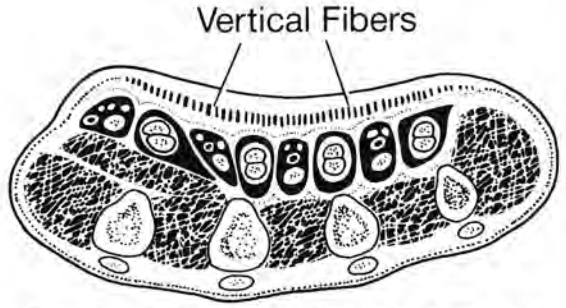

Figure 89–4. The palmar fascia with its longitudinal, transverse, and vertical fibers. The longitudinal fibers take origin in the palmaris longus (when present). Transverse fibers are concentrated in the distal palm supporting the web skin and in the midpalm as the transverse palmar ligament. Vertical fibers extend superficially as multiple, tiny tethering strands to stabilize the thick palmar skin. The deep vertical components concentrate in septa between the longitudinally oriented structures to the fingers.

tendons proximal to the level of the digital pulleys. Longitudinal fibers pass toward the palmar surface of the thumb, but these fibers are generally less numerous and sometimes difficult to identify. The thumb fibers blend into the deep fascia overlying the thenar muscles. The ulnar extreme palmar fascia blends with the hypothenar fascia. The proximal one-third of this border is the attachment site of the palmaris brevis muscle. Laterally, the muscle attaches to the hypothenar skin and hypothenar fascia.

The vertical fibers of the palmar fascia, which lie superficially to the tough triangular membrane made up by the longitudinal and transverse fibers, consist of the abundant vertical fibers to the palm skin dermis. Deep to the palmar fascial plate, the vertical fibers coalesce into septa, forming compartments for flexor tendons to each digit and separate compartments for the neurovascular bundles together with the lumbrical muscles. There are eight such compartments, which extend proximally to about the midpalm. Proximal to this, there is a common central compartment (Bojsen-Moller and Schmidt, 1974). The marginal septa extend more proximally than the seven intermediate septa closing the central compartment laterally and medially. The major septum between the index flexor tendons and the neurovascular and lumbrical space to the third interspace attaches to the third metacarpal, dividing the thenar or adductor space from the midpalmar space (Fig. 89–4).

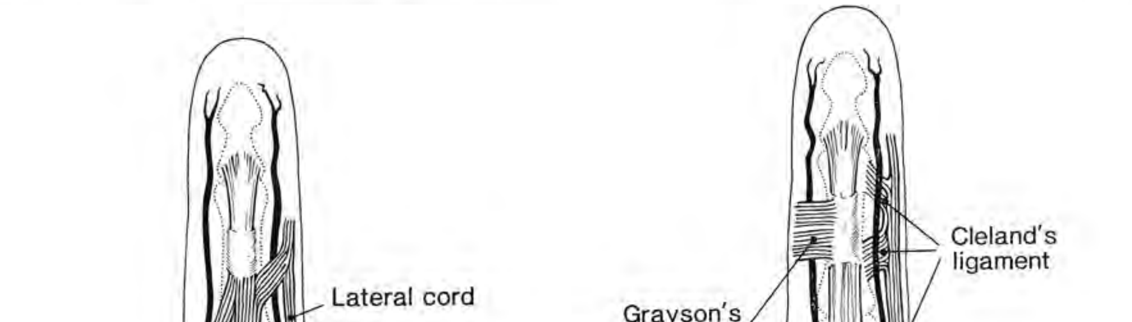

Figure 89–5. *A, B,* The components of the digital fascia that help to anchor the axial plane skin are Grayson's ligaments palmar to the neurovascular bundles and Cleland's ligaments dorsal to the bundles. These fibers, as well as the web or rotatory ligaments and the spiral bands of palmar fascia, may become involved with Dupuytren's contracture. Spiral cords may extend from the pretendinous band at the metacarpophalangeal joint level to pass dorsal, then palmar to the neurovascular bundle before inserting at the midphalanx level. (Modified from McFarlane.)

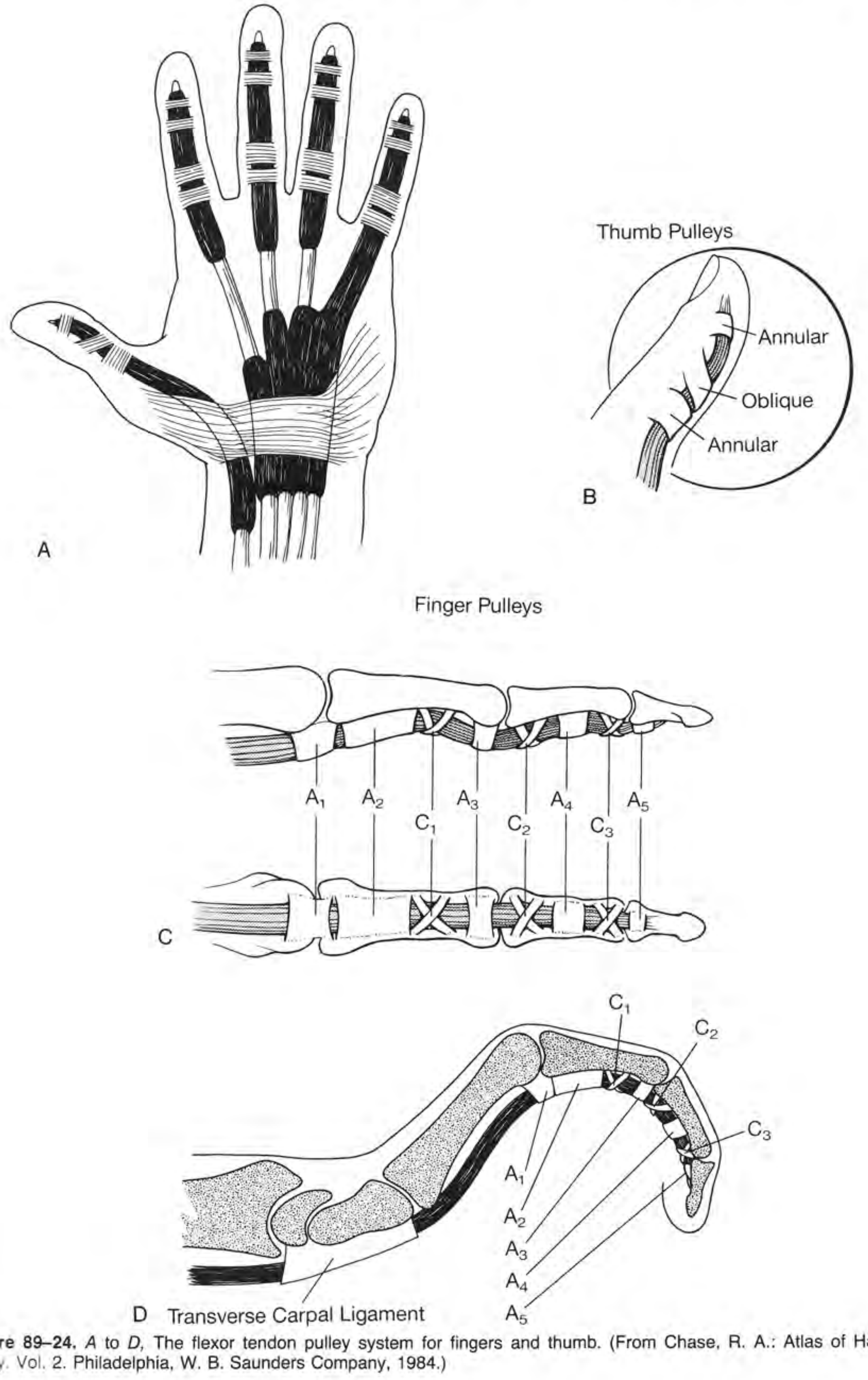

Figure 89–24. *A* to *D*, The flexor tendon pulley system for fingers and thumb. (From Chase, R. A.: Atlas of Hand Surgery. Vol. 2. Philadelphia, W. B. Saunders Company, 1984.)

tendons unless it were prevented by the fixed retinacular conduits at these points. At the wrist the flexor retinaculum is the fixed roof of the carpal tunnel. The fibrous flexor sheath in the digits forms a fitted pulley system with condensed thickening in the areas of greatest fulcrum responsibility. At the wrist and in the digital fibrosynovial sheaths, anatomic structures create full occupancy. Any addition, whether it be more structures, postinjury or inflammatory swelling of the contents, or inflammatory tightening of the sheath, sets the stage for an inflammatory reaction and adhesion formation.

At the wrist the median nerve passes beneath the flexor retinaculum and the transverse carpal ligament as the most superficial structure in this crowded space. It is subject to compression injury when swelling occurs within the carpal tunnel.

Ulnar Carpal Tunnel

Just proximal to the wrist, the ulnar nerve passes from beneath the flexor carpi ulnaris along the radial side of the easily palpable pisiform. At this point the nerve enters a fibromusculofascial space that is tubular in configuration, crossing the entire length of the carpus. This is the ulnar carpal tunnel, which is quite separate from the carpal tunnel, through which the median nerve and longitudinal structures to the digits pass. The ulnar carpal tunnel is composed of three distinct parts from a proximal to distal direction: Guyon's tunnel, the pisohamate tunnel, and the opponens tunnel (Kim, 1986). The nerves accompanied by the ulnar artery enter the ulnar tunnel (Fig. 89–41*A*).

Guyon's Tunnel

Guyon's tunnel (loge de Guyon) starts at a hiatus formed by the distal edge of the volar carpal ligament superficially and the proximal edge of the transverse carpal ligament deeply. The pisiform forms the ulnar side of the tunnel, and fibers from the volar carpal ligament that plunge down to join the underlying transverse carpal ligament form the radial wall. There is no fibrous roof on the proximal part of the tunnel until the pisohamate arcade fibers are encountered distally. The roof of the tunnel, therefore, consists of a thick layer of fascia continuous with the hypothenar fascia and generally a part of the palmaris brevis muscle (Fig. 89–41*B*). Through this rather soft hiatus, the superficial branch of the ulnar artery and the arterial branches to the palmaris brevis and overlying skin pass, together with the superficial branches of the ulnar nerve. Within Guyon's tunnel the ulnar nerve lies ulnar to the artery, and the division of the ulnar nerve into

Figure 89–41. *A*, *B*, The ulnar carpal tunnel consists of Guyon's tunnel beneath the palmaris brevis, the pisohamate tunnel between the pisiform and hook of the hamate, and the opponens tunnel between the deep and superficial fibers of the opponens digiti minimi. (Redrawn from Chase, R. A.: Textbook of Hand Surgery. Vol. 1, 1973. Vol. 2, 1984. Philadelphia, W. B. Saunders Company.)

its deep motor branch and two superficial branches is evident (Fig. 89–41*B*). After the superficial branches of the artery and nerve emerge through the roof of the tunnel, the deep artery and deep branch of the ulnar nerve enter the pisohamate tunnel beneath the pisohamate arcade.

Although the tunnel of Guyon is devoid of a thick, fibrous roof, it is nonetheless covered by palmaris brevis fascia, creating an unyielding space, and its contents are therefore subject to compression from a variety of causes. Repeated trauma, as when one uses the heel of the hand to pound objects, may result in swelling of the tissues and resultant hypertrophy and fibrosis or hemorrhage in the tunnel, which may squeeze the nerve or artery, or both. Ganglia, tumors, or displaced bone may cause compression in the ulnar tunnel, just as occurs with the median nerve in the carpal tunnel. Ulnar and carpal tunnel syndromes may happen simultaneously. Entrapment compression at this site may create ulnar nerve intrinsic weakness or paralysis, usually in combination with sensory symptoms referable to the palmar aspect of the little finger and the ulnar side of the ring finger. Tingling and numbness over the palmar aspect of these fingers are the common sensory findings that usually lead to the diagnosis. The dorsum is not involved, since the dorsal sensory branch of the ulnar nerve comes off in the forearm before the nerve enters the ulnar tunnel. Weakness of ulnar-innervated intrinsic muscles may be evident by the appearance of clawing of the little and ring fingers, and atrophy is usually most obvious in the first dorsal interosseous muscle. Tingling and paresthesias may be precipitated by tapping over the hypothenar ulnar tunnel area.

Sometimes, splinting and protection from continuing trauma reverse the progression of the ulnar tunnel syndrome. If simple measures fail, surgical release of the nerve by unroofing the tunnel is appropriate treatment. This can be done alone or together with carpal tunnel release through an incision made 1 cm more in the ulnar direction than the thenar crease incision. Exploration of the course of the deep branch of the ulnar nerve beneath the origins of the opponens and short flexor from the hamate hook will allow decompression of this nerve as necessary.

When the dissection is carried above the hand to the wrist, the surgeon should be careful not to injure the superficial palmar branch of the median nerve and the palmar cutaneous branch of the ulnar nerve. The superficial palmar branch of the median nerve lies superficial to the carpal tunnel and adjacent to the palmaris longus, and courses to the skin of the thenar eminence. The palmar cutaneous branch of the ulnar nerve takes off from the nerve trunk at various levels and passes superficially across the wrist to the skin of the hypothenar region.

Pisohamate Tunnel and Syndrome

The second, or middle, segment of the ulnar carpal tunnel is the pisohamate portion (Fig. 89–41*A*). This is an oblique-lying space between the hook of the hamate and the pisiform, and is a continuation of the ulnar carpal tunnel distal to Guyon's tunnel. Its roof is formed by the fibromuscular pisohamate arcade. This is a fibrous condensation between the origins of the abductor digiti minimi and the flexor digiti minimi brevis. Parts of these muscles take origin from this arcade. On the deep surface is the pisohamate ligament described by Hayes, Mulholland, and O'Connor (1969). The ligament overlies the triquetrohamate joint. It should not be a surprise that motor problems in the ulnar-innervated interossei and thumb adductor occur in disorders of this joint and the triquetrohamate joint. During surgery on these joints, this important nerve must not be injured.

When compression of the nerve occurs at the pisohamate hiatus, there is no sensory loss, but there is motor weakness and even paralysis of all the ulnar-innervated intrinsic muscles except for the abductor digiti minimi (Fig. 89–41*B*). This is the classic finding in the pisohamate syndrome. Occasionally, even the abductor digiti minimi may be affected. A ganglion arising in the intercarpal or fifth metacarpophalangeal joints is a common cause. Abnormal variants of intrinsic muscles, disease of the fifth carpometacarpal joint, and trauma account for the rest of the cases. Electromyographic studies of the ulnar-innervated muscles show paralysis or signs of compression neuropathy such as fibrillation.

Treatment consists of opening Guyon's tunnel and exploring the deep motor branch passage through the pisohamate hiatus. Release of the hiatus by sectioning the roof and releasing the compressed nerve is usually sufficient treatment. If the compression has been a long-standing one with ulnar intrinsic paralysis, and if the nerve appears choked by scar, a neurolysis using magnification is indicated.

Opponens Tunnel

The third compartment of the ulnar carpal tunnel is the opponens tunnel (Fig. 89–41*A*). The opponens digiti minimi lies immediately distal to the pisohamate tunnel, and at its origin from the hook of the hamate and distal margin of the transverse carpal ligament, the muscle splits into two fibromuscular lamellae, which form a slitlike tunnel. A ganglion of the triquetrohamate joint may herniate in a palmar direction to lie within this part of the ulnar carpal tunnel. Ulnar carpal tunnel ganglia are often found in this vicinity.

The signs and symptoms of compression of the deep ulnar nerve at this level are exactly those described previously for the pisohamate tunnel syndrome. When the deep motor branch is released, the surgeon should be certain that the passage of the nerve through the opponens tunnel is unimpeded.

CONCLUSION

In the human hand the complicated motor balance at each joint resulting from contraction, fixation, or relaxation of opposing muscle groups is worthless in the absence of the precisely fitted elements in the skeletal architecture. The skeletal framework with its restraining ligaments is beautifully designed but is useless without proper dynamic motor tension. The anatomic presence of both architecture and functioning muscles is only serviceable when there is integrity of the central nervous control mechanisms. As a unified interrelated melding of these elements emerges, hand function becomes the marvelous adaptable fact that it is in man. Its function is modified and further refined by sensory integrity. Sensation is protective and influential on central motor function. Moreover, special sensation as it resides in the hand makes the hand a special sense organ with which man explores his environment.

From a practical standpoint, surgeons need repeatedly to remind themselves of the anatomic basis for diagnosis and management of surgical problems in the hand.

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osseous muscles and the lumbrical muscles lie deeper and are better protected by the metacarpals. The intrinsic tendons are more vulnerable after they merge on the dorsum of the middle phalanx.

Extensor Apparatus of Fingers

The complex anatomy and function of the extensor mechanism in the fingers have been detailed and debated by numerous authors. At and beyond the metacarpophalangeal joint, extension forces are transmitted by a fascinating array of fibers held together by a delicate elastic membrane (Schultz, Furlong, and Storace, 1981). This apparatus, also known as the extensor expansion or the extensor hood, covers the dorsum and portions of the sides of the proximal and middle phalanges, and has anatomic or functional insertions into the base of both of these phalanges (Fig. 102–3). It has a tendon system to transmit tension and produce motion, and a retinacular system to stabilize the tendon system (Rosenthal, 1984). A working knowledge of the anatomy and physiology of this apparatus is important to any surgeon treating hand injuries.

Anatomy of Tendon System. The sagittal bands are vertically oriented fibers of the apparatus that cover the capsule and collateral ligaments of the metacarpophalangeal joint, and separate them from the intrinsic muscles (Harris and Rutledge, 1972). During extension, these bands lie as a hood over the metacarpophalangeal joint; during flexion they are distal to the joint axis.

The central band of the tendon system is a continuation of the EDC tendon. Although there may be some proximal attachments (Tubiana and Valentin 1964a,b), most of the central tendon fibers end in the distal part of the proximal interphalangeal (PIP) joint cap-

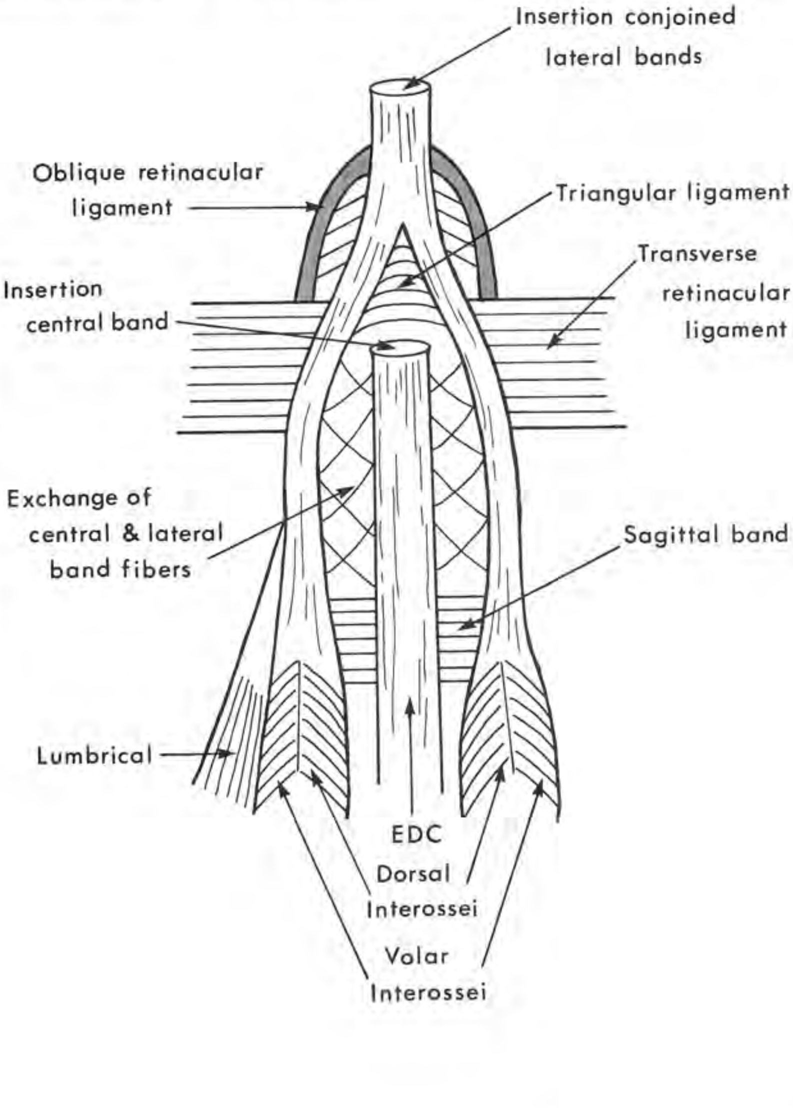

Figure 102–3. Functional anatomy of finger extension. The extensor digitorum communis (EDC) extends the metacarpophalangeal joints; when the latter is fixed it can extend the proximal interphalangeal joints. The interossei and lumbricals are principal interphalangeal joint extensors. The tendon system, stabilized by a retinacular system, exchanges fibers in a delicate elastic membrane of extensor expansion.

sule with a bone insertion on the base of the middle phalanx (Hauck, 1923). Some fibers of the EDC are exchanged with each of the lateral bands (Haines, 1951).

Distal to the sagittal bands, the intrinsic muscles contribute proximal vertical and distal oblique fibers to the sides of the central tendon. The lateral bands are predominantly tendinous extensions of the oblique fibers of the intrinsics, with contributions from the EDC (Smith, 1974). Distal to the proximal interphalangeal joint they first are separated by a portion of the apparatus known as the triangular ligament, and then merge to form a conjoined tendon and a terminal tendon. The latter blends with the capsule of the distal joint and inserts on the base of the distal phalanx.

Anatomy of Retinacular System. The principal components of the retinacular system are the transverse and oblique fibers described by Landsmeer (1963), who called them "ligaments." After arising from the proximal phalanx and flexor tendon sheath in the volar compartment, transverse fibers of the system pass through a window in Cleland's ligament volar to the axis of the proximal interphalangeal joint, to insert on the lateral bands dorsal to the axis and on the triangular ligament that separates them at this level (Milford, 1968). The deeper and more tendinous oblique fibers have a broad insertion on the side of the lateral bands from the level of the proximal interphalangeal joint to at least the distal third of the middle phalanx (Tubiana and Valentin, 1964a,b). One author believes there is also an insertion into the base of the distal phalanx as well. The author's experience with the treatment of the boutonnière deformity would exclude any functional significance of such an attachment, if indeed it exists.

Physiology. The published motion (Hauck, 1923; Stack, 1962; Zancolli, 1968; Evans and Burkhalter, 1986) and electromyographic (Backhouse and Catton, 1954) studies of the extensor mechanism are excellent. Evaluation and treatment of finger deformities caused by division or contracture of the extensor apparatus are facilitated by basic knowledge about the dynamics of the mechanism.

The primary function of the EDC tendon is extension of the proximal phalanx at the metacarpophalangeal joint, but with this joint in extension or flexion and further active extension blocked, the EDC can also extend the middle and distal phalanges (Zancolli, 1968). The EDC is unable to extend the two distal phalanges against normal flexor tone if the metacarpophalangeal joint is allowed to hyperextend.

Normally the extensor hood over the metacarpophalangeal joint level is free to slide proximally with MP extension and distally with MP flexion. With the hood in the distal position, the interossei contribute to flexion of the metacarpophalangeal joint through their vertical fibers, and have little or no effect on the proximal and distal interphalangeal joints. With the hood in the proximal position and the metacarpophalangeal joints stabilized in extension, the interossei can act through the oblique fibers and lateral bands to extend the middle and distal phalanges (Littler, 1967).

The lumbrical muscles, like the interossei, provide flexion of the metacarpophalangeal joint through vertical fibers. In contrast, however, they are effective extensors of the middle and distal phalanges regardless of the position of the metacarpophalangeal joint. If the latter is held in flexion by action of the intrinsic muscles, the EDC tendon is able to exert an effective extension force across the proximal and distal interphalangeal joints (Bunnell, 1964).

The two lateral bands, which normally lay quite dorsal to the axis of motion of the extended proximal interphalangeal joint, shift volarward with PIP flexion. This lateral band shift permits flexion of the distal interphalangeal joint during active flexion of the proximal interphalangeal joint (Smith, 1974). However, the intact triangular ligament limits the extent of the shift and prevents the lateral bands from dropping below the axis of motion to become flexors of the proximal interphalangeal joint.

Thumb Extension

The extensor pollicis longus (EPL) tendon transverses the wrist in the third fibro-osseous compartment, and from this radial dorsal approach is an effective adductor and supinator of the first ray. This tendon also extends the metacarpophalangeal joint and can hyperextend the interphalangeal joint.

The extensor pollicis brevis (EPB) enters the hand via the first dorsal wrist compartment along with the abductor pollicis longus (APL), the important stabilizer of the first