni A, or fasciculated type, there
is an orderly arrangement of parallel cells with dark staining fusiform nuclei arranged in
bundles or whorls separated from each other by areas of relatively acellular fibrous tissue. The
term 'pallisading' is applied to describe this appearance. In the more common Antoni type B,
or reticular pattern, there is a looser reticular arrangement with fewer cellular elements and
a more disorderly arrangement of nuclei. Areas of degeneration may be seen, the result,
according to Hitselberger and House (1968), of the tumour outgrowing its blood supply. There
are also pale tumour cells containing lipid, giving a general rather foamy appearance, and
responsible for the yellow colour of the tumour. This picture has been referred to by Nager
(1969) as Antoni B, subgroup 1. His subgroup 2 describes an appearance in which there is
a relative paucity of cells with transformation of tumour tissue into a hyaline substance. All
of these histological variants may coexist in the same tumour. Malignant change in an
acoustic neuroma is rare, but Schuknecht (1974) described and illustrated one case, a 9-year-
old girl, in whom this did occur.

**Clinical presentation**

Acoustic neuromata are not common, but their true incidence is difficult to ascertain
with any degree of accuracy. All of the frequently reported early estimates were based on
post-mortem studies, usually of unsuspected cases, and these are fallacious for two important
reasons. First, such a study will inevitably select an aged population, and second, they are
usually not consecutive. The estimate of 2.4% by Hardy and Crowe (1936) is based on a non-
consecutive series of post-mortem studies, and is therefore likely to be too high, and the
famous Witmaack collection of 1720 temporal bones was collected over no less a period than
37 years (Tos and Thomsen, 1984). Perhaps the most realistic epidemiological estimates
comes from Tos and Thomsen (1984), who calculated a diagnosis rate for symptomatic
tumours of one per 100 000 of population per year, although these authors emphasized that
this figure understated the true incidence of the condition, because of missed diagnosis. These
tumours have their greatest incidence in the fourth, fifth and sixth decades, and there appears
to be a slight bias towards women. Apart from the hereditary factors in von Recklinghausen's
disease, little is known at present about their cause.
The evolution of the clinicopathological picture in patients with eighth nerve tumours may be considered in five stages.

1. 'Otological' stage in which the changes are confined to the audiovestibular and, to a limited extent, facial nerves. This stage includes all intrameatal lesions, and extrameatal tumours up to about 2 cm.

2. Stage of trigeminal nerve involvement, suggesting a diameter of more than 2 cm.

3. Stage of brainstem and cerebellar compression, with for example ataxia, direction changing nystagmus and long tract signs, and of involvement of the lower cranial nerves.

4. Stage of rising intracranial pressure, with failing vision, headache and vomiting.

5. Terminal stage, with severe disturbance of the vital brainstem centres, and tonsillar herniation.

There may also be another group of patients, in long-term institutional care, because of behavioural or personality changes, who, if examined with CT scanning, would be found to be harbouring large posterior fossa lesions, and who may be transformed and rehabilitated following successful surgery.

**Otological stage**

**Deafness and tinnitus**

The commonest symptoms are unilateral hearing loss and tinnitus, which occur in over 90% of patients. The deafness is usually gradual in onset and slowly progressive over a period varying from as little as a few months to 20 years or more, but averaging about 2 years (King, Gibson and Morrison, 1976). The patient may volunteer the information that his ability to discriminate speech seems disproportionately poor, especially when conversing on the telephone. In perhaps 10% of cases the hearing loss is sudden and may be profound, due presumably to a vascular accident to the cochlea. Nedzelski and Dufour (1975) estimated that 3% of sudden 'idiopathic' deafness cases turn out to be due to acoustic neuroma. The presence of a clinically silent tumour may render the cochlea more sensitive to other damaging influences, particularly acoustic trauma, and a unilateral 4 kHz dip, appearing suddenly and perhaps only transiently after a relatively brief period of noise exposure may be the first indication of the presence of an acoustic neuroma. At times there may be a fluctuating low frequency hearing loss which, if accompanied by attacks of vertigo, may lead one to suspect a diagnosis of Ménière's disease. In particular, variations in speech discrimination may be seen. The tinnitus has no particular diagnostic features, except that it is non-pulsatile, and usually commences at about the same time as, or precedes, the deafness. Occasionally one will encounter the patient with acuity which is clinically and audiometrically normal, and with no tinnitus who, nevertheless, insists that there is 'something the matter with the hearing' in
one ear. It is worth remembering that there are more subtle aspects of hearing other than those which are measurable on hearing tests, and to take such a complaint seriously.

**Imbalance**

The slowly growing tumour destroys the vestibular nerve from which it arises so gradually that the central nervous system is able to compensate for the unilateral loss of peripheral input so that severe disturbances of equilibrium are the exception. Many patients may suffer a total loss of caloric response on the affected side without ever experiencing any dysequilibrium, and others may complain of no more than slight imbalance or lightheadedness on change of head or body position, especially in the dark. A minority of patients, 30% in the series of Hitselberger and House (1968), suffer from true rotatory vertigo. Many of that group experience a prolonged episode of acute labyrinthise failure, lasting for a few days or more, to which a diagnosis of labyrinthitis or vestibular neuronitis may be attached, and which probably has a vascular cause similar to the sudden loss of cochlear function alluded to previously. A small number of patients have recurrent attacks which seem identical to those of Ménière's disease, but a carefully taken history, particularly with respect to the duration, temporal pattern and associated features of the attacks should allow this diagnosis to be excluded with confidence in most instances. The author has encountered a small number of patients whose only vestibular symptom was a Tullio phenomenon brought about by the noise of traffic.

**Facial nerve involvement**

Although the facial nerve is compressed and may be considerably attenuated by the expanding tumour, obvious facial weakness is uncommon. This is because motor neurons, as elsewhere in the body, are more resistant to pressure than sensory fibres. Minor degrees of weakness not apparent to the patient may be detectable on close examination, but if a severe facial weakness occurs in association with other features of a cerebellopontine angle syndrome, the cause is more likely to be a meningioma or primary cholesteatoma than an acoustic neuroma. Facial tic is surprisingly rare, but may occur. Pain, pressure or numbness around the ear are common complaints and may be due to involvement of the sensory branch of the facial nerve. Nervus intermedium involvement is frequently manifested by altered lacrimation, the patient complaining of either a dry irritating eye, or of excessive tearing, and less commonly by alterations in the sensation of taste, with cachoguesia at times. Thomsen and Zilstorff (1975), employing a simple test of the nasolacrimal reflex, found evidence of nervus intermedium involvement in 85% of 125 patients with an acoustic neuroma, an incidence higher than that of trigeminal nerve symptoms, and concluded that apart from audiovestibular findings, a defective nasolacrimal reflex was the most significant clinical evidence of cerebellopontine angle pathology.

**Trigeminal nerve involvement**

The earliest sensory change, occurring when the tumour has reached 2-2.5 cm is nearly always in the cornea, and may result in a feeling of irritation in the eye especially if there is coexisting alteration in tear production. With further growth of the tumour, pain, tingling or numbness may be felt in any or all of the three divisions of the nerve, and occasionally typical trigeminal neuralgia may occur (Bell, 1830). There may also be altered thermal
sensation with a feeling of cold on the face or on the edge of the tongue. There is usually an interval of about 2 years between the first audiovestibular presentation and the appearance of trigeminal signs and symptoms (King, Gibson and Morrison, 1976), but in approximately 5% of patients facial numbness is the initial symptom, particularly when the tumour arises medially.

**Brainstem and cerebellar involvement**

As the tumour enlarges still further, more evidence of neurological involvement appears, with ataxia of the ipsilateral upper and lower limbs presenting as clumsiness due to dysmetria, dyssynergia and dysdiadochokinesia, and with disturbances of gait, the patient tending to lean or stagger to the side of the lesion. Intention tremor may develop and it is important to differentiate it from that of Parkinson's disease which decreases during voluntary movement. Direction changing horizontal nystagmus, vertical nystagmus and rotatory nystagmus are all evidence of involvement of the central vestibular pathways, and although often violent, this is not usually associated with severe imbalance. Clinical involvement of the lower cranial nerves is not frequent, but if present implies the presence of a large tumour. Sterkers has recorded unilateral pharyngeal pain in one case and recurrent laryngeal nerve palsy in another (Portmann et al, 1975).

**Increasing intracranial pressure**

As the intracranial pressure starts to increase, headache becomes more severe and although generalized, is usually worst in the suboccipital region and in the upper neck, and is often associated with nausea and vomiting. The patient may adopt a peculiar head posture, with the neck flexed, a manoeuvre which increases the volume of the cisterna magna by 5-10 mL. There may also be titubation, a rhythmic side-to-side or nodding movement of the head caused by extreme cerebellar distortion. Failing vision due to papilloedema may, even today, be the mode of initial presentation, the earlier otological and neurological symptoms having been ignored by the patient, or worse, by his doctor. Occasionally, however, a cerebellopontine angle lesion can reach this stage with a minimum of symptoms. A patient may present with raised intracranial pressure, no localizing signs, dementia from hydrocephalus and a tremor attributed to Parkinson's disease. Alternatively, vomiting from raised intracranial pressure may be regarded as being of gastrointestinal origin (King, Gibson and Morrison, 1976).

**Terminal stage**

The terminal events in the history are related to failure of the vital centres in the brainstem.

**Examination**

General examination may reveal the presence of cutaneous lesions suggestive of von Recklinghausen's disease, multiple neurofibromata and café-au-lait blemishes. Minor manifestations may not be apparent in the fully clad outpatient, but he should be questioned about the presence of such lesions and if necessary treated to a full examination.
Ears

The tympanic membranes will be expected to be normal in most cases, but they must nevertheless be examined. Chronic middle ear disease can coexist with an acoustic neuroma and even if it is inactive, may present problems to the surgeon by limiting his access to the internal meatus through a sclerotic and acellular petrous bone. Furthermore, there are other causes of a cerebellopontine angle syndrome apart from an acoustic neuroma, and evidence of primary cholesteatoma or glomus jugulare tumour may be apparent on otoscopy. Tuning fork tests will usually confirm a unilateral sensorineural hearing loss.

Cranial nerves

These merit the closest scrutiny, in particular the fifth and seventh.

Trigeminal nerve

All three sensory divisions of the trigeminal nerve should be tested for pin-prick and fine touch, not forgetting to include the tongue, and bearing in mind the fact that the cutaneous branches of the cervical plexus extend up over the angle of the mandible. The most important area for sensory loss is the cornea, which is usually the first to be involved by an expanding lesion in the cerebellopontine angle. The reflex is elicited by stroking the cornea lightly with a wisp of cotton wool, remembering first to remove any contact lenses. Motor function is only rarely impaired, but can be checked by asking the patient to clench the teeth.

Facial nerve

Testing of the facial nerve requires some care. Severe facial weakness is uncommon unless the tumour is very large. All that may be apparent is a slight impairment in the patient's ability to bury the eye-lashes on the affected side when screwing the eyes up tightly. Minor degrees of weakness are more likely to be seen during involuntary movement of the face. Throughout the interview, the examiner should be observing the patient's face and may notice the occasional slight delay in the blink on one side. This may be confirmed by testing the blink reflex by means of a well regulated tap on the forehead with the finger. The cutaneous branch of the facial nerve may be tested by touching the skin of the posterosuperior aspect of the external auditory meatus with the tip of a needle. Loss of sensation (Hitselberger's sign) may occur while the tumour is still confined within the internal meatus, but not all clinicians find this a very reliable test (Portmann et al, 1975). Function of the nervus intermedius is evaluated by testing for lacrimation and taste on the anterior two-thirds of the tongue. Lacrimation may be assessed by carrying out Schirmer's test, in which short strips of filter paper are hooked over the lower eyelid for half a minute. This is a useful test, but there may be a slight theoretical criticism in those patients who have reduced corneal sensation and thus an unequal stimulus to tear production.

A more accurate though more time consuming test may be that of the nasolacrimal reflex as described by Thomsen and Zilstorff (1975). This involves blowing a stream of saturated benzene fumes, 500 mL/minute, into the nostril for 30 seconds directed towards the olfactory area, with Schirmer's paper in the eye. The paper is left in place for a further 30 seconds, before removal, and the lacrimation measured in millimetres. Unfortunately both
sides cannot be tested at the same time, and an interval of 10 minutes is recommended between tests. A difference of 20% between the two sides is considered significant. An elevation in the taste threshold on the anterior two-thirds of the tongue is best measured by electrogustometry, a difference of more than 20 µA between the two sides being considered significant (Pulec and house, 1964).

The other general visceral function served by the nervus intermedius is saliva production in the submandibular gland. There is a submandibular salivary flow test (Magielski and Blatt, 1958), but it is rarely used.

Examination of palatal and pharyngeal sensation and mobility is important, and abnormalities of either may indicate pressure on the glossopharyngeal or vagus nerves by the lower pole of a large tumour.

**Eyes**

The eye is a most fruitful source of information to the neuro-otologist who should be as conversant with the use of the ophthalmoscope as with the otoscope. As stated previously, there are still a surprising number of patients who first present to hospital at the stage of increasing intracranial pressure, and failing vision, and the otologist should be able to recognize not only florid papilloedema, but also the earlier changes of venous congestion and loss of venous pulsation.

Nystagmus is a very common and important sign, its pattern changing at different stages in the growth of the tumour, thus providing useful information about its size. When the tumour is small, fine first degree vestibular nystagmus to the contralateral side may be observed, particularly if optic fixation is abolished by using Frenzel's glasses. As the mass enlarges it comes into contact with the brainstem, producing rather complex changes in the central vestibular connections. Dix and Hallpike (1966) suggested that as the mass made contact with the ipsilateral vestibular nucleus, there was an increase in this fine contralateral nystagmus. Later as the cerebellar connections are involved, the nystagmus becomes direction changing, that is beating to the right on rightward gaze and beating to the left on leftward gaze. The nystagmus to the contralateral side remains fine, rapid and of low amplitude, whereas the nystagmus to the side of the lesion is more coarse and of higher amplitude. The former remains enhanceable when visual fixation is inhibited, whereas this is not true of the latter. The term Brun's nystagmus is often applied to this pattern of direction changing nystagmus. When cerebellar involvement is even more marked, other patterns such as vertical nystagmus, rotatory nystagmus and rebound nystagmus may be seen (Hood, Kayan and Leech, 1973).

The other reflex eye movement that may be disturbed by a large mass in the posterior fossa is the smooth pursuit reflex (Nedzelski, 1983). This is a low velocity tracking movement that allows the eyes to follow accurately an oscillating target such as a finger at frequencies up to about 1-1.5 Hz. At greater frequencies, the eyes cannot follow the target smoothly and the previously clean sinusoidal movement becomes contaminated with small rapid saccadic jumps. 'Saccadic pursuit' is also seen at normal frequencies if there is interruption of the brainstem pathways that subserve it. The reflex can be rapidly assessed by asking the patient
to follow with his eyes the examiner's finger as it moves slowly from side to side, or it can be recorded graphically using electronystagmography.

**Investigation and diagnosis**

The aim of investigation is to diagnose acoustic nerve tumours while they are at the otological stage, and if possible while they are still confined within the internal auditory meatus. This is an ideal which we are still some way from achieving, although considerable advances have been made over the last 30 years. It is, however, more important today than at any time in the past, that early diagnosis is made, because of the evolution of the surgical techniques to enable safe total removal with preservation of the facial nerve in the majority of instances, and of the cochlear nerve in a small number. The surgical nihilism embodied in the writing of Pennybacker and Cairns in 1950 is a thing of the past: 'While in general we welcome early diagnosis, it is sometimes possible to make the diagnosis long before there is any indication for operation'.

There are two prerequisites: a high index of suspicion on the part of the otologist; and a programme of investigations, both audiovestibular and radiological, which can be relied on to be both sensitive and specific. In effect, every case of unilateral sensorineural hearing loss, or tinnitus, and every case of unilateral vestibular hypofunction, should be investigated to exclude the diagnosis of an acoustic neuroma. Since acoustic neuromata represent only a small minority of cases of unilateral sensorineural deafness, logistic and economic factors may start to become important, as highly sophisticated but expensive imaging techniques such as CT and MR have become available. These imaging techniques have become so refined, that in a society freed from financial constraints, all suspects would proceed straight from pure-tone audiometry to MR. In some parts of the world, that state of affairs may not be far away. More usually, however, suspects are selected for CT or MR through an investigative filter of audiovestibular tests and 'conventional' X-rays, and the exact strategy that is followed again depends upon the facilities available in individual centres.

**Audiovestibular investigation**

Traditional audiometric techniques evolved throughout the 1960s and 1970s as it was discovered that there were differences in certain functions of the ear and hearing depending upon whether the lesion was situated in the cochlea or the auditory nerve. The tests developed during that time are still, in various combinations, the mainstay of initial investigation, although one or two, such as Békésy audiometry and the short increment sensitivity index (SISI) test, are employed less frequently now than perhaps 10 years ago.

The functions traditionally studied are:

1. pure-tone threshold
2. speech discrimination
3. loudness recruitment
4. auditory adaptation.
Pure-tone threshold

There is no characteristic curve for the pure-tone audiogram. Many patients have a high frequency loss, others a flat loss, some a mid-frequency notch; a salutary proportion have a low-tone loss similar to that in Ménière's disease, and a small but disconcerting number may be normal. A total or subtotal hearing loss is present in 16% which makes the assessment of other functions impossible (Johnson, 1968).

Speech discrimination

The cochlear nerve does not require a large population of intact neurons to transmit relatively simple pure tone messages. Speech, however basic, demands a disproportionately greater number of healthy neurons, capable of coping with the complex coding involved, particularly of temporal patterns. For this reason the typical finding in the patient with a neural lesion is of a speech discrimination score which is much worse than one would expect from consideration of the pure-tone threshold, and worse than in a patient with the same degree of cochlear deafness (Schuknecht and Woellner, 1955). Hood and Poole (1971) studied a series of patients with Ménière's disease and defined the broad limits within which the speech audiograms of subjects with cochlear deafness might be expected to fall. By comparing the results from a series of patients with acoustic neuroma with these limits, they found that most of the tumour results fell outside the limits, but that unfortunately, there was some overlap and some of the neural lesions did have 'cochlear' speech patterns. There have been many modifications of the technique from different centres, and there is a wide variation in the percentage of positive retrocochlear results from different series. Sheehy and Inzer (1976) found that speech audiometry yielded no positive results in a series of 24 patients, Hirsch and Anderson (1980a) found it of value in 45% of patients, whereas in the series of King, Gibson and Morrison (1976), 78% of tumour cases gave retrocochlear results. Even these authors warned against placing too much reliance on the test. Rudge (1983) pointed out that one of the problems of speech audiometry is the lack of standardization of technique. Taylor (personal communication, 1986) has recently re-emphasized the fact that the score a subject may achieve on speech audiometry is very dependent upon the time and care that the audiometrician applies to the test.

Loudness recruitment

This phenomenon was first described by Fowler in 1936, but was thought by him to have a neural basis. It was Dix, Hallpike and Hood (1948) who opened the door of neuro-otological diagnosis when they reported to the Royal Society of Medicine in London their finding that total recruitment, as assessed by Fowler's alternate binaural loudness test (ABLB) occurred in every one out of 30 patients with Ménière's disease, and was absent in 14 out of 20 cases of neural pathology (in other six cases it was present but incomplete). For the first time, a simply performed test was available which allowed differentiation of neural from cochlear lesions. This observation has, for most investigators, stood the test of time, despite the assertion of Jerger and Jerger (1974) that the concept behind it had in a sense retarded subsequent progress. Hirsch and Anderson (1980a), however, found it to be positive in 64% of acoustic neuromata, Thomsen and Terkildsen (1975) in 77% of all tumours, and King, Gibson and Morrison (1976) in 90% of large tumours. These authors pointed out that the phenomenon of 'decrrection' may be seen in some cases of acoustic neuroma, that is the
sensation of loudness grows more slowly in the affected ear than the normal ear. The fact that full recruitment, a supposed end-organ phenomenon, may be seen in a number of cases of acoustic neuroma was said by Dix and Hood (1953), writing some years after their original observation, to be 'connected with hair cell changes resulting from occlusion of the cochlear blood supply'. There is again no doubt that good test technique influences the accuracy of the results (Simmons and Dixon, 1966). It is suggested that the procedure is, if possible, carried out at more than one frequency; not uncommonly a hearing loss that appears to be recruiting or even over-recruiting at one frequency will be found not to be so at another, even if separated by as little as 250 Hz.

Other tests of recruitment include Reger's monaural balance test, and the loudness discomfort level (LDL). Both tests were evolved to try to differentiate cochlear from retrocochlear lesions in situations in which the contralateral ear was not normal for comparison, but neither is commonly performed today. Another test which for years was a standard part of the audiological battery, but which has fallen from favour, is the short increment sensitivity index test.

Auditory adaptation

This term describes the observation that a sound presented to the ear at a level just greater than threshold, will become inaudible after a short period of time, the length of which has a predictable value in normal ears. In ears with cochlear deafness, the values are similar to those in normal subjects, but with neural pathology, the speed of this adaptation is classically greatly increased. This phenomenon forms the basis of Carhart's tone decay test (1957). Hirsch and Anderson (1980a) found that it gave positive results in 53% of patients, King, Gibson and Morrison (1976) in 80%, and Johnson (1977) in only 40%. The main criticism of the test is the very high number of 'false positive' results, that is patients with cochlear lesions who have 'retrocochlear' tone decay.

The other great diagnostic tool of the 1960s and 1970s was the Békésy self-recording audiometer, which compared threshold values for pulsed and continues tones. Patterns or response were identified for cochlear, retrocochlear and non-organic hearing loss (Jerger, 1960). In addition to providing information about threshold, the test identified the presence of abnormal adaptation, and also, in the view of some workers, evidence of recruitment. The problem was, as Jerger himself pointed out (Jerger and Jerger, 1974), that both the Békésy and Carhart tests studied phenomena close to the auditory threshold, and it became clear that more information was to be gained from suprathreshold studies, particularly those of the stapedius reflex.

It is apparent from the preceding account that no single test had the reliability or even uniformity from centre to centre to allow a confident diagnosis of acoustic neuroma, and even if employed en masse the tests were still capable of missing an appreciable number of cases. It is remarkable how few proven cases of retrocochlear pathology in any series have a full complement of retrocochlear features on every audiological test. Accuracy of audiological diagnosis has increased dramatically however with advent of two more recent techniques: stapedius reflex studies and electric response audiometry.
**Stapedius reflex measurements**

There are two parameters of the stapedius reflex which have proved of great value in the identification of retrocochlear pathology, the reflex threshold itself, and its rate of decay. Although the activity of the middle ear muscles has been studied since the last century, it was Metz (1946, 1952) who first studied their role in clinical cases. The use of the test became widespread when the original mechanoacoustic bridges were superseded by the simpler electroacoustic equipment. Following the observations of Anderson, Barr and Wedenburg (1970), many studies have confirmed that in the presence of retrocochlear pathology, the stapedius reflex threshold is elevated above normal levels, whereas in cochlear deafness the threshold is usually normal. They defined significant elevation as 95 dB HL at 250, 500, 1000, 2000 and 3000 Hz, and 100 dB HL at 1500 Hz and stated that for the threshold to be abnormal it must be significantly raised at four out of the six test frequencies (250 Hz - 3 kHz). Subsequent work has suggested that these thresholds are too low and result in a large number of 'false positives'. Chiveralls et al (1976) introduced a concept of 'reflex asymmetry', and proposed that a difference in the reflex threshold between the two ears of more than 15 dB should be regarded as abnormal.

Not infrequently the reflexes are absent at some or all frequencies; in many instances this is presumably because the threshold is beyond the maximum output of the audiometer. Hirsch and Anderson (1980b) found that in the majority of cases of acoustic neuroma, the elevation of the reflex threshold was greater in the higher than the lower frequencies. They also emphasized that the test should be carried out using contralateral recording. There is a possibility that absence of a reflex on ipsilateral recording could be due to interference with the efferent limb by pressure on the facial nerve from a lesion in the cerebellopontine angle. Gibson (1981) reported significant elevation of the stapedius reflex threshold in 75% of small and medium tumours and in 90% of large tumours, and this is fairly typical of the general experience.

Stapedius reflex decay is the decline in amplitude of the reflex on prolonged stimulation, and in individuals with neural pathology the rate at which the decay occurs is increased. Pathological decay is judged to be present if the response amplitude declines by more than 50% in 5 seconds at 500 Hz and at 1 kHz. At higher test frequencies, decay of this magnitude may be normal. The cause of pathological decay is unclear. Rudge (1983) suggested that impaired conduction in the cochlear nerve may result from demyelination, impaired blood supply or some abnormality of axoplasmic flow. It may well be related to the fact that demyelinated fibres cannot sustain a train of electrical impulses. It is clear, however, that the phenomenon arises in the eighth nerve and not the seventh, because it occurs on both ipsilateral and contralateral recording. Hirsch and Anderson (1980b) regarded abnormal stapedius reflex decay as a more specifically retrocochlear finding than elevation of the threshold. They considered the interrelation between the stapedius reflex threshold and decay abnormalities and concluded that an elevated stapedius reflex threshold with normal stapedius reflex decay was a relatively poor indicator of the presence of a lesion in the cerebellopontine angle, whereas abnormal stapedius reflex decay with or even without elevation of the stapedius reflex threshold was highly significant. These writers concluded that the probability of encountering normal stapedius reflex characteristics in a case of a tumour of the cerebellopontine angle seems very slight.
The value of the combined test of stapedius reflex threshold and decay has been confirmed by many subsequent studies (King, Gibson and Morrison, 1976; Chiveralls, 1977), and it has taken its place as one of the simplest and most reliable techniques available to the clinician. One shortcoming of the test, as Flood et al (1984) pointed out, is that the acoustic reflex will be abolished even by a cochlear hearing loss of greater than 60-75 dB, and the coexistence of middle ear disease renders the test impossible. One further parameter of the reflex which has received some attention is its latency. Clemis and Sarno (1980) felt that in patients with an eighth nerve disorder, there was significant delay in the onset of the acoustic reflex compared with the normal contralateral side, but this was not confirmed by Jerger and Hayes (1983), who felt that the concept of latency measurement should be abandoned.

**Electric response audiometry**

The advent of electric response audiometry has been one of the most important events in the history of audiological medicine and neuro-otology. In the investigation of patients with unilateral sensorineural deafness, two tests are of particular importance; electrocochleography and brainstem electric response audiometry. The main role of electrocochleography in neuro-otological diagnosis seems to be in the identification of endolymphatic hydrops (Gibson, Moffat and Ramsden, 1977), but brainstem electric response audiometry has emerged as the single most reliable audiological indicator of retrocochlear pathology, and has gone far towards superseding traditional psychoacoustic tests. The detailed test procedure has been described elsewhere (Volume 2). In brief, a sound wave entering the cochlea is transduced into an electric potential which is transmitted via the eighth nerve to the brainstem, where it passes through a series of relay stations on the way to the higher auditory centres. This process is associated with a sequence of electric phenomena, which can be detected by scalp electrodes and after a process of 'time-domain averaging', displayed on an oscilloscope screen. Within the first 7 milliseconds following acoustic stimulation, a series of five negative deflections appears. Their sites of origin are thought to be as follows:

- **N<sub>1</sub>** cochlear nerve
- **N<sub>2</sub>** cochlear nucleus
- **N<sub>3</sub>** superior olivary complex
- **N<sub>4</sub>** lateral lemniscus
- **N<sub>5</sub>** inferior colliculus.

In normal individuals, the latency of these responses is very predictable and reproducible, not only from person to person, but from test to test in the same person. The early identification of these potentials was largely the result of the work of Jewett, Romano and Williston (1970), while Selters and Brackmann (1977) were the first to explore the possible application of the technique to the detection of lesions of the eighth nerve. They argued that any delay in electrical transmission in the nerve, caused for example by a tumour, would be passed on to all subsequent points in the auditory chain, and would be detectable in latency delays in wave V, which by virtue of its magnitude has proved the most convenient for study. They found the interaural latency difference of wave V to be superior to the absolute latency of wave V for the detection of acoustic tumours. They used the terms ‘T<sub>v</sub>’ to identify the latency of wave V, and ‘IT<sub>v</sub>’ for the interaural difference, and regarded the upper limit of normal for IT<sub>v</sub> to be 0.2 ms and correctly identified 91% of tumours using this criterion. Terkildsen and Thomsen (1983) preferred an IT<sub>v</sub> of 0.3 ms.
Apart from delay in wave V, two other abnormalities may be seen in certain tumour cases. In some patients, there may be no recognizable response despite adequate levels of hearing, and this may be due to a loss of the synchrony of neural discharge necessary to produce an identifiable waveform. The other effect sometimes seen is a slight delay in the contralateral wave V in patients with large tumours causing distortion of the brainstem and of the contralateral auditory pathways.

The main disadvantage of the test is that it can only be relied upon to produce consistent waveforms at hearing levels better than 75 dB. At higher levels, therefore, there will be an increasing number of 'false positive' results. However, the chances of a subject with a normal brainstem electric response having an acoustic neuroma are very slight, certainly less than 5%, and this test is now well established as the single most reliable audiological screening test for the condition (Selters and Brackmann, 1977; Glasscock et al, 1979; Terkildsen and Thomsen, 1983).

Gibson and Beagley (1976) and Morrison, Gibson and Beagley (1976) have reported on the electrocochleographic abnormalities in cases of acoustic neuroma, and described three typical findings - broadening of the eighth nerve action potential, good preservation of the cochlear microphonic, and preservation of the action potential at stimulus intensities that are inaudible to the patient. Unfortunately, as these authors pointed out, the broadening of the action potential waveform is not pathognomonic of retrocochlear disease and a very similar waveform is commonly seen in Ménière's disease and other hydropic disorders. In addition, cochlear microphonic measurements are notoriously variable and hard to standardize. Because of these objections, and the simplicity and reliability of brainstem electric response audiometry, electrocochleography has not gained widespread acceptance in the assessment of retrocochlear pathology.

**Caloric testing**

The traditional bithermal caloric test of Hallpike and Fitzgerald remains an invaluable aid to diagnosis, with a significant canal paresis in well over 90% of patients with an acoustic neuroma, although King, Gibson and Morrison (1976) found that in smaller tumours of less than 2 cm diameter, the test gave normal responses in 20% of instances. It is a fair observation that the pattern of abnormality does not allow one to differentiate between acoustic neuroma and other causes of unilateral vestibular hypofunction such as Ménière's disease. What is highly suggestive, however, is the finding of an absent or considerably reduced response without any dramatic history of vertigo, and this should always increase the clinician's suspicions. The end point of caloric-induced nystagmus may be more obvious if Frenzel's glasses or electronystagmographic techniques are employed.

**Radiological investigation**

Although high quality plain X-rays of the temporal bones, particularly the transorbital view, can reveal pathological changes in the internal auditory canals in a large number of instances, there is no doubt that the proportion of abnormalities detected is increased by the use of tomography (Harner and Reese, 1984). Valvassori (1969), by studying anatomical specimens as well as tomograms, established the limits of normal variation of certain parameters of internal meatus anatomy, and defined three important measurements: vertical
diameter of the internal canal - in over 90% of normal individuals the difference in the vertical diameter between the two sides measured at the same point did not exceed 1 mm; length of the posterior wall of the canal - in over 90% of normal individuals the difference between the two sides did not exceed 2 mm; crista falciformis was always located at or above the midpoint of the vertical diameter of the internal canal. In 90% of normal individuals the difference in position on the two sides, measured from the crista to the superior and inferior walls did not exceed 1 mm. The canal is considered abnormal when there is enlargement of 2 mm or more of any portion, compared with the opposite side, when there is shortening of the posterior wall by at least 3 mm compared with the normal side, and when there is displacement of the crista by at least 2 mm compared with the normal side. Using these criteria the diagnosis of acoustic neuroma was definite in 78% of cases and suggestive in a further 13%. When studying tomograms of the internal auditory meatus, it is important to appreciate that there are variations in the normal canal. Thomsen et al (1981) found that in 70% of normal canals, the shape of the internal meatus was straight, that is the upper and lower walls were parallel to each other, in 14% it was narrow medially, in 14% it was oval and in 2% narrow laterally.

Computerized tomography has proved the greatest radiological advance of recent years in the detection of acoustic neuromata, and as each new generation of scanner emerges, with software programmes that allow coronal and three-dimensional reconstructions, so ever smaller lesions can be diagnosed with confidence. Whereas with the early models, tumours smaller than about 2 cm could not be demonstrated, the current situation is that in most instances an extension of 0.5 cm into the posterior fossa can be readily demonstrated. It is, of course, essential to administer an intravenous contrast agent which is taken up by the vasculature of the tumour and enhances the image. In the event of a negative result, a small volume of intrathecal air may be introduced, and this may demonstrate not only a small intrameatal tumour, but also detail of the related neurovascular structures. Computerized tomography also provides the surgeon with information about the state of the ventricular system and any shift in the brainstem that may have occurred. The technique has largely replaced the traditional air encephalography and myodil meatography, but angiography still has a place in occasional instances, if doubt exists as to the true nature of the lesion in question.

Magnetic resonance

Where available, MR is now an established alternative to CT in the detection of posterior fossa lesions (Jenkins and Isherwood, 1986). The theoretical basis of the technique is discussed in Volume 1. The advantages over conventional imaging methods are a high intrinsic contrast between tissues, an absence of bone artefacts, an ability to image directly in the coronal, sagittal and transverse planes, and an avoidance of ionizing radiation. In the specific case of an acoustic neuroma, there is a high contrast between neural structures, the surrounding temporal bone and cerebrospinal fluid. Large tumours can be more readily identified than with contrast enhanced CT scanning (Kingsley et al, 1985), and in particular the intracanalicular extent and the associated brainstem distortion are more distinctly demonstrated. Small tumours totally confined within the meatus may be seen very clearly, because of the contrast between tumour and bone, and their detection may be improved by the use of contrast enhancement using gadolinium-diethylenetriamin-penta-acetic acid (Gd-
DTPA) (Curati et al, 1986). At the present time, the higher costs of MR compared with CT precludes its routine use, but its future potential seems enormous.

**Diagnostic screening for acoustic neuromata**

As pointed out earlier in this chapter, logistic and economic factors decree that there must be some sort of screening strategy that selects those patients for CT or MR that are most likely to yield positive results, because in the final analysis, the preoperative diagnosis of acoustic neuroma must be made on the basis of positive radiological findings. However suggestive they may be, audiovestibular tests are no more than a means of allowing the clinician to decide which patients to investigate further, and are not in themselves an indication for surgery. There is no single test short of a full CT scan, with or without contrast, or MR which will allow the condition to be diagnosed. It is important that the conventional audiological tests should be carried out with skill and care, and in many otolaryngology departments throughout the world they will be the only options available to the clinician. Ideally, however, the most efficient routine screening programme is, in the experience of the author, a combination of three tests:

1. brainstem electric response audiometry
2. tomography of the internal auditory meatus, applying the criteria of Valvassori (1969)
3. bithermal caloric test of Hallpike and Fitzgerald.

This test battery effectively eliminates all 'false negative' results. In other words, if a patient with a suspected tumour produces normal results from all three tests, his chances of harbouring an acoustic neuroma are virtually nil. Terkildsen and Thomsen (1983) using a very similar strategy suggested that if two or more of these tests gave positive results the patient should be submitted to CT scanning, with air-cisternography if necessary. If only one test gave a positive result, they recommend re-screening after one year. Using this approach, they claimed not to have missed any cases of acoustic neuroma. Mafee et al (1985) also recommended the use of brainstem electric response audiometry and caloric tests in the selection of patients for CT scanning.

**Differential diagnosis**

Acoustic neuroma is by far the most common lesion of the cerebellopontine angle. A meningioma is the next most frequently encountered condition in this region. The majority of posterior fossa meningiomas arise on the posterior surface of the temporal bone and may be differentiated from an acoustic neuroma on CT scanning by the fact that they may not be centred on the internal auditory meatus, and indeed may not be associated with expansion. Furthermore, they are usually clearly evident on the unenhanced scan, whereas an acoustic neuroma requires intravenous contrast for clear visualization. Meningiomas may be seen in association with acoustic neuromata in von Recklinghausen's disease.

Next in the order of frequency are primary cholesteatomata arising from congenital epithelial remnants within the temporal bone. These typically present with facial weakness as
an early sign, and have a characteristic appearance on petrous tomography with a widespread area of destruction bounded by a scalloped edge (Fisch, 1978). Arachnoid cysts of the posterior fossa may occur in the cerebellopontine angle. The usual hypotheses to explain their development include congenital malformation, infection (adhesive arachnoiditis), trauma, increased intraventricular pressure and embryonic rests (Little, Gomez and MacCarty, 1973). They are also commonly described in association with acoustic neuromata, indeed they may be a very large cyst associated with quite a small tumour. The cysts are characteristically thin walled and appear to develop between the layers of the arachnoid. They contain clear fluid identical to cerebrospinal fluid. Vascular causes of a cerebellopontine angle syndrome include basilar artery aneurysm or ectasia (Gibson and Wallace, 1975), von Hippel-Lindau syndrome, or compression of the eighth nerve by a loop of the anterior inferior cerebellar artery. Other neoplastic causes include pontine glioma, in which there are progressive brainstem and cerebellar signs without obvious temporal bone changes, cerebellopontine angle lipoma, which is rare and very difficult to remove totally (Rosenbloom et al, 1985; Pensak et al, 1986), and a secondary deposit.

The commonest condition to be distinguished from acoustic neuroma is Ménière's disease. An acoustic neuroma does not, however, usually cause the typical intermittent severe vertigo of Ménière's disease; it usually produces a retrocochlear picture on conventional audiometry, is not associated with a positive response to glycerol dehydration, and is characterized by unique brainstem electric response audiometry and tomographic changes. Nevertheless, the occasional tumour case presents with a history typical of Ménière's disease, and with a fluctuating low frequency hearing loss with good speech discrimination, full recruitment, normal tone decay and normal stapedius reflex functions. It is desirable for the vigilant clinician to subject all such cases to brainstem electric response audiometry, petrous tomography and caloric testing.

**Surgical management**

The transformation in the prognosis in acoustic neuroma surgery over the last 25 years, is largely as a result of the universal adoption of the operating microscope by both otologists and neurosurgeons. Mortality has dropped to 3% or less, and functional preservation of the facial nerve has proved possible in the great majority of cases (Lye et al, 1982). Furthermore, on a limited number of occasions, it may be feasible to conserve useful hearing. There is no doubt that better results are achieved with small tumours than large. Morrison and King (1982) reported no mortality for small tumours, rising to 2% when the tumours were large. As regards the facial nerve, the same authors reported functional preservation in 100% of small, in 80% of medium-sized, but in only 20% of large tumours. In nearly every instance, therefore, it is desirable to remove an acoustic neuroma at the earliest possible opportunity.

There are certain exceptions to this rule. A small tumour in an aged patient or in one who is a poor anaesthetic risk can be monitored by check CT scanning at annual or biannual intervals. There is also a good case for withholding surgery as long as possible in the patient with an acoustic neuroma in his only hearing ear; this situation is most commonly encountered on the second side of patients with bilateral tumours. In the great majority of cases, however, surgical removal should be total, but in the elderly patient with a large tumour it is often sufficient to carry out a partial or intracapsular removal thus shortening the operation and minimizing the risk of damage to the brainstem or facial nerve. The residual
tumour can then be observed at regular intervals by scanning. Silverstein and Norrell (1982) who have particular experience of this problem, by virtue of the popularity of Florida with the elderly, reported the case of an 83-year-old woman who had a radical intracapsular resection of a large tumour, and was alive and well 10 years later with no apparent increase in the size of the residual mass. There are also occasions when the surgeon has to terminate the operation on the advice of the anaesthetist before total removal has been achieved, usually because of changes in the vital signs occurring when attempting to remove the last portion of capsule from the brainstem. In that event, it is usually possible to complete the removal at a second stage operation.

There are several different surgical approaches, and over the years there have been many modifications and combinations of approaches devised. The main requirement of any approach is access, which must be sufficient to ensure total tumour removal, and to allow the surgeon control over any possible bleeding in the posterior fossa, but with a minimum of trauma to the brainstem and cerebellum. The second requirement is a reliable means of identifying the facial nerve early in the operation, preferably within the internal meatus. There are basically three routes to the cerebellopontine angle - the middle fossa, translabyrinthine and posterior fossa approaches - each with its advantages and disadvantages.

The middle fossa approach offers the possibility of total removal with preservation of hearing of small tumours confined to the meatus. Most of the dissection is extradural, and facial identification at the lateral end of the meatus is unequivocal. The main disadvantage of this approach is the limited access to the posterior fossa, which not only limits the size of tumour that can be removed but also restricts the ability of the surgeon to deal with bleeding in the posterior fossa either at surgery or postoperatively. A bleed from the anterior inferior cerebellar artery would be very difficult to control from the middle fossa. The other disadvantage is that the facial nerve, although easily recognized may be traumatized during tumour removal because it lies between the surgeon and the tumour. The risk of temporal lobe epilepsy from prolonged retraction, although often quoted appears slight.

The translabyrinthine approach developed by William House is the most direct route to the cerebellopontine angle, and allows early and reliable identification of the facial nerve at the lateral end of the internal meatus. Cerebellar retraction is minimal, and as a result the patients tend to have a speedier postoperative recovery. A further important advantage is that in the event of postoperative haemorrhage, the postauricular incision can be rapidly re-opened, the fat packing removed and the situation immediately rectified (House, 1977). Critics of the approach claim that the access is cramped and that it is difficult to remove a large tumour through it, and that, furthermore, the control of posterior fossa bleeding is less secure than with the retrosigmoid approach. One self-evident objection to the technique is the inevitable loss of residual hearing, but Brackmann (1982) pointed out that so far as is known, no single patient out of 1400 operated on for unilateral acoustic neuroma by the House group developed a serious loss of hearing in the opposite ear.

The posterior fossa or retrosigmoid or suboccipital transmeatal approach is the traditional neurosurgical procedure (Di Tullio, Malkasian and Rand, 1978), evolved by Dandy from the original Krause operation. It is the preferred route in cases where preservation of hearing is the aim (Smith, 1982). The good exposure it affords certainly makes it very suitable for the removal of the larger tumours, but it is also favoured by many for the removal
of all acoustic neuromata regardless of size (Welch and Dawes, 1985). The disadvantages include the necessity for cerebellar retraction, although the most skilled proponents of the technique are able to minimize this; there is now never any need to resect part of the cerebellum. Perhaps the greatest criticism (Brackmann, 1982) is that it is difficult and, in some cases impossible, to visualize the lateral end of the internal meatus without opening the labyrinth, so there is the risk that a small fragment of tumour could be left in that site.

Other modifications of approach that have been employed at various times, and which may still have an application include the translabyrinthine - transtentorial operation of Morrison and King (1973), the combined suboccipital-petrosal approach (trans-sigmoid approach) described by House, in which the standard translabyrinthine dissection is extended posteriorly over the divided sigmoid sinus to include that portion of the skull removed in a suboccipital approach, and the retrolabyrinthine approach, which allows partial removal through the mastoid with preservation of the labyrinth.

The questions as to choice of technique and whether acoustic neuromata should be removed by otologists or neurosurgeons have occasioned much, often vitriolic, debate over the years. The real answer is that there is more than one way to achieve the same goal. Ultimately, the most important consideration is, who does the job best in a particular area? In the best hands, there is very little to choose between the results of translabyrinthine and posterior fossa removal. In the most successful series, there is close collaboration between otologist and neurosurgeon, each of whom brings his own expertise to the team, and in many centres each partner learns the skills of the other so that both are totally familiar with all steps in the operation. This then allows the surgeons to change over during the operation and overcomes the problems of fatigue (and hunger). Familiarity with all approaches is desirable and confers a degree of flexibility to the team.

Apart from the operating microscope, other technical advances are constantly appearing, all of which, in a small way, help the surgeon to achieve better results. These include the cavitron ultrasonic surgical aspirator (CUSA) (Epstein, 1983), which reduces the operating time particularly with large tumours, and the CO₂ or argon laser (Glasscock, Jackson and Whitaker, 1981; Smith, 1982). Moller and Jannetta (1984a) have refined the technique of peroperative monitoring of the electromyographic responses from the facial muscles so that an acoustic warning is given when the facial nerve is stimulated. Similarly, the same authors (Moller and Jannetta, 1984b) and Ojemann et al (1984), attempting to preserve hearing, carried out peroperative recording of the electrocochleographic and brainstem electric response from transtympanic and scalp electrodes and found that changes in these potentials provided the surgeon with an early warning of possible damage to the hearing.

A full description of the anaesthetic considerations involved in the management of these cases is inappropriate in this chapter. Suffice it to say that the services of a skilled and experienced neuroanaesthetist are of paramount importance.
Surgical techniques

Middle fossa approach

The incisions begins in front of the ear at the level of the zygomatic arch and curves gently upwards and backwards to the superior temporal line. The temporalis muscle may be divided in a linear manner to expose the squamous temporal bone, and a 4-cm square craniectomy cut, the lower edge of which is on a level with the upper surface of the petrous bone. Approximately two-thirds of the bone flap should be in front of the external meatus and one-third behind it. Alternatively, the flap may be left attached to a pedicle of temporalis muscle and turned inferiorly. The dura is then gently elevated first to the arcuate eminence, and then anteriorly and medially until the superior petrosal sinus is reached and the middle meningeal artery is exposed as it enters the skull through the foramen spinosum.

The greater superficial petrosal nerve is found about 1 cm behind and slightly lateral to the artery and, using a diamond burr, is followed to the geniculate ganglion which may, in fact, be immediately under the dura without any bony covering. The facial nerve is then traced backwards and medially to the meatus, passing deeply between the cochlea and the superior semicircular canal, neither of which should be opened. As it leaves the meatus, the facial nerve is separated from the superior vestibular nerve by a very obvious vertical crest of bone - 'Bill's bar'. The meatus is exposed from its lateral to medial ends through as wide a bony trough as possible and the dura is incised along the posterior wall of the meatus, that is away from the facial nerve. After positive identification, the tumour is carefully dissected off the facial nerve, taking care to minimize the manipulation of both it and the cochlear nerve which is to some extent protected by the facial nerve. Both superior and inferior vestibular nerves must be totally ablated as the tumour is removed as otherwise there is a risk of postoperative imbalance.

If hearing is to be conserved, care must be taken to avoid damage to the internal auditory artery. Division of the superior petrosal sinus may occasionally be necessary to facilitate removal of a tumour extending into the posterior fossa. After careful haemostasis, the meatus is sealed using fascia or muscle, the middle fossa dura is allowed to sink back over the defect, and the wound is closed in layers, replacing the bone.

Translabyrinthine approach

The incision is an extension of the standard postauricular wound, the upper end reaching as far as the line of the anterior wall of the external meatus, and the lower limit being a point about 2 cm behind the tip of the mastoid. A superiorly-based periosteal flap is preserved in continuity with the lower edge of the temporalis muscle for use in eventual wound closure. An extended mastoidectomy is carried out, removing the bone over the lateral sinus, middle fossa dura and superior petrosal sinus until it is 'eggshell-thin'. The facial nerve is identified at the second genu and its vertical portion is skeletonized. A total labyrinthectomy is then performed taking particular care to avoid trauma to the facial nerve as the inferior crus of the posterior canal is followed into the vestibule, a point at which the drill will be immediately medial to the nerve. The subarcuate artery is encountered under the superior semicircular canal and after labyrinthectomy is the only feature in a dense triangular wall of bone separating the surgeon from the internal meatus. Bleeding from the artery is a
recurrent nuisance, but is not a real problem. The meatus is now skeletonized superiorly, posteriorly and inferiorly by careful removal of more bone during the process of which the endolymphatic duct and sac will be seen and destroyed. Above the meatus, dissection may be greatly facilitated if there is a well developed air cell system.

The anatomical limit above the meatus is the middle fossa dura with the superior petrosal sinus. Posteriorly, bone is removed from a wedge-shaped area between the internal meatus and the posterior fossa and, eventually, when the porus is reached, continuity between the meatus and the posterior fossa can be demonstrated. Inferior to the meatus the limiting factor for bone removal is the jugular bulb, and the other structure encountered in this region is the cochlear aqueduct. Bone is finally picked off the dura of the posterior fossa and the internal meatus.

The facial nerve may now be identified at the lateral end of the meatus separated by 'Bill's bar' from the superior vestibular fibres which may be seen entering the vestibule. The intrameatal portion of the tumour can then be separated from the facial nerve. The posterior fossa is then opened by cutting a laterally based U-shaped dural flap, the main bulk of the tumour is exposed, and an intracapsular removal performed, using the House-Urban rotary dissector, or the CUSA. The remaining capsule is then removed by careful dissection in the plane between the tumour and the arachnoid taking particular care to avoid damage to the branches of the anterior inferior cerebellar artery and the lower cranial nerves which are in the arachnoid layer and to the brainstem and trigeminal nerve. The previously identified facial nerve is traced medially. At the porus, it turns sharply forwards and may become very thin and hard to follow but, by careful adherence to the arachnoid plane, it is usually possible to preserve it. If the nerve is known to have been sacrificed, an immediate repair should be effected using a graft from the cervical plexus or sural nerve with re-routing of the horizontal portion of the facial nerve into the meatus if necessary (Barrs, Brackmann and Hitselberger, 1984; Samii, 1984). After tumour removal is complete, the middle ear should be packed with muscle, and the cavity with 1 cm strips of abdominal fat, held in place with the periosteal flap. These measures minimize the risks of a cerebrospinal fluid fistula.

Suboccipital transmeatal approach

The patient is positioned in the reclining lateral 'park bench' position and an S-shaped retromastoid incision is made from the level of the upper edge of the pinna to the spine of C2, taking care to avoid the vertebral artery. After separation of the muscular attachments, the craniectomy is carried out, the limits of which are the transverse sinus superiorly, the foramen magnum inferiorly and the sigmoid sinus laterally. It is important that the occipital bone be removed as far laterally as possible so that the surgeon's line of vision is along the back of the petrous bone, thus minimizing the amount of cerebellar retraction necessary. If the tumour is very large it may be necessary to remove the arch of the atlas. The dura is opened through a triradiate incision and cerebellar retractors gently introduced protecting the underlying cerebellum with patties. The intracranial segment of the tumour is debulked intracapsularly, as described above, taking care to identify and protect the lower nerves, and the trigeminal nerve, as well as the anterior inferior cerebellar artery. A laterally based dural flap is raised over the internal meatus, and the posterior wall of the meatus carefully drilled off, exposing the intrameatal portion of tumour which protects the facial and cochlear nerves in the anterior half of the meatus. If hearing preservation is intended, the labyrinth must not
be entered, but if this is unimportant there is no doubt that extending the dissection as far laterally as possible increases the chances of total tumour removal. The transverse crest and 'Bill's bar' are identified and the tumour gently separated from the facial nerve using Malis or Yasargil's dissectors. The operation is completed in the manner outlined above, and before closing the wound the internal meatus should be sealed with a muscle plug, and the mastoid air cells inspected for any possible cerebrospinal fluid leak which should be sealed with bone wax.

**Postoperative care**

The patient is returned from theatre to an intensive care unit for regular neurological observations and cardiac monitoring. A nasogastric tube is inserted to minimize the risk of aspiration, particularly if there has been trauma to the lower cranial nerves, and the patient should be catheterized. There will be an intravenous line, but over-hydration must be avoided. The patient will be on broad-spectrum antibiotics, and possibly steroids if there has been any threat of brain swelling. The cornea should be protected until it is obvious that facial function is satisfactory. As a temporary measure a simple silk stitch in the upper lid taped on to the cheek will suffice, but if the weakness is marked, and the Bell's phenomenon poor, and particularly if there is coexisting corneal anaesthesia, a formal lateral tarsorrhaphy should be performed. Tracheostomy may occasionally be necessary if aspiration and swallowing disturbances are a problem. Cerebrospinal fluid fistula is a dangerous condition which cannot be allowed to persist. It may settle spontaneously or with repeated lumbar punctures, but if in doubt, it is advisable to return the patient to theatre for repair.

As recovery proceeds, the patient is mobilized quickly, and is usually ready to go home by about the tenth postoperative day. Occasionally, in the case of a large tumour, postoperative hydrocephalus may be seen and this may require treatment by daily lumbar puncture or possibly ventriculoperitoneal shunting. Imbalance from loss of vestibular function is not usually a major problem because, in most instances, vestibular function has already been considerably reduced prior to surgery. The great majority of patients are fully rehabilitated to their previous levels of activity, and should be able to play golf, jog, cycle, and sail normally. Tinnitus is a surprisingly rare long-term complaint. One of the least appreciated problem areas is the eye in patients who have suffered partial or total facial weakness. Not only may the loss of the protective blink reflex expose the eye to the risk of foreign bodies, but there may be subtle changes in the physical properties of the tear film with resultant pain, grittiness, blurring, dryness or watering. If there is coexisting loss of corneal sensation, neurotrophic changes may occur with the risk of corneal ulceration. It is a clinical problem which demands close ophthalmological attention and possible tarsorrhaphy.

One of the most difficult problems concerns the non-recovering facial nerve. If the nerve is known to have been severed immediate repair is indicated if possible. If it is not possible, an immediate hypoglosso-facial anastomosis should be carried out. The problem arises when the nerve is thought to be partially preserved but no recovery ensues over a long period of observation. Recovery from a degenerated nerve will usually be apparent by one year after surgery. If no recovery is visible at 2 years, a hypoglosso-facial anastomosis should be carried out.
**Hearing preservation**

In a minority of patients with small tumours it is possible to preserve useful hearing by carrying out a middle fossa or posterior fossa removal. While this may seem a laudable objective, the facts must be looked at very critically. First, except in generalized neurofibromatosis the disease is almost invariably unilateral, so that most patients have normal or good hearing in the contralateral ear. Second, emphasis must be placed on the concept of 'useful' hearing, minimum criteria for which should be a 50 dB pure-tone threshold, and 50% speech discrimination score. Only a minority of patients will satisfy these criteria preoperatively, and certainly any postoperative result worse than these levels will not be appreciated by the patient. Furthermore, there is the problem of how results of surgery are reported. If a centre reports '40% hearing preservation' this does not mean that 40% of all patients with acoustic neuromata retain useful hearing, but that 40% of those patients in the series in whom preservation of hearing has been attempted, have retained hearing; this may be nearer 4% of the series as a whole. On the other hand, one has to remember that the risks of leaving a tumour fragment in the lateral end of the meatus are increased if hearing preservation is attempted. In considering an attempt at hearing preservation, the surgeon should always ask himself whether the object of the exercise is the good of the patient or his own self-satisfaction!

**Bilateral lesions**

Bilateral acoustic tumours pose a particularly challenging problem to the otologist (Hughes et al, 1982). They differ in many important respects from unilateral lesions, and merit special consideration. Bilateral tumours may occur as a part of a central form of von Recklinghausen's disease, the commoner characteristics of which are generalized cutaneous neurofibromata, café-au-lait spots, skeletal abnormalities, mental retardation and certain intracranial tumours, of which the most frequently encountered is acoustic neuroma; others include neurofibromata on other cranial nerves, meningiomata, gliomata and ganglioneuromata. von Recklinghausen's disease is an hereditary autosomal dominant condition, with a positive family history in only 50% of cases, suggesting either incomplete penetrance, or a high incidence of spontaneous mutation. On the other hand, a high percentage of bilateral tumour cases occurs in patients without evidence of von Recklinghausen's disease, and some authorities would regard it as a different genetic disorder, notably Moyes (1968), who described a series of 14 members of four generations of one family, all with bilateral tumours, but with scanty or absent evidence of von Recklinghausen's disease. Morrison (personal communication, 1986), however, stated that a careful examination of all unilateral acoustic neuroma patients will reveal some signs of von Recklinghausen's disease in about 10%.

The clinical picture differs from the unilateral lesion. The patients are usually younger, often in their teens or early twenties, with bilateral, symmetrical or asymmetrical hearing loss. The hearing is often remarkably well preserved, even in the presence of very large tumours, and there may be a cochlear picture on conventional audiological testing (Linthicum, 1972), but brainstem electric response audiometry will nearly always reveal bilateral wave V delay. Bilateral loss of vestibular function may lead to ataxia which is worse in the dark, rather than true vertigo, and caloric tests indicate hypofunction on both sides. There may be neurological abnormalities associated with other intracranial or spinal tumours, or with hydrocephalus.
Plain or tomographic radiographs may show bilateral widening of the internal auditory canals, but they may be normal even in the presence of a large tumour if it arises medially in the cerebellopontine angle. Computerized tomography in addition to confirming the presence of bilateral eighth nerve tumours, may show up other cranial nerve lesions.

Pathology

There has been much debate as to the true histological nature of the tumour in von Recklinghausen's disease, the House group maintaining that it is a neurofibroma and not a schwannoma (Linthicum and Brackmann, 1980). This distinction is of some importance in considering the effect on the cochlear nerve. A schwannoma will tend to compress the nerve, causing deafness, whereas a neurofibroma infiltrates the nerve, spreading its fibres apart without compressing them, thus conserving good hearing. De Moura, Hayden and Conner (1969b) on the other hand stated that it is impossible to differentiate between these two groups of tumours by light microscopy. The other interesting feature in von Recklinghausen's disease is the growth of tumour into the cochlea, so-called 'intracochlear neurofibromatosis', which may in part explain the cochlear audiological picture often seen. The rate of tumour growth may differ from unilateral tumours. Whereas many bilateral lesions are very large on presentation, there is no doubt that, in some instances, the growth rate seems very slow indeed, allowing a conservative approach to management.

Surgical management

The surgeon caring for these unfortunate patients has a difficult task, his decisions taking account of many factors - tumour size, level of hearing, age of the patient, and neurosurgical considerations. If one tumour is large and associated with poor hearing, and the other is small and associated with good hearing, then clearly total removal of the large tumour is the first step. What, however, is the correct management of the second side? One school would argue that early surgery should be carried out when the tumour is still small and there is some chance of preserving the hearing (Hughes et al, 1982), whereas others would preserve the second tumour (and with it the hearing) until such times as rising intracranial pressure necessitated surgery, and then carry out a subtotal removal in the hope of preserving some useful hearing (Morrison, 1975). The surgeon's view as to the feasibility of preserving hearing is clearly influenced by whether he believes the lesion to be a schwannoma, in which case there ought to be a plane of dissection between the cochlear nerve and the tumour, or a neurofibroma, in which case the nerve is in theory unsavable. It appears from reported cases of total tumour removal with hearing preservation, that in some instances, at least, there cannot have been infiltration of the cochlear nerve by tumour. The difficulties of management of bilateral eighth nerve lesions are well reviewed by Hughes et al (1982).
Chapter 22: Epithelial tumours of the external auditory meatus and middle ear

P. M. Stell

Case reports of cancer of the ear began to appear about 1875. Furstenberg (1924) stated that carcinoma of the ear was first reported around 1775 by Wilde, Schwartze and others, but this statement is wrong: first because histopathology was not available in 1775; and second because Wilde was not born until 1815 and Schwartze not until 1837! This typographical error was later copied by others and illustrates well the dangers of quoting historical references secondhand, particularly when the original paper is in another language.

The first systematic description of the disease appeared in 1883 in Politzer's classic textbook, based mainly on cases reported by others, for example Schwartze. It was already recognized that carcinoma of the middle ear arises 'either during an existing suppuration of the middle ear or after exhaustion of carious processes in the temporal bone'.

The available literature was reviewed in Zeroni's monograph of 1900, and by Newhart in 1917. In 1921, Broders presented a study of 63 epitheliomata of the ear. His paper covered nine tumours of the external meatus, one of the middle ear and 53 of the auricle. It was the first pathological account of a large number of cases and it includes interesting details of histological types and differentiation, lymph node metastases, etc, but, as all the cases were grouped together, it is not possible to deduce anything specific about tumours at individual sites.

The major contributions in the twentieth century are the accounts of radiotherapy by Lederman (1965) and of surgery by Lewis (1975).

Aetiology

External auditory meatus

The most commonly discussed aetiological factor is chronic inflammation. Irradiation injury in the form of repeated treatment of external otitis has also been mentioned. Highly speculative uninvestigated causes include carcinogens produced by the indigenous microbial flora. Aflatoxin B, a potent hepatic carcinogen, is produced by Aspergillus flavus, an occasional transient contaminant of the ear canal. Equally speculative is the production of carcinogens within cerumen. If chronic inflammation and infection are important it is curious that carcinomata arising in patients with long-standing chronic otitis media always do so in the remnants of the middle ear cleft and never in the external auditory canal over which the discharge also flows.

Tumours of the ear can be chemically induced in animals. One dose of azoxymethane (a derivative of dimethylhydrazine) injected into rats induces squamous cell carcinoma of the sebaceous glands of the external auditory meatus in about 15% of animals. Epidermoid carcinomata develop spontaneously in the external canal and middle ear of elderly female gerbils.
Middle ear

Pre-existing chronic otitis media is commonly believed to be the main predisposing cause of carcinoma of the middle ear.

The progression from chronic otitis media to squamous carcinoma was certainly well known a century ago and was reported by Politzer in his textbook of 1883; a frequent history of chronic otitis media in patients with carcinoma of the middle ear has been reported over a long period. As many as 85% of all cases of malignancy have chronically discharging ears.

Irradiation-induced carcinomata have been recorded after irradiation therapy to the head and neck, and exposure to radium has also been implicated.

Pathological anatomy

External auditory meatus

The external auditory canal can be subdivided into two parts:

1. A cartilaginous portion: tumours arising here spread easily because the cartilaginous walls present little resistance; spread may be anteriorly into the parotid gland or posteriorly into the postauricular sulcus. The cartilage of the external auditory canal is an inward prolongation of that of the pinna, so that tumours may readily spread in this layer outwards into the concha.

2. The bony portion: this is surrounded by dense bone which provides an effective barrier to spread of the tumour which is then deflected along the canal into the middle ear.

Middle ear and mastoid

The middle ear and mastoid may be divided into two parts: petromastoid and tympanotubal.

Petromastoid tumours

The petromastoid unit includes the tympanic cavity and the mastoid antrum. Tumours arising here may include:

1. those limited to the tympanic cavity
2. those limited to the mastoid antrum
3. those involving the tympanic cavity and mastoid antrum
4. those involving the tympanic cavity and external auditory canal.

Descriptions of the pathological anatomy in these cases rest on the descriptions of normal anatomy. Almost all carcinomata of the middle ear arise in patients with long-standing chronic otitis media who have usually undergone previous mastoidectomy. The anatomy is then very different from the normal state and this factor contributes largely to the poor
prognosis in these patients. Superiorly, the mastoid cavity is bounded by the thin tegmen tympani which may have been breached at previous surgery or disease. Medially, the promontory of the middle ear is usually exposed, with two important practical results: first, the facial nerve is either exposed or covered only by a thin layer of bone in its intratympanic course so that facial paralysis is a frequent accompaniment of disease in this area; second, there are several pathways readily available for medial spread of the tumour into the petrous apex. The oval and round windows are theoretical pathways, but more important is the track of cells leading above, below and behind the labyrinth into the petrous apex. The tumour thus gains access to the petrous pyramid lying medial to the bend of the internal carotid artery.

In the patient who has undergone a mastoidectomy operation, the tumour has ready access to the base of the skull, particularly the jugular foramen, and this fact is one explanation for the paralysis of the lower cranial nerves. An alternative explanation is metastasis to the node situated over the transverse process of the atlas in the lateral compartment of the parapharyngeal space.

Post-mortem examination of patients who died of middle ear carcinoma has shown the possible pathways of spread. In addition to local invasion of the remnants of the ossicles, the stapedius muscle and the facial canal, there are two important directions of spread. The first is within the eustachian tube; the medial bony wall of the eustachian tube and the associated bony wall of the middle ear cavity are separated from the carotid canal by a thin layer of bone, and this appears to be a frequent route of spread of tumours to the carotid canal. Second, the tumour spreads into the mastoid air cells, penetrates the thin bony wall of the posterior group of air spaces and thus reaches the internal auditory meatus. The structures in the labyrinth are remarkably resistant to the tumour.

**Tympanotubal tumours**

These tumours either arise in the middle ear and spread into the bony eustachian tube or may even arise within the tube itself. The bony portion of the eustachian tube is anatomically part of the tympanic cavity and has been termed the protympanum. Tumour probably spreads within the surrounding fascial space rather than along the tube. Invasion of these fascial spaces gives the tumour access to the trigeminal or oculomotor nerves in the lateral wall of the cavernous sinus.

**Lymphatic drainage**

The lymphatic drainage of the external auditory meatus follows the same course as that of the auricle, that is it may go in one of three directions:

1. anteriorly to the parotid lymph glands, especially to the gland in front of the tragus
2. inferiorly to the lymph glands that lie along the external jugular vein and those under the sternomastoid muscle
3. posteriorly to the mastoid lymph nodes.

The lymphatics of the middle ear and mastoid are less well defined. Anatomical texts state that the lymph vessels are arranged, like the blood vessels, in two sets on the medial and
lateral surface of the tympanic membrane. However, in virtually all patients with carcinoma of the middle ear, the tympanic membrane has been destroyed. The lymphatic pathways in such patients do not appear to have been defined, but are probably sparse, as is shown by the paucity of lymph node metastases in this disease.

**Tumour types**

The following classification of tumours of the temporal bone is expanded from that of Lewis (1975).

**Benign tumours**

(a) Epithelial: primary cholesteatoma (primary cholesteatoma, choristoma, adenoma)

(b) Mesenchymal
   (i) jugulo-tympanic paraganglioma (glomus jugulare tumour, chemodectoma)
   (ii) osteoma
   (iii) haemangioma
   (iv) neurogenic tumours
   (v) xanthoma
   (vi) giant cell tumour
   (vii) benign osteoblastoma

**Malignant tumours**

(a) Primary
   *Epithelial*
   (i) squamous cell carcinoma
   (ii) adenocarcinoma (hidradenocarcinoma)
   (iii) melanoma
   (iv) basal cell carcinoma
   (v) sebaceous cell carcinoma
   *Mesenchymal*
   (i) sarcoma
   (ii) multiple myeloma
   (iii) haemangioendothelioma
   (iv) malignant xanthoma

(b) Secondary
   *Direct extension from:*
   (i) nasopharynx
   (ii) external ear
   (iii) parotid
   (iv) meningioma
   *Distant metastases from:*
   (i) kidney
   (ii) lung
(iii) prostate
(iv) breast
(v) uterus.

Only epithelial tumours arising in the external auditory meatus and middle ear will be discussed here.

**External auditory canal**

**Squamous carcinoma**

Squamous carcinoma constitutes about 90% of all malignant tumours. It can originate in any portion of the external auditory meatus but most often arises in the bony rather than in the cartilaginous portion. Most tumours develop slowly, although occasionally rapid growth is seen.

Invasion of the cartilage of the membranous portion is usually a late development. Since the cartilage provides a barrier, extension is usually along the perichondrium. The tympanic membrane limits spread of the disease, but eventually weakens and breaks down, allowing invasion of the middle ear. Facial nerve paralysis develops when the middle ear and mastoid have been involved. Squamous cell carcinoma extends through the cartilaginous and bony walls of the canal late in the disease, invading the surrounding parotid gland anteriorly or the sternocleidomastoid muscle insertion inferiorly and posteriorly.

Metastasis to cervical lymph nodes from squamous cell carcinoma in this area is a late manifestation of the disease occurring in about 20% of patients. Lesions in the posterior wall of the canal usually metastasize to the nodes in the subcutaneous tissue overlying the insertion of the sternocleidomastoid muscle. Tumours originating in the inferior portion of the canal generally metastasize directly into the subdigastric (jugulodigastric) lymph nodes, while those originating in the anterior portion of the canal metastasize to the preauricular lymph nodes lying in the parotid gland.

**Adenocarcinoma (including hidradenoma)**

The so-called ceruminous glands of the external auditory meatus are typical apocrine sweat glands. Their secretion is a watery fluid devoid of lipids. These glands do not secrete the wax of the meatus which is produced by sebaceous glands, and their title is therefore not justified. Tumours arising from these ceruminous glands may be divided into adenomata, mucoepidermoid carcinoma, adenoid cystic carcinoma and adenocarcinoma.

The terms hidradenoma and ceruminoma are synonymous, and either may be used as a 'blanket' term for all these benign and malignant tumours. Hidradenoma is a better term because ceruminoma is a misnomer as the so-called ceruminous glands, as mentioned above are modified sweat glands.

Hidradenomata have two histological features of diagnostic significance: first, a two-layered epithelial structure analogous to that of the normal sweat gland consisting of an inner oxyphilic columnar layer and an outer myoepithelial layer. The second is a variable degree
of glandular stroma. They may also have a papillary or a cystic pattern. They cause obstruction but seldom pain. An adenoma which is clearly benign requires local excision.

For *mucoepidermoid carcinoma*, wide excision of the entire external auditory canal, radical mastoidectomy, excision of the mandibular condyle and total parotidectomy with preservation of the facial nerve is recommended. *Adenoid cystic carcinoma* is by far the most common ceruminous tumour and resembles that found elsewhere. It causes pain, and has a long natural history ranging from 10 to 30 years terminating in death from local invasion or distant metastases. Radiotherapy has little to offer these patients and the recommended treatment is wide excision of the external auditory canal and surrounding bone, part of the pinna, extended radical mastoidectomy, excision of the dura, total parotidectomy, and excision of the mandibular canal and any involved surrounding structures. Finally, simple *adenocarcinoma* may occur; it has a wide histological spectrum of glandular adenoid tubular and adenoid cystic patterns. The basic pattern is that of adenocarcinoma with two-layered eosinophilic glands. This tumour infiltrates widely into the middle ear and mastoid, etc. It is a very aggressive disease often presenting with facial paralysis, and usually proving fatal within 4 years.

**Malignant melanoma**

Malignant melanoma is exceedingly rare; only one authentic tumour arising primarily in the meatus has been recorded (Friedmann and Radcliffe, 1954).

**Basal cell carcinoma**

Basal cell carcinoma arising primarily in the external auditory meatus is rare. It tends to affect the sexes equally and occurs in late middle life. Good results can be obtained by sleeve resection. The prognosis is favourable.

**Sebaceous tumours**

Sebaceous cell carcinoma is extremely uncommon; fewer than 100 cases affecting any part of the body have been described. These tumours may arise anywhere but their greatest concentration is in the head and neck, mainly on the concha and nose. There are three types:

1. sebaceous adenoma
2. basal cell carcinoma with sebaceous differentiation
3. true sebaceous carcinoma.

One case has been reported affecting the ear (Doble, Snyder and Carpenter, 1981).

**Middle ear**

**Choristoma**

A choristoma is a mass of normal tissue at an abnormal site. Seven salivary gland choristomata of the middle ear have been reported - six were in females. The tumours all presented with deafness, usually lifelong, and many patients showed other anomalies of the
middle ear such as absence of the stapes and an abnormal course of the facial nerve. Attempts to remove the tumour were abandoned in most cases because it was attached to the facial nerve, and because other middle ear structures could not be identified.

Benign adenoma

Benign adenomata of the middle ear have recently been reported. The tumour is divided equally between the sexes with a maximum age incidence between 40 and 50 years. The main symptom is unilateral progressive deafness, and the principal clinical finding is a conductive hearing loss. The external canal is usually normal, and the tympanic membrane intact in 75% of patients; 25% have a perforation through which the middle ear tumour can often be seen. Preoperative radiology shows a mass in the middle ear or mastoid, but no bone destruction.

Some adenocarcinomata of the middle ear, previously described, may be benign adenomata, which would explain the unusually good prognosis reported for adenocarcinoma in some series.

Adenocarcinoma

If glandular tumours of the external ear are rare, such tumours of the middle ear are even rarer. This is interesting since the middle ear is lined by glandular epithelium. Thirteen patients have been reported in the literature with a female predominance and a median age of onset of about 40 years. Deafness, pain and facial paralysis were the presenting symptoms in decreasing order of frequency. Most were treated by mastoidectomy followed by radiotherapy. Prognosis: six out of either patients were alive at 2 years.

Squamous carcinoma

Virtually all malignant epithelial tumours of the middle ear are squamous in type. As the tumour grows it causes extensive bony destruction. The petrous pyramid and especially the labyrinth resist invasion longer than other structures. The pathway of least resistance is through the thin roof of the middle ear into the middle cranial fossa. The dura itself provides a strong barrier and the most common pathway of transdural invasion is along the seventh and eighth nerves in the internal auditory canal, and the petrosal nerve. The temporomandibular joint and the parotid gland may be involved relatively early. Involvement of the ninth, tenth, eleventh and twelfth cranial nerves indicates extension into the neck and along the base of the skull. The tumour may also extend along the eustachian tube to the nasopharynx. These clearly preclude resection en bloc.

Lymph node metastases occur in 10-15% of cases and about 10% develop a node metastasis later. Distant metastases are rare but have been reported in the liver, brain, lung and bones.

The cause of death in most cases is cachexia due to a combination of intolerable pain, opiates and cranial nerve involvement. Occasionally, invasion of the meninges leads to fatal intracranial complications; erosion of the jugular bulb or carotid artery may cause terminal haemorrhage.
Staging

Neither the International Union Against Cancer (UICC) nor the American Joint Committee (AJC) have developed a staging system for carcinoma of the ear. Based on the criteria used for other sites, the following seems to be a reasonable suggestion:

- **T1** tumour limited to the site of origin, that is with no facial nerve paralysis and no bone destruction
- **T2** tumour extending beyond the site of origin indicated by facial paralysis or radiological evidence of bone destruction, but no extension beyond the organ of origin
- **T3** clinical or radiological evidence of extension to surrounding structures (dura, base of the skull, parotid gland, temporomandibular joint, etc)
- **Tx** patients with insufficient data for classification, including patients previously seen and treated elsewhere.

This staging system significantly predicts survival in carcinoma of the ear.

Epidemiology

**Incidence**

Incidence figures for the UK only became available in 1967. The age-adjusted incidence (registration of new cases) rate has remained steady at about 1/million per year for women and 0.8/million per year for men for the 10 years to 1977. The male (M) to female (F) sex ratio was also stable, at about 1:1.2.

**Mortality**

The age-adjusted mortality rates are similar for each sex but there is a falling trend for men which has resulted in a decrease in the M:F sex ratio between 1960 and 1980 from 1.2:1 to about 1:2.

Mortality from cancer of the middle ear for the 10-year cohorts born around 1881-1921 reveals a marked difference between men and women. Each male cohort has experienced a lower age-specific mortality than the preceding cohort while there has been no apparent change in the age-specific death rates for successive female cohorts. In men, the mortality decreases after 70-75 years of age, whereas the mortality continues to rise for women. The falling trend in mortality for men but not for women may be due to exposure to an occupational carcinogen which was the cause of the relatively high rate in men in the nineteenth century. Also, these men were involved in the 1914-18 war and it has been shown that mustard gas is associated with a higher risk of death from neoplasm of the respiratory tract (including paranasal sinuses) than expected.
Assessment

Clinical

Local assessment is designed to identify the extent of the tumour, and particularly those factors which render the patient incurable.

A history of chronic otitis media suggests a tumour arising in the middle ear, and absence of this history suggests origin in the external canal. Rarely, the history may also indicate aetiological factors such as previous irradiation. Most patients complain of discharge and deafness, but vertigo is rarely seen. Pain, particularly if deep and boring, indicates dural invasion. Clinical examination of the meatus and middle ear and mastoid cavity (if present) demonstrates the tumour.

Facial paralysis, trismus (indicating invasion of the pterygoids or temporomandibular joint), fullness of the parotid gland (indicating spread through the cartilaginous meatus), fullness of the infratemporal fossa, and perichondritis of the auricle are all important physical signs. Cervical nodes should be felt for, especially in the upper deep cervical and pre- and postauricular groups. Lesions of the lower cranial nerves indicate extension of the tumour to the base of the skull.

Laboratory tests

In addition to the usual general laboratory tests, the aural discharge should be tested for glucose to exclude a cerebrospinal fluid leak.

Radiology

Radiological techniques include plain mastoid and temporal bone radiographs, hypocycloidal tomograms in the coronal and sagittal plane, and computerized tomographic (CT) scans. Plain views and tomograms are used to look for erosion of the petromastoid and tympanic bones, whereas CT scans are used to assess soft tissue extension of the tumour upwards and backwards to the cranial cavity and downwards and forwards into the infratemporal fossa.

Most patients give a history of chronic ear infection, so that sclerosis of the mastoid and clouding of the cells are to be expected and are of no diagnostic value. Ragged erosion - often extensive or an unusual site - suggests tumour. An important sign on the lateral mastoid view is erosion of the articular fossa of the temporomandibular joint, and this is present in 30% of patients. Erosion of the bone of the external auditory meatus is best shown by lateral tomograms.

The avascular bone of the labyrinth is relatively unaffected by carcinoma, and erosion of this area with direct invasion of the inner ear is a late radiological feature.

Extension of the tumour anteriorly to penetrate the bony septum separating the middle ear cavity from the carotid artery is of great pathological importance. This is followed by spread around the artery and extension around the eustachian tube towards the postnasal
space. Erosion of the carotid septum and the margins of the bony eustachian tube, and even soft tissue extension of the tumour anteriorly can be demonstrated by tomography and high resolution CT scanning. Enlargement of the retropharyngeal lymph nodes may also be demonstrated by CT scan.

Other routes of spread of the tumour are upwards through the tegmen tympani, backwards through the mastoid air cells and then through the thin plate of bone forming the posterior wall of the pyramid and underlying the lateral sinus. Erosion of these areas may also be demonstrated radiologically. Once the tumour reaches the cranial cavity, the dura is infiltrated and this is rapidly followed by death. It is thus unlikely that any significant extension into the middle or posterior cranial fossa would be shown on a conventional CT brain scan. A carotid angiogram is thus of no value except to demonstrate a blocked lateral sinus. When the carotid artery itself is infiltrated death soon follows. Retrograde jugular venography may be useful to assess the extent of the disease by demonstrating obstruction of the lateral sinus by tumour.

The differential radiological diagnosis of squamous carcinoma of the middle ear includes tuberculous otitis media, malignant otitis externa, and glomus jugulare tumour.

Many clinicians still depend heavily on the submentovertical view. The spine of the sphenoid provides a readily seen and conventional landmark serving the following purposes:

1. Radiological evidence of invasion of the petrosphenoidal region medial to the spine of the sphenoid may indicate a tympanotubal rather than a petromastoid tumour, particularly if symptoms such as oculomotor paralysis, obscure facial pain or trigeminal sensory loss are present.

2. Bone destruction medial to the sphenoidal spine also indicates that cure by any method of treatment is unlikely. The presence of such an extension is an absolute contraindication to radial surgery as the disease is no longer contained within the temporal bone.

3. A submentovertical view occasionally shows destruction of the arch of the atlas due to metastases to the lateral retropharyngeal node with paralysis of the last four cranial nerves.

Clinicians are more interested in eliciting those signs which influence treatment and prognosis. One of the most important of these is dural invasion, and there seems to be no reliable radiological method of assessing this before operation at present.

**Treatment**

**Untreatable patients**

Very few papers comment on the patients who are impossible to treat, and those who are perhaps better left alone. Clearly poor general condition may preclude major surgery, and distant metastases contraindicate treatment, but are rare. Lederman (1965) apparently treated all of his 129 patients. Similarly it appears that Lewis (1975) treated every one of his 143
cases. Six of the author's personal series of 62 patients could not be treated: three because of extensive disease, one because of poor general condition and two because of distant metastases.

**Radiotherapy**

This alone has seldom been recommended except at the Christie Hospital in Manchester. The most favoured role for radiotherapy has been in conjunction with surgery, and the usual routine is to carry out a radical mastoidectomy and to follow this by postoperative radiotherapy. The advantages are:

1. Reactions are lessened and the patients are made more comfortable
2. Higher doses can be given with less risk of complications
3. At lower energy, irradiation is selectively absorbed in bone and cartilage compared to soft tissue, whereas radiation in the higher range is transmitted with relatively little loss.

This treatment produces a crude 5-year survival of about 35%. In most series results for tumours of the external auditory meatus are about 10% better than those for tumours of the middle ear and mastoid. Little attention has been paid to the problem of primary recurrence after failed radiotherapy. This is surprising because the chance of failure of treatment at the primary site has been high in almost all reported cases. In the author's experience, surgery has been of no value for recurrence of a middle ear tumour after radiotherapy, but is occasionally of value for recurrent tumours of the external meatus, particularly of the non-squamous variety.

**The effects of radiation on the ear**

These are well described by Lederman (1965).

**External ear**

1. The was in the external ear canal thickens and dries.
2. The tympanic membrane becomes red and congested, particularly in the region of the handle of the malleus.
3. Oedema may occur particularly antero-inferiorly.
4. Radiation membrane forms along the floor of the external canal, but in the absence of ulceration, widespread membrane formation within the lumen of the canal is rarely seen.
Middle ear

The changes in the middle ear during and after radiation depend on:

1. The state of the middle ear. The response to treatment is dominated by the changes observed in the neoplasm. Unfortunately, an initial radical mastoidectomy means that the radiotherapist is presented with a cavity in bone devoid of the vasculature essential for the development of the classical responses to radiation. The discharge from the mastoid cavity should diminish with radiotherapy and the bony cavity may become lined with radiation membrane at the end of treatment. In the successful case the cavity should ultimately become quite dry.

2. The technical method of radiation employed.

Severe reactions and risks of postradiation complications are more likely if large doses are given in a short time by any form of external irradiation or when local contact or implantation methods of treatment are used.

Inner ear

The vestibular apparatus is relatively immune to radiation damage and vestibular symptoms are exceptional. The patient who already suffers from tinnitus, giddiness or sensorineural deafness is uninfluenced for better or worse by irradiation.

Complications of radiotherapy

The external auditory canal

Osteonecrosis of the bony portion of the canal and stenosis are two possible complications. The necrotic bone is usually seen as an exposed area of bone that ultimately forms a scale-like sequestrum. The process is painful and tedious, but healing ultimately occurs. Stenosis of the canal can occur if radiation is given after a sleeve resection or if local radium is inserted into the canal.

The middle ear and mastoid

The possible complications are:

1. osteonecrosis

2. damage to the brain, brainstem or eyes.

Osteonecrosis

Osteonecrosis after radiotherapy usually means persistent disease unless the dosage given has been excessive.
Damage to the brain, brainstem or eyes

Damage to the eyes should be avoided, but it is impossible to irradiate the petrous temporal bone and much of the middle cranial fossa without irradiating cerebral tissue. Provided that large volumes of tissue are not irradiated to high doses the risk of damage seems to be small. Brain necrosis is more likely to follow radiotherapy in elderly patients whose vasculature is already the seat of arteriosclerotic changes.

The facial or auditory nerves in their extracranial course are never damaged by therapeutic radiation, and any impairment of their function is due either to involvement by cancer or to a postoperative complication if radical surgery has been employed.

Conductive deafness after radiotherapy

The loss of hearing following radical mastoidectomy for petromastoid carcinoma is not influenced in any way by radiation. Postradiation conductive deafness may occur in patients who have been successfully irradiated for carcinoma of the external auditory meatus. If the middle ear was normal to start with and the patient is free of recurrence, the possible causes include:

1. thick mucus in the nasopharynx blocking the eustachian opening
2. atresia of the eustachian orifice which is rare and is the result of necrosis of the eustachian cartilage, characterized by severe earache and trismus
3. fibrosis of the fascial space surrounding the levator palati muscle.

Surgery

Surgery to the primary tumour may be used in the following ways:

1. as a preliminary measure, usually a radical mastoidectomy, before radiotherapy
2. as a primary form of treatment
3. for salvage after failed radiotherapy.

Combined surgery and postoperative radiotherapy

This is the routine used most often and consists of a radical mastoidectomy (extended if necessary), followed as soon as healing is complete by radiotherapy. This was the policy advised by Lederman (1965), a radiotherapist who has almost certainly had the greatest experience of this disease. He only recommended radiotherapy alone for a tumour localized to the external canal not involving the tympanic membrane or the middle ear. Such tumours are rare. For all other tumours he recommended an initial radical mastoidectomy for the following reasons:
(1) the temporal bone is one of the densest bones in the skull, and its invasion by tumour is inevitably associated with sepsis which militates against the use of radiotherapy.

(2) it is very difficult to assess by clinical or radiological means the full extent of the petromastoid tumour. Preliminary surgical exploration is therefore necessary because this helps to remove necrotic or invaded bone and determine the extent of the tumour.

(3) the patient is usually made more comfortable by the operation and loses many of his symptoms.

(4) a cavity is provided for drainage and inspection.

The only major authors to demur from this view are the Manchester School who recommend the use of radiotherapy alone.

**Primary surgery**

The first subtotal petrosectomy was reported by Lewis in 1954. He has been the surgeon mainly responsible for developing surgery in this area (Lewis, 1975). The mainstay of surgical treatment is petrosectomy, but as pointed out by Lewis, the operation usually carried out is more than this, and consists of a block resection of the involved portion of the auditory canal, middle ear, mastoid process, petrous bone, temporomandibular joint, parotid gland, base of the zygoma, and usually the auricle and surrounding skin. The highlights of this procedure, mainly taken from Lewis's descriptions are as follows.

(1) Preliminary packing of the lateral sinus. The lateral sinus is exposed by routine cortical mastoidectomy about 10 days before the main procedure and the sinus packed off tightly with BIPP gauze. This induces thrombosis in the venous lake in which the bone lies and drastically reduces bleeding at the main procedure.

(2) Incision and exposure. If the auricle is to be preserved, a U-shaped incision should be made and the auricle reflected upwards. However, the auricle is more usually sacrificed and a large circular incision to include the auricle, and any invaded skin, is then made around the ear.

(3) Temporal craniotomy is made early in the procedure to assess invasion of the dura and the apex of the petrous pyramid. Invasion of a small part of the dura is not an indication of non-resectability, but invasion of the petrous apex is. Cerebrospinal fluid may be removed at this point by a malleable needle to allow the dura and brain to be separated from the underlying bone.

(4) Parotidectomy with tagging of the peripheral branches of the facial nerve if a graft is to be carried out.

(5) Division of the temporomandibular joint and zygomatic arch.
(6) Division of the styloid process to define the position of the carotid artery.

(7) Division of the posterior border of the mastoid process posterior to the lateral sinus.

(8) Division of the floor of the middle ear and the bulb of the jugular vein.

(9) Transection of the petrous pyramid lateral to the internal carotid artery and medial to the arcuate eminence using a Stryker saw or curved chisels.

(10) Cover of the soft tissue defect by grafts, muscle or skin flaps.

(11) Reconstitution of continuity of the facial nerve.

**Reconstitution of the facial nerve**

The following procedures have been advised.

(1) Facial-hypoglossal anastomosis is recommended by Lewis. He does not quote any results. A lateral tarsorrhaphy should, of course, be performed in addition.

(2) Fascial slings. A cross-face graft using the sural nerve is another possible technique but does not appear to have been described in this disease.

**Soft tissue cover**

If the auricle is preserved it is only necessary to apply a skin graft to the mastoid cavity. If the auricle has been resected cover by a skin flap is required. Many authors still favour the use of a local scalp flap based anteriorly or posteriorly and this remains the simplest and most reliable method in the author's experience. A nape of neck flap has been used, but this type of flap has now passed into history. The deltopectoral flap has been advocated by some but it, too, is now obsolete.

With the development of musculocutaneous flaps, particularly the pectoralis major, it is inevitable that they have been used to close this defect. The pectoralis major flap is said to have significant advantages over a scalp flap because it provides a large surface area and adequate bulk to fill defects after removal of the temporal bone. Osteoradionecrosis does not occur because the muscle of the pectoralis major flap provides rich vascularity for healing of an area contaminated with bacteria. Furthermore, the flap can tolerate postoperative radiation, and the muscle provides a seal in the event of a cerebrospinal fluid leak. A further advantage is that reconstruction can be performed in one stage without the need for skin grafts; this causes less pain in the postoperative period and allows earlier discharge from hospital.

**Management of lymph node metastases**

Lymph node metastases in this disease are unusual. The highest rate quoted is that of 21%, but most authors report a lower incidence. A figure of 10% for tumours of the external meatus would be more usual. All appear to be agreed that there is no place for prophylactic
Complications of surgery

These include:

1. Bleeding. This can be reduced to relatively negligible amounts by preoperative packing of the lateral sinus.

2. Infection is common because many of the patients have long-standing chronic otitis media with infection by Gram-negative organisms. Appropriate chemotherapy is therefore required.

3. Loss of facial nerve function. The facial nerve is divided both in the temporal bone and parotid gland.

4. Deafness and vertigo. Deafness is complete following this procedure because of the removal of the structures of the inner ear. The patient is also vertiginous for a period of up to 3 weeks until compensation occurs.

5. Carotid artery thrombosis, may occur due to trauma to the carotid vessels and has, on occasion, led to hemiplegia.

6. Damage to the lower cranial nerves.

7. Cerebrospinal fluid leak.

Choice of treatment

The criteria for choosing primary radiotherapy or primary surgery have not been defined; both give a 5-year survival of 30-35%, but the morbidity and mortality from primary surgery are clearly greater. Certainly small tumours without a facial paralysis, bony erosion or lymph node metastases should be treated by radiotherapy. Sadly these patients are uncommon. Patients with disease beyond the temporal bone are almost certainly incurable by either method. It remains uncertain what to do for the patient with disease spreading within, but still confined to, the temporal bone.

The recommended treatment for hidradenomata of the external auditory canal is as follows: local excision for ceruminous adenoma, excision en bloc of the canal and surrounding bone with preservation of the facial nerve for adenoid cystic carcinoma, subtotal petrosectomy and postoperative radiotherapy for ceruminous adenocarcinoma, and excision biopsy for pleomorphic adenoma.
Prognosis

The prognosis for squamous carcinoma of the external meatus is better than that for the middle ear.

Tumours of the external canal may be classified as localized or extensive. The prognosis of the former is of course better. Invasion of the petrous apex, the eustachian tube or the dura indicates incurability. Lymphadenopathy at the time of presentation is a grave prognostic sign. The histological grade of squamous cell carcinoma of the external meatus is not a prognostic indicator.

The prognosis for benign and malignant glandular neoplasms of the external meatus varies with the histological type.

Sophisticated mathematical techniques (generalized linear interactive modelling) are not available to assess the prognostic factors, taking into account both survival and length of survival. These techniques have shown that the staging system suggested above, histological type, the patient's general condition and the presence of lymph node metastases are significant predictors of survival.

Acknowledgements

This chapter is based on a review (Stell, 1984) where a full list of references is available.
Chapter 23: Glomus and other tumours of the ear

A. D. Cheesman

Glomus jugulare

The glomus jugulare is a collection of ganglionic tissue within the temporal bone in close relation with the jugular bulb. The first description of this tissue were probably by Valentin (1840), who described his 'ganglia tympanica', and Krause (1878), his 'glandula tympanica'. Both writers described ganglionic-like tissue, but the credit for recognizing the histological relationship to the carotid body goes to Guild in 1941. He originally called the structure the glomus jugularis, but in a later report (Guild, 1953) he accepted the terminology glomus jugulare accorded by Lattes and Waltner (1949). Lattes also suggested that the generic term for these structures in the body should be non-chromaffin paraganglia (any associated tumour being called a non-chromaffin paraganglioma).

The paraganglia are cells derived from the neural crest and are found widely distributed in the autonomic nervous system, the usual sites being the carotid, ciliary and vagal bodies, along the aorta and its main branches, in the glomus jugulare complex, in the bladder, in the para-adrenal area, and most notably the adrenal medulla. The paraganglia of the adrenal medulla secrete adrenaline and noradrenaline and histologically they stain chromaffin positive, hence the term 'chromaffin paraganglia'. Paraganglia having a negative chromaffin reaction are termed 'non-chromaffin'; they do not normally secrete hormones. The nerve supply of the latter is mainly sensory and, although the carotid body has been shown physiologically to be a chemoreceptor, responding to changes in blood pH and oxygen tension, the glomus jugulare has never been shown to be a physiologically active chemoreceptor.

Guild's (1953) anatomical studies were based on 88 temporal bones, in which he found an average of three glomus bodies in each bone. They were usually found in close relationship with either the tympanic branch of the glossopharyngeal nerve or the auricular branch of the vagus nerve; both nerves had an equal distribution of glomus bodies. The bodies were supplied with non-medullated sensory fibres from the adjacent nerve and, in most cases, the blood supply was from the ascending pharyngeal artery. Apart from their close relationship with the two nerves, their anatomical position was very variable, but 50% could be found in the adventitia of the jugular bulb and 25% in the mucosa of the promontory. Histologically, they were similar to the carotid body with epithelioid cells interspersed in a highly vascular stroma of capillary and precapillary vessels. The proportion of cells to vessels was variable and Guild recognized two groups, the cellular glomus bodies and the vascular glomus bodies, with a slight preponderance of the former. Their size was variable, but they tended to be ovoid in shape with a long diameter of 0.5 mm, equally distributed between the two ears in both sexes and found more commonly in the middle age group.

Glomus jugulare tumours

There are several reports of vascular tumours in the ear over the latter part of the eighteenth and the early part of the nineteenth century (Simpson and Dallachy, 1958). In
particular, Lubbers (1937) reported a case of metastatic carotid body tumour in the ear, with a contralateral carotid body tumour.

Rosenwasser (1945) was the first surgeon to recognize the relationship between these tumours and the normal glomus jugulare. In 1942, he removed a vascular tumour from the middle ear and mastoid and, on histological examination, found it to be very similar to the carotid body, but he could find no other primary tumours in the neck, and called it a carotid-body-like tumour. In his 1945 paper, Rosenwasser proposed that the tumour arose from the glomus jugularis described by Guild. Since that time there have been a variety of names attached to the tumour in an attempt to indicate its pathological origin.

Winship, Klopp and Jenkins (1948) first used the term 'glomus jugulare', and Latters and Waltner (1949) proposed that the tumours were called non-chromaffin paragangliomata. Mulligan (1950) introduced the general term 'chemodectoma' for the carotid body and glomus jugulare tumours, based on their common histological appearances and probable origin from chemoreceptor tissue. Boyd, Level and Griffith (1959) objected to this term as the glomus jugulare has no demonstrable chemoreceptor function.

Current usage suggests that these tumours should be considered as non-chromaffin paragangliomata. The most common term used is 'glomus tumours', and the terms 'glomus tympanicus' and 'glomus jugulare tumours' are used primarily for the clinical description of a particular tumour.

**Pathology**

Histological examination of the glomus jugulare tumour shows a similar appearance to the normal glomus jugulare; cytologically they are not very active with only rare mitotic figures, and they usually have a well-defined thin fibrous capsule. Clinically, however, they can be locally invasive and destructive of bone and facial nerve. In the author's series, they showed a great propensity to infiltrate through the mastoid air-cell system.

**Sex and age incidence**

The glomus tumour, in contradistinction to the glomus body, shows a predominance in females, but both tend to be more common in the middle age group.

**Endocrine activity**

They are usually considered to be non-chromaffin paragangliomata with no endocrine function, but there has been an increasing number of reports of vasoactive tumours (Duke et al, 1964; Matishak, Symon and Cheesman, 1987), and clinically it is important to look for evidence of endocrine activity by urinary assay of the metabolites dopamine and 3-methoxy-4-hydroxymandelic acid (vanillylmandelic acid).
**Multicentricity**

Glomus tumours are sometimes multicentric presenting in both ears (Winship and Louzan, 1951), or in conjunction with other paragangliomata, the carotid body commonly being the second site (Spector et al, 1975).

**Metastases**

The glomus jugulare is generally considered to be of low malignancy, mainly causing problems because of its site in the complex anatomy of the skull base. However, there are well documented cases of malignant glomus jugulare tumours, with both nodal and distant metastases; fortunately the incidence is very rare (Brown, 1967).

**Natural history and presentation**

The slow growth of these tumours means that the diagnosis is often missed until the tumour is very extensive. Alford and Guilford (1962) found the average delay to diagnosis was 6 years from the original symptoms, the extremes being 42 years and 2 weeks. The first symptoms noted generally follow middle ear involvement, and are often ignored. Pulsatile tinnitus and conductive deafness are, equally, the commonest presenting symptoms. A red mass (the rising sun behind the drum) on routine examination is not uncommon, but quite a high proportion do not present until cranial nerve palsies occur. Some 30% of cases, in most series, present with facial palsy; the pareses, resulting from involvement of the nerves of the jugular foramen, often do not cause sufficient symptoms in most cases to warrant presentation. Table 23.1 shows the clinical findings in the author's series of 21 cases and is similar to most other reports. Otalgia and aural bleeding are other fairly common symptoms.

**Table 23.1. Presenting clinical features in 21 patients with temporal region glomus tumours**

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<thead>
<tr>
<th>Symptoms and signs</th>
<th>Cases</th>
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<td></td>
<td>No of cases</td>
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<tr>
<td>Hearing loss</td>
<td>18</td>
</tr>
<tr>
<td>Middle ear mass</td>
<td>15</td>
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<tr>
<td>Tinnitus (pulsatile)</td>
<td>14 (5)</td>
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<td>Cranial nerve deficits</td>
<td>11</td>
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<td>II</td>
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<td>VI</td>
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<td>VII</td>
<td>8</td>
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<tr>
<td>IX</td>
<td>6</td>
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<tr>
<td>X</td>
<td>7</td>
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<td>XI</td>
<td>5</td>
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<tr>
<td>XII</td>
<td>7</td>
</tr>
<tr>
<td>Unsteady, dizzy, vertigo</td>
<td>5</td>
</tr>
<tr>
<td>Otorrhoea</td>
<td>2</td>
</tr>
<tr>
<td>Endocrine syndrome</td>
<td>1</td>
</tr>
</tbody>
</table>
**Classification**

There have been many attempts at classification. Lundgren (1949) used a basic division into glomus tympanicus tumours arising from the promontory, and glomus jugulare tumours arising from the jugular bulb. This had clinical value in planning the surgical approach for small tumours. Bickerstaff and Howell (1953) used a symptomatic classification, but this had little value, either for management or prognosis. Alford and Guilford (1962) reviewed the world’s literature and proposed a staging system for their own cases. The staging was determined by the degree of spread shown radiologically and symptomatically; they then used the staging to indicate various combinations of surgery or radiotherapy.

The most widely used classification was devised by Oldring and Fisch (1979). They proposed four types, A, B, C, D, based on site and size:

- **Type A:** tumours localized to the middle ear cleft (glomus tympanicus tumours)
- **Type B:** tympanomastoid tumours with no destruction of bone in the infralabyrinthine compartment of the temporal bone
- **Type C:** tumours invading the infralabyrinthine region and extending towards the petrous apex with destruction of infralabyrinthine compartment of temporal bone
- **Type D:** tumours with intracranial extension.

This classification, although anatomically based, was primarily differentiated by the surgical approaches used. In 1982, Fisch further subdivided types C and D to cope with the different surgical problems encountered. While the original classification into four types has considerable clinical value, Fisch’s further subdivision is of limited value unless one follows his surgical approach exactly.

**Investigation**

Those cases presenting to the otologist usually have a red mass behind the tympanic membrane and this should indicate the probable diagnosis. The two other conditions that mimic this appearance are the high jugular bulb or an aberrant carotid artery. The red drum of otitis media should be obvious from the history. More extensive spread involving the external auditory meatus may appear to be a squamous cell carcinoma, which can often bleed profusely. Those cases presenting to the neurologist often cause considerable diagnostic problems, as neuromata of the last four cranial nerves have a common symptomatology.

The first step in investigation entails a careful clinical examination. Observation of the drum under the microscope will frequently show pulsations of the mass, which will be soft and often blanch on palpation. The hearing loss is generally conductive. Neurological assessment of the cranial nerves is very important, and often gives considerable information regarding the extent of the tumour.

**Radiological**

The main investigation must be radiological and, with the advances in imaging over the last decade, a very detailed assessment of the tumour can be made. Although
computerized tomographic (CT) scanning and angiography are the main techniques utilized, mention must be made of plain X-rays, tomography and venography.

For type A and B tumours, plain mastoid X-rays will show only clouding of the middle ear and mastoid air cells, although special views of the jugular foramen may show unilateral enlargement. Type C tumours may show bone erosion on plain films, but the jagged erosion of the normally well corticated jugular bulb is best seen on polytomography. The absence of the normal crest of bone between the carotid canal and jugular fossa on lateral tomography is virtually diagnostic of a glomus jugulare tumour (Phelps’ sign).

Retrograde venography by catheterization of the internal jugular vein was popular to differentiate between a glomus tympanicus and glomus jugulare, the latter showing as a filling defect. However, with modern CT scanning this invasive technique is no longer necessary.

High resolution CT scanning is the technique of choice for establishing the diagnosis in those cases presenting with a red mass behind the drum (the rising sun sign). The first step is a conventional axial scan; this will show whether the jugular bulb is enlarged and, if there is any erosion of the cortex, a glomus jugulare tumour is likely. Smooth well-corticated enlargement is generally due to the abnormally high jugular bulb. If the jugular fossa has normal dimensions, coronal CT scanning is necessary (the coronal cuts obtained by scanning with the patient's head in the submentovertical position are necessary as the coronal computer reconstructions do not give adequate detail). If on coronal cuts the carotid canal is normal, the mass must be a glomus tympanicus. An aberrant carotid artery is demonstrated by a more laterally placed carotid canal often with a deficient bony wall. With the more extensive glomus tumours, the erosion of the infralabyrinthine part of the temporal bone and intracranial spread are clearly demonstrated.

In the unlikely event of doubt as to the correct diagnosis still existing after CT scanning, angiography will demonstrate virtually all glomus tumours apart from the very early glomus tympanicus tumour which may not be obvious even with selective angiography of the ascending pharyngeal artery. If the requirement is to establish the diagnosis, digital subtraction angiography using intravenous contrast injection will often confirm. Arteriography is best reserved for the preoperative detailed assessment of the extent of the tumour and indication of the arterial blood supply. If the arteriography is accompanied by preoperative embolization, it should not be performed more than 8 days prior to the planned surgery, otherwise collateral vessels may open, thereby restoring the tumour's vascularity.

Endocrine

Prior to any surgery, it is important to exclude the secretion of any vasoactive hormones by the tumour, particularly in those cases with an elevated blood pressure. A 24-hour urine collection will demonstrate any raised vanillylmandelic acid levels (normal level up to 7 mg/24 hours). Direct biopsy of the tumour should not be necessary if the suggested radiological assessment is used. Biopsy of an obvious tumour presenting in the external auditory meatus is occasionally performed to exclude a squamous cell carcinoma; in such cases bleeding will occur, but it is rarely severe and always stops with a (BIPP) pack.
Management

After many years of controversy, it is now possible to propose a series of reasonable therapeutic options in the management of glomus jugulare tumours. In the past, the main arguments have been over the value and place of radiotherapy. Initially it was used when surgical resection was deemed impossible or, more often, when the operation had to be curtailed because of unpredicted technical problems in the hands of a surgeon unfamiliar with this particular tumour. Subsequently, it was used as the sole form of treatment in many centres, and presently tends to be used mainly as an adjunct to surgery.

The main types of surgical procedure described over the years have often reflected the interests of general otology. In the 1940s and 1950s, open techniques were usually performed. In the 1960s the intact canal wall procedures were popular, and since 1970 increasingly more sophisticated skull base procedures have been described.

The use of other modalities of treatment have been suggested, but none have found wide acceptance. Tumour reduction by diathermy was initially popular and, with the evolution of cryotherapy, the cryoprobe was suggested, but in both cases it was found impossible to treat any tumours apart from the smallest glomus tympanicus. Intra-arterial embolization under radiological control is useful for intracranial vascular malformations, but when used for glomus tumours the duration of tumour reduction is very limited. It has no place as a permanent treatment, but is excellent as a preoperative adjunct to surgical resection.

The current treatment options for glomus tumours may be summarized as follows:

1. no active treatment and continued observation
2. primary radiotherapy
3. surgical resection with planned adjunctive radiotherapy
4. surgical resection.

No treatment

Glomus tumours are extremely slow growing and may have a long natural history. They usually present in the middle age groups and, where general health is good, treatment is definitely indicated in view of the patient's expected lifespan. Some patients do not present until the latter part of their sixth or seventh decades and, providing that repeat CT scans do not show very extensive spread or rapid growth, and the patient's symptoms are minimal, no treatment is indicated apart from explanation and reassurance.

Radiotherapy

There have been several detailed studies on the effects of radiotherapy monitored clinically and radiologically, and several workers have also looked at the histopathological changes in irradiated tumours (Capps, 1952; Silverstone, 1973; Spector, Maisel and Ogura, 1974). Unfortunately, there is too much variation in both method and dose of radiation to draw definite conclusions. Most clinicians agree that radiotherapy is rarely curative, but it does have some effect on slowing tumour growth. Rosenwasser (1968) made the profound generalization 'that the inherent tendency of the glomus jugulare tumours to slow growth may
be more important in determining its radiocurability than is its actual responsiveness to irradiation. Clinically, following irradiation, visible tumour often shrinks and bleeding generally ceases, and although tinnitus and vertigo may improve, the deafness and other cranial nerve palsies persist. Repeat angiography shows little change in either vascularity or in the extent of the tumour, apart from intracranial extensions which often regress.

Histopathological examination of irradiated tumour shortly after radiotherapy may not give the true picture, as radiation fibrosis generally develops 6-12 months later. Most advocates of radiotherapy stress that improvement may take several years to become obvious. Cytologically, the epithelioid or chief cells show very little change apart from being broken up into nests of tumour surrounded by sheets of fibrous tissue. Most of the radiation effects appear to involve the stroma with changes typical of endarteritis obliterans, and this in some cases causes thrombosis of some areas of the tumour.

Many of the documented complications of radiation, such as cerebral necrosis and radionecrosis of the temporal bone, can probably be attributed to the use of older methods of radiation such as orthovoltage (Jackson and Koshiba, 1974). Today, better tumour localization and megavoltage irradiation should result in fewer complications. The usual practice is to deliver 4000-5000 cGy (rads) over a 3-4 week period.

Most clinicians agree that an elderly or infirm patient with a symptomatic, growing tumour should be treated solely with radiotherapy. In the absence of an experienced surgical team, radiotherapy will probably cause less problems than surgery with types C and D tumours, but it must be remembered that 40% of tumours may continue to grow after initial radiation control (Spector et al, 1974). Rosenwasser, reviewing the results of treatment in 1969, came to the conclusion that surgery, if possible, was the method of choice in the management of glomus jugulare tumours. Despite the advances in skull base surgery over the last decade, it is extremely difficult to eradicate those extensive tumours that invade the petrous apex around the internal carotid artery. If such cases have limited neurological deficit on presentation, surgery may well increase the neurological deficit, and in such cases subradical surgery with postoperative radiotherapy is probably the method of choice. In this respect, the use of the newer interstitial radioactive implants, such as iodine-125 with its long half-life, may well be the ideal form of treatment in the future.

**Surgery**

The objectives of surgery are total resection of the tumour where possible, and this should ideally be achieved without increasing the patient's neurological deficit. In certain cases, improvement of the hearing may also be achieved.

Most of the frightening complications described in the past have resulted from inadequate appreciation of the extent of the tumour preoperatively, and from inadequate exposure of the tumour at the time of surgery.

Type A tumours, or glomus tympanicus tumours, can usually be approached via the external auditory meatus.
Type B tumours can often be encompassed by a combined approach (intact canal wall) procedure.

Type C tumours need some form of skull base approach utilizing an upper cervical dissection and transmastoid approach.

Type D tumours require a skull base approach and posterior fossa craniotomy, some surgeons preferring to perform the resection in two stages.

**Surgical technique**

The various techniques available are well described in the textbooks of operative surgery, but considerable experience is also required for the surgery to be performed safely.

Various methods of reducing the tumours' vascularity have been suggested. Spector et al (1974) favoured preoperative irradiation which reduced vascularity and, by inducing stromal fibrosis, permitted easier tumour dissection. Other surgeons including the author have favoured the use of preoperative embolization. This requires the help of an experienced neuroradiologist as there is about a 1% chance of inadvertent embolization of the internal carotid artery system leading to a stroke. Selective angiography of the individual vessels supplying the tumour is performed and embolization achieved either with gelfoam or lyophilized dural fragments. The procedure should be performed some 4-8 days prior to planned resection, and a light general anaesthetic is used.

The highest quality of anaesthetic help is required for this type of surgery. Careful work-up should have excluded any production of vasoactive hormones by the tumour. Profound hypotension controlled by intra-arterial monitoring reduces bleeding to an acceptable level, and dissection with gauze soaked in 1:1000 adrenaline is also useful.

**Transmeatal approach**

The very small glomus tympanicus tumours can be removed by simple tympanotomy if all their borders can be visualized and additional exposure can be obtained by dissecting the malleus handle free of the drum.

Additional exposure can also be obtained by lowering the inferior annulus in the hypotympanic approach described by Shambaugh (1955); in 1967, Farrior described further extension of this approach by removing the mastoid tip and mobilizing the vertical portion of the facial nerve.

**Extended facial recess approach**

With the advent of combined approach mastoidectomy for cholesteatoma, it became clear that large type A and moderate-sized type B glomus tumours could be removed with an intact canal wall procedure instead of by the traditional radical cavity. House (1968) combined the intact canal wall procedure with a neck approach to the jugular bulb, but did not transpose the facial nerve. Glasscock, Harris and Newsome (1974) further developed this technique.
By extending the facial recess inferiorly, reasonably good access is obtained to the hypotympanum, particularly if the chorda tympani is sacrificed. Even better exposure is obtained by skeletonizing, in turn, the vertical portion of the facial nerve, the sigmoid sinus, and the posterior semicircular canal. With these structures clearly identified, the tympanic recess can be opened widely medial to the vertical portion of the facial nerve and this gives adequate exposure for type B tumours. In such cases, total tumour removal can be accomplished with restoration of hearing.

Infratemporal fossa approach (lateral approach)

The essential features of this approach are: (a) the resection of the jugular bulb after ligating the internal jugular vein in the neck, and packing off the sigmoid sinus superiorly, and (b) the anterior transposition of the facial nerve to allow direct access to the jugular bulb region. Such an approach was attempted by Capps in 1955, but the stormy postoperative period caused him to recommend radiotherapy for such extensive tumours. The approach was successfully used by Shapiro and Neues (1964) and Gejrot (1965). Gejrot, in particular, emphasized the importance of preserving the medial wall of the sinus if possible, thus protecting the neural compartment of the jugular bulb and maintaining intact the dura of the posterior fossa. Since that time, many surgeons have utilized this basic approach but especial credit must be given to Fisch (Fisch, Fagan and Valvanis, 1984) who extended the approach for a variety of lesions in the lateral skull base.

The basic steps of Fisch's infratemporal fossa approach are as follows: a postaural incision is extended both superiorly and inferiorly into the neck. The facial flap and pinna are raised and reflected anteriorly. The cartilaginous meatus is transected and closed off as a blind-ending sac. The parotid region is dissected to mobilize the peripheral branches of the facial nerve, and the nerves and vessels of the upper neck are carefully mobilized up to the skull base. Control ligatures are placed around the internal jugular vein and internal carotid artery, but not tied at this stage. A complete mastoidectomy (subtotal petrosectomy) is performed removing all the air cells, the posterior meatal wall, the drum, malleus and incus. The outer wall of the hypotympanum is drilled away and the facial nerve skeletonized along both its horizontal and vertical portions. It is dissected free from the canal and permanently transposed anteriorly.

If, during mobilization of the facial nerve, it becomes apparent that it has been invaded by the tumour, the involved section is resected and a cable-graft using sural nerve is placed between the cut ends.

The sigmoid sinus is ligated in the region of the sinodural angle and the internal jugular vein is ligated in the neck. The tumour is then mobilized, first peripherally then centrally. If possible the medial wall of the sinus is preserved, but if infiltrated with tumour it is resected along with the nerves of the medial compartment. At this stage bleeding occurs from the inferior petrosal sinus where it enters the jugular bulb medially. It is controlled by packing the lumen with Surgicel gauze. A plane of cleavage can often be found between the tumour and the internal carotid artery, otherwise the tumour on the wall of the carotid is controlled with judicious diathermy. At the completion of the procedure, any dural defect is repaired with fascia, the eustachian tube is closed off with bone wax, and the whole cavity filled with a free fat graft.
The anterior transposition of the facial nerve may occasionally be achieved without immediate loss of function. It is more usual to develop a temporary paresis which recovers in 2-3 months with a satisfactory final result in 85% of cases.

Intracranial extensions of greater than 2 cm are best managed, according to Fisch, by a second-stage procedure to reduce the chances of cerebrospinal fluid leak and meningitis.

**Posterolateral approach**

Cheesman and Symon (1987) have recently described a modification to the infratemporal fossa (or lateral) approach of Fisch. They have termed it the ‘posterolateral approach’ and with it have been able to achieve total resection of most type C and D tumours without transposition of the facial nerve. They originally managed type D tumours by combining a posterior fossa craniotomy with a ‘Fisch-type’ infratemporal fossa approach at the same operation, and were fortunate not to suffer the same complications as seen by Fisch. Their wide posterolateral exposure allows preservation of the posterior meatal wall and does not require transposition of the facial nerve in most cases. Radical mastoidectomy and transposition of the facial nerve was only necessary in those cases with extensive tumour around the internal carotid artery. In such cases the necessary medial dissection of the skull base often resulted in increased neurological deficit, particularly when the intracranial extension reached anterior to the internal auditory meatus, and they currently feel postoperative irradiation is a useful adjunct in such cases, enabling a more conservative resection. However, long-term follow-up will be necessary to validate their views.

**Management of secretory glomus jugulare tumours**

There has been an increasing number of functionally active paragangliomata reported (Matishak, Symon and Cheesman, 1987), of which nine have been functional glomus jugular tumours. Many of these cases present as phaeochromocytomata and their localization often creates a diagnostic problems. The management of the blood pressure, however, creates even greater problems for the anaesthetist. The initial hypertension often requires both alpha- and beta-blockade and, following embolization and surgical resection, the loss of vasoconstrictor tone results in circulatory collapse, needing correction with massive intravenous infusion, and the use of an anti-gravity suit to the lower body to increase venous return.

To anticipate these potential problems, it is prudent to perform a routine vanillylmandelic acid estimation of a 24-hour urine collection preoperatively.

**Postoperative neurological complications**

The slow development of nerve palsies preoperatively generally allows adequate compensation, and few patients on presentation have any aspiration or swallowing problems. However, if the vagus and glossopharyngeal nerves are further damaged at surgery, there is often an acute swallowing problem postoperatively. Fortunately, most patients rapidly adapt to the unilateral paresis and generally return to normal function after 1-2 weeks. Nasogastric feeding is used in the intervening period and occasionally temporary tracheostomy is necessary. Hoarseness also generally improves with time, but if it persists for more than 6 months the unilateral paralysed cord can be corrected with an intralaryngeal Teflon injection.
The temporary facial palsy following anterior transposition has already been discussed. When the patient has a facial palsy on presentation, nerve grafting is invariably needed and the results depend on the duration of the preoperative facial palsy. Palsies of greater than one year's duration often achieve poor results, and adjunctive facial rehabilitation is often necessary.

**Infratemporal fossa route to lateral skull base**

Fisch, in particular, has developed the infratemporal fossa approach as a route to the lateral skull base. He has described a type B approach to the region of the clivus, and a type C approach to the posterior aspect of the maxillary antrum, parasellar region, nasopharynx and sphenoid sinus.

He uses the type B approach primarily for a chordoma of the clivus, cholesteatoma of the petrous apex, and meningiomas. The operation is an anterior extension of his glomus approach (type A) and he gains further access by removing bone of the posterior zygomatic arch and occasionally the head of the mandible. He then works forward along the eustachian tube, dividing the mandibular branch of the trigeminal nerve and middle meningeal artery to gain access to the clivus anterior to the carotid artery. His type C approach is basically the same, except that the zygoma is divided more anteriorly and he continues the dissection more medially by removing the pterygoid plates, and also divides the nerves of the pterygopalatine fossa to enter the nasopharynx and sphenoid region. He uses this latter approach for the removal of some large juvenile angiofibromata, adenoid cystic carcinoma, and squamous cell carcinoma of the nasopharynx, which extend laterally into the infratemporal fossa.

The author has used both of these approaches in the past for access to the lateral skull base, but now favours the lateral craniofacial approach (Cheesman and Symon, 1987) to this region via the temporal fossa and floor of the middle fossa, which leaves the ear and facial nerve intact. However, in surgery, the description of any particular technique merely increases the number of possible approaches to solve any particular problem. The way forward in skull base surgery is to consider all the possibilities for each case, and to provide an individual solution for each. This often entails the combined approach by both otolaryngologist and neurosurgeon; if they can work well together the patient benefits.

**Epithelial tumours**

The only benign epithelial tumour found in the middle ear is the rare adenoma and this can usually be excised by the standard combined approach mastoidectomy with preservation of hearing. The common malignant tumour is the squamous cell carcinoma and this is dealt with in Chapter 22, the essence of treatment being a combination of radiotherapy and radical surgery. The other malignant epithelial tumours are adenocarcinoma and adenoid cystic carcinoma, both being relatively radioresistant, and initial radical surgery offers the best chance of cure. Radiotherapy postoperatively may have some effect on residual disease.

**Mesenchymal tumours**

The paragangliomata have already been discussed in detail. Schwannomata of the nerves of the jugular foramen, in particular of the glossopharyngeal nerve, present in a similar
fashion, but are avascular and produce symptoms by expansion. Radiological examination confirms an avascular tumour. Surgical resection by the posterolateral approach is the treatment of choice, but as the tumour is so closely applied to the other nerves of the jugular foramen, additional neurological deficit may result. In view of this, simple decompression in the elderly patient is sometimes more sensible. A schwannoma may occur on the facial nerve. Providing the facial palsy has been of short duration, simple resection and repair by cable-graft can produce excellent results. However, if the facial palsy has been present for more than one year, the results of grafting are less satisfactory, and a hypoglossofacial anastomosis for rehabilitation is more beneficial.

Primary sarcomata of the temporal bone are rare, the most common type being the embryonal rhabdomyosarcoma. This is the most common childhood malignancy; unfortunately it is sometimes initially missed, being reported on pathologically as granulation tissue, but the rapid growth and extensive destruction should make the diagnosis obvious. The more recent use of combination chemotherapy and radiotherapy (Raney et al, 1983) has produced spectacular improvements in prognosis and, although these must remain the main modalities, adjunctive surgical debulking occasionally can be beneficial.

Secondary tumours

The temporal bone may occasionally be the site of metastatic tumour, usually the hypernephroma. More commonly, it is involved by direct spread from tumours of the parotid and nasopharynx. In most cases, palliative radiotherapy is indicated, unless the primary tumour can be controlled in which case the metastasis can occasionally be encompassed by radical surgery.

Primary meningioma of the middle ear has been reported, but it is usually associated with an en-plaque meningioma of the middle fossa not demonstrated radiologically. A good clearance of the tumour from the middle ear can be achieved by a middle fossa approach, but extensive en-plaque involvement of the middle fossa dura is left as its rate of growth is extremely slow.

Granulomata of the temporal bone

Wegener's granulomatosis may occasionally present in the middle ear and, if the general condition of the patient is good, may present a diagnostic problem with histological reports of granulation tissue only. Management is discussed in Volume 4, but see also Chapters 15 and 17.

Eosinophilic granuloma or histiocytosis X is a rare condition of unknown aetiology, typified by single or multiple osteolytic lesions with granulomatous replacement. The granulomata are composed of histiocytes and eosinophils. Three distinct clinical variants are recognized: eosinophilic granuloma, Hand-Schüller-Christian disease, and Letterer-Siwe disease.

Eosinophilic granuloma is a disease of young adults with a male predominance. The granulomata present in the middle ear and meatus often complicated with secondary infection. The osteolytic lesions seen on X-ray are generally assumed to be cholesteatoma
preoperatively, but at surgery the granulomatous replacement of bone is obvious, and confirmed by histological examination. Local resection followed by low dose radiotherapy is generally curative.

Hand-Schüller-Christian disease was originally described as a triad of skull base granulation, exophthalmos and diabetes insipidus. It is a more severe form of the disease with multifocal granulomata. It is usually a disease of childhood and there is accompanying systemic upset with recurrent respiratory infection, hepatosplenomegaly, lymphadenopathy and, frequently, diabetes insipidus if the sella is involved. Low dose chemotherapy has been used to control the condition, but it tends to be a chronic disease with a mortality of 10-20%. Letterer-Siwe disease is a fulminating condition in children under 3 years old. The diffuse granulomatous deposits replace the bone marrow, and skin deposits are frequent. Death generally follows intercurrent infection and bleeding diathesis. (See also Chapter 15.)
Chapter 24: Disorders of the facial nerve

Mark May

The material presented is based on the author's experience in managing over 2000 patients over a period of 20 years. The emphasis is on management in terms of diagnosis, prognosis, and treatment. The presentation begins with applied basic science and progresses to clinical evaluation, stressing pathophysiology, differential diagnosis, special tests, natural history, and treatment of specific disorders. For more details the reader is referred to May (1986).

Embryology

Normal and abnormal presentations of the facial nerve can best be understood through an awareness of its embryonic development (Gasser, 1967a, b). The main pattern of the nerve's complex course, branching pattern, and relationships is established during the first 3 months of prenatal life. During this period the muscles of expression also differentiate, become functional, and actively contract. Important steps in facial nerve development occur throughout gestation and the nerve is not fully developed until approximately 4 years after birth (Table 24.1).

Table 24.1. Time during gestation that anatomical structures appear

<table>
<thead>
<tr>
<th>Week of gestation</th>
<th>Structures noted</th>
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<tbody>
<tr>
<td>Week 3</td>
<td>Collection of neural crest cells to become seventh cranial nerve identifiable</td>
<td></td>
</tr>
<tr>
<td>Week 5</td>
<td>Chorda tympani, greater petrosal, VII motor nucleus</td>
<td></td>
</tr>
<tr>
<td>Week 6</td>
<td>External genu, postauricular branch, branch to posterior belly digastric</td>
<td></td>
</tr>
<tr>
<td>Week 7</td>
<td>Geniculate ganglion, nervus intermedius</td>
<td></td>
</tr>
<tr>
<td>Week 8</td>
<td>Stapedius nerve, temporofacial and cervicofacial part of extracranial facial nerve becomes apparent</td>
<td></td>
</tr>
<tr>
<td>End of week 8</td>
<td>Rest of terminal branches of VII form</td>
<td></td>
</tr>
<tr>
<td>Week 7-8</td>
<td>Myoblasts that will form the facial muscles are noted</td>
<td></td>
</tr>
<tr>
<td>Week 12</td>
<td>All facial muscles are identifiable.</td>
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Congenital anomalies can be understood by relating them to embryological development. The facial nerve develops within the second pharyngeal arch during the time that closely adjacent derivatives of the first arch and first external groove and internal pouch are forming the external and middle ear regions. Anomalies of the facial nerve within the temporal bone should therefore be anticipated whenever there is an associated malformation of the external or middle ear. If the stapes or incus is deformed the surgeon should be on guard for a possibly misplaced and exposed facial nerve; a soft tissue mound over the footplate of the stapes or the promontory may actually be the facial nerve (Jahrsdoerfer, 1981).
A great variety of facial nerve arrangements have been encountered within the temporal bone (Proctor and Nager, 1982). The nerve may course with the chorda tympani nerve, bifurcate, trifurcate, or take innumerable other aberrant pathways within the temporal bone. When a large chorda tympani nerve is encountered it may be carrying motor fibres to the face. In such instances, the vertical segment of the facial nerve just distal to the point where the chorda tympani nerve branches off may dwindle to a fibrous strand and lie in a narrowed fallopian canal. This condition has been encountered in children born with facial paralysis. The nerve may be dehiscent and it may herniate into the middle ear cavity (Johnson and Kingsley, 1970). This unusual presentation of the facial nerve, when encountered during otological surgery, must not be confused with a facial nerve schwannoma. Excision or biopsy of such a structure would cause iatrogenic facial paralysis which would have to be repaired by surgery.

**Anatomy**

A general knowledge of the anatomy of the seventh cranial nerve is essential for diagnosis and treatment of facial nerve disorders. For example, specific differential diagnostic possibilities can be derived by localizing the site of the lesion (Table 24.2) and, in the event that surgical therapy is inappropriate, defining the level of facial nerve involvement is critical.

**Cortex and internal capsule**

Anatomy of the pyramidal system from the cortex to the pontine nucleus is illustrated. Facial motor nerves are represented with the forehead uppermost and the eyelids, midface, and lips located sequentially below the representation of the forehead. Note that the tracts to the lower face are crossed while innervation to the forehead is both crossed and uncrossed. Sparing of the forehead movement is considered to be characteristic of a cortical lesion. However, it is also possible to have forehead sparing with a lesion of the pontine facial nucleus, with selective lesions within the temporal bone, or even in association with an injury to the nerve in its distribution in the face. Since preservation of forehead function is not sufficient to make a diagnosis of a central lesion, other neurological signs must be looked for (Table 24.3).

**Extrapyramidal system**

The extrapyramidal system consists of the basal ganglia and the descending motor projections other than the fibres of the pyramidal or corticospinal tracts. This system provides for automatic associated movements and spontaneous, emotional, mimetic human facial language which accompanies the more precise voluntary responses. The interplay between the pyramidal and extrapyramidal system accounts for tonus and stabilizes the motor responses. The affect of parkinsonism is known to be the result of extrapyramidal pathway destruction, and the facial dystonia of Meige's syndrome, a rare clinical entity, is thought to be due to basal ganglion disease. The severe progressive hemifacial spasm that accompanies Meige's syndrome will be discussed further under central nervous system facial nerve disorders.

Emotion is another function of the extrapyramidal cortical system and is mediated by discharges passing through the cingulate, orbital, and other frontal cortical areas and the basolateral portion of the amygdala.
**Upper midbrain**

A lesion in the upper midbrain will involve the oculomotor pathways and result in ipsilateral loss of direct and consensual pupillary light reflexes, ipsilateral external strabismus, and oculomotor paresis. In addition, paresis of contralateral muscles of the head and body will be noted. This symptom complex is referred to as unilateral Weber's syndrome.

**Lower midbrain**

A lesion in this region that is above the facial nerve nucleus involves the tracts of the abducens and may cause contralateral paresis of the face and muscles of the extremities, ipsilateral abducens paresis, and internal strabismus. A lesion that extends far enough laterally to include the emerging facial nerve fibres may present as peripheral ipsilateral facial paralysis associated with loss of taste and papillae on the anterior two-thirds of the tongue, and a dry eye on the same side. In addition, salivary flow from the submaxillary gland on the side of the lesion may be greatly diminished or absent.

It is important to emphasize that the peripheral topognostic tests for tearing, taste, and lacrimal flow can be altered by supranuclear lesions. However, a lesion in this region of the brainstem would involve other neural functions as well, and would be highly unlikely to involve only facial function.

**Pontine nucleus**

The facial motor nucleus contains approximately 7000 neurons and is seated in the lower third of the pons, beneath the fourth ventricle. The neuronal processes that leave the nucleus pass around the abducens nucleus (cranial nerve VI) before emerging from the brainstem. A peripheral seventh nerve paralysis, an internal strabismus on the same side, and inability to turn the non-paralysed eye toward the nose when asked to look toward the paralysed side of the face, suggest a single lesion near the floor of the fourth ventricle involving the sixth and seventh cranial nerves. A lesion near the ventricle at the level of the superior salivary nucleus causes peripheral facial paralysis, a dry eye, paralysis of voluntary muscles, loss of following gaze toward the side of the facial paralysis, and often vertical or rotatory nystagmus.

**Cerebellopontine angle**

The facial nerve emerges from the brainstem with a more slender nerve, the nerve of Wrisberg or nervus intermedius. Because of the association of the facial nerve with the nervus intermedius and the vestibulocochlear nerve at the level of the cerebellopontine angle and in the internal auditory canal, tearing, taste, submandibular salivary flow, and hearing and balance may be disturbed with a facial nerve lesion at this level. Large lesions filling the cerebellopontine angle may compress other cranial nerves and cause deficits of the fifth cranial nerve and later the ninth, tenth, and eleventh cranial nerves. Lesions that may occur in the area include temporal bone fractures, acoustic neuromata (schwannomata), meningiomas, primary cholesteatomas, and perhaps hyper- and hypokinetic disorders from vascular cross-compression of cranial nerves.
Transtemporal bone portion of the facial nerve

An understanding of the gross and microscopic anatomical relationships between the facial, acoustic, and vestibular nerves, described by Silverstein and Norrell (1980), is essential for performing a retrolabyrinthine vestibular neurectomy. The intracranial segment of the facial nerve from the brainstem to the fundus of the internal acoustic meatus is covered only by a thin layer of glia, which makes it quite vulnerable to any type of surgical manipulation but also quite resistant to a slow process of stretching or compression. Thus, the facial nerve in this region can become quite elongated and spread out over the surface of a sizeable but slow-growing vestibular nerve schwannoma without any gross evidence of facial weakness.

Fallopian canal

The course of the facial nerve through the fallopian canal is unique. No other nerve in the body covers such a long distance through a bony canal. The nerve is also remarkable for the Z shape of its infratemporal portion, in that it has a ganglion, and that the length of its course is 28-30 mm. The nerve in the fallopian canal can be divided into three segments: labyrinthine, tympanic, and mastoid. The labyrinthine segment is the thinnest part of the facial nerve within the fallopian canal. The narrowest part is at its entrance, where it averages 0.68 mm in diameter (Fisch and Esslen, 1972). Fisch (1977) feels that this bottleneck at the entrance of the fallopian canal predisposes the nerve to strangulation in cases of oedematous swelling. The observation is supported by post-mortem findings reported by Fowler (1963) and by Proctor, Corgill and Proud (1976). The blood supply to the nerve in this region is unique; this is the only segment of the facial nerve in which there are no anastomosing arterial arcades.

The labyrinthine segment of the facial nerve includes the geniculate ganglion. The somatosensory (pain), and special sensory (taste) fibres are afferent fibres that synapse in the geniculate ganglion, while the autonomic secretomotor fibres to the lacrimal gland pass through the geniculate ganglion and form the first branch of the facial nerve, the greater petrosal nerve. The secretory fibres to the parotid gland are carried with the ninth cranial nerve. They travel through the tympanic plexus and form the lesser petrosal nerve. There are communications with the nervus intermedius, which provides an alternate route for the parasympathetic fibres to reach the parotid, thus bypassing the tympanic plexus and the ninth cranial nerve branch of Jacobson. This might explain why sectioning Jacobson's nerve, in many cases, have little effect on parotid salivary flow.

In the region of the geniculate ganglion there are ample alternative pathways and connections for parasympathetic fibres to reach their terminations. Such alternative pathways explain how lacrimal flow may be unaffected by slow-growing lesions at or proximal to the geniculate ganglion, and the spontaneous recovery of tearing following resection of the geniculate ganglion or nervus intermedius, such as might occur with posterior fossa surgery. The geniculate ganglion lacks a bony covering in approximately 15% of temporal bones, an arrangement which makes the facial nerve quite vulnerable to injury during surgery involving the middle cranial fossa, especially in children. Further, the bone of the tegmen tympani and middle fossa plate over this region may be quite thin.
In the author's experience with temporal bone fractures, this is the area of the facial nerve most often compressed by crushed, thin, bony fragments. The change in direction taken by the facial nerve at the genu is another reason why this site is the most common focus of injury when severe traction is applied to the nerve along the axis of its tympanic segment, as may occur in longitudinal fracture of the petrous pyramid. The fact that the arachnoid pia mater extends to the geniculate ganglion, as well as the complex embryological development of this portion of the nerve, may explain why this area of the facial nerve is so often the site of primary cholesteatomata, vascular malformations, meningiomata, and schwannomata (Fisch, 1977).

The geniculate ganglion marks the proximal end of the tympanic portion, and from this point the nerve courses 3-5 mm, before passing just behind the cochleariform process and the tensor tympani tendon. The cochleariform process is a useful landmark to find the facial nerve when other landmarks are obscured by granulation tissue or cholesteatoma, or in cases of trauma. The entire tympanic segment is approximately 8-11 mm long and the tympanic wall of this part of the fallopian canal is thin and easily fractured. In addition, dehiscences occur frequently, allowing the uncovered nerve to prolapse into the oval window niche, partly or completely concealing the footplate of the stapes; this makes the nerve subject to trauma during stapes surgery. The tympanic segment is divided from the mastoid portion by the pyramidal eminence.

At this point the fallopian aqueduct makes another turn downward, forming the second genu. The latter is another area where the facial nerve is vulnerable to injury during mastoid surgery. The distal aspect of the tympanic segment is found by the surgeon through the mastoid approach by entering the suprapyramidal recess (retrofacial recess). Here, the facial nerve is lateral and distal to the pyramidal process. In the presence of chronic infection, care must be taken not to confuse a pathological dehiscence of the facial nerve in this region with a mound of granulation tissue. The best way to avoid this is to identify the nerve proximal and distal to the area that looks suspicious. The second genu, which marks the beginning of the mastoid segment, is lateral and posterior to the pyramidal process, which houses the stapedius muscle that lies on the deep side of the facial nerve; this explains the fact that the facial nerve lies lateral to the pyramidal process. The nerve continues vertically down the anterior wall of the mastoid process to the stylomastoid foramen. The distance from the beginning of the second genu to the stylomastoid foramen varies between 10 and 14 mm. This segment of the facial nerve has three branches:

1. the nerve to the stapedius muscle
2. the chorda tympani nerve
3. the nerve from the auricular branch of the vagus.

The nerve to the stapedius muscle arises from small neurons within the pons, located outside the main facial nerve nucleus, which interface with the rostral end of the facial nucleus and the caudal end of the lateral superior salivatory nucleus (Lyon, 1978; Joseph et al, 1985). Although Lyon (1978) studied cats and Joseph et al (1985) studied rabbits to determine the location of the motor neurons relative to the stapedius muscle, it is quite likely that these neurons lie in a similar location in man. If so, this may help to explain why
alterations in the middle ear reflex occur when a brainstem lesion is present. Further, the separate nucleus for the stapedius muscle innervation provides the anatomical basis for sparing of the stapedius muscle in patients with congenital facial palsy such as Moebius' syndrome.

**Surgical landmarks to identify the facial nerve**

The facial nerve will usually be found just deep to the short process of the incus, in a line between the short process of the incus and the anterior extent of the digastic ridge. The facial nerve is thus posterior to the chorda tympani nerve and just lateral to the ampullary end of the posterior semicircular canal. Skeletonizing the posterior canal is helpful in order to avoid fenestrating this part of the labyrinth. The tympanomastoid suture line is another useful landmark since it lies just anterior to the facial nerve and close to the course of the chorda tympani nerve. The chorda tympani nerve and facial nerves are deep to this suture. The facial nerve lies anterior to the sigmoid sinus and leaves the temporal bone through the stylomastoid foramen just anterior and lateral to the sigmoid sinus, where the digastic ridge turns and runs in the direction of the stylomastoid foramen.

**Facial nerve sheath**

The sheath that surrounds the facial nerve through its course in the fallopian canal consists of periosteum, epineurium, and perineurium. Although surgical decompression and opening of the perineurium of the facial nerve are controversial in the management of Bell's palsy and herpes zoster cephalicus, opening the sheath is imperative in cases of suspected tumour or trauma. A tumour of the facial nerve may be discovered when the sheath is opened, or a traumatic haematoma may be found compressing the nerve deep to the sheath. Finally, when the nerve has been disrupted, it is necessary to open the sheath to find the proximal and distal ends for repair.

**Spatial orientation**

Agreement is lacking, in spite of efforts to determine it, as to whether or not the facial nerve is spatially oriented in its extra-axial course from the brainstem to the periphery, as it is in the cortex and pontine nucleus. Evidence against topographical organization of the facial nerve fibres has come from several investigators who have found that the fibres destined for each peripheral branch are diffusely located in the facial nerve trunk (Sunderland and Cossar, 1953; Harris, 1968; Sade, 1975; Thomander, Aldskogius and Grant, 1982).

Thomander, Aldskogius and Grant (1982) exposed the individual peripheral facial nerve branches to horseradish peroxidase, permitting retrograde transport of the tracer to demonstrate the location of these fibres in the cat facial nerve trunk. The study indicated that the fibres to each peripheral branch were diffusely arranged in the facial nerve trunk at least as far proximally as the tympanic segment.

Gacek and Radpour (1982) studied the cross-sectional anatomy of the facial nerve through its course in the temporal bone by making discrete lesions in the facial nerve of the cat proximal to the geniculate ganglion and documenting anterograde wallerian degeneration. Gacek and Radpour (1982) discovered degenerated myelin sheaths in all three of the
peripheral branches studied, regardless of whether the lesion involved the rostral, caudal or middle fascicles of the facial nerve. They concluded that small fascicles of the facial nerve at the level of the internal auditory meatus carried motor fibres to all peripheral branches, and that motor axons of the facial nerve in the cat are not topographically arranged in the facial nerve trunk, as had previously been proposed. Jannetta (1975) described 31 patients with hemifacial spasm treated by removing a vessel compressing the facial nerve in the cerebellopontine angle. In those cases where the compressing vessel was found on the cephalic aspect of the nerve, the spasm was more severe in the upper part of the face. In cases where the vessel compressed the caudal aspect of the nerve, the spasm began in the lower face in an atypical fashion. This observation lends support to the existence of spatial orientation of the nerve in its most proximal intracranial portion.

Considering all the evidence, it is likely that there is some degree of spatial organization of facial nerve fibres, especially at the level at which the axon processes leave the brainstem nucleus and course toward the periphery. Accepting the fact that the peripheral facial nerve is at best only partially topographically oriented, with some axons carried with the upper division terminating in muscle groups of the lower face and vice versa, it is understandable that regeneration following facial nerve injuries usually results in some degree of mass movement and synkinesis.

**Blood supply**

The nerve receives its nourishment from the anterior inferior cerebellar artery, which enters the internal auditory meatus in close association with the seventh and eighth cranial nerves, the petrosal branch of the middle meningeal artery which runs along with the greater petrosal nerve, and the stylomastoid branch of the postauricular artery, which enters the facial canal at the stylomastoid foramen. The territories supplied by the three arteries tend to overlap at any given level. As mentioned previously, the anastomosis between the arterial systems is immediately proximal to the geniculate ganglion, making this segment of the facial nerve vulnerable to ischaemia from oedema. This might have bearing on the pathogenesis of facial paralysis following embolization of the middle meningeal artery (Metson and Hanson, 1983).

**Extracranial segment of the facial nerve**

The facial nerve leaves the fallopian canal at the stylomastoid foramen. In newborns and in children up to 2 years of age, the facial nerve as it exits the skull is just deep to the subcutaneous tissue underlying the skin. After 2 years of age, as the mastoid tip and tympanic ring form, the facial nerve takes a deeper position and, in an adult, it may be up to 5 cm below the level of the skin. Beyond the age of 2 years, the facial nerve is protected by the tympanic bone, the mastoid tip, the ascending ramus of the mandible, and the fascia between the parotid and cartilaginous external canal.

The position of the facial nerve in the young child must be kept in mind by the otologist and head and neck surgeon. To avoid unintentional injury to the facial nerve, a postauricular incision should be modified to avoid coursing near the junction of the tympanic ring and mastoid tip, and this area should be protected by placing a finger over the area at the time the incision is made. The surgeon is cautioned not to depend upon a nerve stimulator to find the facial nerve in the region of the stylomastoid foramen. A muscle response may be
noted in spite of the fact that the stimulator is not directly on the facial nerve, or the stimulator may give no response when on the facial nerve, if a thin layer of connective tissue is insulating the nerve. The nerve must therefore be identified by its anatomical location and appearance.

The main trunk may be identified entering the substance of the parotid and then bifurcating into an upper and a lower division. The facial nerve passes through the parotid gland and emerges over the fascia of the masseter muscle. There are communications between the upper and lower divisions in the majority of patients, and these form a variety of patterns. The rich plexus of nerve filaments that forms in the peripheral zone, just before entering the undersurface of the facial muscles, provides for free intermingling between branches carried by the upper and lower divisions, which may explain the diffuse distribution of axons within the main trunk of the facial nerve throughout its course from the brainstem.

**Communications of the facial nerve**

There are diffuse intra-axial connections within the central nervous system and, in addition, the facial nerve communicates with the vestibulocochlear nerve within the internal auditory meatus, with the otic ganglion and sympathetic fibres in the area of the geniculate ganglion and, just before it leaves the stylomastoid foramen, with the auricular branch of the vagus nerve. Outside the stylomastoid foramen the facial nerve communicates with the glossopharyngeal nerve, the vagus nerve, the great auricular nerve, and the auriculotemporal nerve. The peripheral branches communicate behind the ear with the lesser occipital, on the face with branches of the trigeminal, and in the neck with the cervical cutaneous nerve. These relationships have been documented by the meticulous dissections of Bischoff (1977). The fact that myriads of strands of the facial nerve interconnect with the fifth, seventh, eighth, ninth, tenth, eleventh, and twelfth cranial nerves, and with the cervical cutaneous nerves, may help to explain the symptoms of many syndromes; head and face pain, and ear, throat, eustachian tube, and neck pain. These syndromes are extremely hard to treat when the cause is malignant disease or a functional imbalance such as that which causes cluster headaches or atypical facial neuralgia. These interconnections also explain mastoid, ear, face or neck pain associated with Bell’s palsy and herpes zoster cephalicus, the presence of residual facial sensation after the trigeminal nerve has been cut, preservation of taste and tearing after facial nerve severance, and the occurrence of pain with skull base cancer after resection of the fifth, seventh, ninth, or tenth cranial nerve, the first or second cervical nerve, or the nervus intermedius.

**Spontaneous recovery of facial nerve function**

This free intermingling fibres of the facial nerve with fibres of other neural structures (particularly the fifth cranial nerve) has been proposed as the mechanism of spontaneous return of facial nerve function after peripheral injury to the nerve. Although spontaneous recovery of facial function was noted in approximately 25% of patients studied by Martin and Helsper (1957), this potential should not be relied upon for spontaneous reanimation of the face following resection of the facial nerve. There is no question that appropriate nerve repair at the earliest possible time following injury yields the best results. Nevertheless, spontaneous recovery does occur and may play a part in some of the cases in which the results of surgical reanimation are superior.
One other mechanism for the spontaneous recovery of facial function should be discussed. The plasticity hypothesis was first proposed by Cajal (1894), and was discussed in detail by Kandel (1977). This hypothesis offers the most plausible explanation, not only for spontaneous recovery of facial function following facial nerve sectioning, but also for repair after interruption of infranuclear pathways. The plasticity hypothesis, according to Cajal, is based on pre-existing connections between groups of cells that are reinforced by multiplication of terminal branches of protoplasmic appendices and nerve collateral, thus bringing about functional transformations in particular systems of neurons as the result of appropriate stimuli or their combinations.

**Neuropathophysiology**

**Nerve injury**

The facial nerve carries approximately 10,000 fibres, of which 7,000 are myelinated motor axons that reach the facial muscles (Van Buskirk, 1945). It must be understood that none of the various injuries and disorders involving the facial nerve causes an all-or-nothing lesion, but rather each of the fibres is capable of being spared or injured to a different degree at any one time.

**Classification of injury and recovery**

Sunderland (1978) described five possible degrees of injury that a peripheral nerve fibre might undergo. This classification system is depicted diagrammatically and is more comprehensive than the classification of Seddon (1943), which described only neuropraxia, axonotmesis, and neurotmesis. The Table 24.4 shows the pathological changes that occur in the nerve and the anticipated responses of the nerve to electrical testing, as well as the type of recovery that might be expected with the various types of injuries. The span of possibilities in terms of electrical responses, as well as recovery, reflects the possible mixtures of degree of injury which might occur. The five degrees of injury suggested by Sunderland describe very nicely the pathophysiological events associated with all types of disorders that afflict the facial nerve. The first three degrees of injury can occur with the viral inflammatory immune disorders, such as Bell's palsy and herpes zoster cephalicus. The fourth and fifth degrees of injury occur when there is disruption of the nerve, as in transection, which might occur during surgery, as a result of a severe temporal bone fracture, or from a rapidly growing benign or malignant tumour.

Fortunately, the pathological processes causing facial paralysis in patients with Bell's palsy and herpes zoster cephalicus usually do not progress past the first or second degree of injury, which accounts for the fact that most individuals recover satisfactorily. A similar process causes facial paralysis due to acute suppurative otitis media, chronic otitis media associated with a cholesteatoma, slow-growing benign neoplasms, and temporal bone fractures. In each of these disorders, the nerve is usually not transected, but rather compressed. In acute otitis media and trauma, compression may be sudden or slowly progressive, evolving over 5-10 days, just as is noted with Bell's palsy and herpes zoster cephalicus. However, unlike the process that occurs with Bell's palsy or herpes zoster cephalicus, and these other disorders pressure is exerted on the nerve from without rather than from within the intraneural space; nevertheless, the results of compression of the nerve are
the same. Eventually, axoplasm is dammed up, compression of venous drainage leads to further compression of the nerve and loss of axons, and eventually loss of endoneural tubes which leads to third-degree injury. In fourth- or fifth-degree injury, since most or all of the endoneural tubes have been disrupted, as well as the perineurium in the fourth-degree injuries and the perineurium and epineurium in the fifth-degree injuries, recovery even under ideal conditions is never as good as with the first three degrees.

Correlation of degree of injury, morphological changes in the nerve, and expected type of recovery.

- First degree: compression.
- Second degree: interruption of axoplasm and myelin.
- Third degree: disruption of endoneurium.
- Fourth degree: disruption of endoneurium and perineurium.
- Fifth degree: transection of nerve.
- Regeneration: as the degree of injury becomes more severe the quantity and quality of recovery become worse.

(From May (1986)).

Altered function of the facial nerve following injury

Three major changes that occur in the axon following regeneration may contribute to a combination of hypo- and hyperkinesis:

1. the distance between the nodes of Ranvier is altered
2. the newly formed axons are covered with myelin that is much thinner than the normal axon
3. there is a splitting and crossing of axons that reinnervate denervated muscle groups without necessarily corresponding to the cell body-motor unit arrangement that was present prior to degeneration.

As a result of these factors a tic or involuntary twitching occurs. In addition, inappropriate movement may be noted, such as movement of the mouth with blinking, or closing of the eye with smiling. Another cause of abnormal facial movements following regeneration may be changes that occur at the myoneural junction. In addition to these factors, it is quite likely that there are changes within and around the facial nerve nucleus in the brainstem, as well as alterations in central connections to the cell body. The combination of these factors may lead to spasms that occur on the involved side of the face, causing the eye to close and the corner of the mouth to pull. These spasms may be quite painful.
**Table 24.4. Neuropathology and spontaneous recovery correlated with degree of facial nerve injury**

*Degree of injury*

<table>
<thead>
<tr>
<th>Pathology of injury</th>
<th>EEMG (evoked electromyography)</th>
<th>MST (maximal stimulation test)</th>
<th>Neurobiology of recovery</th>
<th>Clinical recovery begins</th>
<th>Spontaneous recovery - result one year postinjury</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Compression persists. Increased intraneural pressure. Loss of axons but endoneural tubes remain intact. (Axonotmesis)</td>
<td>0-10% of normal.</td>
<td>Axons grow into intact empty myelin tubes at a rate of 1 mm/day which accounts for longer period for recovery in 2° injuries compared to 1°. Less than complete recovery is due to some fibres with 3° injury.</td>
<td>1-2 months.</td>
<td>Grade II: Fair: some noticeable difference with volitional or spontaneous movement, minimal evidence of faulty regeneration.</td>
<td></td>
</tr>
<tr>
<td>3. Intraneural pressure increases. Loss of myelin. (Neurotmesis)</td>
<td>No response.</td>
<td>With loss of myelin tubes the new axons have an opportunity to get mixed up and split causing mouth movement with eye closure referred to as synkinesis.</td>
<td>2-4 months.</td>
<td>Grade III-IV: Moderate to poor: obvious incomplete recovery to crippling deformity with moderate to marked complications of faulty regeneration.</td>
<td></td>
</tr>
<tr>
<td>4. Above plus disruption of perineurium. (Partial transection)</td>
<td>No response.</td>
<td>In addition to problems caused by 2° and 3° injuries, now the axons are blocked by scarring which impairs regeneration.</td>
<td>4-18 months.</td>
<td>Grade V: Motion barely perceptible.</td>
<td></td>
</tr>
</tbody>
</table>

Classification by groups I-VI modified from House and Brackmann (1985).
Facial hyperkinesis may be due to another mechanism referred to as ephaptic transmission. This term describes facial hyperkinesis or a hemifacial spasm that seems to occur spontaneously, without any discoverable cause. It is theorized that depolarization at the site of injury acts as a stimulus to the intact portion of the fibre, and that the action potential in one fibre is capable of exciting adjacent fibres in the area of injury. Granit, Leksell and Skoglund (1944) demonstrated ephaptic transmission at the site of compression in a nerve that was still capable of transmitting impulses across the site, and Kugelberg and Cobb (1951) demonstrated an acute, reversible phenomenon in the peripheral nerve of man. After producing ischaemia by means of pneumatic cuffs, Kugelberg demonstrated the development of foci of spontaneous, repetitive, and synchronized discharges, both during the ischaemia and after release of the cuff.

**Synkinesis**

This is an abnormal synchronization of movement, occurring with voluntary and reflex activity of muscles that normally do not contract together. This phenomenon may be grossly deforming and debilitating. In its worst form, mass movement of all parts of the involved side of the face occurs; the patient is unable to move each part of the face separately. In its subtlest form it may consist of no more than a tiny twitch of the chin accompanying blinking on the side of the involvement. This may be the only sign of previous facial paralysis, and to detect it requires very close observation.

**Crocodile tears**

Increased unilateral lacrimation on the involved side associated with eating may occur with a severe denervating lesion when it involves the facial nerve at or above the site of the geniculate ganglion or along the greater petrosal nerve. This phenomenon is probably the result of faulty regeneration of parasympathetic fibres, which innervate the lacrimal gland instead of the salivary glands.

**Stapedius tendon contraction**

This is a hyperkinetic syndrome which occurs with faulty regeneration and causes fullness or roaring in the ear. The complaint is noted with facial movements and often coincides with facial spasm. The diagnosis can be confirmed on tympanometric recordings employing the electroacoustic bridge; sectioning the stapedius tendon through a tympanotomy approach has been effective in relieving the spasm.

**Hemifacial spasm**

Unilateral facial nerve hyperactive dysfunction is characterized by the onset of mild intermittent spasms in the orbicularis oculi muscle that gradually increase in severity and frequency and spread downward to include all of the muscles of facial expression, including the platysma. The most common cause is cross-compression from vessels in the posterior fossa. On rare occasions this syndrome may be mimicked by benign lesions in the parotid gland (Horne, Crumley and Schindley, 1981), temporal bone (Bokeen, Pulec and Haleberg, 1969; Jackson et al, 1980), or cerebellopontine angle tumours such as meningiomata, cholesteatomata, and schwannomata (May and Hardin, 1977). The most effective treatment...
of hemifacial spasm is vascular decompression of the nerve at its root entry zone by the retromastoid approach (Jannetta et al, 1977).

**Facial myokymia**

A continuous fine fibrillar or undulating movement of the facial muscles gives the face an appearance suggesting a 'bag of worms'. This condition has been associated with multiple sclerosis and intrinsic tumours of the brainstem.

**Blepharospasm**

Involuntary spasmodyc eye closure may start on one side but classically it is a bilateral disorder. It is characterized by symmetry and the electromyogram shows that individual contractions are asynchronized. This condition has not been noted in children. Treatment involves selective neurolysis or myolysis or, more recently, injections of botulinum A toxin (Biglan, May and Walden, 1986).

**Psychogenic or habit tic**

This condition is usually noted in children. The movements are repetitive and may involve muscles outside the distribution of the seventh nerve. There is a compulsion to perform facial movements and they are under voluntary control. These movements are not observed during sleep, as are the movements of hemifacial spasm, facial myokymia, and blepharospasm. Psychological evaluation and treatment are indicated for this disorder.

**Focal cortical seizures**

These movements involve the face and are usually tonic, often spreading beyond the distribution of the seventh nerve. After a seizure, there may be transient postictal facial paralysis of the supranuclear type that spares the forehead muscles. The results of electroencephalographic recording during a seizure are diagnostic of this condition.

**Evaluation of facial nerve function**

**Differential diagnosis**

Peripheral facial paralysis is a diagnostic challenge. Every effort must be made to determine the aetiology, since often a treatable cause can be found. The differential diagnostic possibilities are numerous (Table 24.5). However, diagnostic clues are obtained from a carefully taken history, from the findings upon physical examination, and from the results of special tests (Tables 24.6 and 24.7). The relative incidence of the variety of causes in the author's experience can be noted in Table 24.8. In spite of the fact that, in the majority of patients, a cause cannot be found and their condition is labelled idiopathic (Bell's palsy), the clinician must not be discouraged from taking the time required to make an accurate diagnosis, since without this approach a treatable, progressive, or life-threatening disorder may be overlooked. It must be emphasized that Bell's palsy is a diagnosis by exclusion (Table 24.9).
History

The type of onset of facial palsy is not diagnostic, whether incomplete, complete, sudden, or delayed. All of these patterns of onset have been noted with idiopathic (Bell's) palsy, as well as with other conditions in which the facial nerve may be compressed or invaded within its anatomical course from the brainstem to the parotid. These other conditions include herpes zoster cephalicus, temporal bone fractures, parotid or otological surgery, infections, and neoplasms. However, the type of onset may have prognostic significance. Complete recovery will most likely occur in cases of incomplete palsy that do not progress to complete palsy. The exception is the patient who does not begin to recover in 3-6 weeks or if the paresis progresses for more than 3 weeks; in such cases a tumour must be considered as the underlying cause. Although slow progression beyond 3 weeks is diagnostic of a tumour, progression that occurs within the first 10 days of onset has been noted with idiopathic (Bell's) palsy, herpes zoster cephalicus, external blunt trauma, and surgical trauma to the facial nerve within the parotid, temporal bone, or posterior fossa.

Half of the patients with Bell's palsy present with a sudden complete onset of facial paralysis. In spite of this, it is not diagnostic of Bell's palsy since the onset was noted to be sudden and complete in 40% of patients with confirmed tumours involving the facial nerve. In half of these patients the tumour was malignant. A sudden complete onset associated with trauma may indicate that the facial nerve has been transected, while a history of a delayed onset or a slowly progressive onset would rule out nerve transection.

Facial paralysis has been noted to recur with idiopathic (Bell's) palsy, Melkersson-Rosenthal syndrome, and tumours. The incidence of recurrence in the author's experience with Bell's palsy was 12%, with 36% on the same side and 64% on the opposite side. The incidence of patients with idiopathic (Bell's) palsy who had ipsilateral recurrence was 4%. Of the total number of patients in this study who had ipsilateral recurrent facial palsy, 17% had tumours. Thus, the onset of facial palsy is not, of itself, diagnostic; tumours, like Bell's palsy, can present with incomplete, complete, sudden, delayed, or recurrent ipsilateral peripheral facial palsy.

In contrast to recurrent facial paralysis on the same side, recurrence involving the opposite side is almost always diagnostic of idiopathic (Bell's) palsy, since alternating recurrent facial paralysis has been noted only rarely with other disorders.

Melkersson-Rosenthal syndrome is the most common example of a rare disorder that is characterized by recurrent alternating facial palsy. This syndrome is characterized by:

1. recurrent alternating facial palsy
2. recurrent oedema of the lips, face, and eyelids
3. cheilitis
4. fissured tongue.

Most authors agree that the presence of any two of these four manifestations permits the diagnosis. The syndrome may be accompanied by migraine phenomena (Stevens, 1965).
Malignancies

A history of cancer, particularly involving the breast, lung, thyroid, kidney, ovary, or prostate, associated with a facial paralysis suggests that a metastatic lesion is causing the palsy. Appropriate radiographic and laboratory studies are indicated to search for the primary site as well as to localize the site of facial nerve involvement. In some cases, surgical exploration of the temporal bone and extracranial course of the facial nerve is recommended to locate the lesion.

Bilateral simultaneous palsy

Bilateral facial nerve paresis may be a medical emergency and presents a special diagnostic and therapeutic challenge. The therapeutic challenge is early diagnosis and appropriate treatment of a potentially progressive and life-threatening disorder. The most common cause of acute simultaneous bilateral palsy in the author's series was Guillain-Barré syndrome. Other less common causes included idiopathic (Bell's) palsy, leukaemia, bulbar palsy, sarcoidosis, skull fracture, Moebius' syndrome, and myotonic dystrophy. Guillain-Barré syndrome, acute leukaemia, and bulbar palsy due to rabies immunization presented as life-threatening medical problems.

Differential diagnosis of bilateral facial palsy by physical findings

Guillain-Barré syndrome

Guillain-Barré syndrome is an acute inflammatory polyradiculoneuropathy evolving as a paralytic disease of unknown cause. The characteristic pathological feature of Guillain-Barré syndrome is a lymphocytic cellular infiltration of peripheral nerves and destruction of myelin. The major complaint is weakness with the severity of the motor weakness covering a wide continuous spectrum from mild ataxia to total paralysis of every motor and cranial nerve. In most instances it is noticed first in the legs, but can begin in the arms. Tendon reflexes are abolished in the affected areas and facial diplegia is seen in at least half of the cases. Weakness can evolve to total motor paralysis and, when respiratory muscles become involved, respiratory embarrassment may lead to death. Abnormal cerebrospinal fluid findings are characteristic of this disorder, although in the first few days cerebrospinal fluid may be normal. After several days, the cerebrospinal fluid protein begins to rise and may become very high and peak at approximately 4-6 weeks after the onset of clinical symptoms. Cells in the cerebrospinal fluid are not prominent. The absence of cells in conjunction with an elevated protein level is the 'albumino-cytological dissociation' which at one time was thought to be characteristic of the disease. Guillain-Barré syndrome is a recognizable disease entity; its diagnosis is based on clinical, laboratory, and electrodiagnostic findings. In the author's experience, the prognosis for spontaneous recovery in Guillain-Barré syndrome is the same as for idiopathic (Bell's) palsy.

Infectious mononucleosis

Infectious mononucleosis is characterized by fluctuating fever, sore throat, and lymphadenopathy. Uncommonly, unilateral, recurrent, and simultaneous bilateral facial paralysis has been caused by this disorder. The syndrome of infectious mononucleosis, caused
by Epstein-Barr virus, has a classical presentation and can often be diagnosed on clinical grounds. The prodrome lasts from 3 to 5 days, and consists of headache, malaise, myalgia, and fatigue. Sore throat occurs in the first week and is the most common feature of infectious mononucleosis. A greyish-white exudative tonsillitis is practically pathognomonic, persists for 7-10 days, and is present in approximately 50% of cases. Petechiae located near the border of the hard and soft palates are observed in about one-third of patients towards the end of the first week of illness. Lymph node enlargement is a hallmark of infectious mononucleosis. The onset is gradual, and anterior and posterior cervical lymph node chains are the most commonly involved. Infectious mononucleosis resembles a number of febrile disorders characterized by fever, sore throat, adenopathy, and lymphocytosis. It may be difficult to distinguish from the early stages of other forms of febrile exudative pharyngotonsillitis, such as streptococcal infections, and exudative tonsillitis of viral aetiology. The differentiation depends upon the results of throat cultures as well as haematological and serological features characteristic of infectious mononucleosis.

Sarcoidosis

A patient presenting with bilateral facial paralysis and uveitis should be suspected of having sarcoidosis. Sarcoidosis is a granulomatous disease of undetermined origin that involves multiple systems. Although there is no single laboratory test that is absolutely diagnostic, sarcoidosis is characterized by an elevation in serum and urinary calcium levels, an increase in serum globulin, and an elevated serum angiotensin-converting enzyme level. A chest X-ray may demonstrate hilar adenopathy or diffuse pulmonary infiltrates, and examination of the eye grounds may indicate uveitis, supporting the diagnosis of sarcoidosis. The diagnosis is made on the basis of clinical findings together with biopsy of tissue involved by the sarcoid. Such tissue will contain a non-caseating granuloma with giant cells. Facial palsy is the most commonly seen clinical neurological deficit to accompany sarcoidosis. Uveitis occurs four times more commonly in patients with neurological symptoms than in those without. The peripheral neuropathy associated with sarcoidosis has been shown to be due to perineural inflammatory changes, with the nerve fibres themselves undamaged. This might account for the favourable prognosis with steroid therapy.

Lyme disease

Lyme disease has also been reported to cause bilateral facial paralysis (Clark et al, 1985). This disease is characterized by erythema chronicum migrans, tick-borne meningopolyneuritis, myocardial conduction abnormalities, and Lyme arthritis. The disorder was first recognized in 1975 by close geographical clustering of children with arthritis in the small community of Lyme, Connecticut. This spirochaete disorder is transmitted by an arthropod vector. The disease should be suspected if the patient has been along the northeastern coast in the USA, in the mid-west (Wisconsin and Minnesota), or in California or Oregon during the summer or early autumn months. These are the geographical locations where the tick vector is found. People are most likely to be out of doors and thus exposed to a tick bite in the warmer months of the year. This disorder has been recognized in Europe and Australia as well. In Europe, the disease complex is referred to as Bannwarth's syndrome.

The disease is characterized by a skin lesion that begins as a red macule or papule and expands to form a large red ring with partial central clearing. This lesion typically lasts about
3 weeks. Associated symptoms include malaise, fatigue, chills and fever, headache, stiff neck, backache, myalgias, nausea, vomiting, and sore throat. Some patients may develop a spectrum of neurological symptoms. The diagnosis can be confirmed by sending a blood sample for serological examination to detect characteristic cryoglobulins and circulating immune complexes. In the report by Clark et al (1985), the incidence of facial palsy was over 10% of all patients with Lyme disease and one-quarter of these patients had bilateral paralysis. The prognosis for recovery was excellent. Only one of the 124 palsies in this series had significant sequelae. Tetracycline is considered the drug of choice, with penicillin and erythromycin as acceptable alternatives. The antibiotic therapy is directed at concurrent symptoms and to prevent serious late complications of Lyme disease. The antibiotics did not alter the course of the paralysis.

**Idiopathic (Bell's) palsy**

One must consider a diagnosis of idiopathic (Bell's) palsy for those patients in whom no cause of facial palsy can be found. If vesicles are present, herpetic neuropathy may be the cause. Other physical findings which may help to define the cause of facial palsy as Bell's palsy include the presence of a red chorda tympani nerve or vascular flaring in the posterior superior aspect of the tympanomeatal area, pain and numbness, hyperacusis, dizziness, loss of tearing, and taste.

**Significance of special tests**

Trying to localize the site of a lesion using the results of tests for tearing (Zilstorff-Pedersen, 1965), taste (Kvarup, 1958), and salivary flow (Blatt, 1965), popularized by Tschiassny (1953), has been found to be of limited value when the lesion is acute and of little or no value in long-standing facial paralysis. This is true for the prognostic value of these tests as well, in contradistinction to a previous report by the author (May, Blumenthal and Taylor, 1981).

The lack of correlation between test results and the location of the lesion is related to a number of variables:

1. the anatomy of the facial nerve and its branches is quite variable, allowing for a variety of alternate pathways for the axons to reach their termination
2. the lesion responsible for the paralysis may not be sharply localized to a particular level, since a lesion may affect different components of the nerve at various levels and with different degrees of severity
3. recovery of the various components may occur at different times
4. the techniques used to measure the various facial nerve functions may not be completely reliable.
Electrical tests

Whereas tearing, salivary flow, and taste have not been useful as diagnostic and prognostic tests, the prognosis in acute facial palsy can be accurately determined by serial electrical testing. The time course of the degree of loss of response can be plotted. The steeper the line within the first 10 days the poorer the prognosis. Therefore, prognosis is based upon not only the absolute level in 10 days, but also the acceleration of the loss within that period of time (Fisch, 1984). The response to electrical tests has been found to be most helpful in the first 5 days after onset (Esslen, 1977). A study by May, Klein, and Taylor (1985) showed that, if a response to maximal stimulation or evoked electromyography (EEMG) of 25% of normal or greater is maintained up to the tenth day after onset, the patient has a 98% chance of having a satisfactory recovery. If the response remains at 11-24% within the first 10 days, there is an 84% chance of having a satisfactory recovery when the response to maximal stimulation or evoked electromyography drops to 0-10% within the first 10 days.

Reporting results - facial function recovery

A standardized, internationally acceptable system for reporting recovery of facial function after injury to the facial nerve has been established (House and Brackmann, 1985) (Table 24.10). From a clinical point of view, patients who fell into grades I and II were considered to have a satisfactory recovery compared to those who fell into grades III and IV. The latter group was considered to have an unsatisfactory recovery. Patients with recovery grades I or II can be separated easily from those in grades III and IV by the absence of the ability to lift the eyebrow or the presence of obvious synkinesis on the involved side.

This five degrees of injury suggested by Sunderland (Table 24.4) describe very nicely the pathological events associated with all types of disorders that afflict the facial nerve. Further, the five degrees of injury fit in very nicely with the clinical classification of recovery reported by House and Brackmann (1985).

General management of facial palsy

Office (outpatient) medical management of acute facial palsies

Patients and their families were satisfied if answers could be provided to three questions:

(1) What is the cause (diagnosis)?

(2) When can recovery be expected (prognosis)?

(3) What can be done to promote recovery (treatment)?

In most patients who present with an acute facial palsy these three questions can be answered after a thorough evaluation is performed during the initial office visit. When no specific cause such as trauma, infection, or tumour can be identified and the patient's symptoms fit the picture of idiopathic (Bell's) palsy as described previously (see Table 24.6), the patient is told that the facial nerve weakness was most probably caused by a viral
inflammatory immune disorder often referred to as Bell's palsy. The prospects for recovery from this disorder are excellent, and the patient should be reassured that he or she has not had a stroke, and will not be permanently deformed. Next, the time and degree of likely recovery are predicted by evaluating:

1. the completeness of the palsy
2. the response to the maximal stimulation test or evoked electromyography
3. the time recovery first begins.

The degree of recovery can be categorized (Table 24.10) as grade I (complete, with no detectable difference between the normal and the involved side), grade II (a very subtle deficit remains), or grade III or IV (incomplete recovery marred by more or less severe signs of faulty regeneration, such as synkinesis and spasm as well as facial weakness). Almost every patient with idiopathic (Bell’s) palsy or acute facial palsy due to trauma or infection who maintains some facial movement beyond 14 days after onset will have a satisfactory recovery from this disorder (grade I or II recovery).

Nevertheless, patients must be followed carefully, both in order to document recovery and to watch for signs of progression that indicate a worse prognosis. The prognosis in acute facial palsy can be accurately determined by serial electrical testing, as noted previously.

**Management plan**

As long as patients maintain an incomplete palsy, and have been evaluated within the first 14 days of onset, they can be given an appointment to return in 3 weeks for further evaluation. However, they should be told to return sooner if the palsy progresses as determined by daily evaluation of facial movement. This can be accomplished by the patient standing in front of a mirror or having a family member observe the effects of raising the eyebrows, squeezing the eyes closed, wrinkling the nose, attempting to whistle, blowing out the cheeks, and grinning so as to show the teeth. As long as facial function does not worsen, the patient should have satisfactory return of function with no further treatment. However, if the patient with persistent incomplete palsy does not begin to recover in 6 weeks or the paresis worsens rather than shows improvement, a tumour should be suspected.

When a patient presents with a complete facial motor deficit one must rely upon the response to maximal stimulation or evoked electromyography and the time post-onset that beginning of facial recovery is first noted to determine prognosis and develop a management plan. Early recovery of facial function, within the first 3 weeks, is a reliable indication that recovery will be satisfactory, but this prediction should be supported by electrical tests performed every other day up to the tenth day. If facial paralysis persists and response to evoked electromyography remains above 11% of normal, the patient is re-evaluated every other day up to the fourteenth day post-onset. If on the fourteenth day the response to maximal stimulation persists or evoked electromyography remains above 11% of normal, the patient is informed that the prognosis for early and ultimately satisfactory recovery is excellent. On the other hand, if the response to evoked electromyography drops below 11%
of normal or is lost completely within the first 14 days, then the prognosis for satisfactory recovery drops to 21%.

Once the prognosis has been established, patients are asked to return in 3 months, 6 months, and finally one year for final evaluation of facial function employing the system of House and Brackmann (1985). However, while waiting for recovery to begin, medical treatment is recommended, and precautions must be taken to prevent possible sequelae of facial nerve paralysis.

**Medical treatment**

There are three main types of treatment for acute facial palsy: physical, pharmacological, and psychophysical.

Physical therapy includes heat, massage, and exercises performed twice a day. Patients are advised to wet a Turkish towel with hot water, wring it out, and place the hot towel on the face until the towel cools. Then the patient should massage facial cream into the skin around the eyes and mouth and over the midface for a few minutes, ideally using an electric vibrator. Finally, the patient should stand in front of a mirror and watch the face while raising the eyebrows, squeezing the eyes closed, wrinkling the nose, whistling, blowing out the cheeks, and grinning. Even though no facial movement may be noted, intact nerve fibres will be activated, and the exercises will help to maintain muscle tone.

Although several medications, including steroids, have been used to treat facial paralysis, none has been shown to be efficacious.

Psychophysical modalities such as motor sensory re-education have been useful (Schram and Burres, 1984; Balliet, 1984). In the acute phase, integrated electromyographic tracings of motor strength can often be displayed on an oscilloscope, offering a patient significant encouragement at a time when no visible movement can be seen. The course of the recovery can be followed since there is a relationship between the response of voluntary effort recorded on the oscilloscope and actual recovery. During the post-acute phase, when recovery has begun, the patient can benefit from a combination of strategies using biofeedback, working in front of a mirror, and touching the face while attempting movements. These strategies are particularly useful in the post-acute phase once the patient has plateaued in terms of facial recovery. Further improvement can be achieved using these strategies.

**Depression**

 Patients who suddenly suffer complete facial paralysis of acute onset initially fear that they have a permanent deformity or have suffered a stroke. Once patients have been reassured that they did not have a stroke, the obvious facial deformity often leads to depression. If the prognosis is favourable for early recovery, the patient should be encouraged by this news, but if recovery is not expected for 2-4 months, the patient should be informed of this openly and supported sympathetically. Patient counselling and group therapy have been effective in helping patients to deal with this deformity, especially when patients are selected to be of the same sex and similar age, and the patient counsellor has had a satisfactory recovery or learned to deal with the problem in a positive way.
Physical pain

Approximately half of patients with acute idiopathic (Bell's) palsy and almost all with herpes zoster cephalicus have pain. In most cases pain can be controlled with a non-narcotic analgesic, although in rare instances a narcotic may be required.

Eye care

Efforts should be directed towards keeping the globe moist to prevent keratitis and corneal breakdown. The patient should voluntarily close the eyelids on the involved side whenever the eye feels irritated or burns, about two to four times a minute, and drops should be used during the day and ointment at night. In addition, a moisture chamber should be worn over the involved eye whenever the patient is out of doors or the eye becomes irritated. Surgery to reanimate the paralysed eyelids should be considered if medical treatment is ineffective, in particular when patients lack Bell's phenomenon, have corneal anaesthesia, and lack tears or have a Dry eye - the BAD syndrome. A tarsorrhaphy should be a last resort and revised later using one of the more effective reanimation techniques. A tarsorrhaphy produces a cosmetic blight, limits vision, and often does not protect the exposed cornea. In the event that the tarsorrhaphy can be reversed, sequelae often result including notching of the lid margin and trichiasis. Implantation of a gold weight or eyelid spring for the upper lid and lower lid tightening procedures have been so effective that a tarsorrhaphy is rarely indicated.

Surgical management of facial nerve paralysis

Indications for surgery

The benefit of facial nerve surgical decompression through the transmastoid or middle fossa route has not been established for idiopathic (Bell's) palsy, or herpes zoster cephalicus. Further, surgical decompression for acute suppurative otitis media, necrotizing external otitis, or facial paralysis following iatrogenic or external temporal bone trauma is indicated only in selected cases (Maiman et al, 1985). However, facial paralysis due to an ongoing process such as chronic suppurative otitis media with or without cholesteatoma can only be relieved by eradicating the primary process. It should be performed prior to electrical denervation to give the most satisfactory facial function recovery, and must not be delayed if the palsy has progressed from incomplete to complete over a period of hours or days and if the response to evolved electromyography is less than 25% of normal or dropping precipitously after the third day following onset.

In addition, there are two situations where surgery is absolutely indicated in managing facial nerve disorders: facial nerve transection and tumour infiltration. Further, there are times when nerve transection or tumour infiltration can only be established by surgical exploration, in particular when the temporal bone has fractured or a tumour is suspected.

Technique of transmastoid surgical exploration of facial nerve - labyrinthine segment to stylomastoid foramen

The postaural approach offers direct access to the tympanomastoid, geniculate, and distal labyrinthine segments of the facial nerve. The technique for this approach preserv
hearing. When exposure of the geniculate ganglion and labyrinthine segment is required and preservation of hearing need not be considered, the translabyrinthine route is preferred.

The transmastoid approach to the facial nerve consists of a preliminary mastoidectomy with removal of air cells from the antrum downward to the mastoid tip, and defining the ridge of the digastric groove. Further, cells are removed from the antrum forward to the root of the zygoma until the upper edge of the incus and the prominence of the bony horizontal canal are identified. Care is taken not to disturb the ossicles. The bony meatal wall, while thinned, is left intact. The landmark for the vertical mastoid portion of the facial nerve is the posterior tip of the incus above and the anterior end of the digastric groove below. Under the operating microscope, the periosteum of the digastric groove is exposed and followed forward and upward until the stylomastoid foramen is exposed. Then the bone between the foramen and the horizontal semicircular canal is thinned with a diamond burr, used parallel to the course of the nerve, under continuous irrigation with Ringer's solution or Tis-U-Sol to remove bone dust and blood and prevent overheating. As the nerve is approached, it begins to appear through the paper-thin bone as a pink streak. Brisk bleeding may be encountered from the artery that enters the fallopian canal at the pyramidal bend. With the diamond burr used gently, the final thinning of bone over the nerve is accomplished. Thus, the fallopian canal is exposed from its tympanic portion to the stylomastoid foramen, with care being taken not to disturb the incus or to open the horizontal semicircular canal. With right and left dental curettes the thinned bone covering the facial epineurium is lifted off, exposing the contents of the fallopian canal. With magnification provided by the operating microscope, this can be accomplished safely without injuring the nerve.

When the horizontal segment is involved, decompression is carried out through a triangle bounded by the facial nerve medially, chorda tympani and tympanic annulus laterally, and short process of the incus superiorly which provides the surgical guidelines for this approach. In constructing this triangular window into the facial recess, it is advisable to leave a small pillar of bone over the fossa incudis to prevent accidental brushing of the incus by the burr, which could result in serious, irreversible acoustic trauma. When the hearing is normal and the entire horizontal segment must be decompressed, it may be necessary to disarticulate the incus. In most cases this manoeuvre can be done quite safely through the facial recess by gently separating the capsules of the incudostapedial and malleoincudal joint leaving the short process of the incus attached to the fossa incudis. The incus can thus be rotated toward the middle ear to facilitate dissection over the proximal tympanic, geniculate, and distal labyrinthine segments. The incus can then be rotated towards the mastoid so that the mid-tympanic portion of the facial nerve can be dissected without concern for transmitting vibrations from the incus to the stapes into the inner ear. Following decompression, the incus is replaced in its natural anatomical relationship where it will remain providing the fossa incudis has been preserved.

Decompression of the facial nerve is completed by slitting the sheath vertically on its posterior aspect with a disposable Beaver knife. If bleeding is troublesome it should be controlled with Surgical. Use of electric cautery is discouraged, as even a wet-field bipolar cautery may create an unwanted injury by the transmission of heat at the site of application. If it is absolutely necessary to use the bipolar wet-field cautery, it must be done while the area is being irrigated.
**Exploration and decompression or repair for traumatic facial palsy**

When facial paralysis follows trauma, either surgical or otherwise, the site of injury must be exposed. Since this is most often in the tympanic or pyramidal portion of the nerve, it is possible to expose and decompress this segment by following the nerve into the facial recess through the postauricular approach. In some cases it may be necessary to take down the posterior canal wall for adequate exposure. The tympanic portion of the fallopian canal is examined under the operating microscope to determine the site and extent of injury. If the ossicles are intact, the incus may need to be dislocated from the stapes and later replaced to gain access to the tympanic fallopian canal, as described previously. The nerve is exposed at the site of injury and for at least 5 mm in both directions until normal-appearing nerve is encountered. If the nerve is intact but swollen or compressed by a depressed bone fragment, the latter is removed and the sheath slit. If the nerve has been partially torn, the intact fibres are carefully preserved and the torn fibres approximated or replaced by a small free graft if they cannot be approximated. If the nerve is completely severed, it must be repaired by approximation or by a free nerve graft as described later.

**Repair of severed facial nerve by approximation**

Theoretically, it might seem that regeneration of the facial nerve would be more satisfactory across a single junction than across two junctions at either end of a free graft. For this reason it is tempting to reapproximate the facial nerve when there are just a few millimetres between the two ends. However, re-routing the facial nerve to gain length to accomplish an end-to-end approximation in the horizontal and vertical segments by mobilizing the proximal and distal ends is not the procedure of choice. Often, the more the nerve is freed up, the more it seems to shorten and the more the blood supply to the nerve is jeopardized.

Additional length can be obtained for end-to-end approximation if the injury to the facial nerve is proximal to the geniculate ganglion and hearing and balance function have been destroyed. In this case the facial nerve van be freed from its first genu, separating the nerve from the geniculate ganglion and mobilizing the vertical and horizontal segments posteriorly towards the internal auditory canal. Length can also be achieved for the purpose of an end-to-end anastomosis with injuries of the facial nerve in the region of the parotid gland. However, as a general rule, it is much better to put a nerve graft between severed portions rather than to try to mobilize the ends of the nerve to accomplish an end-to-end anastomosis. Based upon the author's experience, the results were as good or better when a free graft was introduced as when a nerve was re-routed. If the ends cannot be brought together without tension, then a free graft must be inserted. Lack of tension at the site of approximation is the best guarantee that the repair will be a success.

**Repair of a severed facial nerve by graft**

When there is a gap between the cleanly cut ends of a severed facial nerve, so that the distal segment of the nerve cannot be brought up to establish contact with the proximal end without tension, a nerve graft should be inserted. The great auricular and sural cutaneous nerves are most suitable for facial nerve grafting. The great auricular is ideal for grafts up to 10 cm in length and the sural cutaneous for longer grafts.
A segment of nerve, measured so as to be slightly longer than the gap to be bridged, is removed, and its ends are cut sharply at right angles with a safety razor blade against a wooden tongue depressor. The nerve graft is handled carefully to avoid pinching or other trauma. Under a microscope, the nerve graft is carefully approximated to the distal and proximal stumps using 10-0 monofilament suture, employing the technique illustrated. By accomplishing a fascicular anastomosis, the graft need not be protected by covering it with a vein graft or silastic tubing. As long as the two ends of the graft lie within the temporal bone and to not extend outside the stylomastoid foramen or into the internal auditory canal suturing has not been necessary.

Results of facial nerve graft repair

The best results were achieved when the central nerve stump was connected to the peripheral system of the facial nerve within one year of injury. When the central stump was not available or the time between injury and repair was between one and 2 years, the procedure of choice was a hypoglossal-facial anastomosis. When repair was performed between 2-4 years after injury, the distal stump of the facial nerve was biopsied and, if it was fibrotic, a muscle transposition procedure was performed. If injury had occurred more than 4 years previously, or if the facial nerve and muscle system were not suitable for the procedures just described, temporalis muscle transposition was the preferred reanimation technique for the mouth, and separate eye reanimation techniques were combined with mouth reanimation.

Knowing the cause of the facial paralysis may be critical in determining how best to restore function. Most facial palsies evaluated for possible rehabilitation will be the result of trauma, either surgical or accidental. If the injury was acute and the nerve was severed, the best results are achieved when repair is performed within 30 days of injury.

The time following onset of the paralysis must be taken into account. No irreversible procedure such as a nerve graft, facio-facial cross-face graft, or hypoglossal-facial anastomosis should be undertaken while there remains the possibility of spontaneous recovery. If the facial nerve was spared following acoustic tumour surgery, it is advisable not to perform a procedure that interrupts the integrity of the facial nerve less than 12 months from the time of injury, in order to allow adequate time for evidence of spontaneous recovery to occur. Twelve months is a good waiting period before performing such nerve repair procedures, since it has been the author's experience that if no recovery has been noted in this period of time spontaneous recovery of useful function is unlikely.

However, time is of the essence in achieving the best possible results when the nerve has been injured, since an eightfold decrease in axon diameter occurs over 3 months (Sunderland and Bradley, 1950b). The decrease is due to shrinkage and later gradual thickening of the collagen of the endoneurial sheath (Sunderland and Bradley, 1950b). This suggests that nerve repair be undertaken without delay, so that axons which regenerate early can grow into the collapsing tubes, thus re-inflating them and suppressing collagenization before it progresses too far. In general, the sooner re-innervation begins, the better. The ideal time for nerve grafting is within 30 days and not later than one year following injury; beyond one year the results of nerve grafting by any technique have been disappointing. The best results with a hypoglossal-facial anastomosis were achieved when surgery was performed
within the first 2 years after injury, although satisfactory results were noted following surgery performed up to 4 years after injury (Conley, 1975). Recovery has been noted with later repairs in cases where part of the peripheral system was spared or spontaneously regenerated.

There are a number of factors that influence results following nerve repair. Technical flaws that might downgrade recovery include tension at the suture line, residual tumour, lack of suitable nerve ends, and the presence of infection. Other factors, such as the timing of the surgery following injury, the cause of the injury, the site of the injury, the number of anastomotic sites and the length of the graft, have been considered as variables influencing results. Nevertheless, the author's experience has shown that the most important factor is timing after injury.

The first sign of returning function is improving tonus of the paralysed side of the face, actually before there is any voluntary movement. Even in a long graft from the internal auditory meatus to the extracranial segment of the facial nerve, returning motion has been detected as early as 4 months, but it may be delayed as long as 24 months, the average interval being 10 months. In cases of nerve repair, maximum recovery requires 2 years and improvement may continue over a period of 5 years. Under ideal conditions satisfactory recovery following nerve repair can be expected in over 90% of cases.

Other techniques for facial reanimation

Results following facial nerve grafting or hypoglossal nerve anastomosis can be augmented employing reanimation techniques directed to the eye and mouth. Brow lift, gold weight or eyelid spring implantation and lower lid tightening combined with temporalis muscle transposition provide immediate eye reanimation with mouth symmetry and voluntary movement within 3-6 weeks after the procedure. Free muscle neurovascular repair techniques should be reserved for cases where the techniques already mentioned are not possible. The free muscle techniques are still evolving and greater experience is required before precise indications and anticipated results can be proposed.

Management of idiopathic (Bell's) palsy, herpes zoster cephalicus and other facial nerve disorders of viral origin

**Bell's palsy**

Bell's palsy is a term used to designate acute peripheral facial palsy of unknown cause, although accumulating evidence supports a viral inflammatory immune mechanism. The disorder is self-limiting, non-progressive, non-life-threatening, spontaneously remitting, and at this time can be neither prevented nor cured. The incidence varies between 15 and 40 per 100,000 population (Hauser et al, 1971; Adour et al, 1978; Peitersen, 1982).

**Clinical features**

Bell's palsy is characterized by a viral prodrome (60%), which is accompanied by pain around the ear (50%), facial numbness (40%), changes in taste (50%), and numbness of the tongue (20%) (May and Hardin, 1977). A positive family history was obtained in 14% of
patients, and the syndrome recurred in 12%. Of those with a history of recurrence, the same side was involved in 36%, while in the remaining 64% the palsy recurred on the other side. The common involvement of stapedius reflex, and salivary flow indicates that the segment most often involved is the tympanomastoid portion of the facial nerve (May and Hardin, 1977).

**Predicting outcome**

By studying the results of evoked electromyography and evaluating the completeness of the palsy, the patient's prognosis for recovery of facial function can be predicted with a high degree of accuracy. More than 90% of patients will have a satisfactory recovery, provided the palsy is incomplete and response to evoked electromyography remains greater than 10% beyond the first 14 days after onset. Patients with a complete palsy and response to evoked electromyography of 10% or less within the first 5-10 days have an 80% chance of an unsatisfactory recovery. It is this latter group that requires the greatest attention in terms of treatment directed toward improving the natural history of facial palsy and preventing complications of nerve degeneration.

**Natural history**

Peitersen (1982) studied the natural history of over 1000 patients with Bell's palsy seen over a 15-year period, and found that in 84% recovery was satisfactory; 71% recovered without sequelae, and 13% had defects that were barely noticeable. The other 16% of patients had obvious incomplete recovery of facial function, but sequelae were crippling in only 4%, and there was not a single patient who did not have some recovery. Peitersen noted that 85% of the patients in his study began to recover facial function within 3 weeks of the palsy, which in 31% was incomplete at onset. Peitersen concluded that there is a relationship between the degree of injury and ultimate recovery and the time that recovery is first noted; the earlier recovery is noted, the better the prognosis for a satisfactory and speedy recovery.

Treatment for Bell's palsy is supportive, and involves eye care, pain control, reassurance, heat, massage, and facial exercises. Steroids and surgery have not been shown to alter the natural history.

**Herpes zoster cephalicus (Ramsey Hunt syndrome)**

Hunt first described a syndrome, now called herpes zoster cephalicus, or herpes zoster oticus, which is characterized by a viral prodrome, with severe pain in and around the ear, and vesicles involving the pinna (Hunt, 1907, 1908). In its mildest form there may not be any neurological signs, but in a more severe form it may be accompanied by a sensorineural hearing loss and disturbed vestibular function, and even viral encephalitis. The vesicles in Ramsey Hunt syndrome may occur over the ear, face, and neck down to the shoulder, and may also involve the tongue, larynx, or buccal mucosa. The distribution of the vesicles depends on which sensory afferent fibres are involved by the viral eruption, but all of the nerves that communicate with the facial nerve may be involved, including cranial nerves V, VII, VIII, IX, and X and the cervical plexus arising from cervical nerves 2, 3, and 4. The sign common to all forms of herpes zoster cephalicus, and necessary to establish the diagnosis, is the vesicles.
Groves (1976) has presented a comprehensive review of facial nerve disorders, including a review of the literature on the history, aetiology, and treatment of Ramsey Hunt syndrome. Herpes zoster cephalicus is similar to Bell's palsy, except that in the former the vesicles are present, and there is a higher incidence of auditory vestibular involvement, postherpetic pain, and a poorer prognosis. Response to maximal stimulation or evoked electromyography may remain in the normal range beyond 10 days, then be lost by the fourteenth to the twenty-first day. This is in contrast to Bell's palsy, in which electrical response may become abnormal by the tenth day. A sensorineural hearing loss was noted in 10% of patients and a decreased response to electroneystagmography in 40% of patients with herpes zoster cephalicus. Bilateral vestibular suppression has been noted with this disorder, perhaps an indication of brainstem involvement.

Natural history

The natural history of herpes zoster cephalicus differs from that of Bell's palsy in several ways, perhaps reflecting the difference in behaviour of herpes simplex type I and varicella-zoster viruses. Bell's palsy recurs in 12% of cases, but herpes zoster cephalicus rarely recurs. In addition, the acute phase of the infection, as measured by electrical response and progression of palsy, peaks in 5-10 days with Bell's palsy but in 10-14 days with herpes zoster cephalicus. Lastly, 84% of individuals suffering from Bell's palsy have a satisfactory recovery of facial function, but only 60% of those with herpes zoster cephalicus recover a satisfactory degree of facial function.

Treatment

Treatment of herpes zoster is similar to that for Bell's palsy, with the exception that greater attention must be devoted to control of pain and the vesicular eruption. Often narcotics are required and a steroid antibiotic cream is effective for treating the vesicular eruption. Use of antiviral agents may hold promise, but must be subjected to a prospective, controlled randomized study (see Chapters 13 and 17). The availability of a vaccine to prevent chicken pox has been announced but has not yet been released. Prevention of chicken pox would eliminate herpes zoster since it is a reactivation of chicken pox virus.

Other viral disorders

Other viruses in the herpes virus group can cause facial nerve disorders. The Epstein-Barr virus is the known cause of infectious mononucleosis, and has also been isolated in cases of Guillain-Barré syndrome. The cytomegalovirus has also been isolated in patients with Guillain-Barré syndrome, suggesting that multiple viral agents are capable of producing this disorder. The Melkersson-Rosenthal syndrome is still another clinical entity that may masquerade as Bell's palsy. However, although it is possible that a viral agent may play a role in this last disorder, there is strong evidence that it is actually a hereditary autoimmune disorder. It is characterized by recurrent alternating facial palsy, tongue plication, facial swelling, granulomatous labial submucosal lesions, a positive family history, and migraine headaches. The presence of two of these factors associated with recurrent alternating facial palsy satisfies the necessary criteria for diagnosis.
Facial nerve disorders in the newborn and children

Facial disorders in children can be due to a variety of causes and should not be assumed to be of the Bell's type. Further, the type of treatment and ultimate outcome depend on early, accurate diagnosis of the cause of the palsy. The principles of managing facial paralysis in children are the same as those for adults with a few exceptions, and these will be noted. The information presented is based on the diagnosis and management of facial paralysis in 332 patients, from newborn to 18 years, seen between 1963 and 1985. The causes of facial palsy in these children were similar to those in adults, with the exception of paralysis noted at birth and the number of cases due to acute otitis media (Table 24.11).

Facial paralysis noted at birth

The differential diagnosis and treatment of facial paralysis in the newborn has been reviewed by May et al (1981) and Harris et al (1983). The two main differential diagnostic possibilities are developmental and traumatic; the factors that aid in differentiating between them are listed in Table 24.12.

The most common finding associated with congenital facial paralysis was the presence of one or more other anomalies. Weakness of the lower lip has particular significance in that it may be associated with multiple congenital anomalies (Pape and Pickering, 1972). Developmental bilateral facial palsy is frequently incomplete, with the lower portion of the face usually less affected than the upper part. This distinguishes it from facial palsy due to trauma, which is rarely bilateral and in which the upper and lower parts of the face are equally involved. Bilateral immobility of the face may not be apparent at birth and may be manifested by incomplete eyelid closure when asleep, an open mouth, and/or inability to suck.

Syndromes associated with congenital facial paralysis

Moebius’ syndrome

This is a rare congenital disorder which usually includes bilateral facial palsy, unilateral or bilateral abducens palsy, anomalies of the extremities, absence of various muscles, particularly the pectoral group, and involvement of other cranial nerves, particularly the last four and especially the hypoglossal.

Dystrophia myotonica

This disorder is a steadily progressive familial distal myopathy with associated weakness of the muscles of the face, jaw, neck, and levators of the eyelids. Children with muscular dystrophy usually present at birth with congenital facial diplegia, although without abducens paralysis, and only later evidence the progressive nature of the myopathy (Hanson and Rowland, 1971). Congenital facial diplegia associated with dystrophia myotonica that appears at birth is the earliest manifestation of the disease in its severest form. Unlike Moebius’ syndrome, there is muscle wasting, particularly of the sternocleidomastoid, temporal, and facial muscles, creating an expressionless face which is so characteristic that it is referred to as the myopathic facies. Extramuscular dystrophies such as cataract, premature frontal baldness, and testicular atrophy are also present, and the neck is usually described as swan-
like. This latter defect is due to wasting of the muscles of mastication and the sternocleidomastoid muscle.

**Thalidomide embryopathy**

Phocomelia (seal-like limbs) has apparently been known since Babylonian times, and was described by Ballantyne (1904), but the sudden increased incidence of this rare deformity between 1958 and 1962 focused attention on the disorder. Investigations discovered that the sedative thalidomide taken by the mother between the twenty-eighth and forty-second day of pregnancy led to thalidomide embryopathy with associated arrested development of the ear and abducens paralysis (Miehlke, 1965).

**Table 24.11. Causes of facial palsy in 339 patients newborn to 18 years old evaluated between 1963 and 1985***

<table>
<thead>
<tr>
<th>Causes</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bell's palsy</td>
<td>133</td>
<td>39</td>
</tr>
<tr>
<td>Herpes zoster cephalicus</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>Birth</td>
<td>62</td>
<td>18</td>
</tr>
<tr>
<td>Developmental</td>
<td>(46)</td>
<td></td>
</tr>
<tr>
<td>Traumatic</td>
<td>(16)</td>
<td></td>
</tr>
<tr>
<td>Traumatic</td>
<td>62</td>
<td>18</td>
</tr>
<tr>
<td>Accidental</td>
<td>(33)</td>
<td></td>
</tr>
<tr>
<td>Iatrogenic</td>
<td>(24)</td>
<td></td>
</tr>
<tr>
<td>Surgical</td>
<td>(5)</td>
<td></td>
</tr>
<tr>
<td>Infection</td>
<td>38</td>
<td>11</td>
</tr>
<tr>
<td>Acute otitis media</td>
<td>(28)</td>
<td></td>
</tr>
<tr>
<td>Chronic otitis media</td>
<td>(4)</td>
<td></td>
</tr>
<tr>
<td>Chicken pox</td>
<td>(3)</td>
<td></td>
</tr>
<tr>
<td>Mononucleosis</td>
<td>(1)</td>
<td></td>
</tr>
<tr>
<td>Mumps</td>
<td>(1)</td>
<td></td>
</tr>
<tr>
<td>Diphtheria</td>
<td>(1)</td>
<td></td>
</tr>
<tr>
<td>Tumour</td>
<td>19</td>
<td>6</td>
</tr>
<tr>
<td>Other</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>Melkersson-Rosenthal syndrome</td>
<td>(4)</td>
<td></td>
</tr>
<tr>
<td>Poliomyelitis</td>
<td>(3)</td>
<td></td>
</tr>
<tr>
<td>Guillaun-Barré syndrome</td>
<td>(1)</td>
<td></td>
</tr>
<tr>
<td>Hypothyroidism</td>
<td>(1)</td>
<td></td>
</tr>
<tr>
<td>Sickle-cell crisis</td>
<td>(1)</td>
<td></td>
</tr>
<tr>
<td>Myotonic dystrophy</td>
<td>(1)</td>
<td></td>
</tr>
<tr>
<td>Sarcoidosis</td>
<td>(1)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>339</td>
<td>100</td>
</tr>
</tbody>
</table>

* From May (1986)
Osteopetrosis (malignant variant)

Malignant osteopetrosis is a rare cause of facial paralysis at birth, although it may be present later in childhood (see Table 15.2).

Table 24.12. Facial palsy at birth: differential diagnosis*

<table>
<thead>
<tr>
<th>Developmental</th>
<th>Traumatic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>History</strong></td>
<td></td>
</tr>
<tr>
<td>No recovery of facial function after birth</td>
<td>Total paralysis at birth with some recovery noted subsequently</td>
</tr>
<tr>
<td></td>
<td>family history of facial and other anomalies</td>
</tr>
<tr>
<td><strong>Physical</strong></td>
<td></td>
</tr>
<tr>
<td>Other anomalies, bilateral palsy, lower lip upper face palsy</td>
<td>Haemotympanum, ecchymosis, tics, or synkinesis</td>
</tr>
<tr>
<td>Other cranial nerve deficits</td>
<td></td>
</tr>
<tr>
<td>Radiograph of temporal bone</td>
<td>Fracture</td>
</tr>
<tr>
<td>Anomalous external, middle, or inner ear; mandible; or vertical segments of facial nerve</td>
<td></td>
</tr>
<tr>
<td>Maximal stimulation / evoked electromyography</td>
<td>Normal at birth, then decreasing to possible loss of response</td>
</tr>
<tr>
<td>Response decreased or absent and without change on repeat testing</td>
<td></td>
</tr>
<tr>
<td>Electromyography</td>
<td></td>
</tr>
<tr>
<td>Reduced or absent response, no evidence of degeneration</td>
<td>Normal at birth, then loss of spontaneous motor units and 10-21 days later appearance of fibrillations and giant motor unit potentials</td>
</tr>
<tr>
<td>Auditory brain stem response</td>
<td>Normal, providing hearing is normal.</td>
</tr>
<tr>
<td>Abnormality in waves III-V</td>
<td></td>
</tr>
</tbody>
</table>

* From May (1986)

Management of developmental facial paralysis

At the present time, with the exception of free muscle neurovascular transplantation which is still investigational, there is no effective way to restore facial function in the newborn or young child with facial paralysis due to a congenital anomaly. It is in the child's best interest to delay reanimation surgical procedures until the patient reaches his or her adolescent years. Therefore, management of the newborn or young child with a congenital facial paralysis should be directed towards preventing complications and performing animation techniques which have very low morbidity. The main area of concern is the eye. Children with facial paralysis from birth usually do not have problems with keratitis and corneal scarring. However, this may occur, particularly if the child has poor Bell's phenomenon, decreased tearing, or entropion with irritation of the globe from eyelashes rubbing against the cornea. The child should be evaluated periodically by an ophthalmologist and, if there is any evidence of irritation or corneal keratitis, medical and perhaps surgical measures should be considered to correct the deformities.
Trauma

Facial nerve trauma can be either accidental (external trauma), surgical (unavoidable injury during surgery), or iatrogenic (unintentional surgical injury); the incidence of each is approximately equal in the author's experience. Facial paralysis has been noted following infiltration of local anaesthetics to the ear, face, and oral cavity. The mechanism may be either direct infiltration of the trunk or branch of the facial nerve with the anaesthetic or precipitation of an inflammatory immune disorder, as noted with Bell's palsy. The time of onset after injection is most helpful from a differential diagnostic point of view. An unresolved facial paralysis following injection is most probably related to the needle penetrating the nerve; while when a patient recovers from the anaesthesia and then days later develops a palsy, the most likely type is Bell's (idiopathic). Treatment for a patient with paralysis following local infiltration involves all of the recommendations made for Bell's palsy. Prognostic signs include the completeness of the palsy, electrical test results, and the time that recovery is first noted. If the injury is incomplete (first through third degree), then the treatment is the same as that described for Bell's palsy.

Surgical management

There is only one absolute indication for surgical exploration and repair in acute traumatic facial paralysis: when the nerve has been transected. In cases of temporal bone fracture in the author's series, the nerve was most likely to be transected if there was marked displacement of the temporal bone fragments seen on the computerized tomographic (CT) scan and electrical response to stimulation was lost by the fifth day.

If it is known that the nerve has been disrupted, it should be repaired at the earliest possible moment; if the injury occurred during surgery, the ideal time for repair is at the time of operation. However, repair may need to be delayed if the patient's general condition is unstable or the wound is contaminated, although it should be performed within 30 days after injury for best results. The ideal choice is nerve repair, when possible, since this is the only technique that will provide any semblance of mimetic movement. The hypoglossal-facial nerve anastomosis is the procedure of choice when direct nerve repair is not possible, providing it is done within 2-4 years following the injury. Both nerve repair and hypoglossal-facial anastomosis techniques provide useful functional recovery when applied under the appropriate circumstances. However, both may result in mass movement and the inability to separate eye from mouth movement.

Regional reanimation techniques may be used as primary or secondary procedures to restore facial expression when the other two techniques are unsuitable, when they have failed, or when further animation is required. Although spontaneous or mimetic facial language cannot be restored with regional reanimation techniques, they have the advantage over nerve repair and hypoglossal-facial anastomosis of:

1) giving immediate results
2) separating eye from mouth movement
3) being independent of the cause and location of injury and between injury and reconstruction.
By applying the principles just discussed, it is possible to restore facial function to some degree for all patients with facial paralysis following trauma.

**Tumours involving the facial nerve**

**Tumour types**

Tumours of the head and neck may lie in close proximity, envelop, or invade the facial nerve as it courses from the brainstem through the temporal bone and parotid gland to reach the facial muscles. The benign lesion most frequently seen to involve the facial nerve is a schwannoma. Half of these tumours are acoustic neuromata (schwannomata) and are located in the cerebellopontine angle or internal auditory canal and, in the author's series, half were found to involve the facial nerve or chorda tympani nerve within the temporal bone. Vascular lesions such as meningiomata, angiomatata, interosseous haemangiomata, and arteriovenous malformations were the second most common types of benign tumours causing facial palsy and, with few exceptions, involved the facial nerve extraneurally at or proximal to the geniculate ganglion. Unlike schwannomata, these lesions often could be separated from the facial nerve with preservation of residual function.

Malignant tumours may involve the facial nerve. The most common types of malignancy affecting the nerve in the author's series of patients have been adenoid cystic and mucoepidermoid carcinomata, and the most common site of origin of these lesions has been the parotid gland.

**Reanimation immediately after tumour resection**

Since brow function is rarely restored by grafting of the facial nerve or cranial nerve substitution, a brow lift is often performed immediately after resection of a tumour mass. Closure of the upper eyelid may be restored by implantation of a gold weight or a spring, and the lower eyelid may be tightened by a Bick (lid-tightening) procedure to protect the cornea.

The mouth region can be reanimated by transposing the temporalis muscle to the corner of the mouth. By performing this procedure in conjunction with eye reanimation procedures, the mouth and eye can move separately, which is not always possible with nerve grafting or cranial nerve substitution techniques. An additional advantage of this technique is that the results are immediate.

When facial paralysis has been long-standing preoperatively, or excision of the tumour mass leaves a facial nerve not amenable to grafting or even hypoglossal-facial nerve anastomosis, the techniques described for reanimating the eye and mouth may still be performed.

**Facial paralysis in acute and chronic otitis media**

In spite of the frequency of acute otitis media, particularly in children, associated facial paralysis is quite uncommon. A spontaneous satisfactory recovery is the usual course following treatment with an appropriate antibiotic and a myringotomy. Surgical therapy is
indicated if the infection does not respond to these measures. Surgical decompression, even with loss of electrical response, has not been shown to improve recovery of facial function.

Chronic suppurative infection of the middle ear has a different natural history and does call for immediate surgical intervention when associated with a peripheral facial paralysis. Often the pathological process involves compression of an exposed nerve by cholesteatoma or chronically infected granulation tissue. Abscess and osteitis are not unusual findings at the time of surgery. Surgery, for the best possible recovery of facial function, should be carried out within 24 hours, provided that the patient's general condition permits.

**Hyperkinetic disorders**

The variety of hyperkinetic disorders has been mentioned under faulty regeneration. The three most common are essential hemifacial spasm, blepharospasm, and hemifacial spasm of the mass type or synkinetic variety following faulty regeneration. Primary hemifacial spasm is most effectively treated by retromastoid vascular decompression of the nerve. In cases that fail or in patients who are not candidates for an intracranial procedure, selective peripheral neurolysis may be tried, with resulting weakness. Another alternative is injections of botulinum A toxin. The effects of one injection last from 6 weeks to 6 months, and these may have to be repeated. The injections relieve the spasm, but are also associated with weakness, although this is not so marked as with selective neurolysis. Blepharospasm does not respond to retromastoid vascular decompression but has been effectively relieved by peripheral selective neurolysis, or selective resection of muscles in and around the eyelids (Anderson, 1982). Botulinum A toxin injections offer significant relief and are a much more conservative approach (Biglan, May and Walden, 1986). Severe hemifacial spasm secondary to faulty regeneration does not respond to retromastoid vascular decompression but can be relieved to some degree by selective myectomy, neurolysis, or injections.
Chapter 25: Cochlear implants

W. P. R. Gibson

In July 1983, the Council on Scientific Affairs of the American Medical Association recommended endorsement of cochlear implants for postlingually deaf patients. The Council recognized that cochlear implants could enhance lip-reading ability and bring an awareness of environmental sounds which give benefit to the deaf. The recent developments in multichannel devices have exceeded these expectations as speech recognition is often possible.

Cochlear implants are now a routine clinical procedure for postlingually deaf patients in many countries. It is to be hoped that a similar statement regarding those who are prelingually deaf will be made within the next decade.

These simple statements conceal the immense amount of work and perseverance which have been required to establish the cochlear implant. House (1976) wrote 'There have been many and varied pressures to abandon the project. If it had not been for the encouragement and stimulation from the deaf patients who are the centre of this project, it would have died long ago'.

Historical background

Benjamin Franklin has been attributed as the first to suggest, in 1751, that electricity could produce hearing sensations in the deaf. Later Alessandro Volta (1800) placed metal rods into both his ears and connected them to a source of electricity. Apparently he heard the sound of bubbling water before he lost consciousness!

Much later at the end of the 19th century, many famous otologists, including Politzer, Ritter and Gradenigo were interested by the finding that passing an alternating current through electrodes applied around the ear produced sounds. In reality this produces 'electrophonic effects'. The impedance of the electrode interface with the skin, in or near the ear canal, causes the surface to act like the plates of a capacitory causing a slight movement (rather like the diaphragm of an earphone). The sound waves generated in the ear canal are transmitted to the cochlea. Thus a normal hearing person hears a sound at a maximum intensity of 30-40 dB HL with a frequency range of 30-15,000 Hz. Deaf subjects cannot hear anything.

At the end of the 19th century, unscrupulous doctors and charlatans made money by using this technique as a supposed means of preventing or curing deafness. At the same time there was much controversy over electrical therapy for other ailments, including treating the sexual organs for impotence and electrotherapy became so disreputable that established doctors dared not become associated with it.

It is difficult to be certain who succeeded first in producing true direct stimulation of the auditory nerve. Perhaps the Russians led the way. In 1934, Andreef, Gersuni and Volokhov published their paper entitled, 'Electrical stimulation of the hearing organ'. They placed an electrode near the round window and described various hearing sensations ranging from separate short noises to a smooth buzzing sound. Later Jones, Stevens and Lurie (1940)
reported similar findings on placing a saline-soaked cotton ball electrode on the round window in nine subjects. Sounds like 'the chirping of a cricket' were described.

The next significant event was in France when Djurno and Eyries (1957) reported the first 'cochlear implant'. They inserted a single copper wire inside the cochlea of a 50-year-old man who was totally deaf. The electrode was attached to an induction coil placed under the skin and the indifferent electrode was placed in the temporalis muscle. After healing, the induction coil was stimulated by currents produced by a second coil placed against the overlying skin. These investigators initially used an electrophrenic stimulator producing pulsed stimuli at a rate of 100/s. Later, a second implant was performed on a girl suffering from a total hearing loss after streptomycin therapy; this time, the electrode was placed in the round window niche against the membrane. In long-term studies, neither subject developed speech discrimination, although they could perceive speech rhythm and with training could distinguish between simple words such as 'allo', 'maman', and 'papa'. Both subjects claimed the devices helped them greatly with lip-reading. According to Zollner and Keidel (1963), the implants in Djurno's patients were still functioning 4-5 years later and the auditory sensations remained unchanged.

This was a remarkable report and it stimulated further research. In particular, it stimulated two groups in the USA: Blair Simmons and his group in San Francisco, and William House and his group in Los Angeles.

In 1961, House implanted two subjects with a single gold electrode placed in the scala tympani. These subjects were tested for several weeks. Later in 1961, a multiple electrode system was inserted for 2 weeks in one of the subjects but removed as a possible allergic reaction occurred (House, 1976).

In 1964, Simmons et al reported the results of bipolar stimulation of the acoustic nerve in an 18-year-old male undergoing surgery for a recurrent posterior fossa tumour. They stimulated the nerve for only 25 minutes but obtained clear evidence that a wide range of auditory sensations were heard. Later, in May 1964 (Simmons, 1966), they implanted a six-electrode array directly into the modiolus of a 60-year-old man. The patient was investigated extensively until October 1965 when the device was removed for fear of infection. He could distinguish a wide range of sounds. Auditory sensations were reported then 0.1 ms square waves were used at frequencies from 20-4000 Hz. Pitch varied according to the electrode stimulated. The research faced an unforeseen difficulty when the patient's vision was lost due to retinitis pigmentosa and he could no longer lip-read adequately. This report caused consternation among leading specialists who felt the patient's life could have been at risk; they urged no further studies of this kind until much more basic animal research had been completed.

The criticism effectively stopped any further clinical work for several years, although much work continued in the laboratory. Some important animal studies were undertaken: for example Michelson (1968) showed that intracochlear electrodes could be maintained safely in cats and would function over long periods of time.

Human studies began again in 1969 when House implanted a further patient and the following year, two more subjects were implanted. It was a bold move which caused
controversy. House used a six-electrode system designed by Jack Urban which was hard wired (connected percutaneously to the external stimulator device). The patients were tested extensively for 2 years in the laboratory as a wearable external stimulator was not available until 1972. The results were sufficiently encouraging that a further 10 patients were implanted in 1973 and despite much criticism the cochlear implant was established as a means of alleviating total deafness.

Other groups in San Francisco (Merzenich, 1975), France (Chouard et al, 1984), Germany (Banfai et al. 1984), and Austria (Burian et al., 1984) began clinical work during 1970s. In Australia, Clark (Clark et al, 1983) used a prototype 10-electrode system in 1979, which met with some scepticism initially as the technology was considered unnecessarily complex.

Soon commercial companies began to develop the cochlear implants and to provide a standard of product reliability which led to the Food and Drug Administration (FDA) in the USA approving the clinical use of the 3M House device in 1984 (House and Berliner, 1986), and the Nucleus (Clark) device in 1985 in postlingually deaf adults. Cochlear implants were first used in prelingually deaf children by House in 1980 and this group currently has the greatest experience (> 200 children as of May 1986). Children also were implanted by Chouard, Banfai and Burian during the early 1980s and by Clark since 1985.

**The basic concept of cochlear implants**

Although cochlear implants take many forms, they are all composed of similar basic elements:

1. a microphone which picks up sounds, including speech

2. a speech processor which analyses the signal from the microphone. Some devices relay the information in an analogue form, while others perform more complex tasks such as feature extraction

3. a transmitter coil is used in the transcutaneous device. This transmits the signal to the implanted coil without the need for any wires passing through the skin*

   * Percutaneous or 'hard-wired' devices, such as the Eddington (Symbion) device do not have a transmitter coil or receiver as the wire from the speech processor goes directly into a plug placed in the skull.

4. a receiver coil which is implanted into the bone of the skull behind the ear. It receives the signal and relays it to the electrodes

5. the electrodes which are usually placed within the cochlea inside the scala tympani.
Different cochlear implants in clinical use

There are reputed to be over 40 different cochlear implant devices. Table 25.1 lists some of these. The commercial availability of cochlear implants has enabled clinical centres to undertake this work.

The cochlear implants may be classified according to the following features.

Number of electrodes

The simpler devices have only a single electrode. Other devices may have several electrodes ranging from four (Hochmair, Eddington) to 22 (Clark). The number of channels depends on how many electrodes are used and whether they operate in monopolar or bipolar modes (similar to the diathermy in surgery). For example the intracochlear Hochmair (3M) has four electrodes but only one is selected and used as a monopole with a reference electrode inserted into the temporalis muscle. The Eddington (Symbion) device has four channels which are all activated simultaneously with a common reference electrode. The Clark (Nucleus) device has 22 electrodes which are stimulated as bipolar pairs, with two channels giving F1 and F2 frequency information according to position and both firing at the rate of the fundamental frequency, F0.

The electrode position

The electrode may be placed on the round window membrane outside the cochlea (extracochlear); for example Hochmair, Banfai, Fraser and Douek devices, or inside the cochlea, invariably within the scala tympani via the round window (intracochlear).

The speech processor strategy

Most devices use an analogue signal strategy which is usually filtered (for example frequencies outside the 50-4000 Hz range are excluded). The information may be further divided by a filter bank into frequency ranges which are fed to different electrodes according to a place/pitch principle. The Eddington/Symbion device relays information to all four electrodes simultaneously building up excitation patterns within the cochlea.

Other devices such as the Clark and Douek devices use feature extraction. Usually the voicing fundamental is extracted from the speech signal (the voicing fundamental or F0 is the main spectral peak of voice pitch - males 80-150 Hz, females 100-300 Hz). Other spectral peaks occur with speech which are divided up according to their spectral range. Usually the first such spectral peak or formant (F1) lies between 200-400 Hz for males and 250-500 Hz for females. Most vowels can be recognized from F0 and the first two formant frequencies (F1, F2). Consonants usually three formant frequencies to be recognizable. The Clark/Nucleus device relays F0, F1, F2 and fricative (high frequency sibilant) information.

Pathophysiology

It is probable that cochlear implants function best in profoundly deaf ears which have a large number of surviving peripheral neural elements capable of receiving and transmitting
electrical impulses to central nuclei. Studies show (Clopton, Spelman and Miller, 1980) that the neural elements most likely to be stimulated by cochlear electrodes are the spiral ganglion cells. Hinojosa and Marion (1983) have counted spiral ganglion cells in temporal bone specimens. Normal ears had an average of 33,915 spiral ganglion cells. In profoundly deaf ears, despite the presence of severe degeneration of sensory epithelium within the cochlea, only three out of 15 temporal bones examined had ganglion cell counts of less than 10,000 and the majority of counts were over 15,000. These findings completely refute earlier worries that loss of inner ear hair cells would cause massive retrograde degeneration of ganglion cells (Spoendlin, 1975). In another study (Otte, Schuknecht and Kerr, 1978) 34 out of 62 temporal bones were estimated to have fewer than 10,000 ganglion cells.

There appears to be no clear correlation between the duration of the deafness or the pathological aetiology and the number of surviving ganglion cells. Even congenitally deaf ears had high numbers; for example Scheibe's dysplasia resulted in counts of 8626 to 23,912 (Hinojosa, Blough and Mhoon, 1986).

Successful cochlear implants have been reported after all types of acquired deafness affecting the cochlea (for example trauma, labyrinthitis, meningitis, otosclerosis, Ménière's disorder). Cochlear implants cannot be used for eighth nerve disorders (after acoustic neuroma surgery) or for central problems such as bilateral temporal lobe damage.

After infection inside the cochlea, neo-osteogenesis especially in the basal coil may occur causing a bony obliteration (Suga and Lindsay, 1977). It is commonly seen after labyrinthitis and meningitis. In exceptional cases it may prevent the insertion of an intracochlear electrode.

**Otological selection of patients for cochlear implant**

The audiological selection of candidates for cochlear implant surgery is discussed in Volume 2. The final decision to perform surgery rests with the otologist.

It is helpful to classify potential cochlear implant subjects into the following groups:

1. acquired postlingually deaf adults
2. acquired postlingually deaf children
3. acquired prelingually deaf children
4. congenitally deaf children
5. acquired prelingually deaf adults
6. congenitally deaf adults.

The order in which these categories are given gives some indication of the increasing difficulty in auditory rehabilitation.
**Acquired postlingually deaf adults**

Patients who became deafened after 12 years of age usually retain language and have easily recognizable speech. Such subjects need little auditory rehabilitation compared with the subsequent groups.

There are no age limits providing the patient is medically fit; the author has successfully implanted a 79-year-old woman. The patient should be geographically accessible so that rehabilitation and programming of the device are possible and should speak the same language as the audiologist undertaking the rehabilitation.

The following evaluations are undertaken prior to implantation.

**Audiometry** (for details see Volume 2)

All candidates must be audiometrically profoundly deaf (greater than 90 dB HL at any audiometric frequency) and unable to gain any recognition of 'open set' speech using a powerful hearing aid without lip-reading (speech score 0%). Any speech recognition is an absolute contraindication. All patients must undergo a trial with a suitable hearing aid before they are considered.

The audiologist will also undertake other tests of sound recognition (usually the minimal auditory capabilities (MAC) battery of tests). If the patient scores better on these tests than the average for a patient after a successful cochlear implant, then he or she is not suitable for implantation.

**Otological examination**

The tympanic membrane in the intended ear must be intact and there must be no active infection (except for the Douek, EPI implant which has an active electrode which fits on to the end of a hearing aid mould and can be placed through a perforation). It is possible to implant a device despite the presence of a mastoid cavity providing the cavity is stable and dry and has a strong lining. The author has successfully implanted one such patient (Scrivener and Gibson, 1987).

Any chronic active infection of the nose or throat must be eradicated prior to surgery.

**Medical examination**

The patient must be well enough to undergo a 4-hour surgical procedure.

**Psychological evaluation**

The patient must be realistic. All patients must accept that they may not be able to understand any speech at all through the device. In Sydney, Australia a patient self-help group exists (CICADA group) and all potential implant patients and their immediate families spend an evening together with an implanted patient of similar age and his or her family. Some
implant groups ask a psychologist of psychiatrist to see all patients, but the author doubts that this is necessary.

**Laboratory investigations**

The following blood tests are carried out on all patients:

- full blood count
- liver function tests
- serological tests (when appropriate, AIDS antibody testing).

**Radiological investigations**

All patients must have the patency of the cochlear duct assessed. Using polytomography, the cochlear duct should be visible on at least three consecutive films taken at 2 mm intervals. Alternatively, a computerized tomographic (CT) scan may be employed (Ball, Miller and Hepfner, 1986). If there is any suspicion of a pathological condition which could cause central changes, then a CT scan of the head is needed.

**Evoked response audiometry**

The author performs electrocardiography on all candidates to ensure that no useful cochlear function exists. One patient with a non-organic hearing loss has been encountered. Brainstem audiometry can also be used, although the traces are more difficult to interpret when little or no hearing exists.

**Promontory and round window stimulation**

The usefulness of the promontory stimulation test is still disputed as House (personal communication, 1984) reported that several patients who failed to hear on promontory stimulation have received successful cochlear implants. At present there is no clear correlation between the promontory stimulation results and the results after implantation. Nevertheless, all patients who have a positive promontory stimulation test should hear using an implant so investigators may prefer to perform this test early in their series.

**Promontory stimulation**

Promontory stimulation is performed by placing a transtympanic needle electrode on to the promontory as close as possible to the round window membrane and a reference electrode is placed on the earlobe or over the mastoid process. Usually electrocochleography is performed first to check the absence of cochlear action potentials. The electrodes are then connected to an electrically isolated (battery operated) supply to ensure patient safety. The optimum stimulus is a constant voltage (or constant current) source which supplies square wave bursts; the subject usually hearing the transition from an anodal to a cathodal current at the slower presentation rates. (Anodal current may suppress tinnitus if present.) The longer the duration of the square waves, the less current required to evoke a hearing sensation (Gibson, Game and Pauka, 1987). Sadly, any differences observed using different frequencies of stimulation are the result of changing in duration of the stimuli and do not reflect
remaining neural activity in the corresponding frequency ranges. Hope that the growth of loudness versus current levels (Smith and Simmons, 1983) is related to the number of surviving ganglion cells appears unfounded (Van den Honert and Stypulkowski, 1986). The period between two consecutive stimuli needed for the subject to hear two separate sounds rather than one may relate to central processing and may be a useful measure of the ability to utilize an implant.

Many attempts have been made to record the brainstem auditory evoked potentials following electrical stimulation (Van den Honert and Stypulkowski, 1986). There are major problems; first a massive artefacts has to be overcome; second, the responses are very inconsistent from the promontory. The author (Game, Gibson and Pauka, 1987) has only recorded two convincing electrically-evoked brainstem evoked potentials from over 20 patients tested.

**Round window stimulation**

If a tympanotomy is performed and the active electrode is placed directly on the round window membrane, then brainstem evoked potentials can be recorded consistently (Chouard, Meyer and Donadieu, 1979; Black et al, 1987). This test may be useful for confirming the intactness of the auditory pathways especially in prelingually deaf subjects.

**Acquired, postlingually deaf children**

Children who lose their hearing after acquiring speech are assessed in a similar manner to adults. Generally, without a cochlear implant, if hearing is lost before the age of 6 years, recognizable speech is lost; after age 6 until age 12 years, gross voicing errors result; and after age 12 years, recognizable speech remains with some errors as a result of loss of monitoring.

The commonest cause is meningitis. X-rays to exclude neo-osteogenesis of the basal cochlear turn are important (Eisenberg et al, 1984).

**Acquired, prelingually deaf children**

These children will behave as congenitally deaf children, but it can be assumed that the central auditory pathways are intact and there has been some 'priming' of the auditory cortex to sound.

Careful audiometric assessment is needed to avoid the possibility of implanting a potentially hearing ear.

**Congenitally deaf children**

These children may be further classified into two groups - hereditary and acquired. If the deafness was acquired at birth, then it is likely that the cochlea and auditory pathways are anatomically normal. Children who lose their hearing during the first trimester of pregnancy and those with hereditary deafness may have abnormalities of the otic capsule: for example,
a Mondini deformity with a limited number of cochlear turns or a Michel deformity with no cochlear development. Radiology is essential.

The intactness of the central auditory pathways is unknown. Animal studies (Bock, Horner and Steel, 1985) showed larger than normal responses from the inferior colliculus. Brainstem responses in human infants show maturation over the first 6 months of life (Schulman-Galambos and Galambos, 1975); perhaps without auditory input, this maturation cannot occur.

It is important to exclude any hearing before considering implantation. The author suggests testing by electrocochleography and acoustic reflex in addition to careful behavioural investigation.

Electric brainstem 'auditory' evoked potentials are theoretically very useful. Simmons and Black (personal communications) both advocated tympanotomy and placing an electrode on the round window membrane as part of the preoperative assessment.

**Acquired prelingually deaf adults and congenitally deaf adults**

There is a high rate (approximately 30%) of non-use of cochlear implants in this group (Eisenberg, 1985) as patients are accustomed to a world without sound and often only perceive sound sensations as a feeling or vibration in the head.

Thus they have difficulty in understanding sound and only gain limited prosodic information (duration and rise/fall of frequencies and intensity rather than detailed information which allows speech recognition). Extensive and arduous rehabilitation is needed to utilize even this simple information. Very careful counselling of the patient and especially the relatives is needed to avoid a disappointment.

**Preoperative counselling**

The importance of counselling preoperatively cannot be over-stressed. Common patient misconceptions are as follows:

1. An implant will provide recognizable speech sounds - untrue! Even patients who gain 'open set speech recognition' admit that sound is distorted and unlike their previous recollection of speech. If a patient has any 'open set speech recognition' using a hearing aid, her or she is not a candidate for implantation.

2. An implant works better than a hearing aid in a noisy environment - untrue!

3. As the device is 'implanted' it is less noticeable than a hearing aid - untrue! The speech processor looks like an old-fashioned body-worn hearing aid. This seems to upset prelingually deaf teenagers and adults in particular.

4. Once the implant is fitted, no further hospital visits are required - untrue! Several visits are needed to adjust the outputs to obtain the best speech processor settings or 'programmes', especially with multichannel devices. Levels can fluctuate requiring further
adjustments. Several other visits are needed for rehabilitation and assessment if maximum benefit is to be obtained by the patient. These factors and the fact that device breakages occur (broken leads, etc) mean the patient must be prepared to revisit the cochlear implant team many times. Geographical accessibility of the patient is important.

The surgeon and the audiologist should ensure that the patient understands all these facts. A tape recording of a cochlear implant simulation is useful to convey to relatives the limited hearing which will be gained by the patient. It is very helpful to arrange for the patient and his/her family to spend an evening together with a patient who has already received an implant.

**Cochlear implant surgery**

The standard approach now employed by most cochlear implant teams is to embed the body of the implant in the skull behind the mastoid and to trail the electrodes via the mastoid through a posterior tympanotomy to the round window. The following steps are undertaken.

**Access**

The hair should be shaved with a wide margin around the intended incision. The incision should not be placed over the implant. The intended site of the transmitter coil may be marked before incision and a stab incision is made in the centre. A small hole may then be drilled into the skull through the incision and labelled with gentian or some other similar dye. The draping of the wound need not leave the external meatus uncovered; usually the pinna is pushed forwards and an adhesive drape is used.

The scalp incision is made at least 1 cm behind the posterior edge of the transmitter coil site. The limbs of the incision are kept wide to avoid any necrosis of the middle third of the scalp flap. The scalp is raised in two layers: a skin and subcutaneous tissue layer, and a periosteal layer. There is no need to cut into the sternomastoid muscle.

**Mastoidectomy**

A cortical mastoid operation is performed. The edges should be kept overhanging (that is they should *not* be saucerized as in conventional mastoid surgery) as the electrode lead will fit snugly underneath overhanging edges.

**Posterior tympanotomy**

It is usually possible to make the approach via the facial recess in the hypotympanum without disturbing the incus. Theoretically, this affords better support for the tympanic membrane and makes retraction less likely. To gain a sufficient view of the round window niche, the facial nerve has to be skeletonized, but if possible some bone is left to protect it during electrode manipulation and in case revision surgery should be required. The bone anterior to the facial nerve on the edge of the middle ear has to be cautiously removed. With care the chorda tympani nerve can often be preserved. The commonest error which must be avoided is to damage the annulus by making the posterior tympanotomy too laterally. If the ear has been cleaned with povidone-iodide (Betadine) preoperatively, Betadine from the
external meatus will appear on making the posterior tympanotomy - the dreaded 'Betadine sign'.

**Siting the body of the implant**

A circular area of bone is removed from the skull around the initial siting mark. The implant should have the external edge approximately 5 mm above the surface of the skull to allow the patient to site the transmitter coil. When the skull is thin, the author recommends drilling an outer circle completely down to the dura leaving thin bone in the centre ('Scriv's oasis'). Then, on pressing the implant into position, the dura can be safely moved medially averting the need to have the implant sited too externally causing an obvious postauricular lump. The trail of electrodes leaving the implant should be sited in a bony groove leading to the mastoid as this avoids movement on temporalis muscle contraction which could eventually break the electrode lead. Several holes are drilled about the bony groove and around the bony overhang of the mastoid cavity to provide a means of placing sutures to secure the implant.

**Inserting the electrode**

After preparing the site for the body and tail of the implant, the round window can be opened. The anterior bony overhang of the round window niche must be removed. The round window membrane lies anterosuperiorly. It is very easy to mistake a hypotympanic air cell for the round window and basal cochlear turn in a well pneumatized ear. The round window is kidney-shaped lying mostly in the horizontal plane, although the anterior portion is more vertical. The membrane arises from a bony annulus. The inferomedial portion of this annulus projects as the crista semilunaris (or 'scutum'). The round window can be opened by a central cruciate incision and the crista semilunaris has to be drilled. If there is any doubt concerning the location of the basal turn or its patency, the anterior lip of the round window should be drilled to visualize the interior of the cochlea. Care should be taken not to damage the osseous spiral lamina which projects inferiorly.

The electrode should be inserted smoothly and without force. Studies show that at approximately 8-9 mm depth, the tip of the electrode contacts the spiral ligament as it rounds the first cochlear turn (Clifford and Gibson, 1987). Undue force at this stage may buckle the electrode or force the tip through the basilar membrane. If the electrode insertion halts at this point, it may be possible to progress by gently rotation the electrode in the appropriate direction. Usually the Nucleus electrode can be inserted approximately 20 mm and, with this device, the depth of penetration is recorded according to the number of stiffening rings left outside the cochlea.

The round window niche should be filled with soft tissue (usually fibrous tissue) to prevent a perilymph leak postoperatively.

**Closure**

The monopolar diathermy should not be used near the electrode assembly. The periosteal layer is sutured together thus stabilizing the electrode assembly. The author uses surgical staples to close the wound and does not use a drain for fear of infection.
**Postoperative care**

A prophylactic antibiotic (for example erythromycin) is given for 7 days. The patient may be vertiginous and requires suitable medication. Often the tinnitus is increased for a few days postoperatively. The wound should be inspected for any haematoma which can be removed if necessary by aspiration through the suture line. The patient is usually discharged on the third postoperative day. Often polytomograms are obtained to check the exact location of the electrodes.

**Complications following surgery**

Fortunately, serious complications after cochlear implant surgery are uncommon. The following complications have occurred in the author's series.

**Immediate problems**

1. Haematoma under the skin flap.

2. Poor blood supply to the edge of the skin flap. In one case, the skin edge became very dusky but, fortunately, there was no necrosis. It is wise to keep the limbs of the incision broad.

3. Cerebrospinal fluid leak: one patient had a slight tear of the dura under the body of the implant. Postoperatively cerebrospinal fluid tracked along the route of the electrode leads into the mastoid and passed down the eustachian tube to the nose. A lumbar drain was inserted and the leak stopped without the need for further surgery.

4. 'Airocoele': a patient coughed and air blew through the mastoid elevating the skin flap. A ventilation tube was needed temporarily to prevent continual recurrence.

5. Facial palsy: no reports of permanent facial nerve palsy following cochlear implant surgery have been reported. The author had one patient who had undergone previous radical mastoid surgery in which the facial nerve had been exposed (Scrivener and Gibson, 1987). After cochlear implant surgery she had a partial facial palsy for 6 weeks.

6. No cases of postoperative infection have been encountered. The author knows of one case where an implant did become infected and had to be removed some months after surgery (Morrison, personal communication, 1985).

**Long-term problems**

1. Increased tinnitus has occurred in one out of 44 patients using a Nucleus multichannel implant. The majority of patients reported less tinnitus using a cochlear implant.

2. No patient has reported persistent giddiness. Nevertheless, the importance of preoperative vestibular tests to foresee the possibility of implanting the only ear with surviving vestibular function is obvious.
(3) Numbness: although most patients complain of numbness of the ear postoperatively, no patient has complained of this in the long term.

(4) Palpable lump: one patient in the author's series has an obvious lump but she does not appear to find this upsetting (1/18).

(5) No patient has continued to complain of a taste disturbance.

(6) Using the multichannel electrode, several patients (4/44) have reported facial twitching presumably caused by the current spreading across thin or dehiscent bone between the cochlear duct and the facial nerve. This may necessitate programming out the function of the offending electrodes. This is most likely to occur when cochlear otosclerosis has caused defects in the otic capsule.

(7) House (personal communication, 1985) mentioned three patients with persistent perilymph leaks. The author has one such case (1/18). A perilymph leak may present as obvious fluid behind the tympanic membrane, but is more often merely associated with continual fluctuations of the thresholds.

Problems with the implants

(1) Device failure. The commonest cause of device failure with earlier models was breakage of the wires passing from the body of the device. This is much more likely to occur if the implant is not firmly embedded into the skull as the device may rock when the patient contracts his scalp musculature.

(2) Leakage of body fluids into the device has dogged some earlier implants. This seems to have been prevented by improved manufacture and the use of hermetic sealing.

(3) Electrical interference. Some of the single channel devices (for example the House sigma system) can be affected by nearby electromagnetic fields.

Programming

Usually approximately 3 weeks after surgery, the scalp flap has healed sufficiently to allow the cochlear implant to be activated. At the initial postoperative session, the current level which is most comfortable is determined for each channel. In single channel devices, the output is filtered to provide an even sensation throughout the frequency range of the device. Multichannel devices are more complex to programme as the output range for every channel has to be set individually. Once set, the channels in some complex devices (for example Nucleus implant) are tested to determine the rank order of pitch sensation. Theoretically the most apical electrode should provide the lowest pitch sensation and successively more basal electrodes should provide higher pitches. This is rarely the finding clinically. Often several electrodes either provide exactly the same pitch sensation or inappropriate pitches are encountered. This may be a result of damage to the spiral ganglion cells from the original pathological condition which caused the deafness, or of buckling of the electrode during insertion. These inappropriate electrodes can either be re-ordered or switched off.
Usually when the patient is first 'switched on', the dynamic range is minute. There is little difference in current terms between just hearing and the sound becoming uncomfortably loud (reduced dynamic range). Gradually over the following weeks, the dynamic range increases. On average, the patients require eight programmes, set at weekly intervals, before a final programme is reached. This means that the patient must be available for weekly programming for at least 2 months after implantation.

Programmes can suddenly change even some months after implantation. The author has three patients who have suddenly lost 'hearing', twice after viral infections. Fortunately the 'hearing' has always recovered within 2 months.

**Recording results**

There are no standardized tests for assessing the results of cochlear implants which makes cross comparison of data difficult. Furthermore, there is a significant learning effect if a test battery is used on several occasions. Nevertheless, despite these shortcomings some comparisons are possible.

The following tests, commonly employed, may be classified into various groups:

1. Measurement of the threshold of hearing for pure tones using the usual setting of the device. This cannot be compared to an audiogram as the levels can be altered by changing the device settings. Nevertheless, it shows how the device performs across frequencies and indicates the frequency limits of the device.

2. Prosodic or suprasegmental tests. These tests show if gross features of speech are perceived such as distinguishing one versus two syllables, a male or female speaker, a stressed word in a sentence, etc.

3. Vowel and consonant confusion tests. The patient is given a number of vowels or consonants by listening alone. He or she attempts to identify each sound which is charted, each response being charted against the vowel or consonant given. This test not only gives an indication of how many vowels or consonants can be detected using the implant but also gives an indication of where the main errors exist.

4. Closed set discrimination tests. The patient is given a list of alternative choices and has to select the correct answer. For example, the vowel test asks the patient to distinguish between hood, hid, heed, had, hud: there is a one in five possibility of guessing correctly, or the chance level is 20%. Similar tests use the initial and final consonants and a set of five every-day sentences.

5. Open set discrimination tasks. Open set means that the patient can have no hope of guessing the answer so the chance level is 0%. Open set tests must not have any contextual clues; for example, if a patient knows that the subject is 'railways', understanding sentences such as 'When does the next train leave?' is not true open set. Telephone conversations with an implanted patient are impressive but may not be a measure of open set discrimination as so many contextual clues occur.
True open set discrimination tests include the standard Central Institute for the Deaf (CID) sentences and everyday open set sounds (dog barking, telephone ringing, etc). The most difficult open set tasks are monosyllabic words and spondee recognition tests. These latter tests are difficult and usually compared with lip-reading alone and with lip-reading plus audition (through cochlear implant). Using some multichannel devices (for example Nucleus, Storz and Symbion devices) word recognition is possible in some patients with audition alone.

(6) Speech tracking. The patient has to repeat exactly each word read from a book by the tester. If the patient gives a wrong response, the word is repeated and then, if necessary, a careful hierarchy of clues are given until the correct answer is given. The tester cannot proceed until the patient has repeated the correct word. The number of correct words per minute is recorded. The results can be compared using lip-reading alone, lip-reading plus audition and audition alone. The number of contextual clues is often quite small so audition alone gives some indication of 'open set' function.

Results using different implants

Every series has a few patients who manage spectacularly well using cochlear implants and perform far above the average for the device - such individuals are called 'star patients'. Most groups have case reports of star patients who can perform telephone conversations, etc, and often 'open set discrimination' is claimed. It is important, however, that groups other than the development team should be able to substantiate the claims.

Both single channel and multiple channel devices can be of significant benefit in prosodic tasks and provide some 'closed set discrimination' (Gantz and McCabe, 1986). This provides a number of useful clues which help the ability to lipread.

To date only two multiple channel implants (Eddington, Symbio device and the Clark, Nucleus device) have been shown to give the majority of implanted patients true 'open set discrimination' by groups other than the development team (Gantz and McCabe, 1987; Pauka, Gibson and Game, 1987; Cohen, Waltzman and Shapiro, 1987). Other multiple channel implants (Banfai and Chouard devices) have been claimed to provide 'open set discrimination' by the development teams but these have not yet been substantiated. The House 3M device has never claimed to provide 'open set discrimination'. The Hochmair team have claimed some limited 'open set discrimination' for the extracochlear device but this has not yet been substantiated (Risberg et al, 1987; Rosen and Ball, 1987).

There can be no dispute that postlingually deaf patients gain significant benefits from the use of cochlear implants; especially the multichannel devices.

Special considerations for prelingually deaf patients

Postlingually deaf adults require little active rehabilitation as they already understand the significance of speech as a language. Rehabilitation consists of a number of exercises to improve their recognition of components of speech and to improve their ability to follow speech.
Prelingually deaf patients have little or no concept of hearing. They have often developed their language based on signs coupled to lip-reading (for example total communication or cued speech). Prelingually deaf teenagers and adults will have grown accustomed to their own language and will find it a difficult and arduous task to learn a new language - rather similar to an English-speaking/hearing person learning Russian. Often it is the family of these patients who are eager to obtain a cochlear implant because they hope to improve the speech of their deaf relative. Unfortunately, even when a patient has been successfully implanted, the quality of the speech changes very little. Perhaps multiple channel implants coupled with intensive speech therapy can help in the future, but at present it would be misleading for any surgeon to offer this hope to families of deaf people.

There is more optimism regarding the use of cochlear implants in young children who may still have a capacity to learn naturally to utilize sound for hearing and learning speech. Nevertheless, as no cochlear implant device provides more than a shadow of normal speech sounds, it is unlikely that a child would gain sufficient information to learn speech by audition alone. Although children have gained benefit from single channel cochlear implants, there is still debate as to whether the same benefit could have been achieved using a vibrotactile device. Popelka and Gittelman (1984) wrote a most discouraging report of a child who received a single channel implant.

The hope is that multichannel implants will provide more information and better results. However, the programming of a multiple channel cochlear implant in a young prelingually deaf child will be a very difficult task. The author has implanted one prelingually deaf patient with a multiple channel (Nucleus) implant. This subject had a very limited dynamic range initially and was totally confused by the sensation of sound. It is likely that the dynamic range in children will change over the first few months and several programming sessions will be needed.

The difficulties of using cochlear implants in prelingually deaf patients are:

1. Radiology must show a normal otic capsule. Implants are not possible for Michel deformities. There may be a risk of meningitis if an ear with a Mondini defect is implanted.

2. It is essential that the brainstem auditory pathways are intact. This may be checked using electrically evoked brainstem potentials, but at present this requires a general anaesthetic and a tympanotomy operation to place the stimulating electrode directly on the round window membrane.

3. Total loss of auditory function must be confirmed. There is no satisfactory method of testing auditory evoked potentials available for low frequencies.

4. The child must have enough language to be able to cooperate with the implant team. Profoundly or totally deaf children are exceptional if they can communicate by a purely oral system. Most have to supplement their lip-reading by a sign system or by cued speech. The person undertaking the rehabilitation must be able to converse with the child.

5. At present most cochlear implant teams would not attempt to implant a child with other handicaps such as mental retardation.
(6) The programming of the device is likely to take many weeks of painstaking work. The child must be geographically accessible. It would be pointless to implant a child from overseas and for that child to have nobody available to programme the device and undertake rehabilitation.

(7) Even the most optimistic cochlear implant teams accept that a cochlear implant can only take a profoundly or totally deaf child into the severely deaf category (Eisenberg et al, 1986). Special help with education is still vitally important. The parents must accept this fact and be realistic regarding the role that a cochlear implant can play. The deaf child remains deaf, albeit no longer totally deaf. The deaf child does not become a normally hearing child.

False worries:

(1) The cochlear implant is not 'set in concrete'. It can be removed and replaced with a more sophisticated device should one become available at a future date.

(2) There is no evidence to show any deterioration of the spiral ganglion fibres in the long term after cochlear implant surgery.

(3) The operation requires skill but so far few, if any, serious complications have occurred. A cochlear implant operation is no more serious than any other operation to help a handicapped child, for example a hip operation.

**Final conclusions**

The usefulness of the cochlear implant in totally deaf (postlingual) adults is established. Single channel implants give limited benefit, which is confined to improving lip-reading skills, and provide limited environmental recognition. Multichannel implants can, in some patients, provide the ability to understand speech without the need for lip-reading. The results of multichannel implants are superior to those with a single channel and it is difficult to justify the continued clinical use of single channel implants. Despite early worries, intracochlear implants have not been shown to carry any risk to the patient and extracochlear implants appear only to be indicated when the access to the cochlea is blocked (for example by neo-osteogenesis) or could be hazardous (for instance in an ear with a Mondini defect).

The use of cochlear implants in prelingually deaf teenagers and adults is limited and much care has to be taken to ensure that the patient really wants an implant and is not having it forced upon him by his family (House, 1986).

The benefit of cochlear implants for the prelingually deaf child is uncertain, but there are many favourable findings which give grounds for optimism. Cochlear implants in children need a careful team approach which involves the otolaryngologist, the paediatrician, the audiologist, and the teacher of the deaf.