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Fibrous Structure and Connection Surrounding the Metacarpophalangeal Joint

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Abstract

The fibrous components of the metacarpophalangeal (MP) joint including the palmar plate, the collateral ligament and the dorsal plate were studied with particular attention paid to the fibrous structure of the fibrous tendon sheath and the deep transverse metacarpal ligament. The tough fibrillar structure around the MP joint, especially the force nucleus, consisted of three types of mixed fibers: the fibrous tendon sheath of the A1 pulley, the deep transverse metacarpal ligament, and the palmar plate. The tendon sheath was located on the ulnar side in the index and middle fingers, on the central position in the ring finger, and on the radial side in the little finger. These fibrous connections among the fingers formed a transverse arch in the hand. The palmar plate of the MP joint was relatively rigid and appears to function as a cushion when flexed. A fold-like protrusion of the synovial layer of the palmar plate of the MP joint had a meniscoid function, which was larger than that of the proximal interphalangeal joint. The capsule of the MP joint was thicker at the dorsal area, forming a dorsal plate, which is a sliding floor of the extensor mechanism and has a meniscoid function for joint congruity. The main lateral stabilizer consisted of collateral ligaments and accessory collateral ligaments anchored to the palmar plate. These structures act together as a “phalangeal cuff”, connecting the proximal phalanx to the metacarpal head and sta

KEYWORDS: metacarpophalangeal joint, collagen framework

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The fibrous components of the metacarpophalangeal (MP) joint including the palmar plate, the collateral ligament and the dorsal plate were studied with particular attention paid to the fibrous structure of the fibrous tendon sheath and the deep transverse metacarpal ligament. The tough fibrillar structure around the MP joint, especially the force nucleus, consisted of three types of mixed fibers: the fibrous tendon sheath of the A_1 pulley, the deep transverse metacarpal ligament, and the palmar plate. The tendon sheath was located on the ulnar side in the index and middle fingers, on the central position in the ring finger, and on the radial side in the little finger. These fibrous connections among the fingers formed a transverse arch in the hand. The palmar plate of the MP joint was relatively rigid and appears to function as a cushion when flexed. A fold-like protrusion of the synovial layer of the palmar plate of the MP joint had a meniscoid function, which was larger than that of the proximal interphalangeal joint. The capsule of the MP joint was thicker at the dorsal area, forming a dorsal plate, which is a sliding floor of the extensor mechanism and has a meniscoid function for joint congruity. The main lateral stabilizer consisted of collateral ligaments and accessory collateral ligaments anchored to the palmar plate. These structures act together as a "phalangeal cuff", connecting the proximal phalanx to the metacarpal head and stabilizing the MP joint.

Key words: metacarpophalangeal joint, collagen, framework

Each of the distal interphalangeal (DIP), proximal interphalangeal (PIP) and metacarpophalangeal (MP) joints of the finger has a characteristic fibrillar architecture (1) forming the transverse arch of the hand. In particular, the fibrillar architecture of the MP joint is anatomically distinct, joining with other fibrous structures around the MP joint in a way that is clinically significant. Although there have been several macroscopic and histological observations in the relevant medical literature (2), the nature of this fine fibrillar structure has not yet been fully clarified. In this study, we focused on the fine structure of the fibrous components, including the palmar plate, the collateral ligament and the dorsal plate, and their fibrillar connections with the fibrous tendon sheath of the flexor and the deep transverse metacarpal ligament (DTML).

Materials and Methods

Twenty-four hands and 96 MP joints, not including thumbs, were examined. These were obtained from one amputated hand (male, aged 56) and from 23 cadaveric hands (12 males and 11 females, aged 72 to 87 years, mean 82 years).

Thirty-two fingers of 8 hands were cut horizontally at the MP joint level and 48 fingers from 12 hands were cut sagittally. The metacarpal heads were removed in 16 fingers from 4 hands. After macroscopic observation, they were fixed in 10 % buffered formaldehyde overnight, and decalcified in a 10 % folic acid solution for 3-5 days. The samples for the histologic study were embedded in paraffin, cut into thin sections and stained with hematoxylin-eosin (H-E), Azan, Masson-trichrome and Safranin O. They were observed by light and polarized light

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microscopy. For scanning electron microscopy (SEM), the samples were dehydrated through a series of ascending concentrations of ethanol (50, 70, 95, 100 % for 30 min at each step), frozen for 5 min in tert-butylalchol, and cut into two pieces with a sharp razor blade. They were immersed in an aqueous solution of NaOH for 7 days and washed in distilled water for 2 days. After staining with 1 % tannic acid and 1 % OsO_4 (3), they were dehydrated with ethanol, critical-point dyed with liquid carbon dioxide, coated with Pt paradium, and observed with a scanning electron microscope (S-2300 type, Hitachi Ltd., Tokyo, Japan).

Results

The location of the fibrous tendon sheath on the palmar plate varied. When observed macroscopically and histologically from the palmar side, the tendon sheath was found to be located on the ulnar side of the index and middle fingers, in the center of the ring finger, and on the radial side of the little finger (Figs. 1 and 2). On the ulnar side of the index finger, both sides of the middle and ring fingers and the radial side of the little finger, these three fibrous components, tightly connected to each other, were clearly visible macroscopically. The fibers of all three consisted of strong fibrillar architecture what Zancolli (4) termed the 'force nucleus'. The fibrillar architecture of the radial side of the index finger and the ulnar side of the little finger possessed a comparatively simple structure without DTML. In the ring finger, the metacarpal head was located at the center of the palmar plate on the long axis of the exposed surface. However, in the

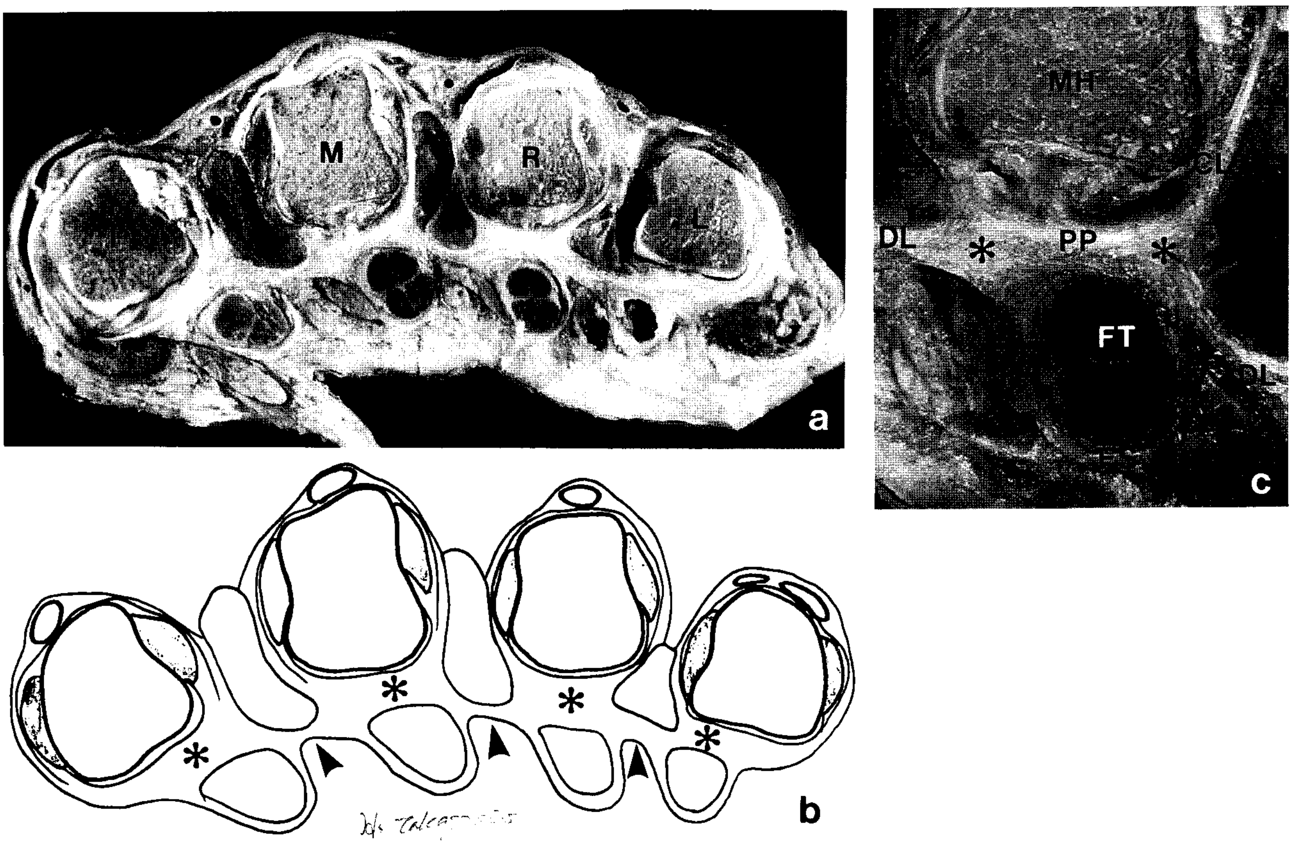

Fig. 1 Macroscopic observation around metacarpal head of the hand.
a) Macroscopic view of the horizontally cut surface at the metacarpal head (I: Index; M: Middle; R: Ring; L: Little finger). The cross section of the metacarpal head showed the relationships among the metacarpal head, the palmar plate, the fibrous tendon sheath and the deep transverse metacarpal ligament (DTML). **b**) Schematic representation (*: Palmar plate; ▲: DTML). **c**) Macroscopic view of the horizontally cut surface at the force nucleus (metacarpal head of the middle finger). CL: Collateral ligament; DL: Deep transeverse metacarpal ligament; FS: Fibrous tendon sheath; FT: Flexor tendon; MH: Metacarpal head; PP: Palmar plate; *: Force nucleus.

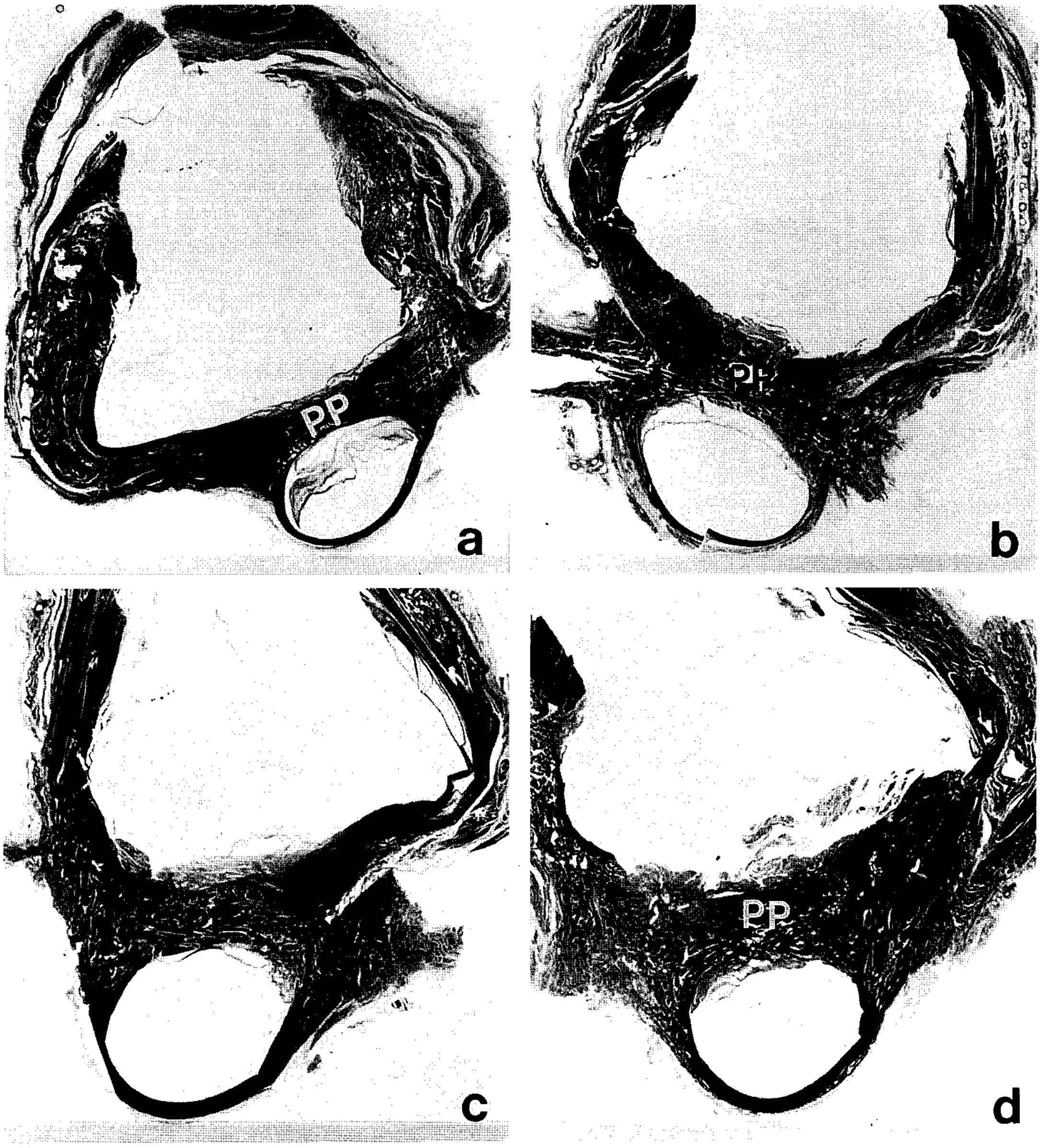

Fig. 2 Transverse section of the palmar plate (PP) of the metacarpophalangeal joint (Masson-trichrome). **a**) Index, **b**) Middle, **c**) Ring, **d**) Little.

index and middle fingers, the metacarpal head was located on the radial side, and on the ulnar side in the little finger. When observed macroscopically, the metacarpal head of the middle finger, a well identified force nucleus was formed by three fibrous components: the collateral ligament, the DTML and the fibrous tendon sheath.

In the central portion of the palmar plate exposed surface, longitudinally running fibers were visible between the transversely running fibers (Fig. 3a). On the ulnar side of the index finger, both sides of the middle and ring fingers, and the radial side of the little finger, three fibrous components from the palmar plate, the DTML and the fibrous tendon sheath were connected by the force nucleus, which appears to be the most rigid fibrous structure around the MP joint (Fig. 3b). The palmar plate consisted of three distinct layers of fibers from the palmar

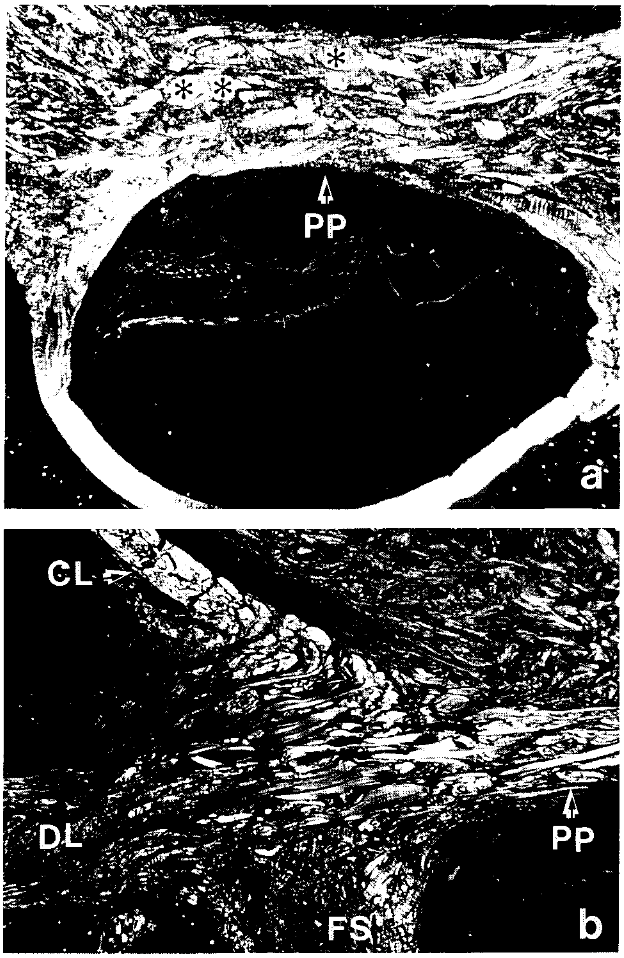

Fig. 3 Fibrillar connection observed by polarized light microscopy. **a**) Central portion of the palmar plate (horizontal section). Longitudinally running fibers (✻) are observed between the transversely running fibers (▼), **b**) Force nucleus (horizontal section). The palmar plate (PP), the deep transverse metacarpal ligament (DL) and the fibrous tendon sheath (FS) were connected by the force nucleus.

to the dorsal side: the outer, intermediate and inner layers. The fibers of the outer layer subtly changed, each fibers through connection with the DTML and the fibrous tendon sheath, in the index to the little finger. The fibers of the outer layer were longitudinally arranged, and interposed with the fibers from the DTML and the tendon sheath that was transversely arranged.

The fibrous structure of the palmar plate was more clear in the sagittal section of the MP joint (Fig. 4a). The outer layer of the palmar plate supplied anchors for the fibrous tendon sheath and the collateral ligament. The density of fibers in the outer layer decreased in the central

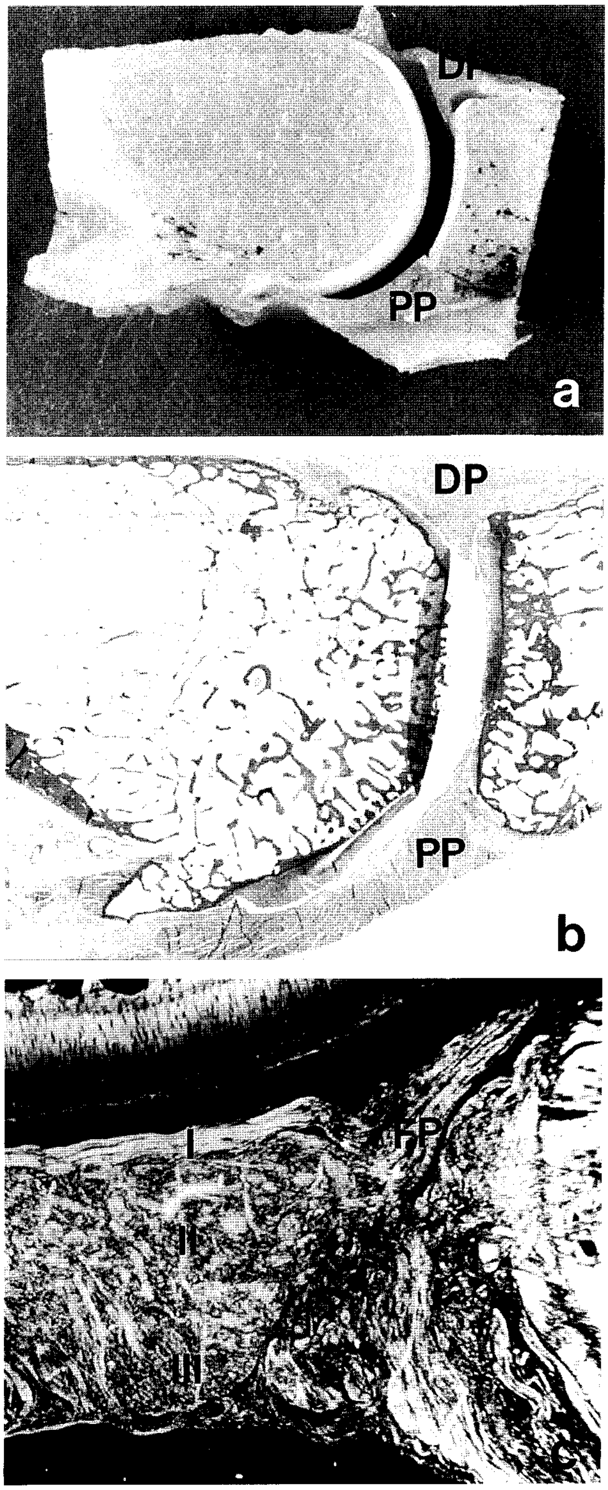

Fig. 4 Sagittal section of the metacarpophalangeal joint. **a**) Macroscopic view, **b**) Hematoxylin eosin, **c**) Polarized light microscopy of the palmar plate. DP: Dorsal plate; PP: Palmar plate; FP: Fold-like protrusion; I: Inner layer; II: Intermediate layer; III: Outer layer.

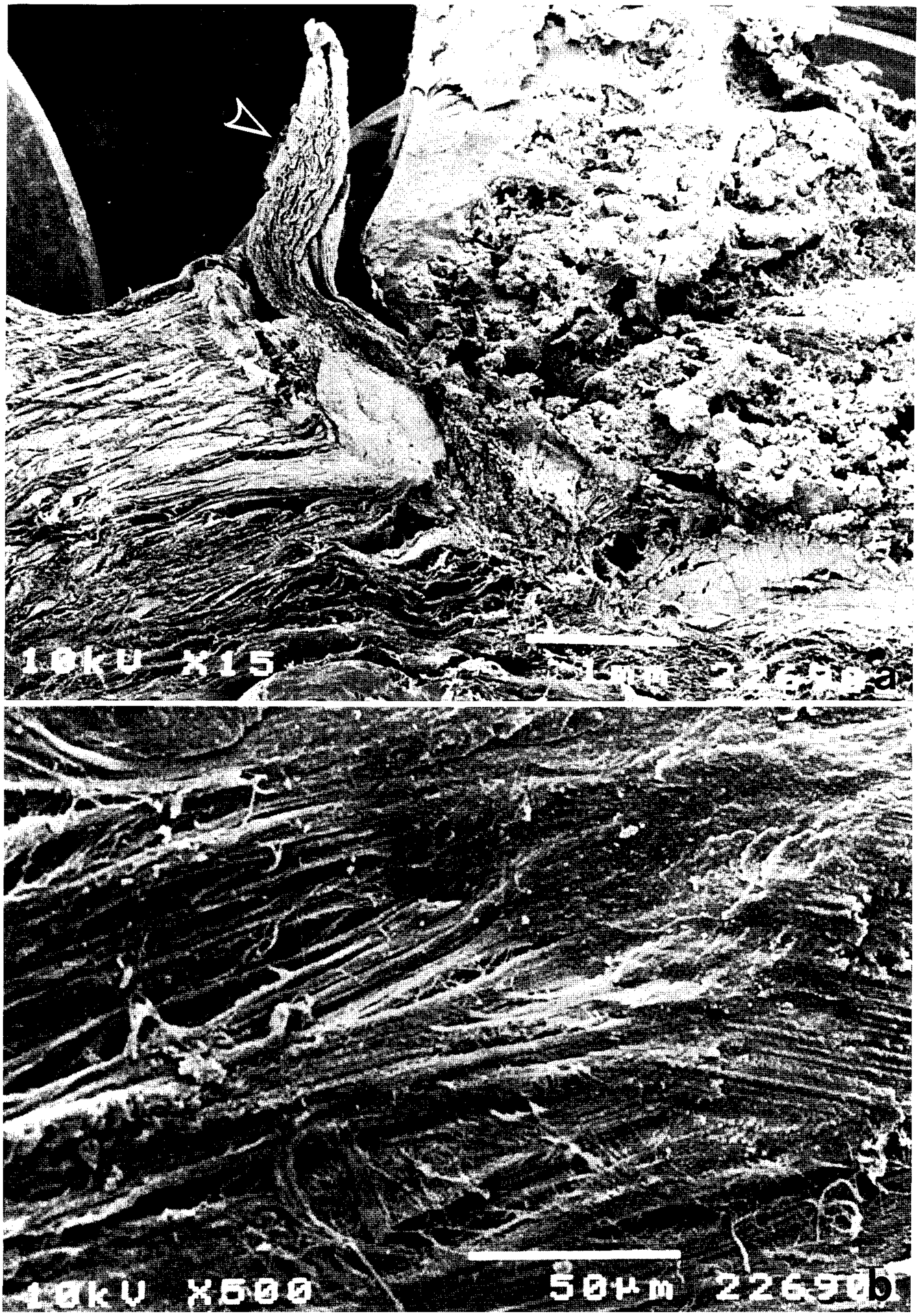

Fig. 5 Scanning electron microscopic observation at the anchoring area of the palmar plate to the proximal phalangeal base. **a**) Fold-like protrusion (▼) and anchoring to the proximal phalanx, **b**) The anchoring to the proximal phalanx by Sharpey fiber.

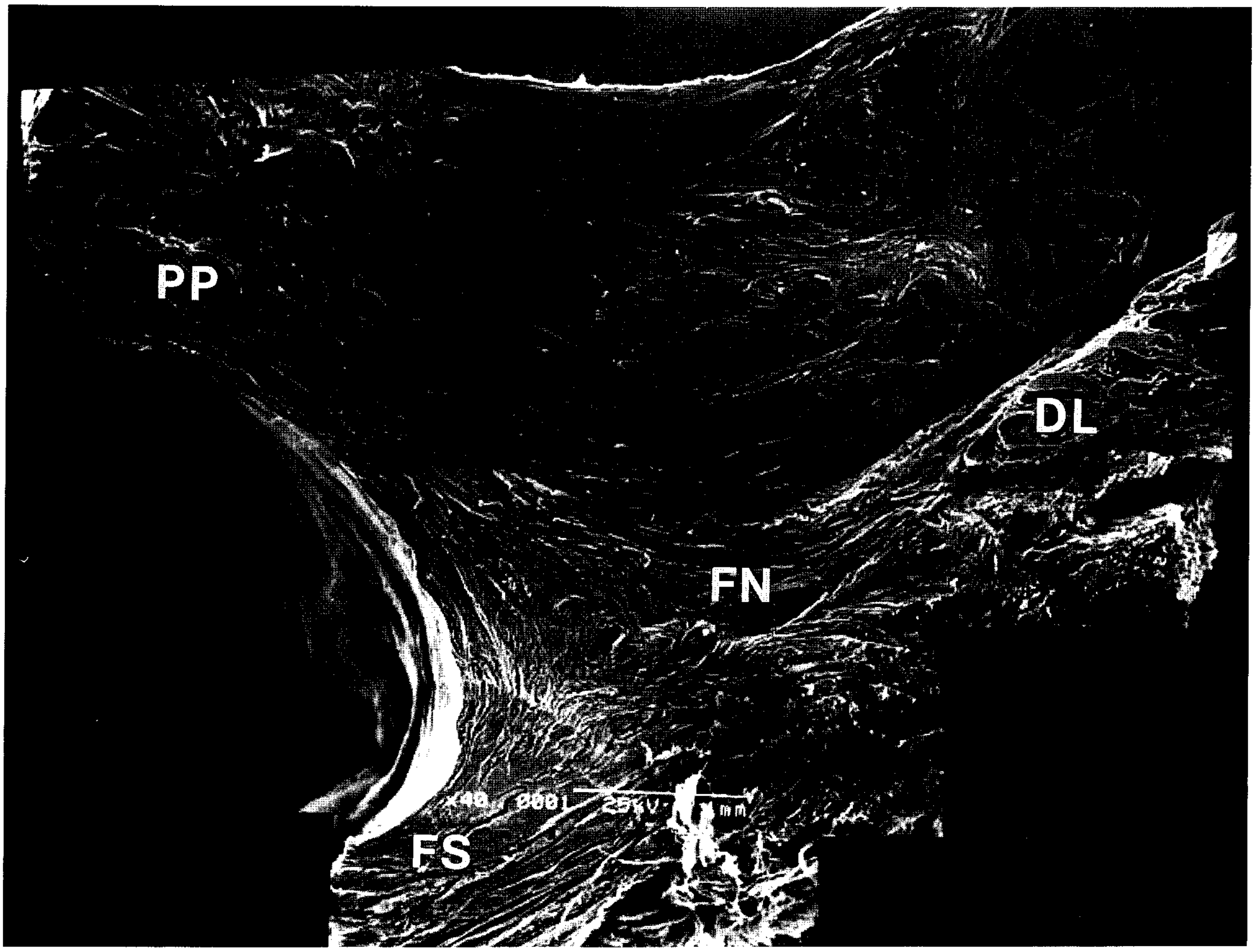

Fig. 6 Scanning electron microscopic observation of the force nucleus.
PP: Palmar plate; FS: Fibrous tendon sheath; FN: Force nucleus; DL: Deep transverse metacarpal ligament.

area. The inner layers formed a fold-like protrusion (1) which protruded over the articular cavity just proximal to the proximal phalangeal base. The inner layer of the palmar plate consisted of the synovial layer, which was continuous with the membranous portion (Fig. 4b, c). The fold-like protrusion was also observed by SEM in the sagittal section (Fig. 5a). The outer layer was also parallel to the longitudinal axis and anchored to the proximal phalangeal base.

The tight fibrillar structure, anchoring to the proximal phalangeal base as Sharpey fibers, was observed by SEM in the sagittally sectioned specimen (Fig. 5b). These fibers composed the intermediate layer, running longitudinally, and consisted of the proper palmar plate fiber. The intermediate layer sometimes consisted of two fiber groups; one running transversely, interspersed with the fibers of the DTML and the tendon sheath, and the other running longitudinally. The fibrillar connection of the force nucleus was clearly visible by SEM (Fig. 6). Each fibril from the palmar plate, the fibrous tendon sheath and the DTML formed the force nucleus.

The dorsal plate also consisted of three layers: an inner layer, connected to the synovial layer of the other area (the center of the inner layer consisted of the collagen fibrils and chondrocyte-like cells), an intermediate layer consisting of tough collagen bundles, and an outer layer connected with the fibrils of the MP joint capsule. SEM revealed a fine collagen meshwork on the surface of the inner layer (Fig. 7).

The area between the collateral ligament and the dorsal

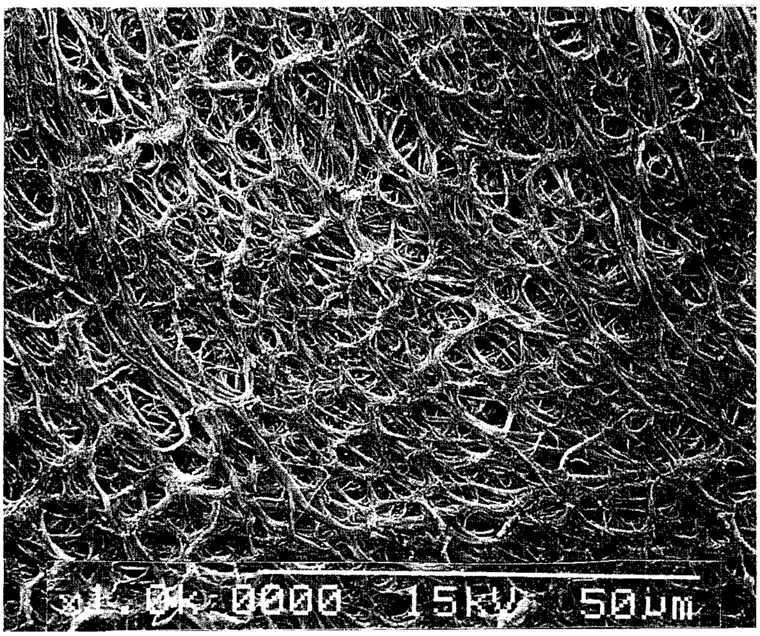

Fig. 7 The surface of the dorsal plate. Scanning electron microscopy revealed a fine collagen meshwork on the surface of the inner layer of the dorsal plate.

plate consisted of relatively loose connective tissue. The deep layer of this area consisted of synovial tissue.

There were few differences in the findings among the specimens we examined.

Discussion

Landsmeer (2) and Spinner (5) performed histological studies of the palmar plate. However, the fibrillar relation among the fibers of the palmar plate, the DTML and the fibrous tendon sheath has never been discussed. The location of the fibrous tendon sheath pulley on the palmar plate shows that it does not disturb the running way of the tendon by kinking the tendon in the frontal plane, but functions as a pulley in the sagittal plane (6, 7). The shift in position of the fibrous tendon sheath and palmar plate in our observation also seemed to result in effectiveness of finger constringency. The position of the fibrous tendon sheath on the palmar plate varied from finger to finger. The fibers of the palmar plate were connected to those of the fibrous tendon sheath, the DTML and collateral ligaments. These fibrous connections among the fingers formed a transverse arch in the hand.

The main and proper fibrous structure of the palmar plate in the MP joint is the intermediate layer. The outer layer intermingles with the fibers from the DTML and the fibrous tendon sheath. The strongest structure is that which Zancolli named the 'force nucleus' (4). The multidirectional arrangement of fibers around the MP joint permits multidirectional movement (8).

The MP joint lacks the so-called "check ligament" of the PIP joint; therefore, it cannot inhibit hyperextension. This structure of the palmar plate seems not to be designed for movement in a single plane, such as a hinge joint like the IP joint, but for the multidirectional movement of a condyloid joint, like the MP joint. It seems to be a strong stabilizer in circular or lateral movement and to have the rigidity to endure external force.

Clinically, knowledge of the exact location of the tendon sheath is necessary for volar exploration and subcutaneous tendon sheath release. The fold-like protrusion, which is located between the proximal phalangeal base and the metacarpal head of the MP joint, is comparatively thicker than that of the PIP joint (1). This protrusion consists of fibers mainly from the intermediate layer, thus, it possesses greater rigidity. It acts as a buffer when the finger flexes, and has a meniscoid function (9), acting as a stabilizer when the MP joint moves.

The collateral ligament also plays an important role as a stabilizer of MP joint movements. The collateral ligament of the MP joint is tight in the extended position and loose in the flexed position. In contrast, that of the PIP

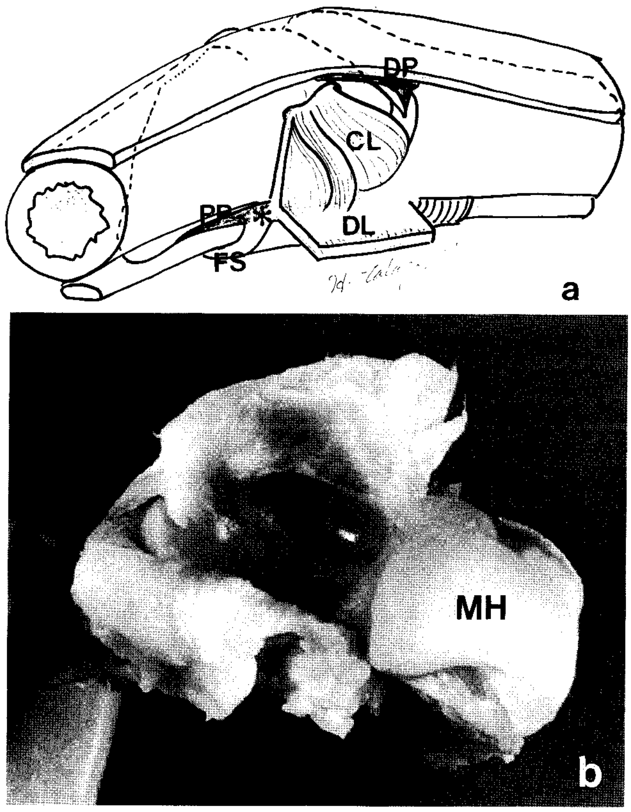

Fig. 8 The "phalangeal cuff" system.
a) Schematic representation of fibrous connection. DP: Dorsal plate; CL: Collateral ligament; DL: Deep transeverse metacarpal ligament; PP: Palmar plate; FS: Fibrous tendon sheath; **b**) The "phalangeal cuff" system is represented after removal of the metacarpal head (MH).

joint is loose in the extended position and tight in the flexed position (1). Therefore, the collateral ligament of the MP joint performs a stabilizing function in grasping. The accessory ligament of the MP joint becomes tightest in the hyperextended position. It acts not only as a stabilizer but as a suspender as it is a fibrous tendon sheath and continues from the palmar plate. They allow for effective movement and disperse excess force, keeping a stable relationship between the motor axis of the joint and the flexor tendon (2, 4, 10, 11). Furthermore, they increase the contact surface of the fibrocartilaginous articular facet together with the palmar plate and collateral ligament.

A part of the dorsal capsule of the finger joint, the "dorsal plate" (12, 13), forms a more developed meniscoid protrusion which increase joint adaptation and contact surface in the flexed position. In other words, they act as a fibrocartilaginous articular surface in the flexed position. Eaton termed this structure a "three-sided box", consisting of the bilateral collateral and accessory ligaments and the palmar plate and functioning to stabilize the PIP and DIP joints (14).

In the MP joint, the well-developed dorsal roof adds the residual fourth side forming a "phalangeal cuff" (Fig. 8). In the phalangeal cuff, the area between the three-sided box and the dorsal plate was the loosest area just like the rotator interval in the shoulder joint. The dorsal plate is reinforced by the sagittal band and the expansion hood. The dorsal component is important as a rivet of the extensor mechanism acting not only as a pulley and extensor of the MP joint but as a buffer for stress.

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