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Histological anatomy of the triangular fibrocartilage complex of the human wrist

T. Nakamura and Y. Yabe

Department of Orthopaedic Surgery, School of Medicine, Keio University, 35 Shinanomachi, Shinjuku-ku, Tokyo 160-8582, Japan

Summary. The triangular fibrocartilage complex (TFCC) was studied in serial histological sections of the human wrist to reveal its three-dimensional fine structure. The TFCC consisted of a fibrocartilaginous disc proper and other fibrous components. Three-dimensionally, the distal portion of the TFCC had a hammock-like contour that partially surrounded the carpus; while the proximal ligamentous portion corresponding to the radioulnar ligament connected the radius to the ulna. The radioulnar ligament originated at the ulna from both the fovea and the basistyloid. The fibres first gathered and then bifurcated palmarly and dorsally, enclosing and partially coalescing with the proximal side of the disc before inserting around the distal rim of the sigmoid notch of the radius. The meniscus homologue, which corresponded to the ulnar internal wall of the wrist joint, was derived from a loose synovial fold adapting to the stresses from radioulnar deviation. The distal side of the disc consisted of a dense population of chondrocytes in a collagen matrix, while the proximal side was rather rich in fibres directed radioulnarly. Inside the TFCC were loose connective tissues. The histological arrangement of the TFCC is compatible with its function of supporting the carpus, stabilizing the joints and allowing smooth motion of the wrist.

Key words: Triangular fibrocartilage complex (TFCC) – Histology – Three-dimensional structure – Wrist function

Introduction

Triangular fibrocartilage complex (TFCC) is a fibrocartilage and ligament structure at the ulnar side of the human wrist, separating the radiocarpal and distal radioulnar joints (Palmer and Werner 1981; Nakamura 1995; Nakamura et al. 1996; Ishii et al. 1998). Although its structure and kinematic behaviour has been controversial, most investigators agree that the TFCC stabilizes the ulnocarpal and distal radioulnar joints, distributes load between the carpus and ulna, and permits complex movements of the wrist as well as prono-supination of the forearm (Kauer 1975; 1980; Palmer and Werner 1981; Kaplan and Taleisnik 1984; Kauer 1992). We previously reported the functional anatomy of this complex (Nakamura 1995; Nakamura et al. 1996). Three dimensionally, the distal side of the TFCC formed a hammock-like concavity to support the ulnar carpus; the proximal side of the TFCC connected the radius to the ulna as the radioulnar ligament (Nakamura and Makita 2000); the ulnar side of the TFCC consisted of the floor of the extensor carpi ulnaris sheath (ECU subsheath) with the thickened joint capsule, corresponded to a functional ulnar collateral ligament (UCL). The disc proper, the base of the distal side of the TFCC, showed little distortion during rotation. In contrast, the origin of the radioulnar ligament and the UCL twisted during rotation. The distal aspect of the disc is considered to be under pressure from the carpus (Chidgey et al. 1991; Mikić et al. 1992), while the proximal side of the TFCC may be affected by a radioulnar directional tensile force. These forces are thought to influence the histological differences on the proximal and distal sides of the TFCC.

Several investigators have described the histological fine structure of the TFCC in both the fetus and adult (Mohiuddin and Janjua 1982; Garcia-Elias and Domènech-Mateu 1987; Benjamin et al. 1990; Kuhlmann et al. 1990; Chidgey et al. 1991; Hogikyan and Louis 1992; Mikić et al 1992). Few studies have addressed the histological differences between the proximal and distal sides of the TFCC with respect to its three-dimensional (3-D) shape (Nakamura and Makita 2000). As the carpus had been removed before sectioning in most of these studies,

Correspondence to: T. Nakamura
E-mail: tn8@acsu.buffalo.edu

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the altered 3-D shape of the TFCC could affect the histological appearance of the fine structure.

Some controversy about the location and form of the radioulnar ligament has also remained. Several reports asserted that the ligamentous tissues lie dorsally and palmarly adjacent to the disc on the distal aspect representing the radioulnar ligaments (Palmer and Werner 1981; Benjamin et al. 1990; Chidgey et al. 1991; Mikić et al. 1992). Others described a superficial portion of the distal radioulnar ligaments (Hagert 1994; Ishii et al. 1998) as distinguished from the deep portion originating from the ulnar fovea. Garcia-Elias and Domènech-Mateu (1987) located the radioulnar ligament just proximal to the disc on axial sections. No obvious connection was noted between the superficial portion and the ulnar styloid macroscopically (Nakamura 1995; Nakamura et al. 1996; Ishii et al. 1998;

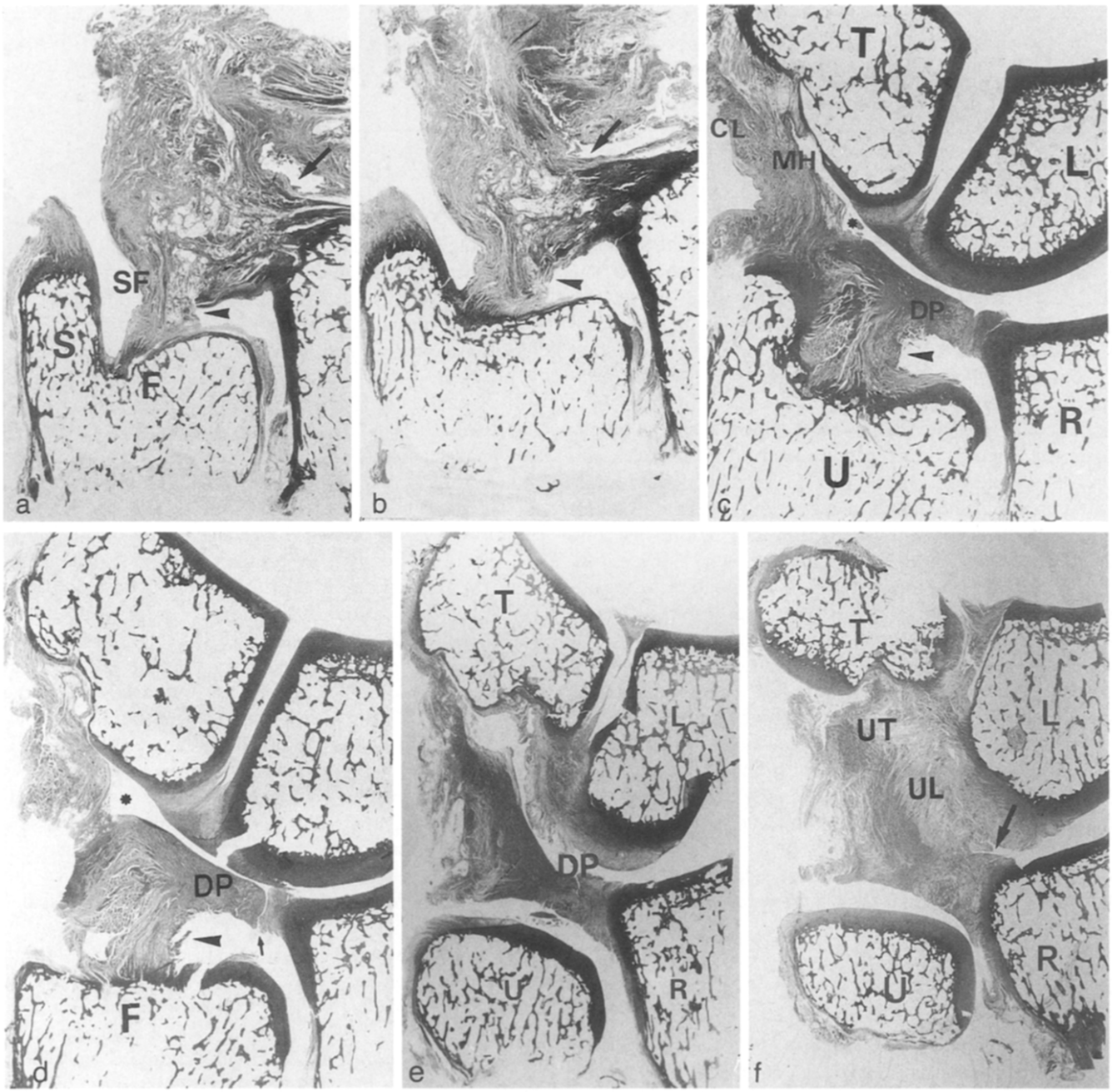

Fig. 1. Coronal serial sections of the TFCC (azan staining, original magnification ×2).
a: 2 mm from the dorsal edge; **b:** 3 mm from the dorsal edge; **c:** 6 mm from the dorsal edge; **d:** 9 mm from the dorsal edge; **e:** 10 mm from the dorsal edge; **f:** 11 mm from the dorsal edge. S = styloid of the ulna; F = fovea of the ulna; SF = sheath floor of the extensor carpi ulnaris; R = radius; U = ulna; L = lunate; T = triquetrum; CL = thickened ulnar joint capsule; DP = disc proper; MH = meniscus homologue; UL = ulnolunate ligament; UT = ulnotriquetral ligament. Large arrows indicate that the ligamentous portion lies besides the distal side of the disc proper. Arrowheads indicate the radioulnar ligament and asterisks demonstrate the prestyloid recess. In Fig. 1 d, there is a tear in the disc (small arrow).

Nakamura and Makita 2000). By definition, the radioulnar ligament must connect the radius to the ulna, and an adequate serial histological study should distinguish the course of the ligament.

We therefore examined histologically the microstructure of the TFCC. Special attention was paid to the difference between the proximal and distal side of the TFCC, and to the reconstruction of the 3-D configuration of the TFCC aided by both coronal and sagittal sections.

Materials and methods

Five right and two left wrists were obtained from seven fresh-frozen human cadavers; one woman and six men aged 17 to 56 years (mean 33 years). There was no history of wrist disease or trauma. The specimens were fixed in a neutral position with two Kirschner wires inserted through the ulna into the radius in order to prevent changes in ulnar variance from rotation at the radioulnar joint. The wrists were preserved in phosphate-buffered 10% formalin, decalcified 2 weeks, then embedded in paraffin with removal of the Kirschner wires. Specimens were sectioned into 10 μ thickness using a microtome (Hacker 5030 microtome, Hacker Instrument, Fairfield, NJ). Serial coronal sections of the TFCC including the radius, ulna, lunate, and triquetrum were taken at 1 mm intervals for 12 mm, beginning 1 mm from the dorsal edge in the five specimens. The other two wrists were examined in serial sagittal sections from the lunate facet of the radius to the ulnar edge of the wrists. Sections were stained with haematoxylin-eosin and azan. The microstructure of the TFCC was analysed via light microscopy and subsequently photographed.

Results

The TFCC was located in an area surrounded by the radius, ulna, lunate and triquetrum on the serial coronal sections (Fig. 1).

On the section 2 mm from the dorsal edge of the TFCC, the most dorsal section of the TFCC exhibited a loose connective tissue structure of nearly triangular shape (Fig. 1 a). The radioulnar ligament originated vertically from the fovea of the ulna. There was no horizontal connection of the TFCC to the ulnar styloid process on this section. The floor of ECU sheath also appeared as vertically oriented fibres from the dorsal area of the fovea of the ulna. On sections 2 to 4 mm from the dorsal edge, dense collagen fibres ran distoulnarly from the radial rim to the triquetrum, which corresponded to the dorsal ligamentous tissue beside the distal surface of the disc proper (Figs. 1 a, b). On the sections 3 and 4 mm from the dorsal edge, the fibrocartilaginous disc, enclosed by the fibrous tissues, was seen (Fig. 1 b). Other parts of the complex consisted of loose connective tissue on these sections.

On the section, 6 mm from the dorsal edge, the disc was located centrally, the meniscus homologue lay distally, the ulnar joint capsule lay ulnarward and the origin of the radioulnar ligament was seen between the proximal side of the disc, the ulnar fovea and styloid process (Fig. 1 c). The origin of the foveal fibres of the radioulnar ligament arose nearly vertically, while those from the styloid base arose more horizontally. They then gathered, curled and coalesced into the proximal side of the disc. The radioulnar ligament origins to the ulna demonstrated a robust direct bone-ligament connection. The disc, more fibrocartilaginous, was thin radially and thick ulnarly. The distal-ulnar end of the disc transited to the meniscus homologue, and the proximo-ulnar side connected to the radioulnar ligament. So, the ulnar side of the disc proper seemed to be an extensive system both distally and proximally. From the tip of the ulnar styloid process, fibres of the thickened ulnar joint capsule arose nearly vertically, then integrated with the meniscus homologue which was a synovial fold. The prestyloid recess appeared in the meniscus homologue in coronal sections 6 to 8 or 9 mm from the dorsal edge of the TFCC (Figs. 1 c, d). In most specimens, the prestyloid recess was a synovial-lined pit in the distal aspect of the TFCC that connected the hyaline cartilage at the tip of the ulnar styloid with the radiocarpal joint. It represented an atavistic remnant of the ulnocarpal joint of lower primates. The internal portion of the TFCC enclosed by the disc proper, meniscus homologue, thickened joint capsule and radioulnar ligament, consisted of loose connective tissue which was previously described as *the ligamentum subcruentum* (Kauer 1975, 1980, 1992).

In the high magnification analysis (×100) of three subjects, the distal side of the disc was rich in chondrocytes and chondro-matrix with fewer fibres than on the proximal side of the disc where less chondroid infiltrated fibres were oriented in a radial-ulnar direction (Fig. 2). The other two subjects also demonstrated chondro-matrix in the proximal side of the disc but rather more fibrous than the distal side.

On the section 9 mm from the dorsal edge, the TFCC again appeared triangular in shape with a vertical origin from the ulna corresponding to the origin of the palmar portion of the radioulnar ligament (Fig. 1 d). There was also loose connective tissue in the area ulnarly from the disc and distally to the radioulnar ligament.

On the sections at 10 to 12 mm from the dorsal edge, the origin of the TFCC from the ulna had disappeared (Figs. 1 e, f). On the sections at 11 and 12 mm from the dorsal edge, the ulnolunate and ulnotriquetral ligaments were seen. The palmar ligamentous portion of the ulnotriquetral ligament adjacent to the distal side of the disc, ran towards the triquetrum (Fig. 1 f).

On the sagittal section of the TFCC, the disc lay between the lunate and the ulna (Fig. 3). The ligamentous tissue extending from the disc palmarly and dorsally attached to the carpus, not to the ulna. On the radial sagittal section of the TFCC, the radioulnar ligament formed a single layer on the proximo-palmar and proximo-dorsal side of the TFCC coalescing centrally into the disc.

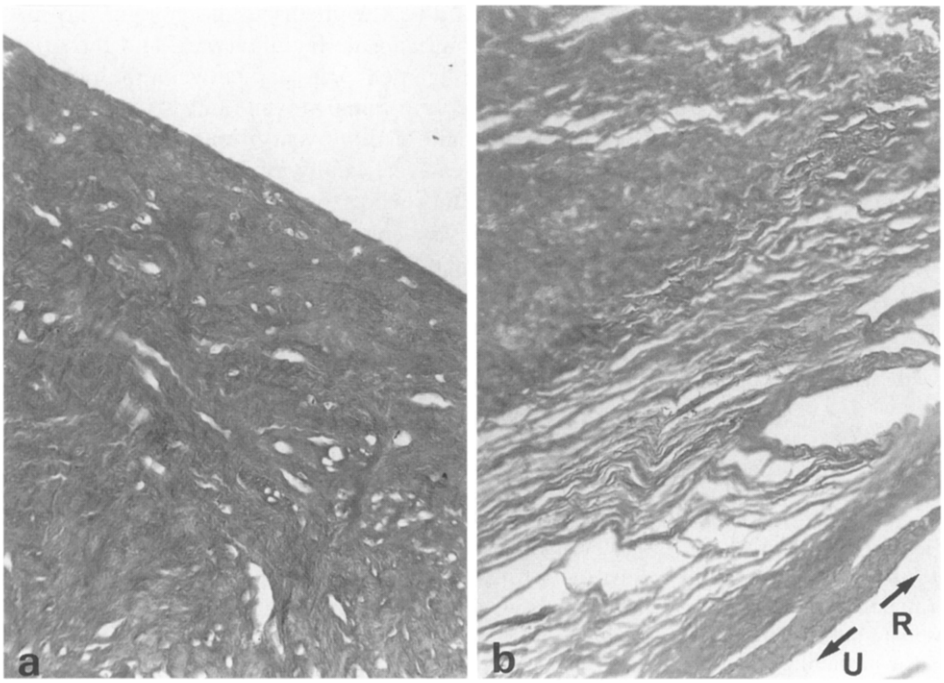

Fig. 2. a) The distal side of the disc proper is a dense matrix with interposed chondrocytes. The direction of the fibres is not obvious. b) The proximal side of the disc proper has fewer chondrocytes and the fibres are oriented radio-ulnarward (arrows). R = radius; U = ulna. (azan staining, original magnification ×100)

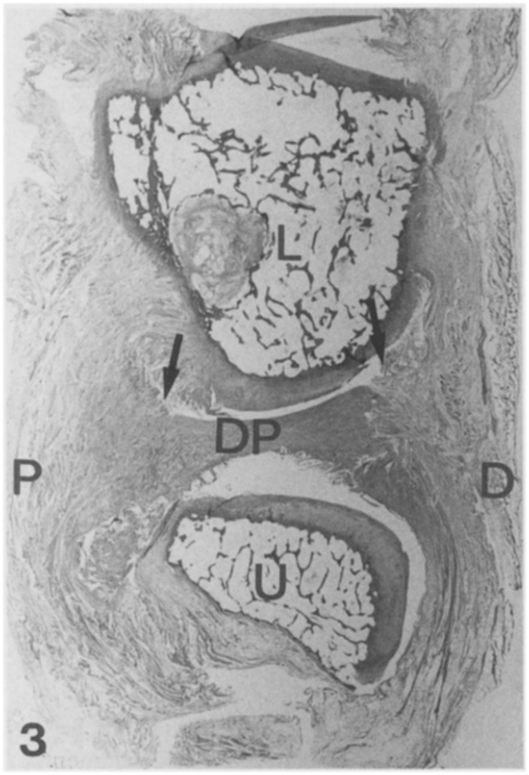

Fig. 3. The sagittal section of the TFCC (haematoxylin-eosin staining, original magnification ×2). Arrows point out the ligamentous portions beside the disc proper, which attach to the ulnar carpus not to the ulna. DP = disc proper; L = lunate; U = ulna; P = palmar; D = dorsal.

Discussion

It is generally agreed that the TFCC consists of a fibrocartilaginous disc and surrounding fibrous structures (Kauer 1975, 1980; Palmer and Werner 1981; Mohiuddin and Janjua 1982; Garcia-Elias and Domènech-Mateu 1987; Benjamin et al. 1990; Chidgey et al. 1991; Hogikyan and Louis 1992; Kauer 1992; Mikić et al. 1992; Nakamura 1995; Nakamura et al. 1996). However, the histological detail of this complex is still controversial. In previous papers, the histological differences between the central and peripheral side of the disc were well described (Benjamin et al. 1990; Chidgey et al. 1991; Mikić et al. 1992). Chidgey et al. (1991) demonstrated that the centre of the disc (80% of area) was avascular and composed of a dense chondrocyte-collagen matrix in which the fibres were oriented in a wavy, trampoline-like pattern. The peripheral (dorsal and palmar) side of the TFCC consisted of longitudinal fibres oriented in a radioulnar direction. They concluded that the central region of the disc bore multidirectional compression force, while the dorsal and palmar tissues adjacent to the disc, affected by tensile force, acted as the radioulnar ligaments. This assumption is supported by several authors (Benjamin et al. 1990; Mikić et al. 1992). However these studies paid little attention to the 3-D structure of the TFCC as the carpus was excluded during the preservation, embedding and sectioning of the specimens (Mohiuddin and Janjua 1982; Benjamin et al. 1990; Chidgey et al. 1991). As this may allow the 3-D shape of the TFCC to flatten (Kauer 1975, 1980; Naka-

mura and Makita 2000), the histological appearance on the proximal and distal side of the TFCC may be altered.

In the present study, the TFCC was serially sectioned from the dorsal to palmar aspects in both coronal and sagittal planes with the surrounding bones included to preserve 3-D details. The distal side of the TFCC consists of the fibrocartilaginous disc, meniscus homologue, ulnolunate and ulnotriquetral ligaments. This forms a hammock-like contour to surround and support the carpus as described in our anatomical studies (Nakamura 1995; Nakamura et al. 1996). On the proximal side of the TFCC, the radioulnar ligament originates nearly vertically from a broad area of the ulnar fovea and more horizontally from the basistyloid (Fig. 4).

The disc disto-centrally was formed of dense chondromatrix with fewer fibres, while proximo-peripherally the proportion of the fibrous component oriented in the radioulnar direction increased. This suggests that the distal side of the disc develops as fibrocartilage (Chidgey et al. 1991) or hyaline-like cartilage (Benjamin et al. 1990; Mikić et al. 1992) to resist the pressure from the ulnar carpus. This histological arrangement allows the distal surface to support the carpus and to resist distortions during rotation (Nakamura et al. 1999). The proximal side of the disc, which was composed of radioulnar directed fibres, constrains the distal radioulnar joint as the radioulnar ligament (Fig. 5).

The shape of the disc is also controversial. The disc has generally been considered as a flattened structure (Palmer and Werner 1981; Ishii et al. 1998), but others have considered it a more curved structure, or an extensive structure distally and proximally (Kauer 1975, 1980; Mohiuddin and Janjua 1982; Benjamin et al. 1990). In this histological study, preserving the 3-D structure, the ulnar side of the disc was thickened and divided distally to connect the meniscus homologue and proximally to connect the radioulnar ligament.

At issue is the form and location of the radioulnar ligament. It has been considered as the distal ligamentous tissues dorsally and palmarly adjacent to the disc. Some authors further described a discrete superficial and deep portion of the ligament throughout the TFCC (Hagert 1994; Ishii et al. 1998), and suggested differing changes in length of each portion during rotation where the dorsal superficial portion lengthens in pronation and the dorsal deep portion becomes taut in supination (Hagert 1994). This must induce some slippage between two portions during rotation. However, we found no ligamentous connections between so-called superficial portion and the ulnar styloid in this serial section study. Neither could we divide the superficial and deep portions on the radial side of the TFCC, even though the ligament has two ulnar origins; foveal and basistyloidal. It is suggested that two fibrous origins of the radioulnar ligament at once coalesce, curl, then divide dorsally and palmarly to form a single layer ligament enclosing the proximal side of the disc. Some central fibres of the ligament are confluent to the proximal disc. The close origins of the radioulnar liga-

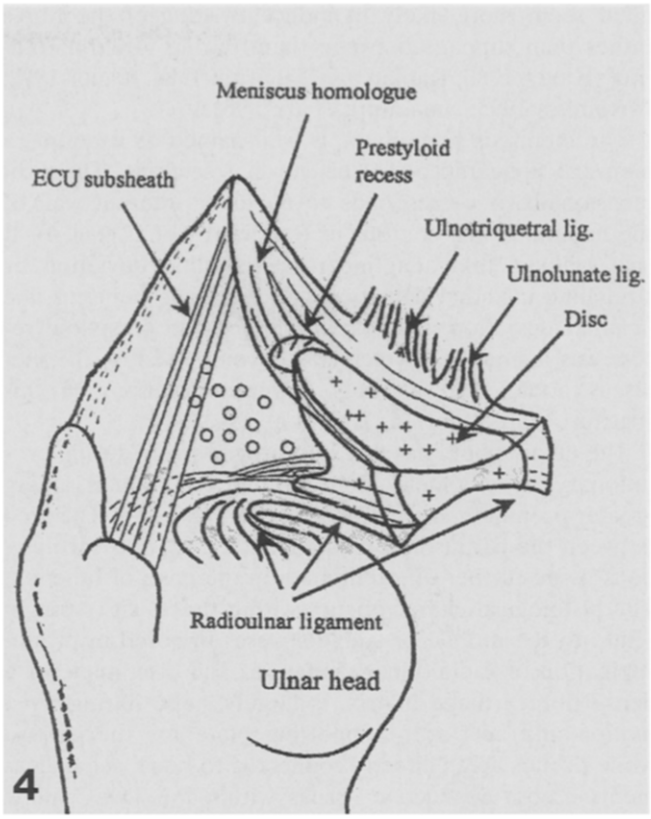

Fig. 4. Diagram of the 3-D structure of the TFCC including histological findings.
+: fibrocartilage, o: loose connective tissue, solid and dashed line: ligaments.

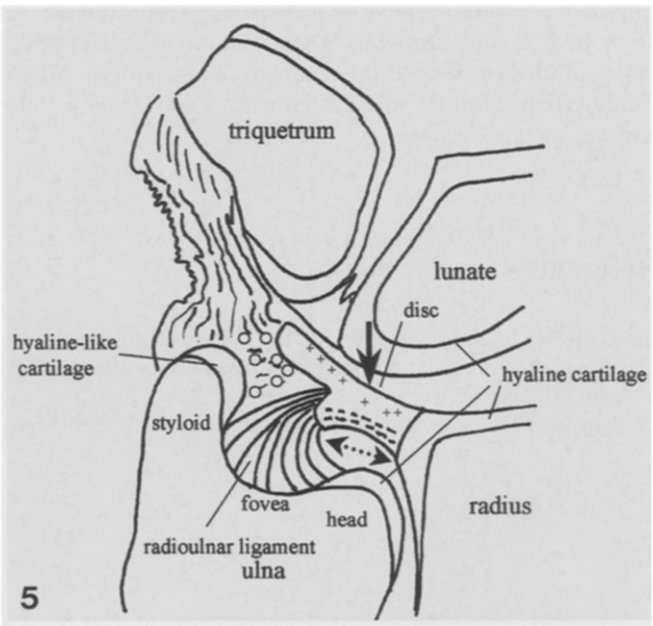

Fig. 5. The distal side of the disc axially pressured by the carpus (solid arrow) is composed of a dense matrix of fibrocartilage (+); while the proximal side of the disc, where the radioulnar tensile force acts (dashed arrow), is composed of a radioulnar oriented fibrocartilage-ligament proper (dashed line). o: loose connective tissue.

ment seem more likely to induce twisting of the fibres rather than slippage between them during forearm rotation (Kauer 1980; Kaplan and Taleisnik 1984; Kauer 1992; Nakamura 1995; Nakamura et al. 1996).

The meniscus homologue is well named as it adopts a meniscal appearance on the coronal sections. Three-dimensionally, it corresponds to an ulnar internal wall of the hammock like contour of the distal TFCC (Fig. 4). It is a synovial fold adapting to radial-ulnar deviation by stretching in radial deviation and crimping meniscus-like in ulnar deviation. In most specimens, the prestyloid recess was a small pit, which was encompassed by the meniscus homologue, although several variations of this structure were reported (Ishii et al. 1998).

The ulnar styloid has recessed progressively during evolutionary development from primate to human aiding greater pronation-supination (Lewis et al. 1970). The area between the carpus and ulna connected by fibrocartilaginous tissue further differentiated on the basis of function. The histological characteristics within the TFCC strongly relate to the mobile or stable stresses imposed in pronosupination or radial-ulnar deviation. The disc, made of a dense fibrocartilage matrix, is largely static during wrist motion and acts as a supporting plate for the carpus; while fibrous areas directly connected to bone, act as ligaments. Loose connective tissues within the TFCC allow tissue adaptation to the motion of the wrist (Nakamura et al. 1996). Each component of the TFCC has changed its macro- and microstructure to be compatible with function.

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References

Benjamin M, Evans EJ, Pemberton DJ (1990) Histological studies on the triangular fibrocartilage complex of the wrist. J Anat 172: 59–67

Chidgey LK, Dell PC, Bittar ES, Spanier SS (1991) Histologic anatomy of the triangular fibrocartilage. J Hand Surg 16 A: 1084–1100

Garcia-Elias M, Domènech-Mateu JM (1987) The articular disc of the wrist. Limits and relations. Acta Anat 128: 51–54

Hagert CG (1994) Distal radius fracture and the distal radioulnar joint – anatomical considerations. Handchir Mikrochir Plast Chir 26: 22–26

Hogikyan JV, Louis DS (1992) Embryologic development and variations in the anatomy of the ulnocarpal ligamentous complex. J Hand Surg 17 A: 719–723

Ishii S, Palmer AK, Werner FW, Short WH, Fortino MD (1998) An anatomic study of the ligamentous structure of the triangular fibrocartilage complex. J Hand Surg 23 A: 977–985

Kaplan EB, Taleisnik J (1984) The wrist. In: Spinner M (Ed) Kaplan's functional anatomy of the hand. Lippincott, Philadelphia, pp 153–201

Kauer JMG (1975) The articular disc of the hand. Acta Anat 93: 590–605

Kauer JMG (1980) Functional anatomy of the wrist. Clin Orthop 149: 9–20

Kauer JMG (1992) The distal radioulnar joint – anatomic and functional considerations. Clin Orthop 275: 37–45

Kuhlmann JN, Luboinski J, Laudet C, Boabighi A, Landjerit B, Guerin-Surville H, Baux S (1990) Properties of the fibrous structures of the wrist. J Hand Surg 15 B: 335–341

Lewis OJ, Hamshere RJ, Bucknill TM (1970) The anatomy of the wrist joint. J Anat 106: 539–552

Mikić Ž, Somer L, Somer T (1992) Histologic structure of the articular disk of the human distal radioulnar joint. Clin Orthop 275: 29–36

Mohiuddin A, Janjua MZ (1982) Form and function of radioulnar articular disc. The Hand 14: 61–66

Nakamura T (1995) Triangular fibrocartilage complex: functional anatomy and histology. J Jap Orthop Assoc 69: 168–180

Nakamura T, Makita A (2000) The proximal ligamentous component of the triangular fibrocartilage complex – functional anatomy and three-dimensional changes in length of the radioulnar ligament during pronation and supination. J Hand Surg 25 B (in press)

Nakamura T, Yabe Y, Horiuchi Y (1996) Functional anatomy of the triangular fibrocartilage complex. J Hand Surg 21 B: 581–586

Nakamura T, Yabe Y, Horiuchi Y (1999) Dynamic changes in the shape of the triangular fibrocartilage complex during rotation demonstrated with high resolution magnetic resonance imaging. J Hand Surg 24 B: 338–341

Palmer AK, Werner FW (1981) The triangular fibrocartilage complex of the wrist – anatomy and function. J Hand Surg 6: 153–162

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