The Unsung Virtues of Ligaments

John V. Basmajian


Modestly laboring behind the scenes, ligaments are often overlooked or disdained while attention focuses on muscles, vessels, and nerves, the dynamic actors on center stage. Yet this attitude - held by surgeons and anatomists alike - is both naive and wrong. Ligaments are often more important than muscles, and in some places where muscles are given the credit, unassuming ligaments carry the entire burden of responsibility. But since their demands are small, we tend to overlook their virtues.

Dynamic and Postural Roles

As one who has devoted a professional lifetime to the electromyographic study of muscles in health and disease, I have become increasingly impressed with the dynamic and postural roles of ligaments. This awareness grew as more and more studies showed inactivity of muscles where my colleagues and I had expected activity. Very early, a principle emerged that stated in its simplest form: Muscles are spared where ligaments suffice. This is true in both postural and dynamic situations; in the pathologic situation, disturbances of ligaments lead to various secondary neuromuscular changes which again create more stir than the loss of function in the ligament.

The quiet and efficient work of ligaments allows for the operation of two laws of muscular function which MacConaill and I proposed.

1. The law of minimal spurt action: No more muscle fibers are brought into action than are both necessary and sufficient to stabilize or move a bone against gravity or other resistant forces, and none are used insofar as gravity can supply the motive force for movement.

2. The law of minimal shunt action: Only such muscle fibers are used as are necessary and sufficient to ensure that the transarticular force directed toward a joint is equal to the weight of the stabilized or moving part together with such additional centripetal force as may be required because of the velocity of the part when it is in motion. That these two laws are valid has been demonstrated clearly by electromyography. In fact, it is the study of muscle that indirectly revealed the role of ligaments.

Contrary to expectation, we found that the vertically running muscles that cross the should and elbow joints are not active to prevent distraction of these joints by gravity. Much more surprising is the fact that they do not spring into action when light, moderate, or even heavy loads are added unless the subject voluntarily decides to flex his shoulders or his elbow and thus to support the weight in bent positions of these joints. Quite often he may do this intermittently or, when uninstructed, from the very onset. But it must be clear that such muscular action is a voluntary action and not a reflex one.
Carlsöö and Guharay confirmed our findings of muscular inactivity in the heavily loaded shoulder and elbow joints - the muscles being biceps, triceps, brachialis, and brachioradialis. In addition, they found that the temperature fell in these muscles, apparently because of a lower oxygen demand.

Even while the muscles were quiescent, our subjects rapidly felt local fatigue. What, then, is fatigue in the heavily loaded limb? Normally, it would be thought of as 'muscular fatigue' but we seen now that this is incorrect. The 'fatigue' that is experienced probably originates from the painful feeling of tension in the articular capsule and ligaments, not from overworked muscles. In fact, as we have seen, the muscles need not be working at all.

An analogous situation occurs in the foot where we found, some years ago, that the muscles that are usually supposed to support the arches continuously were generally inactive in standing at rest. Independently Hicks showed by deduction that the plantar aponeurosis and plantar ligaments were the chief weight-bearers in this position. It would seem, then, that in the normal foot the fatigue of standing is not a muscular phenomenon.

The dual conclusion that articular ligaments suffice to prevent the downward distraction of joints in the upper limb and that fatigue is chiefly a form of pain in the ligaments appears to be of fundamental importance. It not only runs counter to 'common sense' but it is of practical interest, for example, in explaining why dislocations by traction on normal limbs are rare. It should be noted especially that the capsule on the superior part of the shoulder joint including the coracohumeral ligament is extremely thin only when the arm hangs directly downward and the scapula is in its normal position. The special mechanism that includes this ligament together with the supraspinous muscle and the normal slope of the glenoid cavity has been described by me elsewhere. When the shoulder joint is abducted or flexed, however, the capsule is extremely loose and the shoulder joint depends for its integrity on the well-known "rotator-cuff" muscles (see below).

All the experiments reported above finally led to a fascinating one that in turn has led to new ideas. Elkus and I found that healthy subjects suspended by their hands from a trapeze can hold on for less than three minutes even when their fists are kept closed by a special gauntlet. Severe discomfort in the hands (when no gauntlet was used) was the main cause for failure. Action potentials from a large number of muscles were unremarkable and all evidence pointed to a significant ligamentous force rather than muscles preventing articular distraction. Similar EMG studies by Tuttle and myself on apes (gorilla, chimpanzee, and orangutan) confirm these findings.

Quite independent from us, a group in Sweden was arriving at similar conclusions in regard to ligament-sparing from a different type of experiment in cats and man. Thus, when Andersson and Stener greatly increased the tension in the medial ligament of the knee of the cat in specially designed experiments, no reflex muscular contractions appeared in the muscles of the thigh as would have been expected if the usual hypothesis of "ligamento-muscular protective reflexes" were valid. Furthermore, they showed convincingly that the absence of reflex motor effects was not due to the absence of afferent discharges which were well registered from the articular nerves.
Petersén and Stener carried the above experiments forward to human subjects, again using the medial ligament of the knee. Their results were a complete vindication of the conclusions made in the animal experiments described previously. In addition, their work suggests that if injured ligaments are pulled till pain results, muscles do show reflex contraction, but if the torn ligament is then anesthetized, they do not.

Following almost the same line of reasoning, deAndrade, Grant, and Dixon distended human knees with non-irritating plasma (which emphasized the pressure phenomenon as opposed to pain). There was a definite and even marked inhibition of quadriceps contraction with a depression of motor unit activity. This is undoubtedly a reflex inhibition and helps further to explain the muscle weakness, atrophy, and deformity that follow knee injury and disease.

Freeman and Wyke obtained a definite and chronic drop in reflex postural tonus in cats by cutting the sensory nerve supply of the knee joint capsule. The mechanoreceptors in the joint are involved in reflex muscular activity to maintain posture in quadrupeds; undoubtedly the same mechanisms occur in man as well. All the above observations are surely of great importance in orthopedics and surgery of joint injury; they deserve wide attention.

Specific Functions of Selected Ligaments

Axial Skeleton

Spinal Column

The presence of anterior and posterior longitudinal ligaments, binding the fronts and the backs of the vertebral bodies to one another throughout the length of the column, safeguards the movements of the column as a whole. The vertebral arches possess restraining ligaments also. One series consists of the ligamenta flava, rich in yellow elastic fibers; they stretch between the adjacent laminae of the vertebral arches. Being elastic, these ligaments tend to restore the spinal column to a neutral position after it has been flexed. They also serve, with the laminae, to cover the spinal canal posteriorly and so protect the contained spinal cord. A second series unites adjacent spinous processes as interspinous ligaments. Contiguous with these posteriorly are longer fibers which stretch the length of several spines and are, in consequence, supraspinous ligaments. These have the same effect as the ligamenta flava. Undoubtedly, they relieve the back muscles of considerable work.

The amount of movement permitted between two adjacent bodies also depends on the thickness of the intervening disc, itself a modified 'ligament.' Cervical and lumbar discs are thick, thoracic discs are thin; movements, therefore, are freest in the neck and in the lumbar region, and this must be as true for the joints of the vertebral arches as it is for the bodies.

Ligaments of Atlas and Axis

When the 'No' movement occurs, the skull and atlas move on the axis as a unit and the third joint, which is at the center of the movement, plays an important part. This joint, the median atlantoaxial joint, is a pivot. The dens, projecting upwards from the body of the axis,
rotates in a collar formed by the anterior arch of the atlas and the *transverse ligament*. A pair of strong, short, *check* or *alar ligaments* stretches between the tip of the dens and the skull at the margin of the foramen magnum and serves to limit the rotation of the head. They become taut also in head flexion.

The pivot-and-collar mechanism is completely covered and hidden from view by a broad ligamentous band, the *tectorial membrane*; it is the upward and expanded prolongation of the posterior longitudinal ligament that binds together the backs of all the vertebral bodies and discs. The tectorial membrane is attached above to the anterior margin of the foramen magnum and offers a smooth and continuous sloping surface for the support of the brain stem and spinal cord.

*Anterior* and *posterior atlantoaxial membranes* have similar dispositions to the atlanto-occipital ones. Movements between the skull and the atlas as well as those between the atlas and the axis are, of course, augmented by the flexibility of the remainder of the cervical column.

**Upper Limb**

**Ligaments of Clavicle**

Taken too much for granted, the ligaments of the clavicle are truly so important that they determine the very fundamentals of upper limb, and so manual, function. Fortunately, they are seldom seriously injured. The force-transmitting function of the massive *coracoclavicular ligament* is probably too well known to require emphasis here. The play of forces at the medial end of the clavicle is less well known - and more complicated. The joint surfaces of the sternoclavicular joint are not reciprocally shaped - the "fit" is terrible! Contact of the otherwise ill-fitting surfaces is improved by the existence of a *disc*. However, this disc, which is really a ligament in disguise, is much more occupied with the duties of absorbing the forces transmitted to the joint along the clavicle from the shoulder region and preventing the clavicle from being driven out of its socket onto the summit of the sternum. The disc can discharge these duties because it is firmly attached - above, to the clavicle; below, to the first costal cartilage. The rarity of dislocation of the joint testifies to the efficiency of the disc in discharging its duties, even when a hole is worn in its middle with advanced age.

Excessive protraction and elevation of the clavicle are prevented by the existence of two structures. One, a ligament, is fundamental; the other, a muscle, is much less important. Immediately lateral to the sternoclavicular joint, the clavicle is bound to the first costal cartilage by the *costoclavicular ligament*. Being near the center of movement and at first somewhat lax, this ligament allows the lateral end of the clavicle considerable excursion in both protraction and elevation before it finally becomes so taut as to bring further movement to a halt. Lateral to the ligament, acting as a 'dynamic ligament,' the subclavius muscle reinforces the costoclavicular ligament.
Shoulder Joint

As already indicated, the capsule of the shoulder joint plays a vital role in weight-bearing. No other joint has such a loose capsule and is so ill equipped with restraining ligaments. The anterior part of the capsule contains three slight thickenings, the glenohumeral ligaments, which are of doubtful significance. But a ligament with very great significance is the coracohumeral ligament extending from the coracoid process to the greater tuberosity of the humerus. Only its anterior edge may be obvious to the surgeon or anatomist; the remainder blends with, and thickens, the upper part of the fibrous capsule. While this ligament is usually described as becoming taut on lateral rotation (true), it is also taut when the arm hangs vertically because it is part of the superior part of the capsule. It forms a locking mechanism, which, assisted by the supraspinatus muscle, prevents downward dislocation of the humeral head.

When the arm is held directly overhead, the inferior capsule of the shoulder joint becomes extremely taut and then it acts as the restraint. Our experiments indicate that this is effective in the short term with no special fatigue reported in the shoulder region by subjects hanging by their hands. (They let go because of the pain in the hands and forearms.) In the intermediate positions of abduction and/or flexion, whatever security the joint possesses it derives from the rotator cuff muscles that surround and move it, not from ligaments. They pass to their insertions on the two tuberosities immediately adjacent to the head of the humerus. Blending with the capsule and reinforcing it, they deserve the designation of 'dynamic ligaments.' But, as any surgeon can attest, they fail to prevent dislocations in all too many persons.

Elbow and Forearm

Every hinge joint (including the elbow) has a thin loose capsule except at its two sides where the capsule is greatly thickened to form collateral ligaments. The medial (ulnar collateral) ligament is fan-shaped. Fastened to the medial epicondyle above, it spreads to the medial edge of the trochlear notch of the ulna. The anterior part is thickened to form a cord which plays the biggest part in the prevention of abduction at the elbow. The lateral (radial collateral) ligament runs from the lateral epicondyle to the outer surface of the anular ligament and so does not impede supination and pronation. Since the anular ligament grasps the head of the radius firmly in the adult, adduction is effectively prohibited to the radial collateral ligament. (For pedantic reasons, the spelling of "annular" has been changed officially to "anular.")

The fibers of the interosseous radioulnar membrane take a direction downwards and medialwards, a fact which falsely suggests that forces received from the hand by the lower end of the radius are transmitted on their passage up the forearm by the interosseous membrane to the ulna. This function of the membrane has been overemphasized since the hand is usually in a position of pronation when forces are applied to it, and in pronation the interosseous membrane is rather slack. Moreover, there seems to be no good reason why the radius itself should be unable to transmit forces directly to the humerus. The more important use of the membrane would seem to be to increase the area available, both at the front and at the back, for the origins of numerous muscles found in the forearm. Further, the articular
disc of the inferior radioulnar joint is also a force transmitter in addition to its role of stabilizing the radius and ulna while allowing pronation-supination.

Carpus and Hand

In this brief review, space is insufficient to cover the detailed multifarious functions of the many joints and ligaments. A book could be written about them. Only reference will be made to a universal special function of the capsular and interosseous ligaments of the area, viz, their role in producing close-packing. As MacConaill and I have described in detail, every synovial joint contains at least one mating pair of articular surfaces, one of these being male, the other female. When there is more than one mating pair, the joint is 'compound.' When there is an intra-articular disc, the joint is 'complex.'

When one bone articulates with two others within one and the same compound joint, it will have two articular surfaces, one for each of the other two bones. We thus have two mating pairs. For example, the lower end of the radius articulates with the scaphoid and the lunate bones of the radiocarpal joint. Each of these two bones has a male ovoid surface which moves on a corresponding and separate female ovoid surface on the lower end of the radius. Thus we have the two mating pairs that constitute the radioscaphoid and the radiolunate joints. There is an important rule governing the behavior of adjacent mating pairs within any compound joint: No male surface of one mating pair comes into articulation with the female surface of another mating pair. And it is the ligaments that enforce this monogamy!

In all positions except one of any mating pair of surfaces, they fit each other badly, ie, they are not fully congruent. We have called the position in which they are fully congruent the close-packed position. In this special position the female articular surface fits the corresponding (apposed) part of the male surface point-for-point. Moreover, the chief ligaments of the joint are so arranged that they screw the male and female surfaces together in a close-packed position in such a way that they cannot be pulled apart - whence the name. All other positions of a joint are called loose-packed. In the close-packed position we no longer have two bones functionally, only one, because they have been temporarily screwed together. The joints of the carpus and digits are excellent examples of these principles.

Lower Limb

Sacroiliac Joint

Behind and above the 'synovial' joint of the auricular surfaces a large area of the ilium is rough. Over this area, the sacrum and ilium are not in direct contact; a cleft exists between them. The cleft is filled with a heavy mass of fibers known as the interosseous sacroiliac ligament; behind the cleft, the fibers joining the bones are known as the dorsal sacroiliac ligament. As if even these were not enough, the summit of the crest of the ilium is united to the tip of the transverse process of the fifth lumbar vertebra by a strong band of fibers known as the iliolumbar ligament.

All of this ligamentous mass is under constant strain except when the body is recumbent. On it falls the duty of transmitting the weight of the body above to the hip bone.
By permitting only a minimal movement, the ligaments secure the integrity of the synovial joint. The latter is helpless alone, in spite of the interlocking character of its opposed surfaces.

**Hip joint**

The general functions of the fibrous structures around the hip joint are well described in standard texts. Perhaps it should be pointed out that maximum tautness of the iliofemoral ligament is not achieved until hyperextension is produced. Thus, the hip joint probably is not fully close-packed in the relaxed standing position. This would suggest some instability requiring continuous muscular activity during standing, which occurs appropriately in the iliopsoas muscle.

**Knee and Ankle Joints**

As with the section on the hand above, the many functions of the many ligamentous structures in the knee and ankle cannot be dealt with adequately here. While their structural characteristics - with notable exceptions - have been well covered in texts, their functions have been a matter of guesswork. I believe that many of the roles played by ligaments in the knee and ankle are related to achievement of close-pack. This and other functions require intensive research in these important areas. Descriptions of the fine detail (eg, of tendinous expansions) around the knee have appeared in recent years; important as the new reports are, they remain incomplete.

**Foot**

**Subtalar Joint.** The chief restraining ligaments of this joint are those of the ankle which span the talus to attach to the calcaneus. In addition there is the **interosseous talocalcanean ligament.** It lies in the tarsal sinus immediately in front of the subtalar joint and directly below the very center of the ankle joint. It holds the two bones together and, tightened by any undue movement between them, it limits inversion-eversion of the subtalar joint.

**Talocalcaneoclavicular Joint.** The main mass of the head of the talus projects insecurely in front of the sustentaculum. Here the head is capped by the navicular, between which and the sustentaculum is a triangular interval in which the talus hands its head and reaches its lower limit. A very strong ligament fills this interval and on it the head of the talus rests. This ligament, uniting the sustentaculum to the lower edge of the back of the navicular, is known as the "spring" ligament (or plantar calcaneonavicular ligament); on its strength and integrity depends, in large measure, the security of the whole foot. Should it be stretched and the interval between the sustentaculum tali and the navicular be widened, the head of the talus sinks in this interval and the foot becomes flat. The spring ligament, at the highest part of the medial longitudinal arch, is at the keystone of that arch. On the medial side of the joint, fibers of the deltoid (medial ligament of the ankle joint) reach to the navicular and blend with, and support, the medial edge of the spring ligament; they complete the medial wall of the socket. On the lateral side, the (functionally) much less important bifurcate ligament unites the calcaneus and the navicular.
Calcaneocuboid Joint. Just as the strong spring ligament binds the navicular to the calcaneus, so the strong, short plantar ligament (inferior calcaneocuboid ligaments) binds the cuboid to the calcaneus. Indeed, the two ligaments form an almost continuous structure across this vital region, the one supporting the keystone of the high medial longitudinal arch, the other supporting the keystone of the low lateral longitudinal arch.

A Final Word

The functional principles of the ligamentous structures require extensive and intensive exploration. But who is to do this? The practicing surgeons who read these pages are at the mercy of outdated textbooks and fragmentary research. Because the functioning ligaments in health is so smooth and trouble free, surgeons cannot realize their profound significance in the presence of joint disease and trauma - even when they themselves are uninjured. Today, this article well may be unique in the surgical literature in its attempt to throw a spotlight on these important supporting actors; if, however, it remains unique, it will have failed part of its purpose, the stimulation of renewed inquiry into the functional role of ligaments throughout the body in health and disease.