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Abstract

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KEYWORDS: human finger, proximal interphalangeal joint, volar plate, collagen framework

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Collagen Framework of the Volar Plate of Human Proximal Interphalangeal Joint

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The functional roles of the three-dimensional fibrillar ultrastructure of the proximal interphalangeal joint volar plates of human fingers were studied by light microscopy and scanning electron microscopy. The results revealed that the volar plate consists of three layers of fibers. The first layer forms an intracavity wall with two parts, the proximal "membranous portion", and the distal "meniscoid protrusion" that is separated from the middle phalangeal base by a "recess". The second layer contains the "check ligament", which lies parallel to the fibers of the tendon, anchors tightly into the middle phalangeal base, and protects the joint from hyperextension. The third layer connects to the fibers from the accessory ligament and ligamentous tendon sheath of the A3 pulley, perpendicularly crosses the fibers of the tendon, becomes the periosteum of the middle phalangeal base, and functions as a hanging support for the volar plate and as a gliding floor for the flexor tendon.

Key words: human finger, proximal interphalangeal joint, volar plate, collagen framework

Macrosopic and microscopic anatomy of the proximal interphalangeal joint (PIPJ) volar plate has been studied (1-3); however, the collagen fibrillar structure of the volar plate and its relationship to the ligaments have not been investigated, nor are there any descriptions of its ultrastructure in the literature. Recent advances in medical technology, not available to earlier researchers who defined the accepted model of the volar plate, have made it possible to clarify structure and function of the volar plate. PIPJ injuries such as volar plate tear, collateral ligament tear and fracture-dislocation are common and PIPJ impairment almost always results in impairment of the finger. When the surgical approach is required, the

techniques used must be very specific and care must be taken to preserve the volar plate to protect the joint and ensure congruence. A more precise knowledge of the ultrastructure can be expected to contribute to more effective, and perhaps less invasive treatments.

The collagen framework reflects the basic structure and function of connective tissues. The arrangement and distribution of collagen fibers in a joint provide clues as to the functions of the structure. The purpose of this study was to clarify the multi-dimensional nature of the volar plate of the PIPJ by analyzing collagenous structure, the surface structure of volar plate and the attachments to the middle phalangeal base and the proximal phalangeal body.

Materials and Methods

Specimens of PIPJ volar plates were obtained from 20 amputated fingers of five human hands from a group of two men and three women, aged from 20 to 70 years (average, 30 years). All amputations were performed to remove malignant tumors in the forearm. The disease did not extend to the hands. The samples for light microscopy were fixed with 10% neutral buffered formalin. Serial sections of the sagittal, horizontal and frontal planes (Fig. 1) were stained with hematoxylin-eosin (H-E), Mallory-Azan, Masson trichrome and safranin-O. Observations were made by ordinary light microscopy (LM) and polarized light microscopy (PLM).

Specimens sagittally sectioned with a sharp knife by hand were prepared for scanning electron microscopic (SEM) observation to study the fibrillar connection to the middle phalangeal base and proximal phalangeal body. They were washed in 0.2M cold cacodylate buffer and fixed with 2.5% glutaraldehyde. Each sample was freeze-dried, and examined by SEM (JSM-T20 type, JEOL Ltd. Tokyo, Japan, and S-2300, Hitachi Ltd. Hitachi, Japan).

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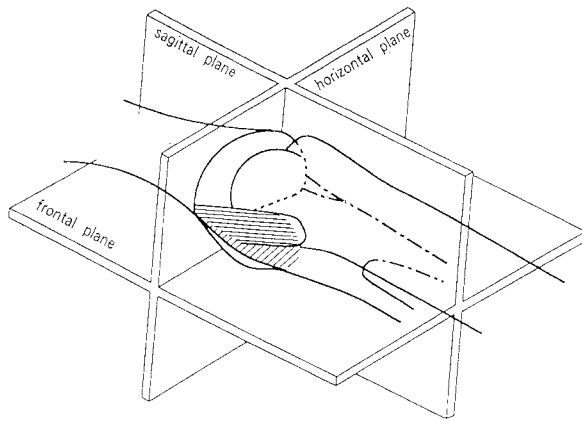


Fig. 1 Sagittal, horizontal and frontal planes of the proximal interphalangeal joint (PIPJ).

Results

The fibrillar structure of the PIPJ volar plate was found to be composed of three layers, from the dorsal surface (PIPJ cavity side) to the palmar side (tendon side) of the volar plates (Figs. 2-4).

Under macroscopic observation, sagittal sections of the PIPJ from the central portion are shown in Fig. 2. In the extended position, the gap between the membranous portion of the volar plate and the proximal phalangeal head disappeared. The volar plate appeared as a meniscus between the middle phalangeal base and the proximal phalangeal head. The form of the recess, the gap between the fold-like protrusion and middle phalangeal base, changed according to the position of the PIPJ from flexion to extension. The membranous portion was seen to ride over the cartilaginous portion during flexion of the PIPJ.

The first layer was composed of loose connective tissue which was well-vascularized and had a synovial coating on the internal surface of the joint. The characteristic structures of this layer were the membranous portion and the recess. Distally, they formed a fold-like protrusion and then interconnected with the middle phalangeal base at the margin of the joint cartilage. In the sagittally sectioned specimens (Figs. 3, 4), differences in fibrillar density between the cartilaginous and membranous por-

tions, especially between the distal and proximal attachments, were noted. The cartilaginous portion, a tight connective tissue, contained a high density of fibers and the membranous portion, a loose connective tissue, contained a low density. Fibers of the membranous portion ran along the dorsal side of the cartilaginous portion parallel to the flexor tendon and were anchored to the middle phalangeal base. This tight construction was due to both the narrow attachment area and the high density of the collagen fibers. The proximal connection to the proximal phalanx was loose but had a wide attachment area. This loose network of fibers formed a wider membranous portion, especially at the central portion, and gradually transformed into the membranous network of the first layer.

The second layer was composed of strands running sagittally in the same direction as those of the tendon (Figs. 4, 5). The fibers on both edges thickened to form the check ligament which arose from the proximal phalanx and was tightly anchored to the middle phalangeal base by



Fig. 2 Sagittal section of the PIPJ of a finger. The proximal direction is to the right. A: extension position, B: flexion position (★: cartilaginous portion, ☆: membranous portion). PIPJ: See Fig. 1.

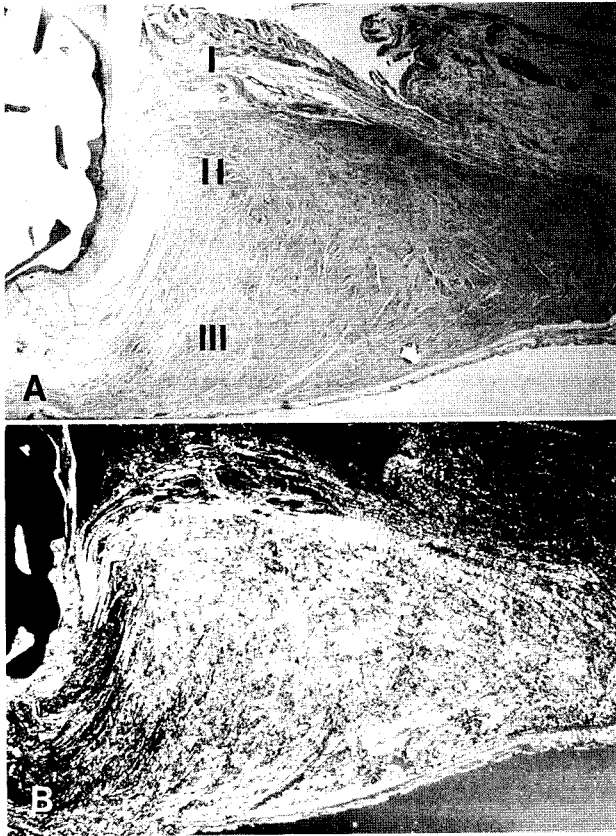


Fig. 3 Sagittal section of the volar plate. A: HE staining, B: polarized light microscopy. Note the difference of the fibrillar density between the cartilaginous portion and the membranous portion.

Sharpey's fibers (Fig. 6). At the central parts of the proximal portion, the fibers interconnected loosely but widely to the proximal phalangeal body (Fig. 7). Along both edges of the second layer, the fibers of the check ligament originating from the proximal phalanx were anchored to the middle phalangeal base (Fig. 8).

The third layer of fibers, which formed the palmar side of the volar plate, were composed of strands that crossed the longitudinal axis of the tendon perpendicularly and were bound to the fibers originating from the accessory ligament and ligamentous tendon sheath of the A3 pulley (Figs. 5, 9). The strands converged at the distal portion as they entered the periosteum at the middle phalangeal base.

Four sagittal sections of a volar plate cut in various planes (Fig. 5) showed the longitudinal axes of different fibers and also clearly showed the differences in the depths of the three layers in each section. The depth of the fibers in the first layer was thicker at the central part and thinner at both edges, especially in the proximal membranous portion. The first layer was defined as the inner wall of the PIPJ including the intermediate gap between the middle and proximal phalanges and excluding the cartilaginous portion. The fibers in the first layer effectively formed an intracavity wall and recess within the PIPJ.

The articular surface of the first layer was clearly seen by SEM. The width of the synovial membrane fold was roughly 20 to 30 μm . The direction of the synovial membrane fold was perpendicular to the tendon in the

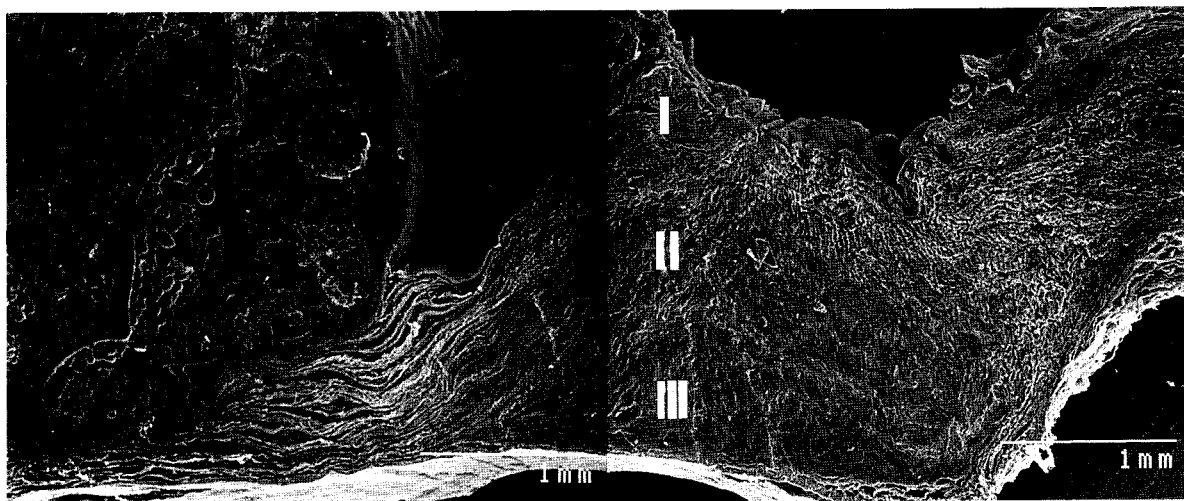


Fig. 4 Sagittal section of the PIPJ volar plate via scanning electron microscopy. PIPJ: See Fig. 1.

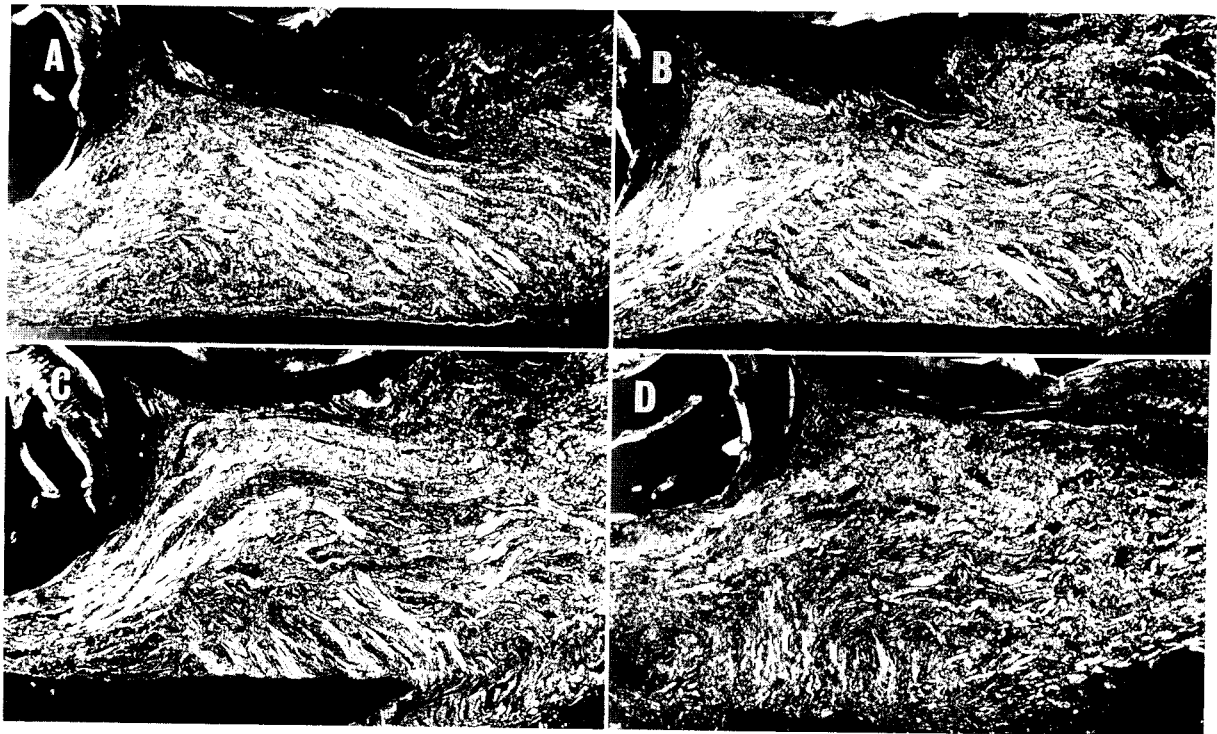


Fig. 5

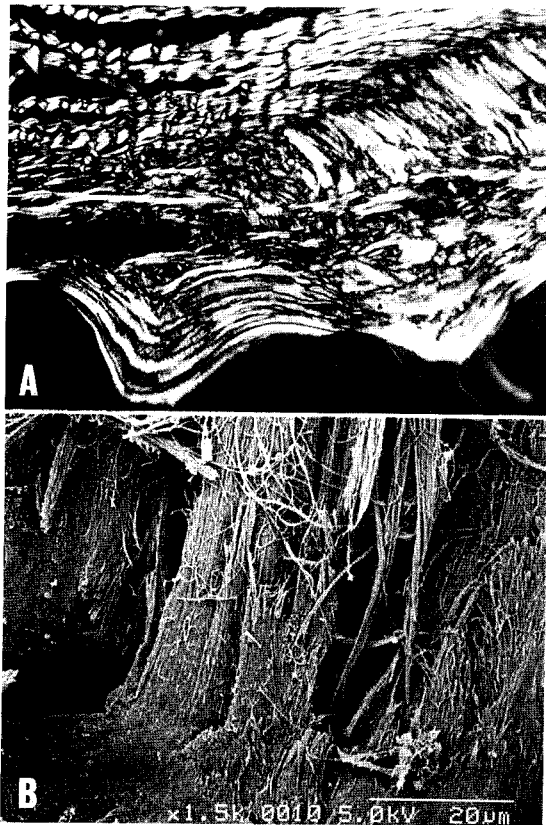


Fig. 6

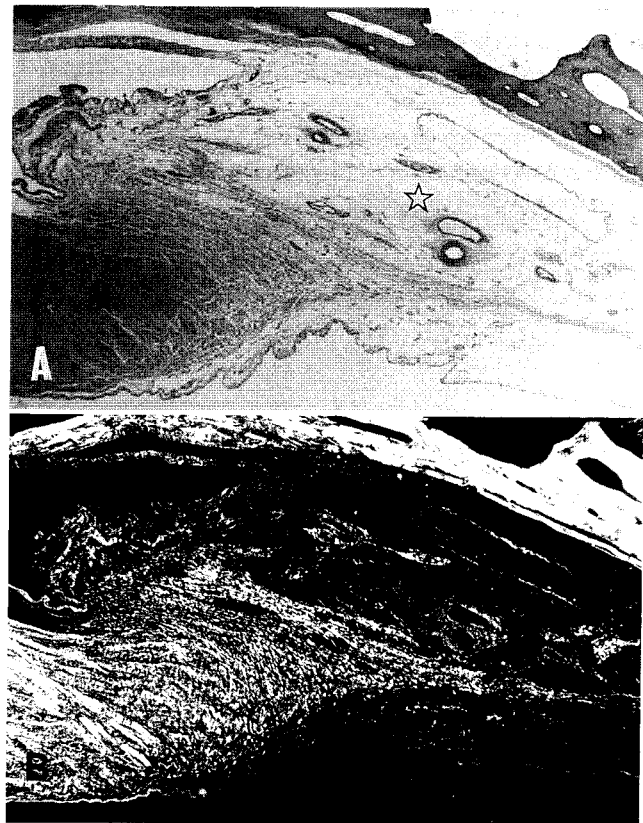


Fig. 7



Fig. 8

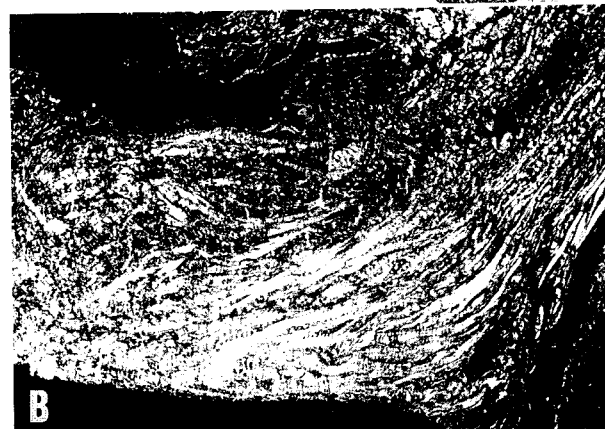
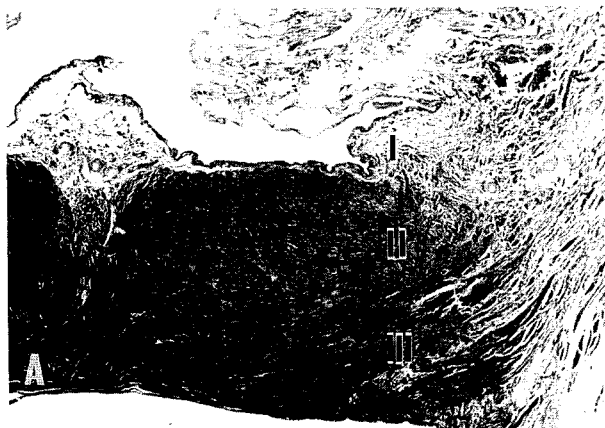


Fig. 9

Fig. 8 Frontal section of the volar plate (arrow: check ligament).

Fig. 9 Cross section of the volar plate.

Note the connection between the third layer and the accessory ligament. A: Mallory-Azan staining, B: polarized light microscopy.

Fig. 10 Articular surface of the PIPJ volar plate. A: scanning electron microscopy, B: enlarged view. PIPJ: See Fig. 1.

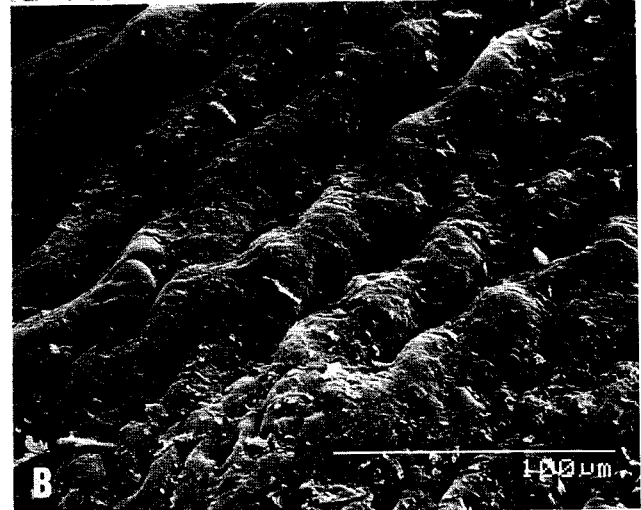
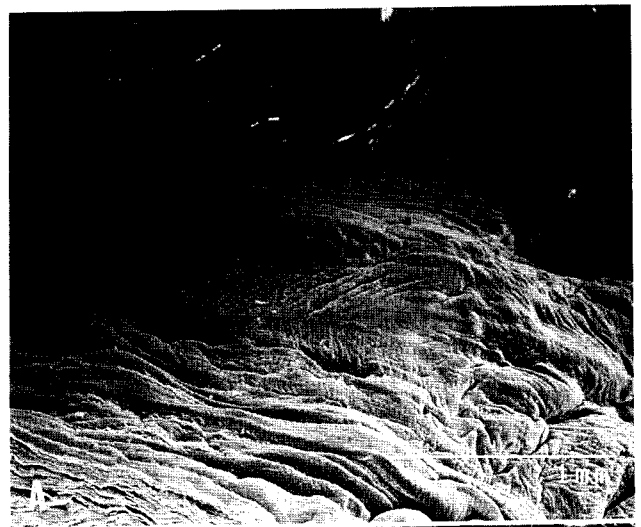


Fig. 10

Fig. 5 Sagittal section of the volar plate of the PIPJ. A: central portion, B: on the condyle, C: check ligament insertion, D: accessory ligament insertion. PIPJ: See Fig. 1.

Fig. 6 Sagittal section of the anchoring to the middle phalangeal base. A: polarized light microscopy, B: scanning electron microscopy.

Fig. 7 Proximal anchorage to the proximal phalanx. A: HE staining, B: polarized light microscopy (★: cartilaginous portion, ☆: membranous portion).

central area. The fold was continuous along the inner corner of the volar plate and the collateral ligament (Fig. 10).

Discussion

A three-layer functional model of the PIPJ volar plate should prove to be more useful to surgeons than the current two-part, distal-proximal model. The three-dimensional collagen framework of the volar plate is shown in Fig. 11.

The volar plate of PIPJ consists of two parts, distal and proximal (3-5). The distal part, the so-called "cartilaginous portion", corresponds to the fibrous cartilaginous plate. The proximal part is a non-cartilaginous membrane and is therefore softer and more flexible. The distal fibrocartilaginous part is so thick and stiff that it bends only slightly on flexion of the joint (6). However, we observed that the membranous part continued through the first layer of the cartilaginous part. The dorsal surface of the volar plate consists of the first layer, which extends from the membranous part to the recess. The inner side of the first layer serves an important role as the synovial membrane of the joint. This is why it is most important for surgeons to repair injury to the volar plate using sutures that maintain the integrity of each layer.

The volar plate is tightly inserted into the distal side of the joint, suspended at its lateral margins by the accessory and collateral ligaments, and restrained proximally by bilateral check ligaments. It forms a semi-rigid floor into which the lateral capsule is anchored, creating a

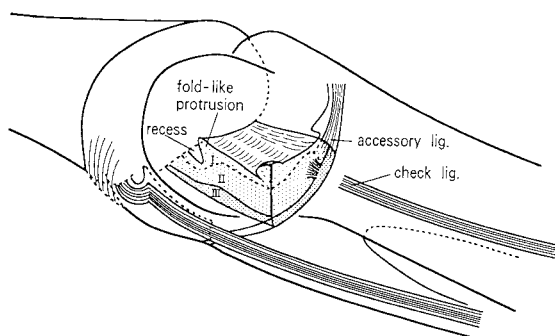


Fig. 11 Schematic representation of the PIPJ volar plate. Note the collagen framework (I: first layer, II: second layer, III: third layer). PIPJ: See Fig. 1.

mobile box around the PIPJ. This complex resembles an armchair where the seat represents the volar plate, the back represents the base of the middle phalanx, and the arms represent the collateral-accessory ligament system (5). Only the distal fibrocartilaginous part was reinforced by the collateral ligament radiating from the sides (6).

In the PIPJ, both the volar plate and the tendon sheath are anchored proximally into the proximal phalanx, quite independently of the distal free border of the tendon sheath on the proximal phalanx. The volar plate extends with two proximal reins into the palmar surface of the proximal phalanx just inside the wall of the tunnel. The strongly anchored suspension system of the volar plate was also demonstrated by the suspension ligaments that covered the collateral ligaments on their lateral aspects. Furthermore, the fibers belonging to the same layer as the collateral ligaments contribute significantly to the volar plate (2). These reports and our results indicate that the volar plate is firmly anchored to the bone at both ends and is hung by the suspension system from the side.

In terms of function, the volar plate provides both mobility and stability of the finger joint. It is of primary importance in static resistance to hyperextension and control of lateral instability (7, 8). To date the function of the volar plate has been discussed as not only in terms of its three-layer structure, but also its cartilaginous and membranous parts. The function of its two parts differs as follows: The membranous part of the volar plate has an accordion design which facilitates flexion (3). On bending movements it is slackened, allowing the distal fibrocartilaginous part to be displaced proximally. As flexion proceeds, the membranous part is bent around so that on maximum flexion it is folded between the bone to which it is attached and the fibrocartilaginous plate (6). Our study also confirms past descriptions of this anatomical structure.

Firstly, regarding the relationship between structure and function, our study clearly shows that this accordion function depends on the first layer. The distal area which protrudes toward the proximal joint surface of the middle phalangeal bone was called the "meniscal leaf" and had the same function as the meniscoid (3). We think that it is, in fact, the protrusion of the synovial fibrous layer and therefore it should be called a "fold-like protrusion" serving as a cushion between the middle phalangeal base and the proximal phalangeal head during flexion of the PIPJ. It was determined that the fibers in the first layer effectively form an intracavity wall and recess within the

PIPJ which moves in connection with the membranous portion. Furthermore, the first layer has a meniscoid function of the volar plate during flexion, as suggested by Gad (1) and Bowers *et al.* (3).

Secondly, our histological observation shows that the stability of the volar plate depends on the second layer which seems to act as a check ligament. Another important role of the check ligament is that it protects the vessels of short and long vinculae (5, 9). Furthermore, it seems reasonable to expect that there is a structural restraint in the PIPJ, such as a check ligament, which can be adjusted by the length and strength of the respective fibers to prevent hyperextension (2).

Thirdly, concerning the suspension system, the third layer of the volar plate plays an important role both in the connection to the lateral wall of the joint including the accessory ligament and in the sliding floor of the flexor tendon. The distal fibrocartilaginous part, which supports the volar side of the joint, forms the dorsal wall of the tendon sheath in which the flexor tendons slide (6). The fibers in the third layer are considered to simultaneously aid the tendon by functioning as a gliding floor and by moving in concert with the accessory ligament as it is drawn toward the dorsal portion during extension.

From a clinical standpoint, an accurate understanding of the joint's stability is essential to diagnose correctly and initiate proper treatment. Initial treatment, duration of immobilization and prognosis are directly related to the postreduction stability of the injured joint (5). Our fibrillar structural theory makes it easier to understand the onset mechanism of these injuries.

A discussion of the pure extension injury at the PIPJ was offered for the first time in 1936 and the major static role of the volar plate-collateral ligament complex was emphasized (7, 10). Forced hyperextension of the fingers can cause rupture of the volar plate in the PIPJ at either its distal or proximal end. The precise site of rupture of the volar plate, however, is still controversial (7, 8, 11). The Instron-controlled variable-rate-loading hyperextension studies by Bowers *et al.* suggest that rapid-loading produces a clear, anatomic failure site of the distal volar complex, whereas slow-loading produces gradual attenuation of the proximal attachments (3). The isolated volar plates ruptured under a load of 5 to 8 kg in the fingers; they were as strong as the collateral ligaments. The role of the volar plates in maintaining the stability of the joint is equally as important as the collateral ligaments. It is apparent from these tests, as well as from observations

made at operation, that rupture of both the collateral ligament and volar plate can occur either at the origin or insertion (6). Modification of Bower's system for PIPJ injuries is present. The location of the tear varied (12).

Minimal further loading produced a longitudinal tear at the junction of the proper collateral and accessory ligament; the middle phalanx, pivoting on the proper collateral origin, tended to subluxate dorsally, leaving the volar plate and accessory ligament complex volarly. Dorsal dislocation required incision of the lower third of the fibers of the origin of the proper collateral ligament. In each case, the joint remained stable to lateral stresses when returned to a normal position (3). Lateral instability of PIPJ depends on the degree of injury to the collateral ligament and the volar plate. Distal collateral ligament tear was sometimes accompanied with a partial tear of the volar plate (13, 14). A lateral or jack-knife dislocation described above is one of the two types of ligamentous injuries. The other is a dorsal or sagittal dislocation. We believe that the direction of a partial tear in the volar plate and collateral ligament (14) and the direction of a partial tear in the avulsed collateral ligament and disrupted volar plate in the case of irreducible PIPJ palmar dislocation (15), follow the longitudinal direction of the fibers of the third layer.

The majority of the failures occurred across the entire face of the distal insertion of the volar plate into the middle phalanx, often with avulsion of a volar flake of metaphyseal bone or cartilage covering the volar tubercle (3, 16). The avulsion-fracture in injuries of the PIPJ in clinical cases was therefore probably due to the tight anchor to the middle phalangeal base of the volar plate and the collateral ligament, especially to the second layer of the volar plate. This fracture due to hyperextension stress to the PIPJ was more easily understood by our observation of Sharpey's fibers shown in Fig. 6, which anchor this layer including the check ligament.

A precise understanding of the anatomy of the volar plate of the PIPJ is necessary to effectively treat the pathological problems in that lesion, such as ligament and volar plate injuries. The volar plate, which consists of synovial membrane as the first layer, its check ligament as the second layer and accessory collateral ligament connections to the volar plate as the third layer, represents the key to the three-box system (5) of the PIPJ. Our study shows that there are three fibrillar layers in the volar plate and that each layer has its own characteristic function. Our theory of the stratified structure of the volar plate

suggests that the layers may be separated by force, but further investigation is needed. In cases of volar plate injury, we may have to repair each layer individually. In clinical cases, the approach must be specific and based on exact knowledge of the anatomy. The volar plate has important roles in the PIPJ and must be carefully preserved to protect the joint and ensure congruence.

References

1. Gad P: The anatomy of the volar part of the capsules of the finger joints. *J Bone Jt Surg* (1967) **49B**, 362-367.
2. Landsmeer JMF: Atlas of Anatomy of the Hand. Churchill Livingstone, Edinburgh, London and New York (1976) pp 179-215, pp 238-263.
3. Bowers WH, Wolf JW, Nehil JL and Bittinger S: The proximal interphalangeal joint volar plate: I. An anatomical and biomechanical study. *J Hand Surg* (1980) **5A**, 79-88.
4. Kuczynski K: The proximal interphalangeal joint. *J. Bone Jt Surg* (1968) **50-B**, 656-663.
5. Eaton RC: Joint Injuries of the Hand, Charles C Thomas, Publisher Springfield (1971) pp 9-34.
6. Moberg E and Stener B: Injuries to the ligaments of the thumb and fingers. *Acta Chir Scand* (1953) **106**, 166-186.
7. Kaplan EB: Extension deformities of the proximal interphalangeal joints of the fingers. *J Bone Jt Surg* (1936) **18A**, 781-783.
8. Bowers WH: The proximal interphalangeal joint volar plate: II. A clinical study of hyperextension injury. *J Hand Surg* (1981) **6A**, 77-81.
9. Kamata Y: Microvascular study on volar plate of the proximal interphalangeal joint. *J Kyoto Prefect Univ* (1988) **97**, 479-493 (in Japanese).
10. Manset MF: Volar aspect of the proximal interphalangeal joint. *Bull Hosp Jt Dis Orthop Inst* (1984) **44**, 309-317.
11. McCue FC, Honner R, Johnson MC Jr and Gieck JH: Athletic injuries of the proximal interphalangeal joint requiring surgery. *J Bone Jt Surg* (1970) **52A**, 937-955.
12. Liss FE and Green SM: Capsular injuries of the proximal interphalangeal joint. *Hand Clin* (1992) **8**, 775-768.
13. Hashizume H, Akabori O, Kondo Y, Aoike K, Yamamoto K, Munetomo K, Akagi K, Yokoto T, Sato K and Kobika K: Collateral ligament injuries of the proximal interphalangeal joint. *J Jpn Soc Surg Hand* (1985) **2**, 493-496 (in Japanese).
14. Ruby LK: Common hand injuries in the athlete. *Orthop Clin North Am* (1980) **11**, 819-823.
15. Ostrowski DM and Neimkin RJ: Irreducible palmar dislocation of the proximal interphalangeal joint: A case report. *Orthopedics* (1985) **8**, 84-86.
16. Hashizume H, Nagasawa D, Wake H, Hara S and Akabori O: Study of middle phalangeal base fracture. *J Jpn Soc Surg Hand* (1991) **8**, 709-713 (in Japanese).

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