

Anatomy of the flexor retinaculum

For an accurate definition of the anatomic limits of the carpal tunnel, 26 cadaver upper extremities were studied by gross (10), histologic (3), and radiographic (13) methods. The mean proximal limit of the central portion of the flexor retinaculum was 11 mm distal to the capitate-lunate joint, and the mean distal limit of the distal portion was 10 mm distal to the carpometacarpal joint of the third metacarpal. Carpal tunnel width at the hook of the hamate (20 mm) was significantly smaller than its proximal (24 mm) or distal (25 mm) extent. The flexor retinaculum extended from the distal aspect of the radius to the distal aspect of the base of the third metacarpal. We redefined the palmar boundary of the carpal tunnel to include three continuous segments of flexor retinaculum: the thin proximal segment composed of thickened deep investing fascia of the forearm; the transverse carpal ligament; and the distal portion of the flexor retinaculum, composed of an aponeurosis between the thenar and hypothenar muscles. In light of recent operative procedures that divide only the transverse carpal ligament, this study provides an anatomic basis for a more extensive release. (J HAND SURG 1993;18A:91-9.)

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The ligamentous structure that attaches to the pisiform, hook of the hamate, tuberosity of the scaphoid, and ridge of the trapezium has been termed the flexor retinaculum.¹⁻³ The older term for this structure is the *transverse carpal ligament*.⁴⁻⁶ *Flexor retinaculum* and *transverse carpal ligament* are considered synonymous terms by some authors.^{4,6} A second separate layer of fascia lies superficial to the flexor retinaculum and has been referred to as the superficial part of the flexor retinaculum or the antebrachial fascia.

On the basis of our observations, we propose that the flexor retinaculum consists of three distinct and continuous segments that extend from the level of the distal part of the radius to the level of the distal aspect of the base of the third metacarpal. As defined in this study, the proximal portion of the flexor retinaculum is continuous with the deep investing forearm fascia, which lies deep to the antebrachial fascia. The trans-

verse carpal ligament, which represents the central portion of the flexor retinaculum, remains defined by its bony attachments to the pisiform, hook of the hamate, tuberosity of the scaphoid, and ridge of the trapezium and serves as the roof of the anatomic carpal tunnel. The distal portion of the flexor retinaculum is composed of an aponeurosis between the thenar and hypothenar muscles.

Materials and methods

A total of 26 upper extremities were used in the study. Twenty-four were harvested from embalmed cadavers and two from fresh cadavers.

Radiographic studies. In 7 of the 26 cadavers, the central and distal portions of the flexor retinaculum were delineated and transected longitudinally. A surgical steel monofilament wire (8.0 metric) was fixed to the distal and proximal extents of these segments of the flexor retinaculum to define their anatomic limits. The proximal limit was determined by an abrupt change in thickness at the site where the fibers of the transverse carpal ligament attached to the pisiform and tubercle of the scaphoid. Anteroposterior (AP) x-ray films were taken in the anatomic position to define the proximal and distal limits of these portions of the flexor retinaculum relative to their underlying bony landmarks.

To illustrate its dimensions, we removed the contents of the carpal tunnels of six specimens while the transverse carpal ligament and distal aponeurotic portions

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Table I. Anatomic limits of the classic portion of the flexor retinaculum*

Specimen No.	Proximal extent (distal to CLJ) (mm)	Distal extent (distal to LFCMJ) (mm)	Length† (mm)	From radial styloid to proximal extent (mm)
1	6	17	30	8
2	2	7	24	4
3	17	13	26	5
4	11	8	24	15
5	14	9	18	16
6	10	6	18	12
7	16	8	12	11
Mean	10.9	9.7	21.7	10.1
SD	5.43	3.90	6.05	4.67

CLJ = Capitate-lunate joint; LFCMJ = long finger carpometacarpal joint (measurement at midpoint of joint); TCL = transverse carpal ligament.

*That portion enclosing the classic carpal tunnel that includes the TCL and the distal (aponeurotic) portion of the flexor retinaculum. Measurements were taken from anteroposterior x-ray films after marking the proximal extent of the TCL and the distal extent of the flexor retinaculum.

†Measurement taken in the midline of the canal, from the proximal aspect of the TCL to the distal extent of the flexor retinaculum.

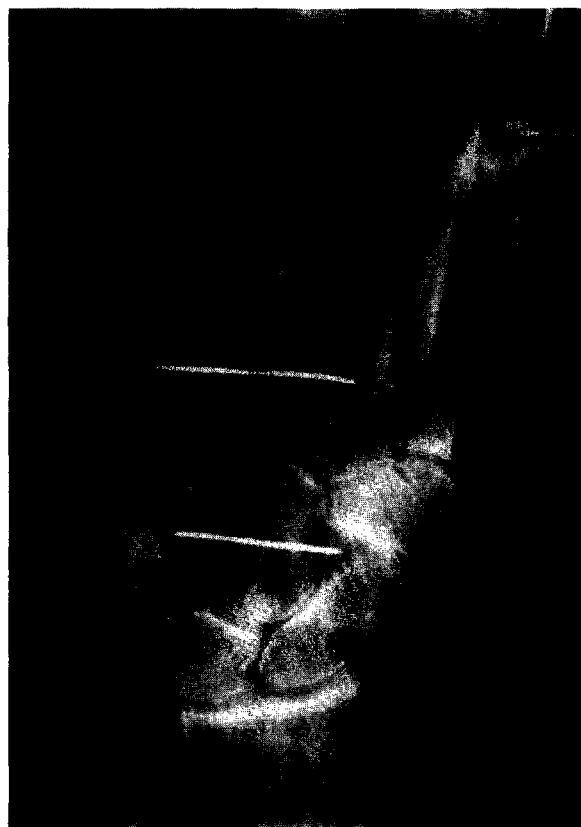


Fig. 1. Anteroposterior x-ray film of dissected right hand. Wires mark the proximal and distal extents of the classic flexor retinaculum, which includes the middle portion of the flexor retinaculum (transverse carpal ligament) and the distal portion of the flexor retinaculum. Note that the proximal limit is at the distal aspect of the pisiform (*P*) and that the distal limit is distal to the hook of the hamate (*H*).

of the flexor retinaculum were left intact. The canals were filled with a radiopaque substance composed of three parts acrylic latex and one part powdered barium. A 60 ml catheter tip syringe was used to inject the viscous solution into the canal of the upright specimen. The distal aspect of the canal was plugged with gauze to prevent leakage. The proximal and distal extents were then cleared of any excess contrast material, and AP and lateral x-ray films were then taken. Diameters of the canal were measured from AP x-ray films at the proximal and distal extents and at the level of the hook of the hamate.

Gross cross-sectional studies. Seven specimens were frozen in liquid nitrogen and sectioned with a band saw to study the relationships of the antebrachial fascia, flexor retinaculum, palmar aponeurosis, and carpal tunnel. Five were dissected in the transverse plane beginning 40 to 50 mm proximal to the tip of the radial styloid and ending 20 to 25 mm distal to the hook of the hamate. Sections were made in 5 mm increments. Two specimens were sectioned sagittally in 5 mm increments. All specimens were examined by means of a dissecting microscope with epi-illumination. Ligamentous and bony variables were measured from photographs taken of gross specimens with a Bioquant II (version 7.2) digitizer (R&M Biometrics, Nashville, Tenn.). Micrometers were placed in the photographic fields for calibration purposes.

Histologic studies. Histologic studies were performed on sagittal sections of two fresh specimens and one embalmed specimen. Longitudinal sections were taken from the central portion of the canal, extending from the level of the distal segment of the radius to the

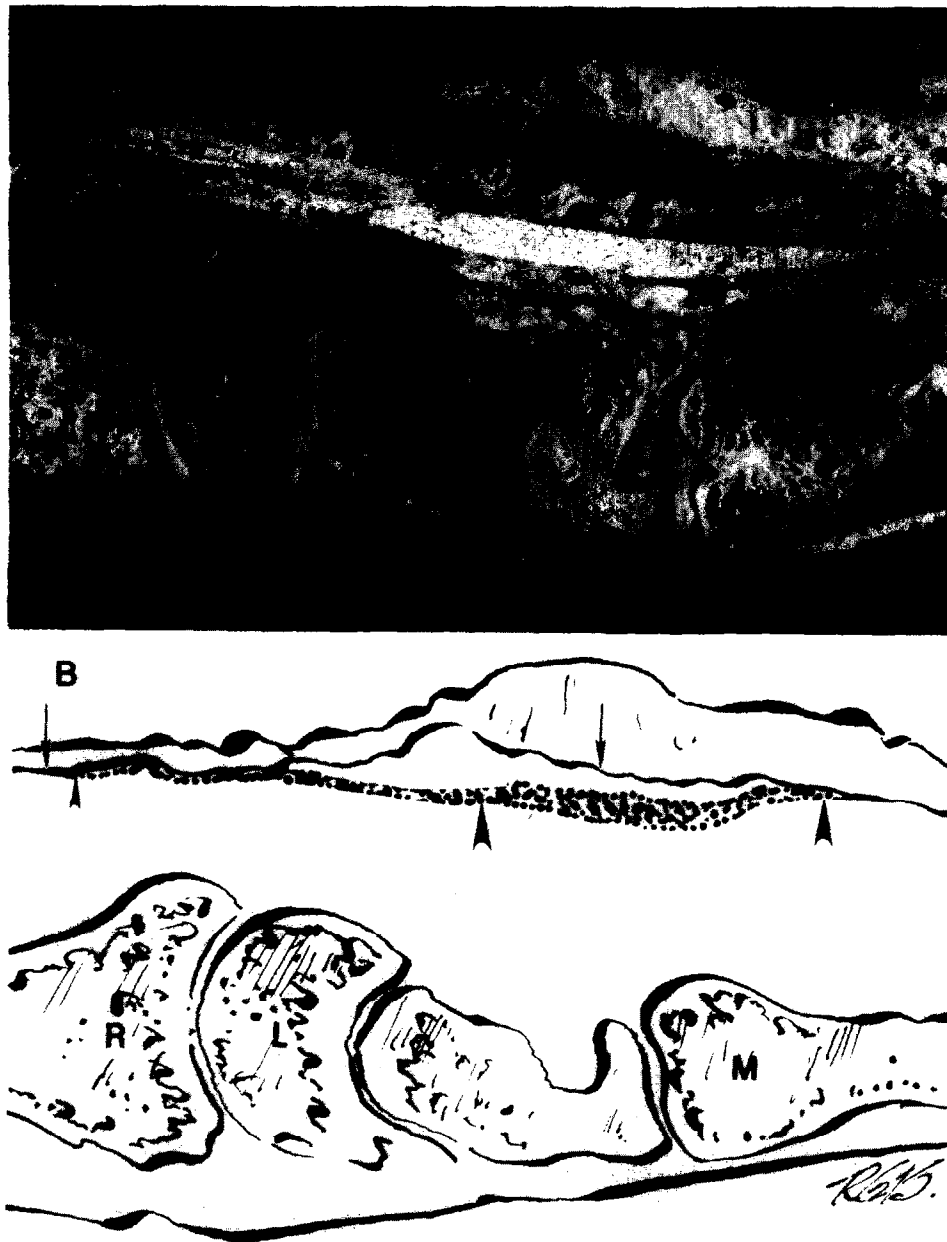


Fig. 2. A, Sagittal section of left wrist and hand, with orthochromatic film used for contrast enhancement. B, Drawing of section shown in A. *Small arrowhead* marks the proximal aspect of the thin portion of the flexor retinaculum. *Large arrowheads* mark the proximal and distal extents of the classic flexor retinaculum. *Arrows* mark the antebrachial fascia proximally and the palmar aponeurosis distally. *R*, Radius; *L*, lunate; *M*, third metacarpal.

level of the distal metacarpals. The integrity of the fascial planes and their relationships were evaluated to determine whether the layers were continuous or merely contiguous. All tissues were postfixed in 10% formalin,

dehydrated in a graded series of alcohols, cleared in xylene, and embedded in paraffin. Longitudinal sections (5 μ m) were cut on a Reichert-Jung 2030 microtome (Leica, Inc., Albuquerque, N.M.), stained with

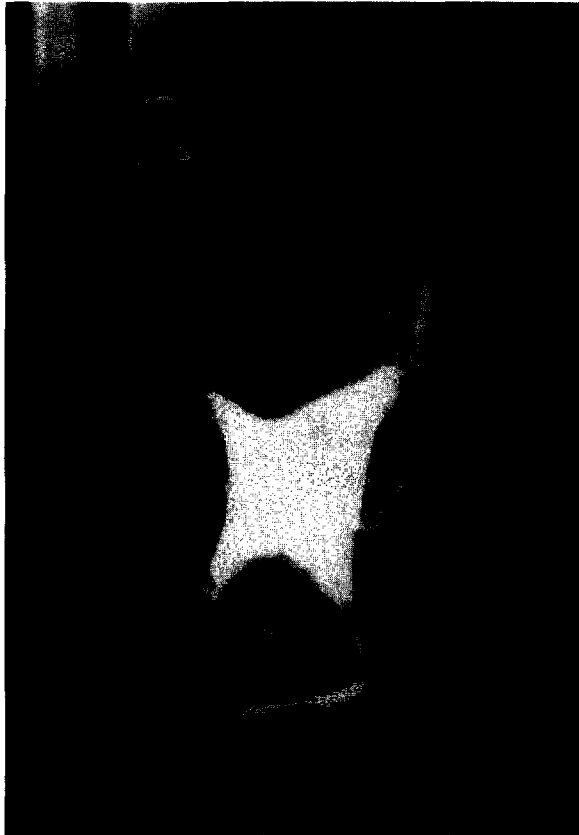


Fig. 3. Anteroposterior x-ray film of right hand with radiopaque material in the classic carpal tunnel. Note that the narrowest aspect of the carpal tunnel is at the level of the hook of the hamate (*H*).

either hematoxylin and eosin or Richardson's elastic trichrome, and viewed with a Zeiss Universal microscope (Carl Zeiss Inc., San Antonio, Texas).

Gross dissection. Three specimens were dissected to delineate the relationships of the fascial layers of the anterior aspect of the wrist and hand.

Statistical analysis. One-way analysis of variance was used to determine the possible differences between mean widths at the proximal extent, hook of the hamate, and distal extent of the carpal tunnel. Duncan's multiple range test was used to determine where, if any, differences occurred. Values are reported as mean \pm standard deviation.

Results

The portion of the flexor retinaculum consisting of the transverse carpal ligament and distal aponeurosis demonstrated a great degree of variation in size (Table I). It began an average of 11 mm distal to the capitate-

Table II. Width of the classic carpal tunnel*

Specimen No.	Proximal extent (mm)	Hook of hamate (mm)	Distal extent (mm)
1	26	20	25
2	24	20	25
3	23	18	25
4	24	21	28
5	25	21	24
6	26	19	24
Mean	24.7	19.8	25.2
SD	1.21	1.17	1.47

*Including that portion enclosed by the transverse carpal ligament and the distal (aponeurotic) portion of the flexor retinaculum.

lunate joint and extended to an average of 10 mm distal to the carpometacarpal joint of the long finger (Fig. 1). The fibers of the transverse carpal ligament attached to the proximal aspect of the pisiform in all specimens and ran distally for a variable distance before curving radially to cross the carpal arch.

Sagittal sections of gross specimens demonstrated thickening of the antebrachial fascia overlying the distal aspect of the radius (Fig. 2); distally it was continuous with the palmar fascia. The flexor retinaculum was deep to the antebrachial fascia and extended from the level of the distal radius to the level of the distal aspect of the metacarpal base of the long finger.

The proximal portion of the flexor retinaculum was composed of the deep investing fascia of the flexor compartment; its proximal margin was not always clearly defined. On gross dissection, the antebrachial fascia was inseparable from the anterior surface of the proximal aspect of the flexor retinaculum.

Histologic evaluation of the flexor retinaculum demonstrated large numbers of transversely oriented collagen fibers and an overall thickness approximately 10 times that of the antebrachial fascia. In contrast, the collagen fibers in the antebrachial fascia were oriented longitudinally, thereby allowing for histologic differentiation between the proximal flexor retinaculum and the antebrachial fascia.

Evaluation of AP x-ray films of the anatomic carpal tunnel containing contrast material demonstrated the dimensions of the carpal tunnel and its corresponding bony landmarks (Fig. 3). The mean width of the carpal tunnel was 25 ± 1.2 mm proximally, 20 ± 1.2 mm at the hook of the hamate, and 25 ± 1.5 mm at its distal extent (Table II). One-way analysis of variance showed that there was a difference

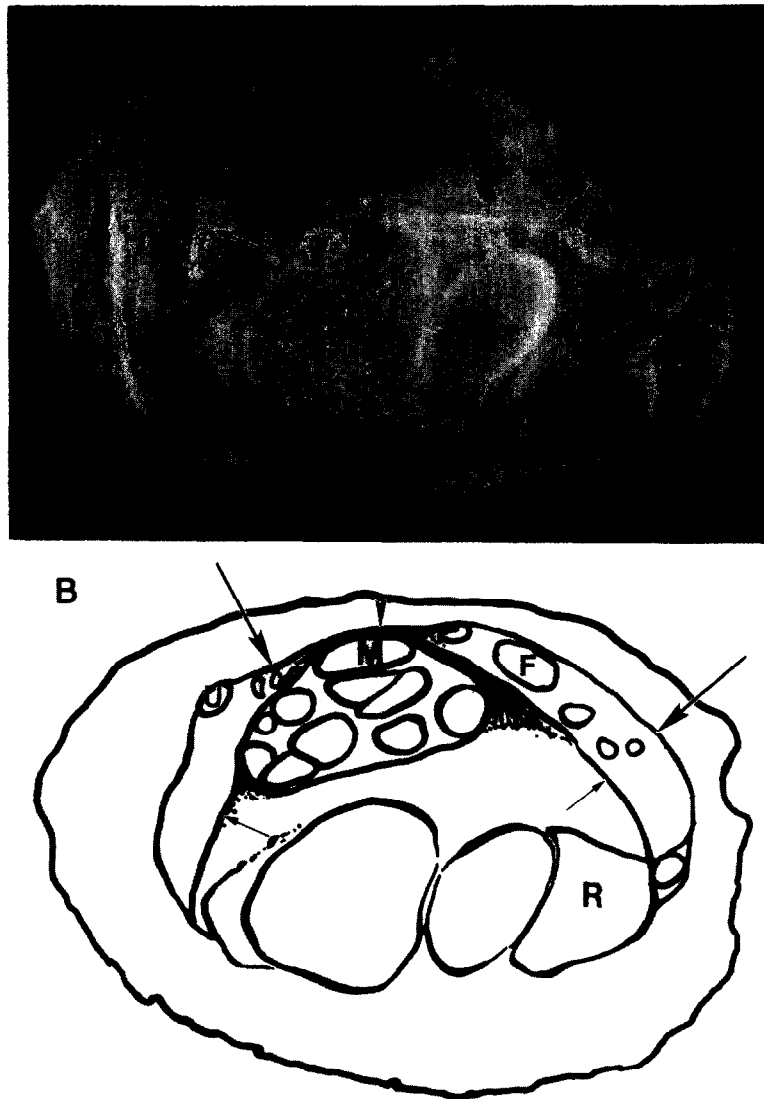


Fig. 4. A, Cross section of wrist at the tip of the radial styloid (*R*). B, Drawing of section shown in A. Note the nine flexor tendons and median nerve (*M*) enclosed in the functional carpal tunnel. The flexor retinaculum and antebrachial fascia are closely apposed anteriorly (*arrowhead*) and split medially and laterally. *Large arrows* show antebrachial fascia. *Small arrows* show flexor retinaculum. *F*, Tendon of flexor carpi radialis; *U*, tendon of flexor carpi ulnaris.

between carpal tunnel widths at the proximal extent, hook of the hamate, and distal extent ($p < 0.0001$). Multiple comparison analysis showed that the canal was narrowest at the hook of the hamate ($p < 0.05$). In lateral x-ray films the carpal tunnel sloped from a palmar to a dorsal direction as it progressed from proximal to distal.

Studies of cross-sectional anatomy at the tip of the

radial styloid demonstrated the presence of a sheath containing the nine digital flexor tendons and the median nerve (Fig. 4). This sheath was proximal to the transverse carpal ligament and was bordered dorsally by the lunate, scaphoid, and triquetrum. The palmar aspect of this sheath consisted of both the antebrachial fascia and the investing fascia of the forearm. The more superficial of these, the antebrachial fascia, enclosed

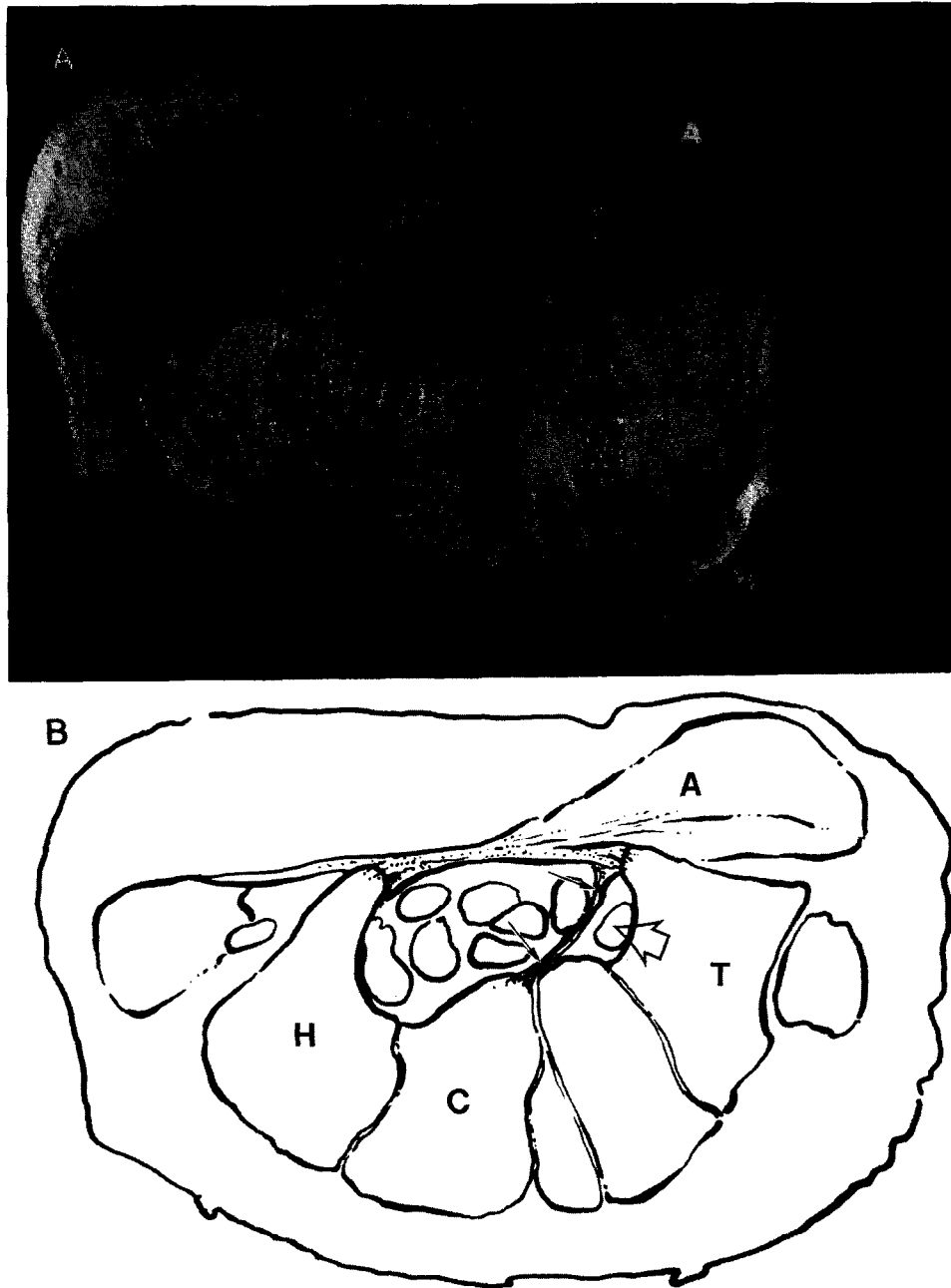


Fig. 5. A, Cross section at central portion of hook of hamate (*H*). B, Drawing of section shown in A. The transverse carpal ligament is seen passing from the hamate to the tubercle of the trapezium (*T*). Note the abductor pollicis brevis muscle (*A*) extending over and taking origin from the radial half of the transverse carpal ligament. *Dark arrows* show capitotrapezium ligament. *Open arrow* shows tendon of flexor carpi radialis. *C*, Capitate.

all the structures of the flexor compartment of the forearm, whereas the investing fascia enclosed only the contents of the carpal tunnel. These two fascial layers were closely apposed anteriorly, separated laterally and medially, and then became reapposed as they attached to the borders of the radius and ulna.

The deeper layer of the sheath formed by the investing fascia was continuous with the transverse carpal ligament. The fascia forming the palmar boundary of the carpal canal proximal to the transverse carpal ligament ranged in thickness from 0.4 to 1.0 mm, with a mean of 0.62 mm.

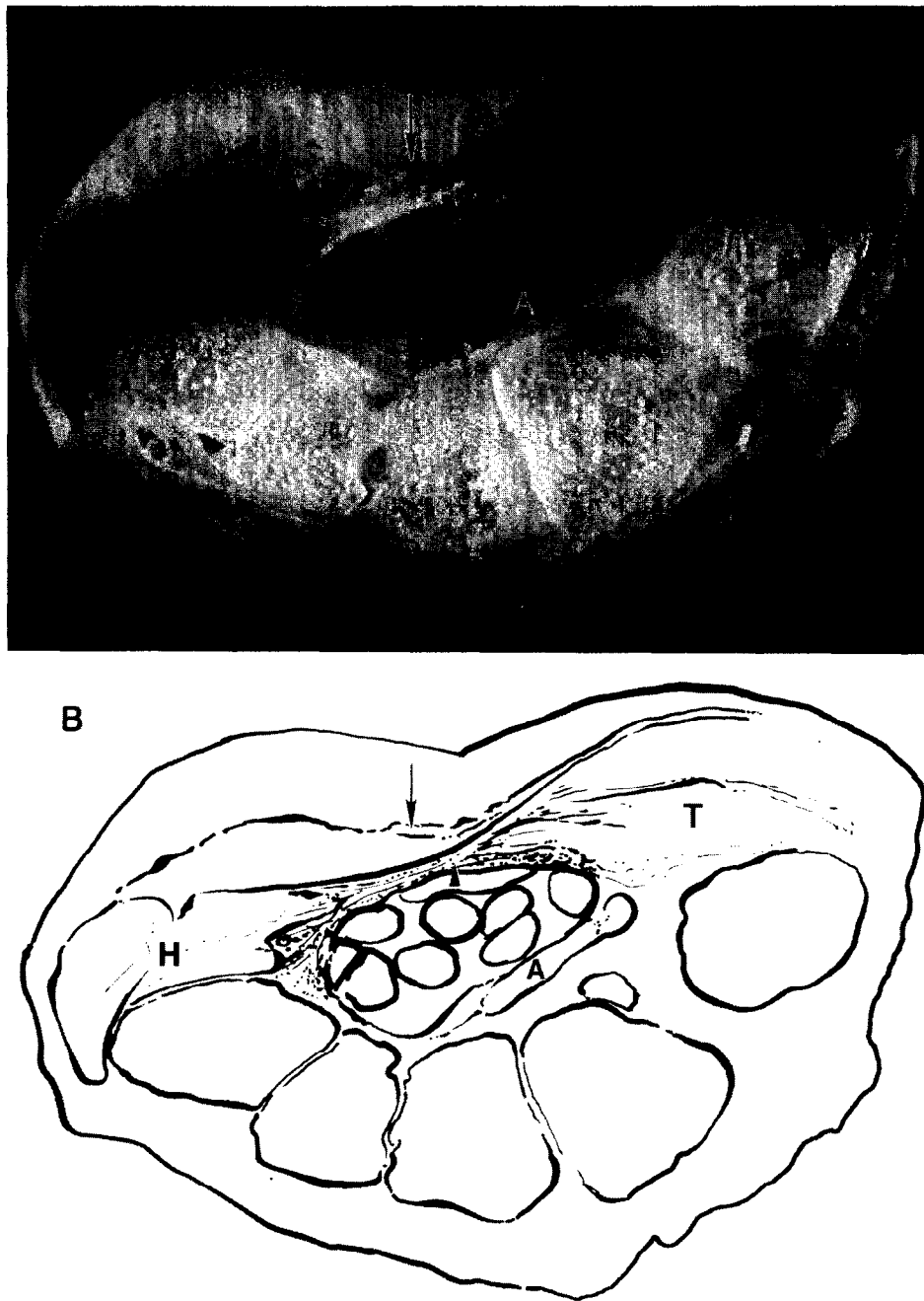


Fig. 6. **A,** Cross section through metacarpal bases. **B,** Drawing of section shown in **A.** Note the thenar (*T*) and hypothenar (*H*) muscles, forming a thick aponeurosis (*arrowhead*) that represents the distal extent of the flexor retinaculum. Superficially the palmar fascia (*arrow*) can be seen. *A,* Adductor pollicis muscle.

The carpal tunnel, at the level of the center of the hook of the hamate, was enclosed by the transverse carpal ligament on its palmar aspect (Fig. 5). The transverse carpal ligament passed from the hook of the hamate to the tubercle of the trapezium. The thenar muscles attached to the radial half of the transverse

carpal ligament. The hook and body of the hamate formed its ulnar and a portion of its palmar boundaries. The dorsal boundary was formed primarily by the capitate and, to some extent, the trapezoid. The transverse carpal ligament width ranged from 0.8 to 2.5 mm, with a mean of 1.52 mm.

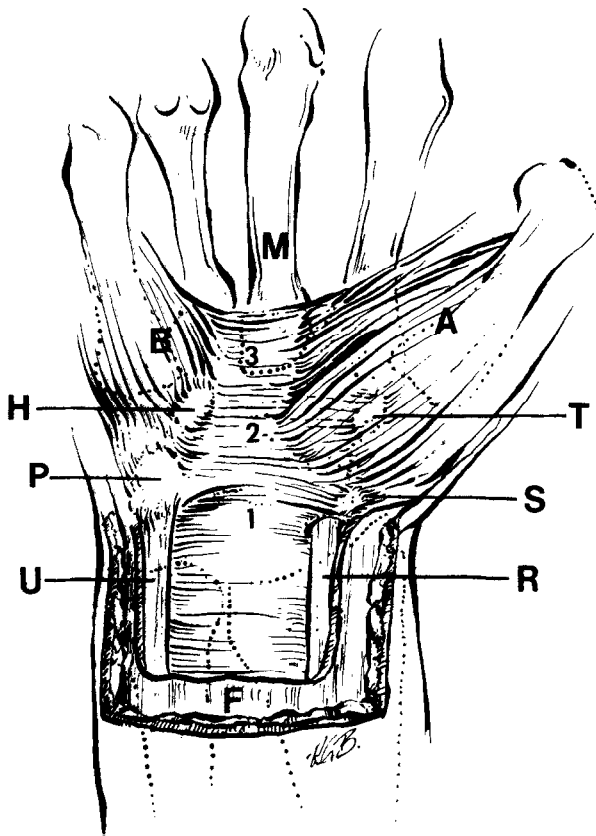


Fig. 7. Drawing demonstrating the three portions of the flexor retinaculum. The distal portion of the flexor retinaculum (3) consists of a thick aponeurosis between the thenar (A) and hypothenar (B) muscles. The thenar muscles attach to the radial half of the classic flexor retinaculum, composed of the distal portion of the flexor retinaculum (3) and the transverse carpal ligament (2). Bony attachments of transverse carpal ligament—pisiform (P), hamate (H), tubercle of trapezium (T), and tubercle of the scaphoid (S)—are also shown. The proximal portion of the flexor retinaculum (1) courses deep to the flexor carpi ulnaris (U) and flexor carpi radialis (R). The flexor carpi radialis tendon is shown as it pierces the flexor retinaculum at the junction of the proximal and middle portions to enter its fibroosseous canal. F, Antebrachial fascia; M, third metacarpal.

At the level of the metacarpal bases, the transverse diameter of the canal increased, whereas the vertical diameter remained roughly the same (Fig. 6). The metacarpals formed the dorsal boundary, with the adductor pollicis muscle intervening between the canal and the metacarpals. The thenar muscles overlay the palmar aspect of the radial three sevenths and the radial border of the canal. The hypothenar muscles overlay

the palmar aspect of the ulnar one seventh and the ulnar border of the canal. The thenar and hypothenar muscles appeared to take much of their origin from the distal aponeurotic portion of the flexor retinaculum. The central three-sevenths segment of the distal region of the flexor retinaculum was formed by a broad aponeurosis between the thenar and hypothenar muscles. The center of the aponeurosis ranged in thickness from 1.4 to 2.8 mm. It had a mean thickness of 1 mm (range, 0.7 to 2.5 mm) on the ulnar and radial margins.

The palmar fascia, which was continuous with the distal extent of the antebrachial fascia of the forearm, was superficial to this aponeurosis. Small, fibrous septa fused the palmar fascia to the flexor retinaculum at this level.

Discussion

The transverse carpal ligament is generally defined as the palmar boundary of the carpal canal. The commonly accepted limits of the transverse carpal ligament correspond to its bony attachments to the pisiform and hook of the hamate on the ulnar aspect and to the tuberosity of the scaphoid and ridge of the trapezium radially. In some writings, *flexor retinaculum* and *transverse carpal ligament* are accepted as synonymous terms.^{4, 6}

We observed two separate layers of fascia over the palmar aspect of the carpal canal. The more superficial layer comprises the thickened antebrachial fascia proximally and the palmar fascia distally. The deeper layer, which we call the flexor retinaculum, has three continuous portions. Proximally it is represented by a thickening in the deep investing fascia of the forearm. The transverse carpal ligament makes up its central portion, and the distal portion is formed by an aponeurosis between the thenar and hypothenar muscles (Fig. 7). Anteriorly the proximal portion of the flexor retinaculum is inseparable from the thickened antebrachial fascia. On the ulnar and radial aspects, however, the two become separated (Fig. 4). The antebrachial fascia takes a more superficial course to enclose the tendons of the flexor carpi radialis, the flexor carpi ulnaris, and the ulnar vessels and nerve. The deep investing fascia, on the other hand, takes a deeper course and encloses only the contents of the carpal tunnel.

The proximal and distal portions of the flexor retinaculum have not previously been described. The importance of the proximal and distal portions of the flexor retinaculum has been documented clinically for some time. Much of what is known today about carpal tunnel

syndrome is credited to the early work of Phalen.^{7, 8} He reported a case in which carpal tunnel release failed because of incomplete release of the distal fibers of the flexor retinaculum. In his description of surgical technique, he emphasized the importance of complete incision of the distal extent of the roof of the carpal tunnel, and he also supported release of the fascia proximal to the transverse carpal ligament. His writings suggest that the distal and proximal aspects of the fascia are important sources of carpal tunnel syndrome. Our study demonstrates that fascial components proximal and distal to the transverse carpal ligament are actually part of the flexor retinaculum and constitute proximal and distal extensions of the carpal tunnel.

Anatomically, there appear to be two locations in which median nerve compression is likely to occur in the wrist. The first is at the level of the proximal edge of the transverse carpal ligament. Morphologic changes in the median nerve have been previously observed at this location.⁸⁻¹¹ Immobilization in positions of marked flexion after distal radius fractures may also be associated with median nerve compression.^{12, 13} This area of transition between the investing fascia of the forearm and the transverse carpal ligament is the most probable site of flexion-induced deformation of the median nerve and may be responsible for provocation of Phalen's sign. Proximally, the flexor retinaculum is thinner and more mobile, spreading the anteriorly directed deforming forces of the flexor tendons over a greater area. A second potential site for median nerve compression is at the level of the hook of the hamate, where the canal was narrowest (Fig. 3), consistent with previous studies.^{2, 10} Anatomically, it may be considered the most constrictive portion of the carpal canal. Functionally, this site is not likely to be dependent on wrist position and may rely on synovial hypertrophy or other space-occupying pathologic conditions to exceed the critical volume of the canal at this level, leading to median nerve compression.

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