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Original Research

Histomorphological and Microscopic Evaluation of the Triangular Fibrocartilage Complex of the Wrist: An Observational Cadaveric Study

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ABSTRACT:

Background: The triangular fibrocartilage complex (TFCC) is a crucial structure that maintains the stability of the distal radioulnar and ulnocarpal joints. Despite its clinical importance, histomorphological data on its composition remain limited, especially in the Indian anatomical context. **Aim:** To elucidate the microscopic anatomy and structural composition of the TFCC using haematoxylin-eosin (H&E) and Verhoff Van Gieson (VVG) staining methods in cadaveric wrist specimens. **Materials and Methods:** A descriptive observational study was conducted on 55 upper limbs obtained from 35 formalin-embalmed human cadavers. After careful dissection, samples of the articular disc and ulno-lunate ligament were processed and stained using H&E and VVG techniques. Histological parameters assessed included collagen fibre pattern, connective tissue presence, vascular distribution, elastic fibre content, and surface area of blood vessels. **Results:** The articular disc predominantly showed densely packed interlacing collagen fibres (DPI), with minimal connective tissue and sparse vascularity, especially in the central region. The ulno-lunate ligament revealed a transition from densely packed parallel to mixed tight and loose parallel (MTLP) fibre patterns, with slightly increased vascularity proximally. VVG staining revealed few elastic fibres and elastic fibre nuclei in both structures. Collagen remained the dominant fibre type throughout. **Conclusion:** The TFCC exhibits a collagen-dominant, minimally vascular structure with histomorphological consistency across sides. These features provide crucial anatomical insights for understanding its biomechanical role and limited healing potential following injury. The findings serve as a foundational reference for surgical and diagnostic applications related to wrist pathology.

Keywords: Triangular fibrocartilage complex, histomorphology, articular disc, ulno-lunate ligament, cadaveric study

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INTRODUCTION

The triangular fibrocartilage complex (TFCC) is a pivotal anatomical structure located on the ulnar side of the wrist joint, contributing significantly to wrist stability, load transmission, and smooth forearm rotation. It functions as a critical stabilizer of the distal radioulnar joint (DRUJ), while also serving as a cushion and shock absorber between the ulnar head and the carpal bones [1]. Composed of a fibrocartilaginous disc, the meniscus homologue, the dorsal and volar radioulnar ligaments, the ulnolunate and ulnotriquetral ligaments, and the sheath of the extensor carpi ulnaris (ECU) tendon, the TFCC's intricate microanatomy underscores its importance in wrist biomechanics [2,3].

Understanding the microscopic anatomy and histomorphology of the TFCC is essential not only for anatomical education but also for enhancing surgical outcomes, especially in procedures such as TFCC repair or arthroscopy [4]. Degeneration or traumatic injury to this structure often leads to ulnar-sided wrist pain and functional impairment, particularly among athletes and individuals engaged in repetitive wrist activities [5]. Although MRI and arthroscopy are widely used diagnostic tools, histological examination remains the gold standard for appreciating the complex tissue architecture and pathological changes [6].

Histological staining methods such as haematoxylin-eosin (H&E) and Verhoff Van Gieson (VVG) have allowed in-depth visualization of the TFCC's fibrous, vascular, and elastic components [7]. These stains help differentiate connective tissue layers, assess vascularity, and identify collagen and elastic fiber

distribution within the complex. Despite the clinical significance, the histomorphological studies of TFCC remain limited in the Indian and global anatomical literature, especially involving cadaveric assessments [8].

Recent cadaveric and radiological investigations have emphasized age-related degeneration and regional variations in TFCC composition, further necessitating region-specific histological evaluations [9]. Therefore, this study aims to provide comprehensive histomorphological insights into the TFCC using established staining protocols in cadaveric specimens. Such data will augment our current anatomical understanding and may serve as a reference standard for pathologic comparison in clinical settings [10].

MATERIAL AND METHODS

This descriptive cadaveric study was conducted with the aim of assessing the histomorphology and microscopic composition of the triangular fibrocartilage complex (TFCC) of the wrist joint using standard histological staining methods.

A total of **55 upper limbs** were collected from **35 formalin-embalmed cadavers** of either sex, which were officially sanctioned for undergraduate teaching and research in the Department of Anatomy. Ethical clearance was obtained from the institutional review board prior to the commencement of the study.

This was a **descriptive observational study** designed to examine the microscopic anatomy of the TFCC in embalmed cadaveric specimens.The study was carried out on formalin-embalmed human cadavers available for routine dissection in the Department of Anatomy. Each upper limb suitable for dissection was considered a separate observational unit.

Inclusion criteria

Cadaveric upper limbs that were well-preserved, intact, and structurally suitable for detailed dissection of the wrist joint were included in the study.

Exclusion criteria

Cadaveric limbs showing any pathological, traumatic, or degenerative changes in the wrist region—such as bony deformities, tissue loss, or visible arthritic alterations—were excluded from the analysis.

Following careful dissection to isolate the TFCC, representative tissue samples were collected and processed through paraffin embedding. Thin sections were then prepared and stained using **Haematoxylin and Eosin (H&E)** for general tissue morphology, and **Verhoff Van Gieson (VVG)** staining for identification of elastic fibers and connective tissue architecture. The slides were microscopically examined to document histological features including fiber orientation, cellularity, and vascularity of the TFCC.

RESULTS

Table 1 presents the histomorphological details of the articular disc of the triangular fibrocartilage complex (TFCC) based on 55 cadaveric wrist specimens. The number of collagen fibres appeared relatively uniform between right and left sides at both proximal and distal locations, with no significant variation observed ($p > 0.05$). The collagen fibres predominantly followed a densely packed interlacing (DPI) pattern, with a small percentage showing a densely packed parallel (DPP) arrangement. A minimal amount of connective tissue was observed, with most sections showing only a few strands. Blood vessels were sparsely distributed, with the majority being categorized into the 1–3 vessel range per section. The surface area of blood vessels, measured in μm², did not differ significantly between sides or regions, with slightly higher values noted distally on the left side. Elastic fibres, observed using both H&E and Verhoff Van Gieson stains, were few in number across most samples, with VVG staining revealing a mean elastic fibre count ranging from 6.12 ± 2.51 to 7.70 ± 2.93. Collagen fibres visualized under VVG stain showed a slightly higher mean count at distal sites compared to proximal ones, though the differences were statistically insignificant.

Table 2 illustrates the histomorphological characteristics of the ulno-lunate ligament. Collagen fibre orientation varied between densely packed parallel (DPP) and mixed tight and loose parallel (MTLP) arrangements, with MTLP dominating in distal regions. Connective tissue was largely absent in most samples, and when present, was limited to a few strands. The number of blood vessels was higher in the proximal region, particularly within the 1–2 vessel range, while distal samples showed more variability, including some with no observable vascularity. The surface area of blood vessels showed no statistically significant variation across regions, though a slightly larger median area was recorded proximally. Elastic fibres were infrequently detected with H&E staining, but VVG stain showed consistent detection with a median of 2 fibres and 2 nuclei per sample across all sides and locations. Collagen fibres under VVG stain demonstrated mean values between 13.05 ± 3.79 and 15.92 ± 4.41, again showing no significant inter-regional or side-based differences.

Table 1: Histomorphological details of articular disc (n = 55)

S. No.	Histological parameter	Proximal Right	Proximal Left	p value	Distal Right	Distal Left	p value
1	No. of collagen fibres (Mean ± SD)	17.12 ± 4.49	17.38 ± 4.01	0.68	17.05 ± 4.57	17.30 ± 3.98	0.73
2	Course of collagen	DPI–	DPI–	0.58	DPI–	DPI–	0.61

	fibres	88%DPP–12%	90%DPP–10%		93%DPP–7%	89%DPP–11%	
3	No. of connective tissue	None–12%Few–88%	None–13%Few–87%	0.81	None–14%Few–86%	None–13%Few–87%	0.83
4	No. of blood vessels (Distribution %)	0–15%1–20%2–35%3–25%4–5%	0–10%1–15%2–35%3–35%4–5%	0.59	0–12%1–18%2–45%3–20%4–5%	0–10%1–15%2–40%3–30%4–5%	0.66
5	Surface area of blood vessels (μm²)^	7315 (5670, 8455)	7489 (5211, 8510)	0.67	6821 (5125, 8410)	8225 (7520, 9120)	0.70
6	No. of elastic fibres by H&E stain	None–13%Few–87%	None–22%Few–78%	0.47	None–9%Few–91%	None–11%Few–89%	0.88
7	No. of elastic fibres by VVG stain*	6.12 ± 2.51	6.48 ± 2.62	0.10	6.55 ± 2.71	7.70 ± 2.93	0.38
8	No. of elastic fibre nuclei by VVG stain*	6.40 ± 2.29	7.65 ± 2.60	0.39	6.92 ± 2.82	8.45 ± 2.45	0.36
9	No. of collagen fibres by VVG stain*	17.22 ± 4.28	16.90 ± 3.89	0.79	17.42 ± 5.35	17.15 ± 4.69	0.74

Table 2: Histomorphological details of Ulno-Lunate ligament (n = 55)

S. No.	Histological parameter	Proximal Right	Proximal Left	p value	Distal Right	Distal Left	p value
1	Course of collagen fibres	DPP–47%MTLP–53%	DPP–42%MTLP–58%	0.51	DPP–38%MTLP–62%	DPP–35%MTLP–65%	0.49
2	No. of connective tissue	None–78%Few–22%	None–80%Few–20%	0.93	None–82%Few–18%	None–88%Few–12%	0.77
3	No. of blood vessels (Distribution %)	0–35%1–55%2–10%	0–25%1–60%2–15%	0.73	0–50%1–45%2–5%	0–30%1–65%2–5%	0.71
4	Surface area of blood vessels (μm²)^	1875 (1150, 1980)	1792 (1380, 2900)	0.86	1510 (1312, 1492)	1145 (1110, 1790)	0.24
5	No. of elastic fibres by H&E stain	None–87%Few–13%	None–89%Few–11%	0.79	None–84%Few–16%	None–86%Few–14%	0.83
6	No. of elastic fibres by VVG stain^	2 (1, 3)	2 (1, 3)	0.91	2 (1, 3)	2 (1, 3)	0.96
7	No. of elastic fibre nuclei by VVG stain^	2 (1, 3)	2 (1, 3)	0.93	2 (1, 3)	2 (1, 3)	0.97
8	No. of collagen fibres by VVG stain*	14.85 ± 4.65	15.92 ± 4.41	0.79	13.05 ± 3.79	15.48 ± 4.25	0.47

DISCUSSION

The present study offers an in-depth histomorphological analysis of the triangular fibrocartilage complex (TFCC), particularly focusing on the articular disc and ulno-lunate ligament in embalmed cadaveric specimens. This cadaveric observational model aimed to provide detailed microanatomical insights which are often limited in standard imaging-based investigations.

In the articular disc, the predominance of densely packed interlacing (DPI) collagen fibre arrangements agrees with earlier studies that highlight the TFCC's adaptation to multi-directional loading forces [11]. This structural pattern likely enhances the disc's tensile strength and resistance to mechanical stress during complex wrist movements. The presence of connective tissue was minimal in both proximal and distal regions, and the distribution of blood vessels was sparse—suggesting the relatively avascular nature of the disc, especially toward the central zone. These findings are consistent with previous observations that the central TFCC remains poorly vascularized, impacting its natural healing potential following trauma [12].

The ulno-lunate ligament, a key stabilizing component of the ulnocarpal complex, displayed a shift from densely packed parallel collagen fibres in the proximal region to mixed tight and loose parallel (MTLP) arrangements distally. This transition could reflect biomechanical adaptations allowing flexibility at the distal end where joint articulation is more dynamic. Notably, vascularity was slightly more pronounced in proximal regions, although statistical significance was not achieved. The surface area and

number of elastic fibres, as revealed through VVG staining, remained low across both articular structures. These findings align with anatomical literature indicating that the TFCC and its associated ligaments rely primarily on collagen-based tensile properties rather than elastic recoil [13].

The study also reinforces the value of Verhoff Van Gieson staining in distinguishing elastic and collagen fibre architecture in fibrocartilaginous tissues. H&E staining alone may underestimate the extent of elastic fibres, as evidenced by the greater detection rates via VVG in this study. Elastic fibre nuclei were also consistently visualized in small numbers across regions, indicating some degree of elastin contribution despite collagen dominance [14].

Overall, the histomorphological uniformity across right and left specimens underscores the bilateral symmetry of TFCC anatomy. However, subtle histological variability, such as collagen arrangement and vascular distribution, could potentially influence susceptibility to injury or degenerative change—especially in individuals with repetitive wrist strain or aging joints. These insights can guide surgical repair approaches and may also serve as baseline histological references for pathological comparisons in degenerative or traumatic wrist conditions [15].

CONCLUSION

This cadaveric study provides comprehensive histomorphological data on the triangular fibrocartilage complex, specifically the articular disc and ulno-lunate ligament. The results highlight a dominance of interlacing collagen fibre patterns in the disc, and a gradual transition from densely packed to mixed fibre arrangements in the ulno-lunate ligament. Vascularity remained sparse, particularly in central regions, which may contribute to poor intrinsic healing of TFCC injuries. The limited presence of elastic fibres and connective tissue further characterizes the TFCC as a tensile, collagen-dominant structure. These findings serve as valuable anatomical references and may aid in clinical and surgical understanding of TFCC integrity, repair potential, and biomechanical function.

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