Chapter 24: Physiological aspects of wound healing

Principles of head and neck plastic operations and repair

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The physiologic aspects of wound healing

Wound healing is the process by which the body seals off an injury from the external environment and restores the site to structural integrity. Although successful healing depends on the complex and simultaneous coordination of various cells and tissues, the process can be broken down into the stages of inflammation, epithelialization, mesenchymal healing, contraction, and scar formation. Some scientists refer to the various stages of wound healing as the cellular-humoral phase, the phase of glycosaminoglycan accumulation, the phase of collagen deposition and polymerization followed by remodelling of the scar.

Inflammation

Inflammation is the body's means of protecting itself against alien substances, and of disposing of dead and dying tissues, in preparation for repair of the wound. Celsus in the first century AD described the initial process of wound healing, 'Notae vero inflammationia sunt quator: rubor et tumor cum calore et dolore.' (Take heed, however, of inflammation's four indicators: redness and swelling with heat and pain.) Centuries later the response was identified with the local release of humoral substances that mediate redness, swelling, heat, and pain. A noxious agent or stimulus rather than just cell death (necrosis) appears to be the prerequisite for producing inflammation and scarring. Wound healing always follows the same sequence of processes, irrespective of the type of noxious agent which induced the tissue damage (that is, surgery, trauma, burns, frostbite, infections), the site of the injury, or the sex or age of the patient. The only difference which may be evident is the duration or magnitude of the inflammatory response and subsequent cicatrix formation.

Immediately upon injury there is constriction of the small vessels in the area. Vascular occlusion may occur at the actual point of injury, to reduce haemorrhaging. After 5-10 minutes, vasoconstriction gives way to vasodilation. At the same time as these vascular changes are taking place, intracellular materials are being released into the extracellular compartment of injured tissue. These materials then migrate through the wound, with some of them, such as histamine and serotonin, causing increased permeability of the microcirculation. Proteolytic enzymes also help to increase permeability of the microcirculation. This increased permeability causes, in turn, an increase of proteins and cells in the area of the wound. Certain enzymes destroy noradrenaline, thereby helping to increase vasodilation.

Kallikreins - derived from the Greek word for pancreas, kallikreas - are enzyme(s) which convert a precursor protein into biologically active polypeptides, the kinins. One such kinin, bradykinin, is a potent local tissue hormone which mediates the four cardinal signs of inflammation described by Celsus.
During inflammation, prostaglandin levels increase. Certain prostaglandins aid vasodilation, permeability, and lymph flow. Other types of prostaglandin, including leukotrienes and lymphokines, are believed to mediate the final stages of the acute inflammatory response, thus playing a role in the initial stages of wound repair.

The cellular phase of inflammation is initially identified by the presence of blood platelets, red blood cells, polymorphonuclear leucocytes and macrophages. Other cells that subsequently participate in the inducement of inflammation are mast cells, lymphocytes and eosinophils.

Wound hypoxia and tissue bleeding usually occur in the initial stages of wound healing. Low wound oxygenation stimulates the macrophage to produce a growth factor that promotes fibroblast proliferation. Blood clot fibrin serves as a substrate for the attachment and ingrowth of cells, mainly fibroblasts.

**Epithelialization**

The epithelium, which covers all of the body's surfaces, acts as a barrier between the body and the environment. It keeps harmful agents from entering the body, and prevents the loss from within of essential materials, such as water. The surface layer, in particular, undergoes a good deal of wear and must constantly be replaced by the process of cell regeneration. Accordingly, the epithelium responds to a wound by intensifying the normal process of cell replacement.

The primary epithelial regeneration activity takes place in the basal cell layer of the epidermis. The epithelium is a cellular tissue composed of stratified squamous epithelial cells resting on a basal cell layer on dermal connective tissue. Injury causes the basal cells to come loose from their normally firm attachment to the dermal papillary layer, and they migrate upwards to the defective area, travelling as a sheet rather than as individual cells (Ross and Odland, 1967). Once they reach the site of injury, the cells proliferate by mitosis; cells already at the site increase their rate of mitosis. Epithelial cells migrate centripetally to cover open wounds when there are no epidermal formative cells left in the wounded area - for example, following an avulsion injury or after the removal of a skin cancer. Precursor cells that give rise to skin can originate from epidermal appendages that include sweat glands, hair follicles and sebaceous glands. These structures represent an important source of the regenerating layer of epidermis when the overlying epidermis is removed, as in providing donor sites for split thickness skin grafts.

**Mesenchymal healing**

Repair of the connective tissue begins immediately upon injury. In the initial or cellular-humoral phase, the ground substance undergoes changes to prepare the wound for the production of collagen. The damaged tissues are replaced by collagen in order to strengthen the wound. The collagen is produced by fibroblasts that migrate to the wound area approximately 3 days after injury. This later stage of wound healing coincides with the collagen deposition and polymerization phase.
In the early stages of healing, the production of collagen exceeds the production of collagenase (which causes the breakdown of collagen). This overproduction of collagen causes the scar to be temporarily hypertrophied and to feel hard and stiff from the second week after injury until 3 or 4 months afterwards. Later, collagen breakdown may overtake collagen production, until a balance is finally reached; the healed wound will now feel soft and pliable. Widening and depression of scars are evidence of this phenomenon. The process of softening may take several months, and usually becomes clinically evident at 4-6 months. Insufficient collagen can cause scars to weaken; too much collagen can result in the formation of keloids or hypertrophic scars.

**Contraction**

The terms 'contraction' and 'contracture' should not be confused. Contraction is the natural process by which a wound closes, through the centripetal movement of the surrounding skin (Hunter, 1794; Carrel and Hartmann, 1916; Zahir, 1964). Contracture is the condition or the result of excessive collagen production, usually produced in response to motion; it can also be caused by contraction, or by tissue damage such as muscle fibrosis.

Wound contraction can be either desirable or detrimental, depending on the location and condition of the wound. In an area of great skin mobility, contraction can result in a wound closure with minimal scarring. When the skin is attached to underlying structures, contraction can lead to the distortion of surrounding tissues - for example the pulling down of an eyelid, which is called 'ectropion'. If wound contraction proceeds about a joint, permanent flexion may occur, a condition called 'flexion contracture'. In head and neck operations involving the jaw muscles, such flexion can lead to scar contraction, which can result in limited mouth opening, a condition called 'trismus'.

During contraction, the entire dermis moves over the bed of granulation tissue. The movement involves existing tissue at the wound edge and not newly formed tissue. Therefore, the tissue around the wound is stretched and thinned. In compensation, new epithelial cells are formed under these areas of tension, and new connective tissue is formed in the underlying dermis.

Although the skin covering a contracted wound may appear normal, it is nevertheless inferior to uninjured skin. Many components of the dermis are unable to regenerate; only epithelium and collagen fill in for the stretching and thinning of the skin. In addition, a scar of the connective tissue the size of the original wound exists underneath the skin.

Wound size does not affect the rate of contraction. The wound closes most rapidly after a lag phase of 5-7 days following tissue loss. However, wound geometry does affect the rate and amount of closure. Generally, circular wounds close more slowly than rectangular wounds; circular wounds also contract incompletely, if at all, because the force of contraction causes compression of the wound edges.

**Remodelling of scar**

During remodelling of a scar, new collagen fibres are laid down, while others are destroyed. Those that remain are usually orientated along the tension lines of the scar. For the
wound to remain closed, the new collagen must be securely attached to the old collagen in the surrounding tissue. It is believed that the old and new collagen fibres become interwoven, with the new collagen fibres convolutedly cross-linked to the old (Peacock, 1984a). Remodelling of a scar is the final and long-lasting phase of fibroproductive inflammation.

As the scar ages (3-12 months), it loses water and mucopolysaccharides. This results in tighter packing of the collagen fibres and fibre bundles, which in turn aids the molecular cross-linking. As cross-linking occurs, the collagen becomes more insoluble and more resistant to collagenase. Clinically, the incision becomes lighter in colour and scar widening ceases.

**Wound healing: response to injury**

Wounds heal through the processes of cell migration, cell division and the synthesis of various proteins. The result is a fibrous product, that, even when it appears close to normal, is far inferior to undamaged tissue. Rather than simply allow the body to take its own course in wound healing, the surgeon must consider all available options for the manipulation of such aspects of healing as timing, placement and closure. It is important to understand the response to injury of each of the body's components.

**Skin and mucosa**

The skin is a complex organ and, like other such organs, is incapable of complete regeneration. It responds to injury by contraction, epithelialization and the synthesis of fibrous tissue. Contraction plays a much greater role in wounds where there is loss of full thickness dermis than in those in which the dermis remains. Skin thickness varies between 0.025 and 0.233 cm depending on body location. Eyelid skin and postauricular skin are approximately 0.036 cm thick, while leg and back skin thicknesses vary from 0.147 to 0.233 cm respectively. Hence the removal of 0.036 cm thickness of skin from the thigh leaves the dermis and adnexal structures fairly intact. Donor site contraction and scarring are usually minimal. Re-epithelialization occurs from the dermis, principally from hair follicles, sebaceous glands or sweat glands (Bell, 1973). Thus another skin graft can be taken from the original donor site after 6-8 weeks of healing. If the dermis is violated, a host of variables are introduced which influence wound healing. Contraction, increased collagen production and disorganization of tissue forces can produce unsightly scarring.

After epidermal disruption, when there is not enough tissue to allow for immediate approximation of epidermis to epidermis, a graft of epidermis can be used to bridge the defect, thereby reducing contraction and subsequent scarring. Full thickness skin grafts which include dermis are more effective in initiating primary intention wound healing than grafts of epidermis only (Bell, 1973). Immediately following skin disruption, reapproximation of the epidermis by suturing or taping allows for reduced scar formation. This process is referred to as primary intention healing. If the epidermis cannot be immediately reapproximated, because of insufficient tissue or fear of infection, the wound can be allowed to heal by secondary intention - that is, the wound closes itself naturally, influenced by such factors as location, amount of tissue loss, wound geometry, general health of patient, age and motion. Healing by secondary intention usually produces more scarring, and takes a longer period of time. The advantage of secondary healing is that the potential for infection is reduced. In fact,
most head and neck surgical wounds were allowed to heal by secondary intention when antibiotics were not available.

**Bone**

Bone is one of the few organs of the human body capable of regeneration. Bone has exceptional reparative properties in that it can heal without scarring and can alter in response to functional demand (Pritchard, 1969).

Bone healing occurs in two phases. The first is a cellular phase which lasts 2-4 weeks, followed by the remodelling phase which may continue for a full lifespan (Ray and Sabet, 1963; Urist, 1964).

The cellular phase is stimulated by the hypoxic tissue environment around the necrotic ends of fractured bone and torn soft tissues. Specialized cells derived from the bone marrow and also the cortex produce tropocollagen which is mineralized into callus. Periosteum produces osteoprogenitor cells that form an external callus. Osteoclasts, of histiocytic blood origin, appear at the junction of living and dead bone and begin to resorb the non-viable bone. Capillary ingrowth soon occurs, which reverses the hypoxia and stimulates osteoblastic production of new bone.

New bone production is induced by a glycoprotein substance called bone morphogenic protein. In cancellous bone, the process of bone apposition or replacement takes place on the trabecular surface by means of a process called creeping substitution. In the cortical bone, by contrast, osteoclasts first have to burrow into the dead bone to produce an opening for vascular ingrowth and osteoblast production. The osteoblastic penetration of cortical bone may allow for primary bone union.

Two types of bone exist in the facial skeleton (Rowe and Killey, 1968). Endochondral or long bone and intramembranous or flat bone are differentiated both by their anatomy and by the way in which they ossify. Bone that has epiphyses and cartilage, and forms new bone by cartilage formation, cartilage calcification, cartilage resorption and then by bone formation, is called endochondral bone. New bone formed at the epiphyseal plate during growth is called endochondral ossification. Flat bones which make up 95% of the facial skeleton and skull do not have epiphyses and are formed by direct ossification, also termed intramembranous ossification.

The blood supply of a bone determines how it will heal and also differentiates the two types of bone (Trueta and Little, 1962; Ray, 1972). Endochondral bone has three principal vascular supplies, namely nutrient, epiphyseal and periosteal. Flat bones have only a periosteal blood supply. Removal of periosteum from long bones minimally affects bone growth and repair, whereas the same procedure carried out on flat bones significantly alters the process of bone healing.

Another differing property of endochondral and intramembranous bone is the lack of callus formation associated with the healing of the latter. Callus, initially fibrous tissue, quickly calcifies providing an internal and external biological splint for the healing of long bone fragments. From a technological point of view, it is extremely fortunate that
intramembranous bone does not heal by callus formation in that facial plastic operations, such as rhinoplasty and mandibular recessions, as well as facial fractures, would produce hideous bulging deformities if callus participated in the healing process of facial bones.

**Nerve**

When the axon of a nerve is severed, the cell body swells for 4-20 days, until regeneration has been achieved (Cajal, 1928; Grabb, 1977). The closer the site of injury is to the cell body, the greater the amount of swelling. The ends of the severed nerve also swell; this swelling subsides about one week after injury.

The distal portion of the axon undergoes a process called wallerian degeneration. Unmyelinated fibres degenerate more rapidly than myelinated fibres. About 48 hours after injury, the myelin sheaths will begin to degenerate. Other parts of the nerve, such as the blood vessels and endoneurium, survive in the expectation that the axon will be repaired. Within 2-3 weeks, the debris of the disintegrated axons and sheaths is removed, and the vacant sheath of Schwann awaits the regenerated axon.

Although the proximal portion of the nerve also degenerates, this degeneration, unlike wallerian degeneration, extends only a few millimetres beyond the site of severance.

Within 2-21 days after injury, spraying or budding begins on the intact segment of the axon. Six to seven days after injury, myelin sheaths begin to appear on regenerating myelinated axons. Depending on the size of the cylinders, myelin will continue to regenerate for up to one year. Recovery of motor and/or sensory functions takes from several months to as long as 5 years.

Immediate repair of a cut nerve gives the best chance of recovery. Likewise, waiting 21 days after nerve transection for optimum axon sprouting also gives a good chance for a satisfactory repair of the nerve. The assessment of cranial nerve function soon after head or facial injury is important in order to determine whether or not surgical exploration is necessary. If, following injury, the tested facial or mouth part does not move on command or stimulation, the nerve has probably been transected. On the basis of what has been learned from experimental and clinical nerve injuries, the surgeon would either repair the nerve immediately or wait 21 days. The latter situation would be preferred in situations where the patient had received multiple trauma, and there was a possibility of morbidity or mortality if a long and tedious nerve repair were undertaken.

Functional integrity of a cranial nerve can be evaluated through electrophysiological means. Sufficient direct electrical stimulation of a cranial motor nerve will cause that particular muscle group innervated by the nerve tested to contract. The muscle will contract upon electrical nerve stimulation for up to 72 hours following injury whether or not the nerve has been transected. Stimulating the nerve proximal to the transection will obviously not produce muscle contraction regardless of the intensity of the electrical stimulation. The residual capability of a nerve to function for up to 72 hours after severance aids the surgeon to find the distal part of a nerve for subsequent repair. A surgeon confronted with the problem of whether to repair a nerve immediately or whether to wait 21 days before doing so must give consideration to this basic knowledge.
Severity of injury

Nerve injuries can be classified into the following five categories:

(1) **First-degree injury.** Although conduction in the axon has been interrupted, the nerve remains intact. Sensory and motor function may be absent for a period of time ranging from a few days to several months. Some authors refer to this condition as neuropraxia. Expected recovery of nerve function is complete. Bell’s palsy or idiopathic facial nerve paralysis is an example of this phenomenon.

(2) **Second-degree injury.** Minimal crushing of the nerve causes wallerian degeneration of the distal portion of the axon. The endoneural tubes remain intact. Complete functioning is recovered over period of months. This condition is frequently seen after facial trauma and temporal bone fracture. If facial movements are observed immediately following the injury with subsequent loss of function this would suggest a second-degree injury. Watchful waiting will allow time for the nerve to regenerate.

(3) **Third-degree injury.** Continuity of the nerve fibres is interrupted, but the perineurium and funicular arrangements are preserved. This condition is sometimes described as neurotmesis. Degeneration of the proximal portion of the axon is more severe, and regeneration is delayed. Because endoneural tubes have been disrupted, budding axons frequently grow into other tubes. Recovery of sensory and motor functions is incomplete. For example, in such an injury to the facial nerve the face would, after regeneration, move in unison upon blinking the eyelids or smiling, with loss of selective facial movement. This is often referred to as synkinesis.

(4) **Fourth-degree injury.** The nerve trunk in the damaged segment becomes a disorderly strand of connective tissue, Schwann cells and regenerating axons called a neuroma. Excision of the neuronal segment with repair of the nerve is necessary. Recovery of sensory and motor functions is incomplete.

(5) **Fifth-degree injury.** The peripheral nerve is completely severed. Axotmesis is another term to describe this condition. There is no return of function unless the cut nerve is repaired. Even so, function will be reduced. In this case, the face would have no function from the time of the accident, and would never regain function unless a repair were carried out.

As the injured axon regenerates down its empty sheath, it eventually reaches either a muscle and a motor end-plate, or an area such as the skin, where the sensory nerve endings will perceive sensation. Because regenerating motor axons do not know which empty sheaths will proceed to muscle, approximately 50% of them will grow down pathways intended for sensory nerves. This can be a limiting factor in recovery of motor and sensory functions.

**Muscles**

Muscles of the trunk and limbs are primarily striated (Peacock, 1984b). A unique property of facial and laryngeal musculature is that it is of branchomeric origin, unlike other striated muscles which are somatic in origin. Branchomeric muscles can potentially be
reinnervated for many years after neural damage; this is unlike somatic musculature which regains function poorly even if reinnervation is established immediately following injury. Nerve repair, nerve grafts, and neuromuscular implants have all produced significant restoration of facial and laryngeal function following paralysis.

Direct muscle injury usually produces some form of ischaemia which, if severe enough, will result in fibrosis. Muscle shortening is the usual end result of fibrosis. Therefore, injury to muscle about the jaw can produce significant limited mouth opening.

One of the most important steps in either primary or secondary muscle repair is to excise carefully all of the old scar tissue or damaged muscle. The biological key to the healing of muscle is the knowledge that muscle cells do regenerate. Muscle does not grow by mitosis and development of new cells, but old myofibrils have the capability of regenerating if they are not strangled by extensive fibrous tissue. Moreover, healing between muscle ends by fibrous protein synthesis is not as desirable as the regeneration of myofibrils. Careful excision of old scar in secondary repair and precise debridement of damaged muscle, so that fibrous tissue replacement will not occur, offer the best chance of maximal muscle regeneration and minimal fibrous protein synthesis following an acute injury.

An interesting feature of skeletal or striated muscle is that of the atrophy associated with denervation. Branchomeric musculature, on the other hand, undergoes very slow degeneration and atrophy. In fact, facial muscles have been found to exist even 20 years after denervation. Conversely, somatic muscle would atrophy and become fibrotic within months after denervation. An example of skeletal muscle atrophy is often seen after transplantation of musculocutaneous flaps for reconstruction of head and neck cancer defects.

**Fascia**

Fascia is significant in an injury primarily when the undamaged fascia fails to provide sufficient tensile strength and structural support. Although fascia heals well, by means of protein synthesis and collagen remodelling, it is able to regenerate to only a limited degree. Structural stability usually has to be achieved through transplantation of fascia from other sources.

Fascia is frequently used to close soft tissue defects requiring support and/or closure. Dural defects, following removal of temporal bone and ethmoid sinus cancers, are often repaired with grafts of fascia. The otologist uses fascia to repair tympanic membrane perforations. Strips of fascia are also used to suspend the lower lip in order to correct drooling following major resections of the jaw and oral cavity tissues.

**Tendon**

A tendon consists basically of collagen and a few fibroblasts or tenocytes. The tendon’s function is to transmit the force generated by the muscle to the skeleton. Therefore, the objective of repairing a tendon is to restore maximum strength without restricting motion.

It is necessary to regard tendon repair as ‘one wound - one scar’ (Peacock, 1984c). The cavity containing a disrupted tendon also contains injured fat, blood vessels, dermis, and
perhaps bone or cartilage. These layers are ultimately connected by a single medium as healing proceeds. Basically, there is a single wound and a single scar.

**Cartilage**

Cartilage is an elastic skeletal tissue, which, when injured, is replaced not by cartilage but by undifferentiated fibrous tissue (Fry, 1977). An example of this phenomenon is the 'cauliflower' ear so frequently found in wrestlers who do not bother wear ear protectors and thus suffer ear trauma. Although the three traditional classifications of cartilage are elastic cartilage (pinna, alar cartilage of the nose), hyaline - or chondroid - cartilage (thyroid ala, cricoid cartilage), and fibrocartilage (found in intervertebral disc, and in the intra-articular discs of the knee joint and temporomandibular joint), it is important to view each specific cartilage as a specific structure adapted to a specific function.

In elastic cartilage, the perichondrium - the fibrous capsule surrounding the cartilage - is closely bound to the cartilage itself and not easily separated from it. In hyaline cartilage, there is a more distinct division between the perichondrium and the cartilage, and the latter can be separated more easily.

Any segment of cartilage contains a complex balanced system of forces (Fry, 1966). For example, if one surface is interrupted, the more intact surface - released from the opposing tensile surface - will shorten. Because a material is weaker in tension than in compression, the convex side of any curve will be damaged more than the concave side. When cartilage is thus deformed, as in an untreated nasal injury, the collagen will remodel over a period of 6-12 months, and the new shape will be considered neutral, that is with the forces of tension and compression in balance. By making incisions on one side of fibroelastic cartilage, such as the nasal septum, the shape will change according to where the incisions are placed. A deviated septum can sometimes be straightened without removal of any cartilaginous tissue.

**Fat**

Fat provides for insulation, protection, energy storage, and bulk. In the face and neck region, fat is mainly located over the cheeks and under the chin.

Fat is made up of rather large cells containing various lipids in combination with proteins and cholesterol. Fat injury usually produces inflammation with subsequent fibrosis and shrinkage. Liposuction is a technique to remove fat which is frequently used in facial plastic surgery. Essentially, the fat cells are broken and removed by passing a metal sucking rod through the adipose tissues. The damaged fat cells produce inflammation with subsequent scarring and atrophy (Watson, 1959).

**Factors that affect wound healing**

**Extrinsic**

In treating a wound, it is important to consider all the effects and possible side-effects of any drugs administered to the patient (Boucek, 1984). For example, anti-inflammatory
drugs that cause vasoconstriction can interfere with blood flow to the wound. Cytotoxic drugs, which are used to treat cancer patients, interfere with cell proliferation, an important element of wound healing.

Several vitamins may affect wound healing. For example, adequate levels of vitamin C are important, as there is a constant turnover of ascorbic acid in scar tissue. Vitamin A can reverse the inhibition of wound healing, sometimes caused by diabetes, the use of glucocorticoids or high doses of vitamin E. Vitamin E can retard collagen production; this very fact might account for the improvement in scar appearance when vitamin E is topically applied to recently closed incisions. Sufficient levels of vitamin K are necessary for proper blood coagulation. As vitamin K is normally synthesized by intestinal bacteria, certain conditions of the gastrointestinal tract (sprue, antibiotics) may prevent adequate production of vitamin K.

Zinc and copper have been found to influence wound healing through their participation in the synthesis of certain enzymes necessary for epithelial and/or fibroblast proliferation. The two minerals are actually antagonistic to each other. High levels of zinc make copper unavailable for enzyme synthesis. If tissue zinc levels are low - for example in fad diets, poor nutrition, alcoholism, or following irradiation, during chemotherapy, or in cancer - administration of zinc can assist in restoring normal healing. Conversely, excess zinc can be detrimental by inhibiting macrophage migration and phagocytosis and also by interfering with enzyme synthesis of collagen. Zinc administration to patients with normal zinc levels has no accelerating effect on wound healing.

Adequate nutrition is important during healing. Particular attention should be paid to the protein intake (> 1 g protein/kg body weight per day). Inadequate protein can increase susceptibility to infection. A high protein diet will increase the rate of tensile strength gain during the fibroblastic period.

**Mechanical**

Skin tension is an important fact in the way in which a wound heals. In general, it is preferable to place any incision along the lines of relaxed skin tension, as a scar that forms across a tension line is more likely to stretch or bunch up into a hypertrophic scar. Relaxed skin tension lines, sometimes referred to as Langer's lines, are found to lie parallel to facial and neck wrinkles.

**Genetic**

Black and oriental people are more susceptible than white people to the formation of hypertrophic scars and keloids. Heredity does seem to play a role in identifying patients that may be susceptible to bad scarring. Young individuals are much more severely affected by scarring than are adults. The face is particularly vulnerable to hypertrophic scars.

**Physical**

Thickness, tension and extensibility of the skin all change with age (Gibson, Stark and Evans, 1969). The epidermis and dermis thicken during childhood and adolescence, remain
constant throughout adulthood, and then grow thinner during old age. Tension and elasticity decrease noticeably from around the age of 40 onwards.

Skin wounds can be caused by both long-wave or thermal radiation (sun exposure, sun drying or mechanical irritation) and by short-wave or X-radiation. Injuries produced by short-wave radiation are much more likely to result in carcinoma than are those produced by long-wave radiation. In addition, the lapse of time between injury and development of invasive cancer appears to be directly proportional to wavelength of the radiation.

**Blood supply**

Good wound healing depends on the oxygen and nutrients supplied by the microcirculation (Irvin, 1981). Therefore, anaemia, haemorrhage, arteriosclerosis and shock can all inhibit healing. In cases of severe trauma, microvascular constriction or sludging can also limit the supply of oxygen and nutrients.

Irradiation, which is frequently used to treat head and neck cancer, causes irreparable damage to the skin's microvasculature (Archer et al, 1970). As a consequence of reduced blood supply, resulting from irradiation, wounds heal poorly and are much more susceptible to infection than are non-irradiated tissue beds. A reduction in blood supply to the skin may have some influence on the bacterial population, in that there is a notable shift to Gram-negative organisms, responsible for wound infections, following irradiation. It has been conclusively demonstrated that prophylactic antibiotics are indicated when major head and neck cancer operations which enter the upper aerodigestive tract are being carried out (Panje and McCabe, 1979). If the patient has previously undergone irradiation, an antibiotic that kills Gram-negative organisms - such as gentamicin - should be included to provide adequate prophylaxis against subsequent wound infection.

Blood supply plays a very important role in wound healing on the face and neck. Wounds about the face and neck tend to heal more readily than wounds below the clavicle. In fact, the surgeon is encouraged to remove sutures on day 5 rather than day 10 when dealing with face and neck skin wound closures. Leaving sutures in the face and neck for longer than 5 days usually predisposes the area to inflammation and subsequent scarring.

**Lacerations**

Initial decisions regarding the treatment of a skin wound depend on the ability to discern whether the wound is contaminated or infected. A contaminated wound (bacteria, foreign body, animal bite) can usually be made surgically clean by debridement so that it can be closed primarily. An infected wound (abscess, human bite) cannot be made clean quickly, and therefore cannot be closed mechanically. Particularly in the case of the head and neck - principally because of their profuse blood supply - there is no hard and fast rule as to how long after injury a wound can be safely closed mechanically. Wounds have been closed as long as one day following injury without undue risk of infection. The most common contraindication to wound closure is the presence of inflammation, puncture wounds, or of high risk wounds such as human bites.
Principles of head and neck plastic operations and repair

Principles of head and neck plastic operations and repair are based upon basic understanding of wound healing as it applies to tissues above the clavicles. The uniqueness of the head and neck in respect of their function and appearance are all integral to proper repair of tissue dysfunction. Tissue blood supply, the defect and its location are of paramount importance when considering the technical aspects of head and neck plastic operations. Just as important as the technical factors to a satisfactory plastic operation is the necessary understanding of the patient's psychological and sociological needs. Of paramount important is that the patient should be justifiably satisfied, followed closely by the surgeon's own sense of satisfaction. The surgeon's 'golden' rule must be the answer to the question "Would I do (recommend) this operation to members of my family?"

In order to perform head and neck plastic and repair operations, the surgeon must understand basic clinical tenets that individually are intriguing, but together consummate the necessary 'art' work for the repair of head and neck defects. The following are succinct descriptions of the basic clinical tenets necessary for performing plastic and reconstructive surgical repair of the head and neck.

Primary intention closure

Suturing a wound closed with some form of material is the basic method for a surgeon mechanically to produce primary intention wound healing. The way in which the wound is closed greatly affects its final appearance and function. The tissues must be handled gently to reduce the possibility of further injury and ischaemia. Reduced tissue blood supply or ischaemia contributes to infection and excessive scar formation. Fine non-absorbable monofilament suture (for example, 6-0 or 7-0 nylon) is best for closing facial lacerations and incisions. Absorbable sutures (catgut, polyglycolic acid) are best used for closing mucosal wounds and where the suture is buried into the tissues beneath the mucosa or skin.

The avoidance of haematoma and dead space formation is tantamount to satisfactory wound healing. A haematoma provides a medium for bacterial growth and consequential wound infection or abscess formation. Infected wounds will usually heal poorly, with attendant excessive scar formation. Wound drainage with rubber drains is helpful in avoiding haematoma formation. Wound haemostasis is important before closure. Dead space is an opening or cavity which contains air located within the tissue. Dead space is usually produced from tissue loss and/or poor wound closure. Although drains placed in the wound help to eradicate dead space and/or haematoma, by producing a negative pressure, reliance should not be placed on them alone for dealing with this problem. Proper wound closure - that may include transplantation of tissue into the wound to fill the dead space, or placement of absorbable sutures in the wound to approximate the deep tissues - will greatly reduce the problems of dead space or haematoma formation.

Face, scalp and neck wounds heal more rapidly than skin wounds located below the clavicle. Again, this phenomenon is related to the excellent blood supply afforded the face and neck. Sutures used to close wounds above the clavicles should be removed by the fifth or sixth day to avoid infection and scarring. Sutures left in for 10 or more days will cause
excessive scarring where the sutures pierces the skin. The ‘zipper’ scar is characteristic of this healing problem.

Tension across a closed wound can produce infection and hypertrophic scars. To reduce tension, the surgeon will frequently employ pieces of tape applied across the wound after sutures have been removed. The tape, often referred to as ‘steri-strips’, will distribute the tension over a larger surface area and also reduce motion at the wound site. Steri-strips are usually left on for an additional 2-3 weeks following suture removal to facilitate the establishment of wound closure strength and to reduce scarring.

**Sutures**

Sutures can be classified as absorbable and non-absorbable, and as monofilament and multifilament (*Table 24.1*). Generally, absorbable sutures (catgut, cotton) lose strength much more rapidly (10-20 days) than non-absorbable sutures (nylon, silk). Absorbable sutures are usually used beneath the skin and in the mouth and throat; non-absorbable sutures are commonly used on the skin surface. Sometimes, non-absorbable sutures are placed below the skin to give added strength to a wound closure over a longer period of time. However, the use of non-absorbable suture-like silk within the wound’s environment can potentially give rise to serious wound infection. More recently, fabricated absorbable sutures (polyglycolic acid (Vicryl), polyglactin 910 (Dexon) and polydioxanone (PDS)) have been introduced. These sutures have unique properties, when compared with the more common absorbable sutures, in that they are much stronger, are less inflammatory, and yet are resorbed. Multifilament (silk) sutures are usually easier to handle than monofilament (nylon) sutures. Although multifilament sutures are more pliable and easier to tie, they do have the serious drawback of being more prone to producing wound infection, even if used only on the skin's surface; ‘wicking’ of skin surface bacteria along the multiple little strands into the wound is felt to be the cause. This is the reason why a patient is often admonished not to allow a wound to be exposed to water until the sutures have been removed. The basic principle in choosing a suture is to choose one of a material of sufficient strength to last until the wound has healed. For example, a wound that is expected to take a long time to heal will require a suture which maintains its strength for an equally long time (maybe weeks) and which causes minimum inflammation.

**Handling of tissue**

Fundamental to satisfactory wound repair is that healing should be rapid with minimal scar formation. Atraumatic tissue handling is important to good wound healing, as tissue damage will produce necrosis, infection and subsequent scarring. Handling tissues with fine instruments, such as small hooks or grasping forceps, produces the least amount of tissue injury. Excessive clamping and retraction of tissue usually produces non-favourable wound healing. Lesser tissue injury is produced with thin sutures and needles. The length of an incision has no bearing on how the wound will heal.

**Z-plasty**

The Z-plasty (McGregor, 1980), a widely used technique in plastic and reconstructive surgery, is a form of double transposition flap, the purpose of which it to gain length in one
direction at the expense of width in the other. The basic X-plasty consists of two triangular flaps of skin and subcutaneous tissue formed by three connecting incisions of equal length and at a 30-60° angle to one another. Essentially, the two flaps are moved until they have exchanged places. Greater elongation is achieved by the use of wider flaps with concomitant larger angles to the vertical axis. The Z-plasty retards contracture, as the stress that is transmitted to surrounding tissues in a straight scar is cancelled out by the two opposing triangular flaps. The Z-plasty can increase the length of skin (direction of final central member) and change the direction of a scar so that it will lie in the same direction as relaxed skin tension lines.

Table 24.1 Absorbable and non-absorbable sutures

<table>
<thead>
<tr>
<th>Type</th>
<th>Strength</th>
<th>Half-life</th>
<th>Reactivity</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorbable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>gut</td>
<td>± 3.3</td>
<td>5-20 days</td>
<td>++++ 3-4</td>
<td>Low knot security until moist; non-uniform, can fray</td>
</tr>
<tr>
<td>collagen</td>
<td>± 3.3</td>
<td>5-20 days</td>
<td>++++ 3-4</td>
<td>Low knot security until moist</td>
</tr>
<tr>
<td>Dexon</td>
<td>6</td>
<td>10 days</td>
<td>++ 3-4</td>
<td>Half-life pH dependent</td>
</tr>
<tr>
<td>Vicryl</td>
<td>6</td>
<td>10 days</td>
<td>++ 4-5</td>
<td>Half-life pH dependent</td>
</tr>
<tr>
<td>Polydiaxone (PDS)</td>
<td>± 4</td>
<td>4.5 weeks</td>
<td>+ 4-5</td>
<td>New, promising monofilament</td>
</tr>
<tr>
<td>Non-absorbable</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>silk</td>
<td>3</td>
<td>0.5-1 year</td>
<td>+++ 3-4</td>
<td>Inconsistent strength</td>
</tr>
<tr>
<td>cotton</td>
<td>≤ 3</td>
<td>&gt; 1 year</td>
<td>+++ 2-3</td>
<td>Drags, cuts tissue</td>
</tr>
<tr>
<td>Dacron</td>
<td>4</td>
<td>*</td>
<td>+++ 2-3</td>
<td>Rough surface causes capillary action</td>
</tr>
<tr>
<td>coated Dacron</td>
<td>4</td>
<td>*</td>
<td>+++ 4-5</td>
<td>Coatings may fragment</td>
</tr>
<tr>
<td>nylon monofilament</td>
<td>3.6</td>
<td>0.5-1 year</td>
<td>+ 5</td>
<td>Can fracture</td>
</tr>
<tr>
<td>nylon braided</td>
<td>4</td>
<td>≤ 1 year</td>
<td>++ 3-4</td>
<td>Dead spaces</td>
</tr>
<tr>
<td>polypropylene</td>
<td>3.5</td>
<td>*</td>
<td>+ 5+</td>
<td>Can fracture</td>
</tr>
<tr>
<td>stainless steel</td>
<td>9.5</td>
<td>*</td>
<td>+ 2-3</td>
<td>Poor handling</td>
</tr>
</tbody>
</table>

In any Z-plasty, the limbs should be along either the lines of minimal tension - that is, the relaxed skin tension lines - or the pre-existing skin wrinkle lines. If necessary, the angles formed between the wrinkle line and the triangular flaps may be a good deal less than 60°. Depending on the specific conditions - for example the skin on one side may be looser and require less elongation - the triangular angles of each flap may be of unequal size (for example a 30° and a 60° flap). The Z-plasty has been used for releasing cervical contracture scar following neck surgery, and for facial scars, burns and skin grafted sites.
W-plasty

The W-plasty is a technique using multiple triangular incisions along either side of an unsightly scar. The W-plasty resembles the blade of a hand-saw. Although the triangles opposite each other are of equal size, those towards the ends of the scar becomes smaller, and the length of the limbs tapers to avoid puckering at the ends of the incision.

Both the Z-plasty and W-plasty break up the linear scar into smaller compartments, and move the scar into a better relation to the lines of relaxed skin incision. The visual appearance of a scar is an important factor in the way in which it is perceived; an irregular line is less perceptible than a straight line.

Rotation flaps

The rotation flap is among the flaps most commonly used to close skin tissue defects in head and neck plastic and reconstructive surgery. This flap usually has the appearance of a semicircle. It is cut adjacent to the defective area and then rotated around a pivot point until it covers the defect. Because a diagonal line of tension is created from the base of the flap to its leading point, the larger the flap, the more the tension is diffused across the flap. As the flap rotates, it becomes shorter. Therefore, extra tissue must be taken to achieve the desired coverage. Of prime importance in achieving sufficient rotation of a flap is its 'back cut'. An incision place at less than 90° to the arc of the flap's rotation provides the main impetus to flap rotation.

Advancement flaps

An advancement flap is stretched or slid along a single axis or plane to cover an adjacent defective area. Advancement flaps can be used progressively; at each stage, as the skin loses its tension, the flap can be further stretched, or advanced.

Advanced flaps are most successful with infants, whose skin is highly elastic and well vascularized. In essence, stretch or tension does not usually interfere with the flap's blood supply. By contrast, it should be remembered that in the case of the advancement flap, tension usually does retard flap blood supply.

Rotation advancement flaps

Typical examples of rotation advancement flaps would include the Millard repair of cleft lip deformities and that used by the author to repair scalp defects. The flap conforms to a semicircular appearance but, to cover a tissue defect, it must be advanced over the tissue deficiency in order to complete the closure.

Transposition and interpolation flaps

A transposition flap is a rectangular section of skin and subcutaneous tissue that is turned on its pivot point to an adjacent defect. An interpolation flap is like a transposition flap except the recipient site is nearby, thus the flap must pass over or under intervening tissue. Transposition and interpolation flaps usually have a narrower base than rotation or
advancement flaps. As a general clinical rule, the length of a transposition flap should be no more than three times its width. Clinical examples of a transposition flap would include the cervical apical flap or the deltopectoral flap to close an adjacent neck defect. The midline forehead flap frequently used in nasal reconstruction, the deltopectoral flap used in head and neck ablative cancer reconstructive surgery, and the lip switch flap used to repair lip defects are all examples of interpolation flaps.

**Secondary intention closure**

Secondary intention closure, or delayed healing, is often used after breakdown of a primary wound closure, wound infections, cleft palate defects, cryotherapy, cauterization, and CO₂ laser therapy when there is a possibility of finding cancer. Frequently, large wounds are allowed to develop abundant 'proud' flesh to fill in depressions before closure - for example, donor defect forehead flap, following the excision of skin cancers (Panje, Bumsted and Ceilley, 1980). In many cases, the combined use of delayed healing to reduce the wound's size, and subsequent simple reconstructive methods can be used to achieve an acceptable cosmetic result (Goldwyn and Rueckert, 1977). The successful head and neck plastic and reconstructive surgeon always strives to use the more basic and simple rules of tissue closure.

Wound contraction, wherein the margin of the wound closes in on itself, becomes active during delayed healing at 4-5 days after injury. Approximately 24 days after injury, contraction slows markedly. The application of skin grafts or flaps, especially full thickness grafts, as soon as possible after injury is an effective means of reducing contraction.

Up to 80% of a wound's closure can be achieved by contraction of adjacent tissue into the defect (Higton and James, 1964). The presence of lax skin around the soft tissue defect appears to allow dramatic wound closures without producing significant facial distortions. If tissue adjacent to a wound is firmly attached to underlying bone, as on the scalp, there appears to be minimal contraction of the surrounding skin. Instead, granulation tissue builds up until epithelialization or skin coverage occurs (James and Newcombe, 1961). Excessive granulation may develop in the area of tight skin to such a degree that the depressed wound will be significantly filled in. It must be remembered that the more the granulation tissue accumulates, the more connective tissue will make up the closure.

If the wound extends from a densely adherent cutaneous area to a loose area, the most significant part of contraction will occur from the latter. With wounds around the eyes, lips and nose, the surgeon should strive to replace lost tissue in order to prevent distortion of these structures. If the greater part of the wound remains over bone, minimal facial distortion will occur.

Wound contraction is influenced by motion of structures adjacent to the wound area. In general, greater contraction takes place in areas of greater motion. Surface tension lines and geometry of the wound will also influence contraction. Therefore, shaping and location of the wound can be useful in avoiding distortions.

Delayed healing must be used judiciously, as it can cause the development of much more scar tissue than is the case with primary intention healing. A thicker scar will produce more tension, which may distort the facial features. Indiscriminate use of delayed healing can
cause ectropion, stenotic nares, lip retraction, microstomia, velopharyngeal incompetence, stridor, aspiration, drooling and other problems.

Transplantation and replantation

The term 'transplantation' refers to the transfer of tissue or an organ from one part of the body to another, or from one body to another. A graft is basically similar to a transplant. Replantation refers to the surgical replacement of tissue to its original site. An autograft is a piece of tissue that is transferred from one area to another on the same person. An allograft (homograft) refers to a graft transplanted between individuals belonging to the same species. An isograft usually refers to an allograft between extremely inbred, or genetically pure, strains of animals. Syngenesiotransplantation is the transplantation of tissue between individuals who are closely related genetically. A xenograft (heterograft) is the graft of tissue between individuals of different species. Alloplasts are biologically inert foreign materials used for implantation into tissue for augmentation or reconstruction.

Skin grafts

A skin graft consists of both the epidermis and dermis. If the entire thickness of dermis is used, the tissue is called a full thickness skin graft; if only a portion of the dermis is included with the epidermis, it is called a split thickness skin graft. A split thickness skin graft would vary in thickness between 0.0025 and 0.0046 cm. Obtaining a 0.0051 cm thickness skin graft from the postauricular area would include all of the dermis and epidermis, thereby exposing subcutaneous fat. A flap would include skin, subcutaneous fat, fascia and, in some cases, muscle. In general, the successful transplantation or replantation of tissue without a blood supply in situ is limited. Thus a split thickness skin graft is more likely to be viable after transplantation than a full thickness graft. Similarly, a full thickness graft will be significantly more successful than a flap transferred without any blood supply. A successful skin graft depends on initial diffusion of oxygen into the graft, then rapid revascularization and disposal of metabolic waste products (Smahel and Ganzoni, 1970; Smahel, 1971). Researchers are not certain whether revascularization occurs through a connection between existing capillaries in the graft and vessels in the recipient area, or whether an entirely new vascular network develops.

Full thickness grafts

Because full thickness grafts revascularize more slowly than split thickness grafts, the former require optimal wound care. The grafted site must be immobilized and kept free of haematoma formation. The advantages of the full thickness graft are that it is less likely to contract or pigment, and it often produces a superior skin coverage.

Common donor sites for full thickness grafts are the retroauricular area, the supraclavicular area, the upper eyelid and the inside of the upper arm. Although the abdomen and thigh are also good donor sites, the colour match is usually not as good. In addition, the skin of the abdomen and thigh is so thick that split thickness grafts from these areas are usually preferred.
Split thickness grafts

Split thickness grafts are used when the recipient area is either too large or of too poor vascularity to take a full thickness skin graft. The abdomen, hip and thigh are usually considered the best donor sites for split thickness grafts, as they can be covered by clothing to conceal the scarring and they constitute relatively large flat areas for easier procurement of the graft. When a good colour match is desired, the face, neck or upper back is a better donor site. Usually any skin graft site is particularly painful to the patient unless covered by some type of plastic membrane-like material. Because hair follicles and sebaceous glands remain after removal of a split thickness skin graft, the donor site will recover itself with new skin from these sites. In fact, another split thickness skin graft can be taken from these sites once healing has taken place.

Mesh skin grafts

A mesh skin graft is a thin split thickness graft in which multiple slits have been made by means of multiple rotating blades. The graft, which can be stretched in two directions, can be used to cover an area many times its original size. Mesh skin grafts are used to cover extensive burns and other traumatic wounds to facilitate drainage and provide more coverage of an area with a certain amount of skin. If the skin graft is not meshed, it can be incised with a knife in a number of different areas to provide for some expansion and, most importantly, for drainage.

Flaps

A flap is a composite of various tissues transplanted from one location to another to replace or cover similar tissue losses. The flap must have a vascular supply for survival.

Two systems of flap classification have been developed on the basis of the anatomical vascularity of the flap. One system (McGregor and Morgan, 1973) divides flaps into the random pattern flap, which lacks a recognized arteriovenous system, and the axial pattern flap, which exhibits at least one axial arteriovenous system. In the latter case, easily identifiable blood vessels entering the flap would be evident.

Another system (Daniel and Williams, 1973) classifies flaps as cutaneous, arterial and island. Most cutaneous flaps, like the random pattern flap, lack a specific vascular system. Arterial flaps have a skin bridge and at least one direct cutaneous artery and vein located along the longitudinal axis of the flap. Island flaps have a pedicle containing the nutrient artery and vein, but do not contain any skin. Arterial and island flaps, because of their superior blood supply, are much more hardy flaps than cutaneous (random pattern) flaps. In order to improve a cutaneous flap's blood supply, the surgeon will sometimes employ a surgical method, called flap delay, to augment its vascularity. This is done by removing some of the flap's blood supply, waiting 2 weeks and then transplanting the flap into its new position. Delay makes a flap more reliable and enables a larger flap to be used.
Skin flaps

A skin or cutaneous flap consists of skin, subcutaneous tissue and small blood vessels. A skin flap can be used as a local, regional or distant flap. The skin flap can be either a random pattern or an arterialized flap, again depending upon its vascular supply.

A local flap usually means the transposing of skin subcutaneously from an adjacent area into the defect site. Commonly used local flaps on the face include the transposition, interpolation or rotation advancement flap.

A regional flap is considered a tissue transplanted from a site away from the defect to be reconstructed, but yet in close enough proximity to allow closure of the area. Examples of a regional flap include the deltopectoral (Bakamjian), forehead (McGregor), midline forehead, scalp, nape of neck (Zovickian), retroauricular, cervical and so on.

A local or regional flap is usually elevated from its place of origin on to a skin bridge or bridges. Where the flap remains attached to the body is called the pedicle. A flap may be either unipedicle, bipedicle or multipedicle. A unipedicle flap is when the flap remains attached to the body at one site. A bipedicle flap is attached at two different loci and resembles a bucket handle. The more pedicles a flap has, the greater the potential blood supply and, concomitantly, the greater the likelihood of its surviving. On the other hand, the more pedicles a flap has, the less its manoeuvrability when it is being moved to its new location. Making the pedicle wider or increasing the number of pedicles at one end of a flap does not necessarily increase its length of survival (Milton, 1970). Length of survival usually relates to the long axis of the flap drawn perpendicular to its base or pedicle. To increase the likelihood of flap survival or to increase the flap's length of survival, pedicles must be added to the middle or other end of the flap. Similarly, the inclusion of an identifiable artery in the flap will greatly increase its viability and length of survival.

There have been no statistically significant medical ways of improving the changes of length of flap survival. Vasoactive drugs, regardless of how much they vasodilate, cannot improve the tissue's chances of living as the main determinant of its viability is the surgical construction of the flap. Once the flap has been constructed, technical factors influence flap survival more than any others. The presence of either flap tension, stretching, kinking, twisting, compression or constriction can severely compromise a flap's chance of survival. In head and neck flap cases, proper patient positioning can alleviate tension, stretching, kinking, or twisting of the flap. Tracheostomy tapes used to secure a tracheostomy tube in place can compress or constrict the flap's pedicle and simultaneously reduce blood supply to the distal end of the flap. Diseases, such as diabetes, arteriosclerosis, polycythaemia vera, hyperlipidaemia, vasculitides, multiple myeloma and leukaemia, can all increase the chance of flap death or necrosis. The vasculitides decrease the amount of microcirculation to the skin by decreasing the number and diameter of the blood vessels. Conditions that increase blood viscosity reduce the amount of blood flow to the skin. Elementary thinking would indicate that the occurrence of such flap problems would be inevitable as the basic laws of fluid mechanics are adversely affected by the foregoing conditions (Panje, 1984).
Poiseuille developed a mathematical equation to explain the flow \( F \) of the fluid through a rigid cylinder. His equation constitutes a useful approximation of blood flow in a skin flap's vascular system

\[
F = \frac{\pi r^4 (P_1 - P_2)}{8 \eta l}
\]

where \( \pi = 3.14159 \), \( r \) = the radius of the cylinder, \( \eta \) = the fluid viscosity, \( l \) = the cylinder length, and \( P_1 - P_2 \) = the hydrostatic pressure difference between the two ends of the cylinder. From this equation it is apparent that haemodynamic resistance \( R \) is given by

\[
R = \frac{8 \eta l}{\pi r^4}
\]

By substituting \( R \) into the original equation, the formulate then states that

\[
F = \frac{P}{R}
\]

Poiseuille's equation states that blood flow can be essentially affected by the size of the blood vessel(s), the pressure difference between the entrance and exit sites, the length of the blood vessel, and the viscosity of the blood. Although the Poiseuille equation was not derived from the study of human tissue blood flow, it does provide a convenient, albeit severely simplified, means of understanding flap physiology.

**Myocutaneous (musculocutaneous) flaps**

The greater part of the human integument is supplied by small blood vessels called musculocutaneous perforators. These vessels arise from segmental arteries deep to the musculature, traverse the muscle bed, and turn into a candelabra pattern of very small blood vessels that pierce the subcutaneous fat and dermis to communicate with the derma-subdermal plexus of the skin. The myocutaneous flap consists of a patch of skin and muscle with an identifiable vascular pedicle. Some of the most commonly used myocutaneous flaps for head and neck reconstructive surgery are the pectoralis major, trapezius, latissimus dorsi and sternocleidomastoid myocutaneous flaps.

The myocutaneous flap has revolutionized head and neck reconstructive surgery. It has allowed the head and neck surgeon immediately to repair major head and neck tissue losses, with a greater than 90% chance of success (Panje, 1987). The technique is highly reproducible. The myocutaneous flap is today used more than any other type of flap in head and neck cancer reconstructive surgery. This flap is so hardy that the surgeon can confidently repair contaminated and previously irradiated mouth and throat wounds. Irradiation, although quite effective in eradicating a number of head and neck cancers, does produce severe microvascular damage and scarring. Infection as well as bone and cartilage necrosis are potential complications of operating on a previously irradiated head and neck tumour patient. The myocutaneous flap, by reason of its abundant blood supply, seems to reduce the incidence of wound infection and impede the development or continuation of osteoradionecrosis / chondroradionecrosis.

Before the advent of the myocutaneous and free flaps, previously irradiated head and neck wounds were often treated as though it were inevitable that they would all become
infected and break open. Therefore, controlled openings (fistulae) were made between the mouth or throat and the neck skin to reduce the chance of saliva and bacteria penetrating beneath the closed neck and upper aerodigestive tract. Such controlled salivary fistulae markedly reduced complications and the risk of infection, but resulted in prolonged hospitalization and the need for subsequent operations.

The primary problems with myocutaneous flaps are donor site morbidity, including deformed appearance and functional muscle loss, and bulkiness of the flap. Use of the pectoralis major myocutaneous flap probably involves the most significant potential for donor site scarring and deformity, depending on the amount of tissue removed. The trapezius myocutaneous flap can produce the most disabling deformity by paralysing the trapezius muscle and thus severely weakening the should (Panje and Cutting, 1980). For this reason, most head and neck surgeons will not use the trapezius muscle flap unless the accessory nerve (XI) has previously been sacrificed (that is, through radical neck dissection).

The latissimus dorsi myocutaneous flap is taken from the back, and is either passed up through the axilla and neck or is transplanted as a free flap with microvascular anastomosis. This flap has been used primarily for the reconstruction of massive face, mouth and throat defects. It suffers from the disadvantage of being the myocutaneous flap with the greatest potential for complications (Maves, Panje and Shagets, 1984).

At the present time, the most frequently used myocutaneous flap for head and neck reconstructive surgery is the pectoralis major (Ariyan, 1979; Back et al, 1979; Biller et al, 1981). Because this flap is taken from the chest, it can be used without any repositioning of the patient. The pectoralis major myocutaneous flap has been used to repair a host of defects that include: the temporal bone, scalp, mid-face, palate, oropharynx, oral cavity, jaw, through and through defects, pharynx, cervical oesophagus, and neck.

**Free flaps**

Beginning in the early 1960s, surgeons have transplanted tissue by microvascular anastomosis to reconstruct head and neck defects (Nakayama et al, 1964). Free flaps are arterialized islands of tissue that have been severed from their original location and transplanted to a different place on the body. The small blood vessels in the flap are connected to similar size blood vessels at the recipient site. Blood vessels usually range in size from 1 to 3 mm in diameter. These microscopic blood vessels are connected either by very fine sutures (the size of a strand of hair) or by small metal rings. Free flaps of skin, scalp, toes, bone, stomach and intestine have been utilized to replace head and neck tissues lost as a result of cancer surgery, trauma and congenital deformities. Major advantages of the free flap technique over other flap procedures include: one stage operation, reduced stays in hospital, and minimal donor site deformity.

Free flaps have been taken from more or less any place on or inside the body where there is tissue connected to an artery and a vein with a diameter greater than 1 mm (Serafin and Buncke, 1985). The free flap can consist merely of skin and subcutaneous fat based on a vascular supply. The more commonly used examples include the groin skin flap based on the superficial iliac artery and its vein, the forearm skin flap based on the radial artery and cephalic vein, and the top of the foot skin based on the dorsalis pedis artery and
accompanying veins. A free flap can be a myocutaneous flap severed from its blood supply and transplanted to a new area of the body. Some of the most commonly used free myocutaneous flaps include the latissimus dorsi based on the long thoracic artery and accompanying veins, and the rectus abdominis based on the inferior epigastric artery and vein.

Free flaps can be made up of a muscle and its vascular supply. Muscles such as the latissimus dorsi, the gracilis and extensor hallucis longus, and the pectoralis minor have all, at some time, been transplanted to the face for restoration of facial animation. The latissimus muscle has also been utilized as a free flap to rebuild the tongue.

Bone has been used as a free flap primarily to reconstruct the jaw after ablative cancer surgery (Ostrup and Fredrickson, 1975). Bone used for the transplantation is usually based either on a blood vessel that is the nutrient artery or its collateral supply, or on a blood vessel that is connected to an accessory nutrient artery (Panje, 1981). Basing the endochondral bone on its periosteum alone has not proved to be reliable for long-term (years) jaw reconstruction. Examples of bone free flaps include the iliac crest based on either the superficial or the deep circumflex iliac artery - with the latter being preferred - the fibula, the scapula, the radius, or even the second phalanx of the foot.

**Viscus**

Stomach, intestine and colon have all been used as free flaps to replace upper aerodigestive tract defects, usually following cancer or trauma (lye ingestion). The advantage of using these tissues for the repair of mucosal defects in the head and neck is that like tissue is being replaced by like tissue. In other words, mucosa is replacing mucosa. Frequently, head and neck defects are repaired by some form of skin graft. Skin is capable of repairing the mucosal defect but it does not restore graft moisture in the way that viscous replacements do. Another disadvantage of skin replacement of the upper aerodigestive tract is the possibility of hair growth within the mouth or throat, which is an undesirable situation.

**Grafts**

Grafting is defined as the implantation of skin or other tissue from a different site or source to replace damaged structures. A graft could thus also be a flap. In general, however, a graft does not immediately have a blood supply. In some cases the graft will never have a blood supply. Grafts are very useful to the head and neck reconstructive surgeon. Grafts are usually readily obtainable, with minimal morbidity to the patient, and can be rapidly employed for repair of a defect.

**Cartilage**

Cartilage has traditionally been classified into hyaline, elastic, and fibrocartilage, based principally on the kind of fibre make-up of the tissue. Hyaline cartilage, for example, includes the costochondral cartilages, the nasal septum, the alar cartilages, and those of the trachea and larger bronchi. Human cartilage is usually regarded as a unique structure whose physical and mechanical properties are adapted for a specific function. Transplanting rib cartilage to the ear does not cause the cartilage to change into the cartilage associated with that particular
location. Each type of cartilage is adapted to a specific function. Cartilage used as an autograft includes the costochondral portion of the rib, the nasal septum and the ear cartilages.

The balance of stresses in intact cartilage may be released when cartilage is excised for a graft. The portion chosen for a graft should as closely as possible resemble the desired size and shape of the defect. As it takes time for the maximum amount of deformation to occur, a piece of cartilage that is carved and immediately grafted will have warped by the time the dressings are removed. For best results, at least 30 minutes should be allowed to elapse before the cartilage graft is inserted, unless there is a specific wish to exploit the anticipated warp to achieve a particular effect.

Cartilage can be grafted with or without its perichondrium. When transplanted with the perichondrium, the mechanics of nutrition remain unchanged for the cartilage itself. When cartilage is transplanted without the perichondrium, the grafted piece must re-establish its means of nutrition. Revascularization of the perichondrium, or of the naked cartilage, is developed through the apposition of the graft and the tissues at the new site. As with any graft, the greatest risk of rejection results from haematoma formation.

Some immature cartilage grafts exhibit growth after transplantation, while other do not. The reason for the inability to grow may be insufficient nutrition, haematoma, or the incomplete apposition of surrounding tissues.

Surgeons have experimented with the use of preserved cartilage because dead cartilage does not warp, and thus will not change shape after implantation. However, one disadvantage is that, because the matrix cannot be sustained in the absence of live chondrocytes, such grafts are sometimes absorbed. Irradiation of the cartilage before implantation appears to reduce the rate of absorption. Absorption may be an immunological process.

**Tendon, collagen grafts**

The subject of tendon grafts is as controversial as that of fat grafts. Opinion is divided as to whether the tendon autograft survives completely, or whether it becomes reorganized. In order to survive, a tendon autograft must receive a blood supply from the recipient bed. This revascularization can be achieved through direct anastomosis of the bed vessels with those of the graft (primary revascularization), or through the establishment of a new vascular network by the ingrowth of capillaries (secondary revascularization). Although either primary or secondary revascularization can occur, it is believed that tendon graft survival is usually achieved by secondary revascularization (Peacock, 1959).

After a tendon graft, the healing process takes place in three phases. During the first phase - the phase of cellular reaction - the wound fills with blood clot, and granulation tissue is formed, whereupon fibroblast development and then collagen synthesis begin. During the second phase - the phase of fibrous protein synthesis - fibroblast production reaches a peak at about 14 days, and then declines, as does the level of collagen synthesis. The collagen fibres change their orientation from a transverse to longitudinal axis, strengthening the union between the tenon and graft ends. During the third phase - the phase of secondary remodelling of the scar tissue - the union gains enough strength to allow slight mobility. By 8 weeks, the adhesions between the graft and the peritendinous tissue should have loosened. However, it
takes 6-9 months for the intertendinous collagen fibres to arrange themselves in their characteristic bundles.

Age is a significant factor in the success of tendon grafts. The grafts are most successful in persons below the age of 40 years. However, they are somewhat less successful in children below the age of 6 years. Tendon grafts have been used in the head and neck to reconstruct larynges following cancer operations.

**Fascia grafts**

Facial plastic and reconstructive surgeons frequently use fascia transplant to repair facial paralysis by attaching slings or strips of fascia to an active muscle for static support. The fascia for most transplants is taken from the fascia lata of the thigh or temporalis muscle.

**Fat grafts**

The behaviour of transplanted fat cells remains in dispute. There are two basic theories, namely the host cell replacement theory and the cell survival theory. Proponents of the host cell replacement theory believe that none of the fat in a graft actually survives, but that host histiocytes take the lipid released from the dead fat cells and become new adipose cells. Proponents of the cell survival theory believe that the transplanted cells themselves survive.

Fat is most successfully grafted in conjunction with the dermis, as this allows revascularization of the fat through the dermal vessels, thereby helping to limit absorption of the grafted fat. Dermis-fat grafts are considered by some to be the best substitute for soft tissue deficiencies of the cheeks. Fat grafts have been used to augment significant facial depressions (radical parotidectomy, congenital deficiencies) (Leaf and Zarem, 1972). The main advantage of reconstituting blood supply (microvascular anastomosis) to a fat graft is its reliability in maintaining tissue thickness. Maintenance of vascular integrity apparently retards or prevents resorption and substitution.

A fat transplant should never be carried out in the presence of infection. If the transplant becomes infected, the fat will liquefy and the dermis will then be extruded as a necrotic mass with fat attached. However, if this does occur, the wound will heal and another graft can be carried out. Fat grafts have been utilized with considerable success to fill body defects such as the frontal sinus, the mastoid cavity and in the repair of cerebrospinal fluid leaks.

The fat graft should be larger than the desired end result, as it will reduce to approximately 20-30% of its former size over a period of several months.

**Bone grafts**

Bone transplants are used to induce healing in fractures, to bridge gaps caused by compound wounds or after removal of bone tumours, and to restore missing bones, such as after a mandibulectomy (Peacock, 1984d).
Bone grafts heal through a process called creeping substitution. Most of the transplanted cells do not survive, but are replaced by mesenchymal cells from the host bed. The new cells provide support as they slowly remodel the matrix to help reduce stress in the area. These cells are also believed to promote the graft and the other segments. Four to six weeks of healing are usually required before sufficient bone substitution and revascularization have occurred to allow for removal of bone stabilization. In the case of the mandible, a biphasic appliance consisting of a rigid bar attached to the jaw by bone screws provides for stabilization and fixation until bone graft healing has occurred.

The necessary ingredients for successful grafting in mandibular reconstruction include: adequate soft tissue replacement, strict immobilization of the bone graft and remaining jaw, antibiotics, avoidance of oral cavity contamination of the graft site, and revascularization of the graft area or graft if the bone deficiency being repaired is in an irradiated area.

The technique of transplanting revascularized bone has for some time been used to restore mandibular deficiencies. Ostrup and Fredrickson (1975) supplied some of the first experimental evidence to support this innovative method of restoring jaw losses. The author has found the technique reliable but trying to both the surgeon and the patient. This type of grafting may required 14-20 hours of operating time before completion.

**Iliac bone**

The ilium is one of the best sources of bone graft. Its accessibility makes removal simple and the secondary defect easy to cover. The bone consists almost entirely of cortical bone, with a good supply of cancellous bone. However, morbidity after removal, in the form of bleeding, pain, ileus, and muscle spasm, is considerable relative to the amount of bone taken. The ilium is also a good source of bone graft in children, particularly because it remains a separate bone until later in life. The hip also provides a convenient source of marrow when a freeze-dried mandible or some type of alloplastic basket is utilized to reconstruct the jaw. The marrow is packed into the jaw replacement section to provide a matrix and osteocytes for new bone formation.

**Rib bone**

Rib bone is useful for grafts because of its capacity for repeated self-regeneration. In the early part of the century, however, grafts were performed using whole ribs, which allowed vascular penetration only through the ends of the graft. This made it difficult for the grafts to survive. The introduction of the use of split rib grafts greatly improved the results of transplantation.

**Clavicle**

The clavicle has been used to repair mandibular losses. The clavicle is endochondral bone and therefore requires a periosteal and intramedullary blood supply if it is to remain completely intact upon transplantation. Maintaining the vascular supply to the clavicle necessitates the preservation of the sternocleidomastoid muscle attachments. In practice, however, this method of mandibular reconstruction would have only limited application as in
a number of cancer cases the sternocleidomastoid muscle would be removed for oncological reasons.

**Scapula**

The scapula is a membranous bone and consequently needs its periosteal blood supply only for the purpose of surviving as a complete bone. Membranous bone can be transplanted without a vascular supply and be expected to live, provided that the graft is placed into a well-vascularized bed. The spine and the lateral border of the scapula have been successfully used for the reconstruction of particularly difficult jaw deficiencies after cancer ablation. Proximity and sufficient bone for partial mandibular reconstruction provide the main impetus for using the scapula for jaw reconstruction. The scapula can also be utilized as a free (microvascularized) bone graft.

**Calvarium**

The calvarium is a membranous bone. The calvarium has been used for reconstruction of various head and neck defects. Recently, the calvarium has been used to reconstruct the mandible.

**Composite grafts**

Composite grafts of skin and cartilage from the auricle or nasal ala have all been used to repair nasal deficiencies. Composite grafts of skin and fat, and of skin, fat, and cartilage have also been used. Composite grafts have been used to correct cleft lip and partial losses of the nasal columella.

**Alloplastic grafts**

Although autografts have traditionally been considered to be the most desirable in replacement of body losses, there are cases where an inorganic implant better meets the needs of the situation. Some determining factors might be insufficient donor tissue, replacement of the autograft by scar tissue, absorption and shrinkage of the autograft, uncertainty of future treatment that might interfere with autograft success, that is, irradiation, and infection.

In general, the body responds to the presence of an insoluble foreign substance by extruding it, if possible, or by closing it off. Some specialized materials, such as titanium, hydroxyapatite, bioglass, ceramic and carbon, appear to be readily integrated into bone tissue. It has demonstrated conclusively that titanium becomes so well incorporated into various facial bones that new teeth, ears, hearing aids, jaws and noses can easily be fabricated and attached to the face and neck. Other materials may produce different reactions in the body according to the form of the implant. Teflon, for example, usually causes only a mild reaction when used in the form of fibre, cloth or paste, yet in powder form it can cause extensive granulation. Even with those materials that cause minimal reaction, such as silicones and polypropylene, the body responds by walling off the foreign substance with a layer of mononuclear cells and a thin collagenous sheet. Teflon paste has been used successfully for a number of years to restore vocal cord function following a laryngeal paralysis. Teflon paste
has also been injected into the nasopharynx for the purpose of overcoming the hypernasal speech associated with cleft palates or neurological conditions.

It is important to try to prevent haematoma formation around an implant, as this can result in extensive fibrosis. Silicone implants, in particular, have been associated with the development of a hard fibrous capsule. Sometimes a degree of fibrosis is desired as an aid to fixation. Plastics are generally more popular than metals for use in implants, as their malleability makes them easier to handle. The exceptions are the hard plastics such as polypropylene and polyethylene. Polypropylene mesh has found an important role in facial and nasal augmentation (Stucker, 1982). The mesh is a porous malleable material that makes this allograft more acceptable as a graft material.

Silicone

Silicones are especially popular for implants because of their availability in a wide variety of forms, that is as sponges, gels, meshes, foams, liquids, and rubbers. The body's response to the implantation of silicone is usually mild inflammation and the formation of a thin collagen pseudosheath. The tissue around the implant reacts by forming a granulation layer that eventually converts to fibrous tissue.

Dacron and Teflon induce a bodily reaction similar to that induced by silicone.