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**Triangular Fibrocartilage
Complex (TFCC) – Anatomy,
Imaging, and Classifications
with Special Focus on the CUP
Classification**

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Triangular Fibrocartilage Complex (TFCC) – Anatomy, Imaging, and Classifications with Special Focus on the CUP Classification

Der ulnokarpale Komplex (TFCC) – Anatomie, Bildgebung und Klassifikationen mit Schwerpunkt auf der CUP-Klassifikation

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ABSTRACT

Background The TFCC consists of several components whose functional significance has been recognized in detail in recent years. Existing classifications are partly incomplete. In addition, the TFCC requires specific and dedicated imaging techniques.

Method This review describes the anatomy and pathoanatomy of the TFCC. The different types of TFCC lesions on MRI as well as MR and CT arthrography are explained and compared with the current literature. In addition, the novel CUP classification is presented and illustrated with image examples.

Results and Conclusion Anatomically and functionally, the articular disc and radioulnar ligaments with their ulnar insertions and the inhomogeneously structured TFCC periphery must be differentiated. For accurate imaging, thin slices with high in-plane resolution and techniques to optimize contrast are required. Plain MRI is exclusively dependent on T2 contrast, while gadolinium-enhanced MRI offers the additional benefit of focal contrast enhancement, e.g., of fibrovascular repair tissue at the lesion site. However, the reference standard continues to be MR and CT arthrography, which should be used for focused indications. The CUP classification, which allows a comprehensive description and categorization of TFCC lesions, is presented and illustrated.

Key Points

- Anatomically, the TFCC consists of the central ulnocarpal disc, the dorsal and palmar radioulnar ligaments, and the ulnocarpal joint capsule including intracapsular ligaments and the meniscus homologue.
- The most important restraining structure of the TFCC is the lamina fovealis, which stabilizes the DRUJ. This structure constitutes the proximal (deep) continuation of the radioulnar ligaments at the ulnar insertion.
- Imaging of the TFCC requires high spatial and contrast resolution due to its minute structures. MR and CT arthrography are the reference standard in imaging.
- The CUP classification clearly describes all structures of the TFCC with the categorization of individual or combined lesion patterns.

Citation Format

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ZUSAMMENFASSUNG

Hintergrund Der TFCC besteht aus komplexen Einzelstrukturen, deren funktionelle Bedeutungen erst in den letzten Jahren im Detail erkannt wurden. Bestehende Klassifikationen sind zum Teil unvollständig. Zudem stellt der TFCC besondere Anforderungen an die Bildgebung.

Method In der Übersichtsarbeit werden die Anatomie und Pathoanatomie des TFCC beschrieben. Die verschiedenen Läsionen

sionsarten des TFCC werden in der MRT sowie der MR- und CT-Arthrografie erläutert und mit der aktuellen Literatur abgeglichen. Zudem wird die neuartige CUP-Klassifikation an Bildbeispielen vorgestellt.

Ergebnisse und Schlussfolgerung Anatomisch und funktionell müssen am TFCC der Discus ulnocarpalis, die Ligg. radioulnaria mit ihren ulnaren Insertionen sowie die inhomogen aufgebaute Peripherie unterschieden werden. Zur sicheren Darstellung sind in der Bildgebung dünne Schichten mit hoher In-plane-Auflösung und Maßnahmen zur Kontrastoptimierung u. a. zur Differenzierung von Narbengewebe vonnöten. Dabei ist die native MRT ausschließlich vom T2-Kontrast abhängig, während die gadoliniumverstärkte MRT den Zusatznutzen einer fokalen Kontrastanreicherung am Läsionsort bietet. Referenzstandard sind jedoch weiterhin die MR- und CT-Arthrografie, die bei fokussierter Indikation angewendet werden sollten. Vorgestellt und illustriert wird die CUP-Klassifikation,

die eine umfassende Beschreibung und Kategorisierung von TFCC-Läsionen ermöglicht.

Kernaussagen

- Anatomisch besteht der TFCC aus dem zentralen Discus ulnocarpalis, den dorsal und palmar umschließenden Ligg. radioulnaria und der ulnokarpalen Gelenkkapsel mit intrakapsulären Ligamenten und dem Meniscus homologue.
- Wichtigste Haltestruktur des TFCC ist die Lamina fovealis, die das DRUG stabilisiert. Sie ist die proximale (tiefe) Fortsetzung der Ligg. radioulnaria an deren ulnarer Insertion.
- Die Bildgebung erfordert am TFCC wegen dessen geringer Größe eine hohe Orts- und Kontrastauflösung. Die MR- und CT-Arthrografie sind der Referenzstandard in der Bildgebung.
- Die CUP-Klassifikation erlaubt die übersichtliche Darstellung aller Strukturen des TFCC mit Benennung einzelner oder kombinierter Schädigungsmuster.

Introduction

Approximately 30% of all patients seeking consultation regarding hand surgery suffer from ulnar wrist pain [1, 2]. Most of these cases are caused by lesions of the triangular fibrocartilage complex (TFCC). The TFCC itself presents several imaging challenges: First, its anatomy is complex with multiple minute components in the millimeter range [3, 4, 5], and, second, the biomechanical significance of specific structures, particularly the foveal lamina at the ulnar insertion, has been recognized only recently [3, 6]. This has resulted in different classification systems for describing TFCC lesions [6, 7, 8, 9], which hampers interdisciplinary communication. Therefore, the aim of this review is to summarize the relevant anatomy and biomechanics of the TFCC, to recommend appropriate examination protocols for radiological imaging, and to present a comprehensive classification system to assess all subtypes of TFCC lesions [10].

Anatomy of the TFCC

The TFCC fills the space between the ulnar head and the ulnocarpal compartment, where it constitutes a functional unit together with the distal radioulnar joint (DRUJ). The TFCC constitutes a complex dome of fibrocartilaginous and ligamentous elements [11]. Functionally, it serves as a “shock absorber” between the ulna and the ulnar carpus, as well as the most important stabilizer of the DRUJ [12, 13].

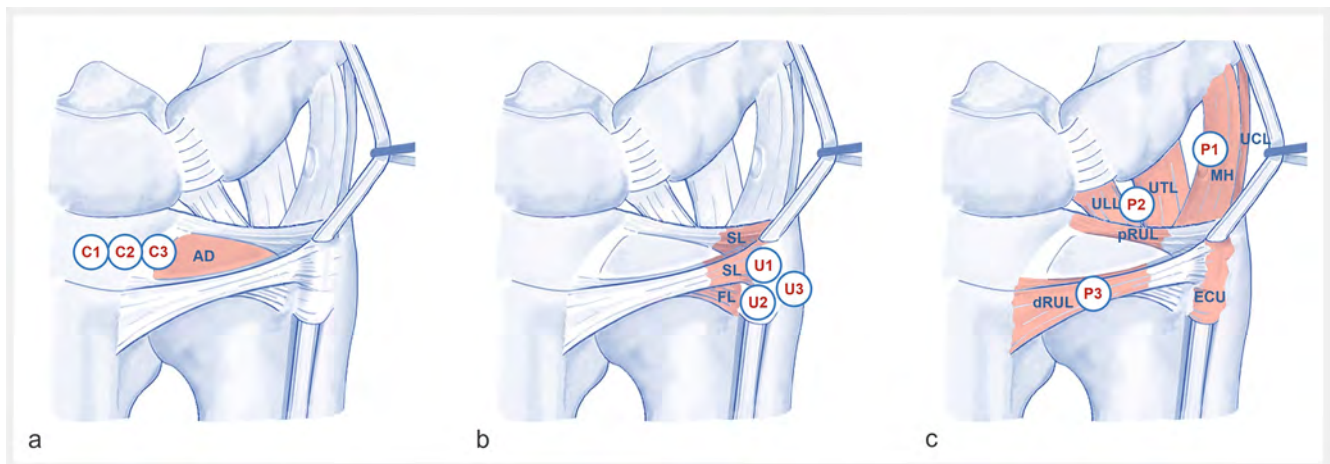
The articular disc (► Fig. 1a)

The articular disc (triangular fibrocartilage, TFC), composed of fibrocartilage (type I and II collagen fibers), is a cushion-like “shock absorber” that transmits approximately 20% of the axial pressure load of the wrist [5, 11]. It originates from the articular cartilage of the radial sigmoid notch, which in PD-weighted MRI sequences is characterized by a side-by-side pattern of hyperintense articular

cartilage and the hypointense fibrocartilage [4]. The disc then takes an almost horizontal course. In transaxial images, it appears as a triangle, in sagittal slices as a biconcave disc. The articular disc is thicker in the periphery ($1.8 \text{ mm} \pm 0.6 \text{ mm}$) compared to the center ($1.1 \text{ mm} \pm 0.6 \text{ mm}$), with its thickness influenced by the length of the ulna [14]. The articular disc has a moderate blood supply in its periphery (“vascularized segment”) with penetrating nutritional vessels, while the bradytrophic center (“avascular segment”) is not supplied with blood [15].

The radioulnar ligaments (► Fig. 1b)

Anatomically and functionally, these ligaments must be separated from the disc. The dorsal and palmar radioulnar ligaments arise directly from the cortical bone of the radial sigmoid notch without an interposed layer [16]. They appear hypointense on all MRI sequences. The radioulnar ligaments enclose the triangular articular disc at its dorsal and palmar aspects and are firmly interwoven with it [17, 18]. Following the shape of the disc, the radioulnar ligaments converge towards the ulnar side and finally unite at the ulnar tip of the disc. Shortly thereafter, they split into a deep ligament, the foveal lamina, and a superficial ligament, the styloid lamina [3, 6]. Both are striated and hypointense on MRI [4]. The foveal lamina inserts at the fovea of the ulnar head, a depression located radial to the styloid process [5, 6]. The foveal lamina represents the most important stabilizer of the DRUJ [17]. In contrast, the styloid lamina extends to the radial side of the styloid process and possesses a less important stabilizing function. The radioulnar ligaments undergo antagonistic tension or relaxation during pro-supination movements. Fatty and vascularized connective tissue is interposed between the foveal and styloid lamina, which is misleadingly referred to as the ligamentum subcruentum (“bleeding ligament”) [19]. In non-fat-saturated MRI sequences, the hyperintense subcrucial ligament defines the border between the laminae [4, 20]. Rarely, the radioulnar ligaments merge with a broad monofascicle at the ulnar styloid process [21].



► **Fig. 1** Schematic drawings of the TFCC anatomy and its pathologies according to the CUP classification. The relevant structures are shown in red. Only non-osseous lesions are illustrated. **a** Central TFCC lesions on the articular disc (AD) are classified according to their severity as C lesions C1–C3. **b** Ulnar TFCC lesions on the styloid lamina (SL) and/or foveal lamina (FL) of the radioulnar ligaments are separately referred to as U1 or U2 lesions and combined as U3 lesions. **c** Peripheral TFCC lesions on the meniscus homologue (MH), the ECU tendon sheath (ECU), the ulnar collateral ligament (UCL), or the joint capsule are each categorized as P1 lesions, on the ulnolunate ligament (ULL) and/or ulnotriquetral ligament (UTL) as P2 lesions or on the radial and middle segments of the dorsal or palmar radioulnar ligaments (dRUL, pRUL) as P3 lesions.

The TFCC periphery (► Fig. 1c)

The meniscus homologue is a phylogenetic relict that is proximally attached to the articular disc and the tip of the ulnar styloid. Distally, it inserts at a shallow depression of the triquetrum [22]. A foramen to the ulnar recess constitutes a landmark at its distal margin.

The joint capsule of the TFCC incorporates several ligaments: The ulnar collateral ligament, which is considered by some authors to be merely a capsular fold, borders the meniscus homologue on the ulnar side [23]. The important ulnocarpal ligaments are located at the palmar aspect. Both the ulnotriquetral ligament and the ulnolunate ligament originate from the palmar radioulnar ligament and extend obliquely to the triquetrum and lunate, thereby stabilizing the ulnocarpal compartment [23, 24]. The existence of an ulnocapitate ligament is occasionally reported. There are no ligaments running in the dorsal capsule, but the sheath of the reinforcing extensor carpi radialis (ECU) tendon is firmly integrated into it [24]. Functionally, the radial and middle sections of the radioulnar ligaments can be regarded as peripheral elements of the TFCC, as the ulnocarpal ligaments originate from them and the ECU tendon is also attached.

MRI and MR arthrography of the TFCC

Imaging of the TFCC is challenging, because minute anatomic components are located in a limited anatomic volume, and additionally the intrinsic contrast of the mostly fibrocartilaginous components is low. MRI is to be considered the most valuable technique for diagnosing TFCC lesions [25]. This requires a magnetic field strength of 1.5 or preferably 3.0 Tesla and the use of dedicated multi-channel phased array coils for parallel imaging [23].

Required image resolution

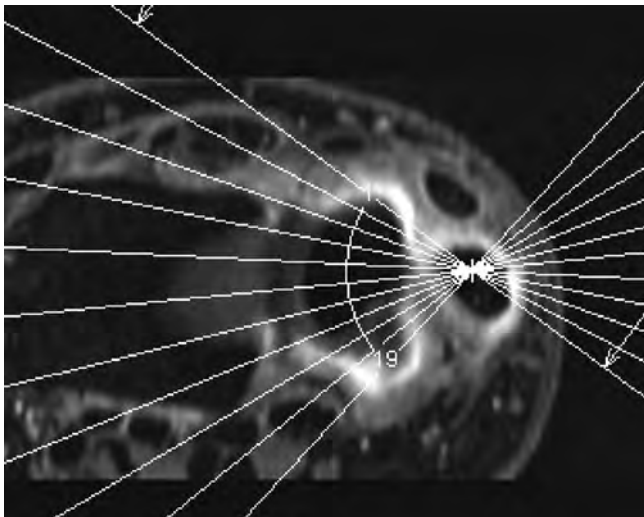
To realize an in-plane resolution of 0.2 mm per pixel, a field of view (FoV) of approx. 80 mm and an image matrix of approx. 384² or 440² are required [4, 18, 23, 26]. The recommended slice thickness for 2D imaging is 2.0 mm or 1.5 mm without a slice gap (using interleaved acquisition). In 3D imaging, the partition thickness should be 0.4 mm or 0.5 mm [27, 28].

Improved image contrast

Plain MRI is exclusively dependent on T2 contrast in order to visualize soft tissue edema or local effusion surrounding a possible TFCC tear [4, 29]. The reliance on T2 contrast for these signs may limit plain MRI, although promising results have been reported in combination with high-resolution MRI [30]. If intravenous contrast agent is applied, the detection rate of TFCC lesions increases significantly, as this setting allows for focal contrast enhancement at the sites of acute and subacute tears [31] due to the presence of hyperemic synovial and fibrovascular repair tissue [15]. The enhancement effect is maintained for up to approx. 6 months after an injury. However, the reference standard is indeed direct MR arthrography with sensitivity and specificity ratios exceeding 90% compared to arthroscopy [32, 33, 34, 35]. The intra-articular contrast agent leads to distension of the relevant structures in the joint and improved contrast due to the T1 time shortening.

Advanced image display (► Fig. 2)

On transaxial MRI slices, the TFCC is triangular in shape with structures originating broadly at the radial sigmoid notch and converging towards the ulnar fovea and the styloid process. In coronal slices, the articular disc and the radioulnar ligaments can, therefore, only be fully covered in the central sections, but not in the outside layers. Isotropic 3D data sets are advantageous in this situation [23]. They can be used to reconstruct radial MPR slices



► **Fig. 2** Multiplanar reconstruction (MPR) of the TFCC with radial slices. On a transaxial slice, the ulnar styloid process is selected as the pivot center for reconstructing radial MPR slices of the TFCC. The radial MPR slices allow the triangular anatomy of the TFCC to be comprehensively visualized.

according to the anatomic extension of the TFCC, with the pivot center positioned on the ulnar styloid process (► **Fig. 2**). Radial MPR images significantly facilitate image interpretation for lesions of the foveal and styloid laminae proven on MR arthrography [36].

CT arthrography of the TFCC

CT arthrography is to be considered a reliable alternative to MR arthrography [27, 37, 38]. For TFCC assessment, the DRUJ and the radiocarpal compartment have to be filled with diluted contrast agent first (150 mg iodine per ml) during direct arthrography. Recommended scan parameters: Field of view 80 mm, slice thickness 0.5 mm to 0.75 mm, increment <70%, image matrix 512^2 or 1024^2 . Multiplanar slices (MPR) are reconstructed from the isotropic data set. Advantages of CT arthrography are the short acquisition time and the high in-plane resolution [37]. Due to the triangular shape of the TFCC, images radially reconstructed from the 3D data set are helpful for assessing foveal and styloid TFCC lesions [39, 40].

Classification systems for assessing TFCC lesions

There are different classifications with an emphasis on pathoanatomical, arthroscopic, and radiological aspects.

Palmer classification

This landmark description is the oldest and most widespread, with a distinction between degenerative and traumatic categories and a total of nine lesion types [7]. The proximal carpal row (articular cartilage and lunotriquetral ligament) is also considered, but not the differentiation of the foveal and styloid laminae at the ulnar aspect.

Atzei classification

Innovatively, its focus is on the ulnar TFCC aspect with differentiation between foveal, styloid, and combined lesion types [6]. Also included are fractures of the styloid process and non-repairable lesions of the articular disc and advanced cases with osteoarthritis of the DRUJ.

Zhan classification

Based on the Palmer classification, several additional lesion types (including foveal and styloid lesions) are integrated into this TFCC classification, resulting in 26 lesion subtypes, thereby reducing clarity and communicability [8].

Herzberg classification

This arthroscopic TFCC classification covers degenerative and traumatic lesions of the articular disc (class D), traumatic lesions of the so-called “reins” (class R), and traumatic lesions of the TFCC wall (class W) [9]. It can also be used to summarize combined TFCC lesions. Apparently, this categorization is inspired by the previously published CUP classification presented below.

CUP classification (► **Fig. 1a–1c**)

This TFCC categorization, which can be used universally for arthroscopy and radiology, distinguishes between central lesions (class C, ► **Fig. 1a**) at the articular disc, ulnar lesions (class U, ► **Fig. 1b**) at the foveal and styloid laminae, and peripheral lesions (class P, ► **Fig. 1c**) at the meniscus homologue, the joint capsule (including the ulnocarpal ligaments and the ECU tendon sheath), and the radial and middle segments of the radioulnar ligaments [10]. Each class is divided into three lesion types by severity. This results in a simple and easily applicable “3 × 3 rule” (► **Table 1**). As the lesion type increases, the more intensive the treatment has to be. While lesion types “a” are often treated conservatively, lesion types “c” usually require surgical intervention.

The CUP classification distinguishes non-osseous lesions from osseous lesions with similar biomechanical effects. Since traumatic injuries cannot be reliably differentiated from degenerative changes [41] and both are often found simultaneously, the differentiation by etiology is not considered in the CUP classification.

A comparison of the CUP classification with other classification systems is provided in ► **Table 2**.

Imaging of TFCC lesions

Below, TFCC lesion patterns are presented and classified according to the CUP classification [10].

Disorders of the articular disc of the TFCC (central lesions – C lesions)

Central lesions (class C) are located in the fibrocartilaginous articular disc with its avascular inner part and its vascularized outer limbus (► **Fig. 3a–3e**).

► **Table 1** The CUP classification for a comprehensive categorization of traumatic and degenerative TFCC lesions [adapted from 10].

CUP class	Non-osseous lesions (CUP types)		Osseous CUP lesions (CUP # types)	
Central (=C)	C1	Degeneration of the articular disc	None	
	C2	Pinhole lesion of the articular disc (<3 mm)		
	C3	Perforation of the articular disc (>3 mm) and atypical disc lesions		
Ulnar (=U)	U1	Tear of the styloid lamina	U1#	Apical fracture of the ulnar styloid (foveal and styloid laminae intact)
	U2	Tear of the foveal lamina	U2#	Basal fracture of the ulnar styloid (+ tear of the foveal lamina)
	U3	Tear of both laminae	U3#	Basal fracture of the ulnar styloid (+ tears of the foveal and styloid laminae)
Peripheral (=P)	P1	Tear of the meniscus homologue and/or the ulnocarpal capsule	P1#	Apical fracture of the ulnar styloid (+ tear of the meniscus and/or capsule)
	P2	Tear of the ulnocarpal ligaments (ulnolunate, ulnotriquetral)	P2#	Osteoligamentous avulsion fracture of the lunate and/or the triquetrum
	P3	Tear of the radioulnar ligaments (radial or mid segments)	P3#	Marginal fracture of the sigmoid notch in distal radius fracture

► **Table 2** Overview of the non-osseous TFCC lesion types in the existing classifications.

Type of TFCC lesion	CUP classification	Palmer classification	Atzei classification	Zhan classification	Herzberg classification
Degeneration of the articular disc	C1	IIA, IIB	4	IIA, IIB	DD
Pinhole lesion of the articular disc	C2	IA	4	IA	DT
Perforation of the articular disc*	C3	ID, IIC–IIC	4	IA, ID1, IE, IG	DD
Tear of the styloid lamina	U1	IB	1	IB2	W2
Tear of the foveal lamina	U2	IB	3	IB1	R1 deep
Tear of both laminae	U3	IB	2	IB3	R1
Tear of the ulnocarpal capsule	P1	–	–	IF1–IF4	W1, W3, W4
Tear of the ulnocarpal ligaments	P2	IC	–	IC	W5, W6
Tear (radial or mid segments) of the radioulnar ligaments	P3	–	–	ID2	R2–R4
	C = central U = ulnar P = peripheral	I = traumatic II = degenerative		I = traumatic II = degenerative	DD = degenerative disc DT = traumatic disc R = rein W = wall

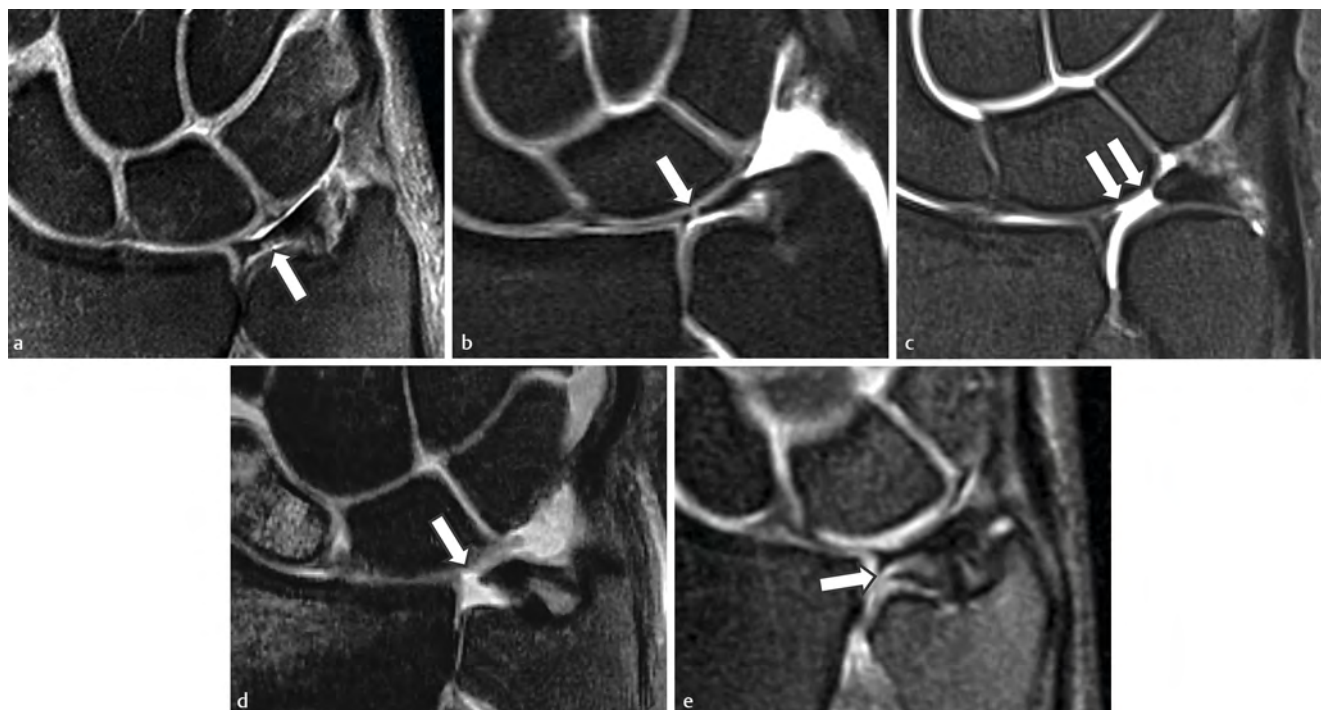
* including atypical lesions

C1 lesions (► Fig. 3a)

These conditions include degenerative changes of the articular disc with preserved structural continuity [42]. Pathoanatomically, there are mucoid areas and/or thinning of the disc body. MRI shows hyperintense inclusions in a linear or oval appearance [43]. Arthroscopy is positive for the trampoline test (reduced TFCC tension when touched with a hook).

C2 lesions (► Fig. 3b)

Type C2 lesions are slit-shaped disc defects less than 3 mm in width in the radial section of the articular disc [7, 9]. They are usually caused by injuries due to preexisting disc degeneration. Due to their small size, these “pinhole lesions” have no biomechanical significance.



► **Fig. 3** Central TFCC lesions (C lesions) of the articular disc. **a** C1 lesion (fat-saturated PD-w FSE): The articular disc is centrally thinned and contains hyperintense, muroid inclusions (arrow). **b** C2 lesion (fat-saturated PD-w FSE): There is a pinhole lesion (arrow) in the radial segment of the articular disc that is not filled with the surrounding effusion. **c** Central C3 lesion (fat-saturated T1-w FSE MR arthrography): There is a wide (>3 mm), contrast-filled perforation (arrows) in the articular disc with contrast communication between the DRUJ and the ulnocarpal compartment. The adjacent articular cartilage is not impaired. **d** Radial C3 lesion (fat-saturated PD-w FSE): In an acute trauma, the articular disc is detached from the articular cartilage of the radial sigmoid notch (arrow). A joint effusion and bone bruises in the scaphoid and radius are present. **e** Atypical C3 lesion (fat-saturated PD-w FSE): The articular disc is divided into two layers by a horizontal split (arrow).

C3 lesions (► Fig. 3c–3e)

These describe large, degenerative, and nonrepairable perforations of the articular disc with gaps of up to 10 mm (► Fig. 3c). The perforations are induced by chronically increased axial force transmission in the ulnocarpal compartment, often caused by a positive ulnar variance [1, 7]. C3 lesions are usually located centrally in the disc body [14], rarely at its origin at the radial sigmoid notch if the cause is trauma (► Fig. 3d) [44, 45]. Large disc perforations may cause instability of the DRUJ by loosening the radioulnar ligaments. The rare, atypical disc lesions are subsumed under the C3 lesions and labelled with the suffix “a” (for atypical). These include horizontal disc tears with or without separation of the ulnar laminae (► Fig. 3e) [26], coronal tears, and bucket-handle tears [46, 47].

Disorders of the ulnar insertions of the radioulnar ligaments (ulnar lesions – U lesions)

Ulnar lesions (class U) are located at the vascularized insertions of the radioulnar ligaments at the fovea of the ulnar head or at the radial side of the ulnar styloid process (► Fig. 4a–4c) and are of traumatic origin. The subdivision into types U1 to U3 constitutes a modification of the Atzei classification [6, 48].

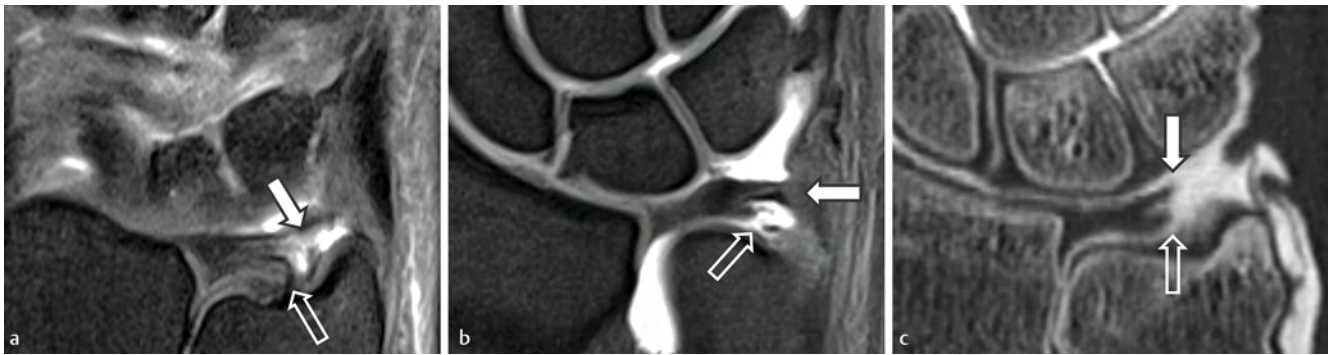
U1 lesions (► Fig. 4a)

These are tears of the styloid lamina of the radioulnar ligaments from the ulnar styloid process. The distal radioulnar joint usually

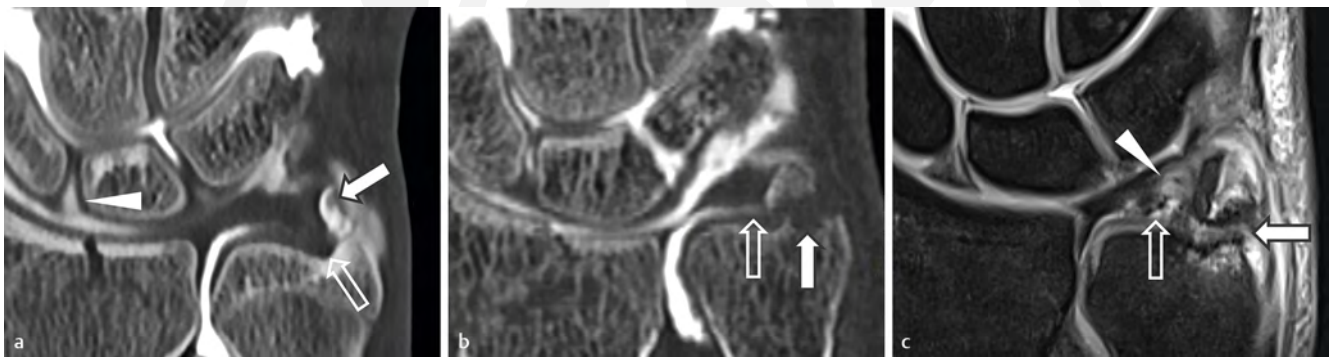
remains stable, whereas the ulnocarpal ligaments become loose with moderate instability of the ulnocarpal compartment [6]. On MRI, there is fiber discontinuity and retraction of the styloid lamina away from the ulnar styloid process or scarring in chronic cases [49]. Secondary signs may be bone marrow edema and cystic changes in the ulnar styloid process. On arthroscopy, the trampoline test is positive, while the hook test (TFCC releases when pulled with a hook) is negative.

U2 lesions (► Fig. 4b)

Type U2 lesions are tears of the foveal lamina of the radioulnar ligaments from the fovea of the ulnar head. Biomechanically, U2 tears lead to instability of the DRUJ. Therefore, surgical refixation is indicated [6, 48, 50, 51]. Secondly, a positive ulnar variance can also occur [52]. On MRI, signal alteration, fiber discontinuity, and retraction of the foveal lamina or chronic scarring at the ulnar fovea are observed [49]. Secondary signs are bone marrow edema or avulsive cystic changes in the ulnar fovea. However, the accuracy of plain MRI for assessing foveal tears is low [25]. The imaging power can be significantly increased by applying an intravenous contrast agent [31]. The main indications for MR arthrography and CT arthrography are foveal lesions, which can be assessed with a sensitivity of 85% and a specificity of 76% [27, 32, 40, 53]. These “hidden lesions” can only be visualized directly with arthroscopy of the DRUJ [6, 9, 50, 54], or indirectly by a positive hook test in radiocarpal arthroscopy.



► **Fig. 4** Ulnar TFCC lesions (U lesions) of the radioulnar ligaments. **a** U1 lesion (fat-saturated PD-w FSE): The styloid lamina (arrow) is torn and dehiscent to the ulnar styloid process. The foveal lamina (open arrow) is intact. **b** U2 lesion (fat-saturated T1-w FSE MR arthrography): The foveal lamina (open arrow) is torn and displaced from the ulnar fovea. The styloid lamina (arrow) is unaffected. **c** U3 lesion (CT arthrography): Both the styloid lamina (arrow) and the foveal lamina (open arrow) are ruptured. The ligament stumps are surrounded by intra-articular contrast agent.



► **Fig. 5** Osseous variants of ulnar TFCC lesions (U# lesions). **a** U1# lesion (CT arthrography): The ulnar styloid process is fractured close to the tip (arrow). The styloid lamina remains attached to the fragment. The foveal lamina (open arrow) inserts uninjured at the ulnar fovea. An intraarticular fracture of the distal radius and a tear of the scapholunate ligament (arrow head) are present. **b** U2# lesion (CT arthrography): There is a base fracture (arrow) of the ulnar styloid process. The styloid lamina remains attached to the fragment, while the foveal lamina (open arrow) is dehiscent. Additionally, an intraarticular fracture of the distal radius and thinning of the central disc are present. **c** U3# lesion (fat-saturated PD-w FSE): The "floating styloid" is a combination of an ulnar styloid process base fracture (arrow) and ruptures of the foveal lamina (open arrow) and the styloid lamina (arrowhead).

U3 lesions (► Fig. 4c)

These are combined tears of the styloid and foveal laminae of the radioulnar ligaments. MRI displays signal alteration and/or discontinuity in both the styloid and the foveal lamina. Radial retractions of both laminae are typical and result in the articular disc also being displaced radially and losing its biconcave shape and appearing thickened [49]. In the case of chronic complete rupture, scar tissue may be present. Secondary signs are DRUJ effusion, as well as bone marrow edema or cystic inclusions in the ulnar styloid process and the ulnar fovea [49]. On MR and CT arthrography, these complete tears lead to intercompartmental (ulnocarpal and DRUJ) communication. There is severe instability of the DRUJ and mild instability in the ulnocarpal compartment [28]. The trampoline and hook tests are positive on arthroscopy.

Osseous U lesions (► Fig. 5a–5c)

These are caused by fractures of the ulnar styloid process and are marked with the suffix "#". A tip fracture of the styloid process (type U1#, ► Fig. 5a) separates the styloid lamina from the rest

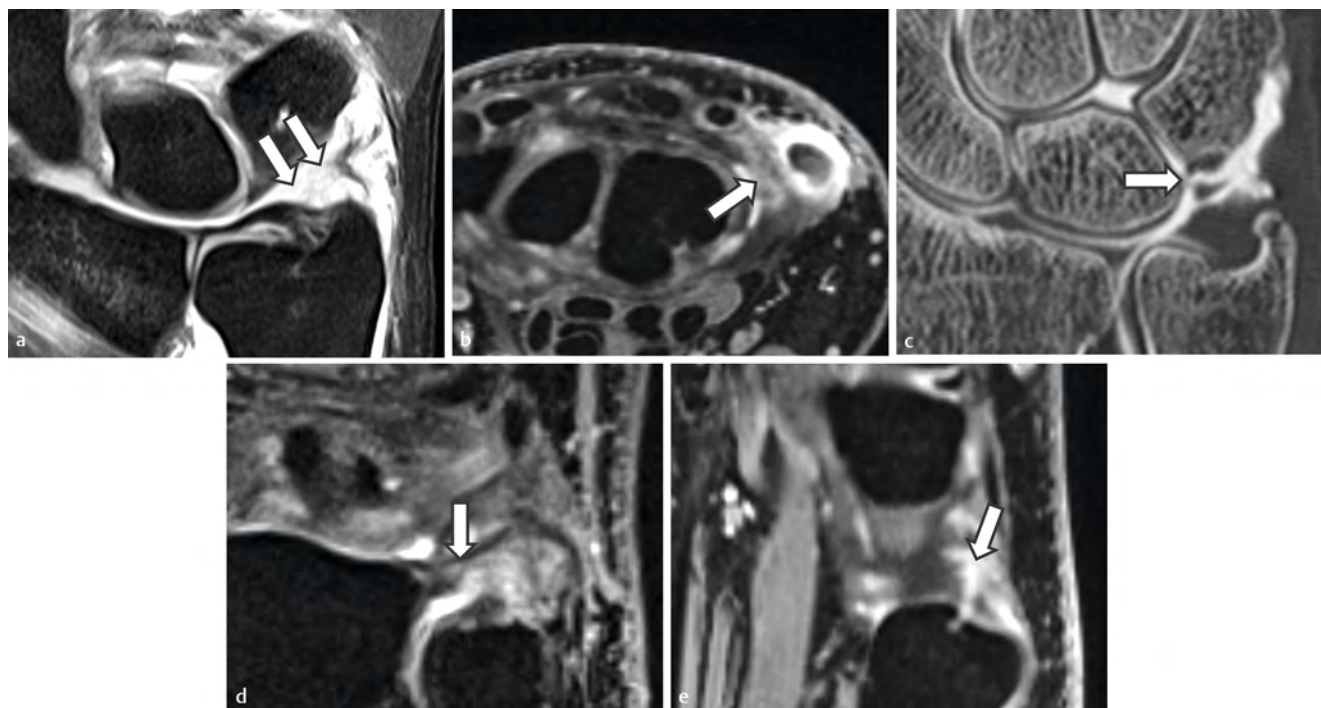
of the styloid process but leaves the foveal lamina intact. In contrast, a base fracture of the styloid process (type U2#, ► Fig. 5b) leads to either a concomitant rupture or to an osteoligamentous avulsion of the foveal lamina, and thus to DRUJ instability [55, 56]. Rarely, the combination of a base fracture of the styloid process and additional tears of both laminae results in the "floating styloid" (type U3#, ► Fig. 5c).

Disorders of the peripheral TFCC structures (peripheral lesions – P lesions)

Class P lesions can affect the meniscus homologue, the ulnocarpal joint capsule, and the peripheral ligaments (► Fig. 6a–6d). They are located in the vascularized TFCC areas and are categorized according to their influence on the stability of the DRUJ and ulnocarpal compartment.

P1 lesions (► Fig. 6a and 6b)

They include injuries to the meniscus homologue [22] and the ulnocarpal joint capsule without involvement of the intracapsular li-



► **Fig. 6** Peripheral lesions (P lesions) of the TFCC. **a** P1 lesion (fat-saturated T1-w FSE MR arthrography): Traumatic tear of the meniscus homologue with a wide gap (arrows) at its distal border. The other parts of the TFCC are intact. **b** P1 lesion (fat-saturated T1-w FSE after intravenous gadolinium): Tear of the dorsal TFCC capsule (arrow), which has resulted in marked ECU tenosynovitis. **c** P2 lesion (CT arthrography): Tear of the ulnotriquetral ligament (arrow) near the triquetrum. Additionally, there is a fracture at the tip of the ulnar styloid process and a perforation of the articular disc. The disc perforation, the tip fracture of the ulnar process, and the rupture of the ulnotriquetral ligament result in a combined “C3U1#P2” lesion according to the CUP classification. **d** and **e** P3d lesion (fat-saturated PD-w FSE, coronal and sagittal images): Tear of the dorsal radioulnar ligament at the level of its mid-segment (arrows) and delamination from the articular disc (arrow in e). The foveal and styloid laminae remained intact (not shown).

gaments. The dorsal capsule is usually affected. In its proximal section, pathology of the ECU tendon sheath is often associated with peripheral TFCC tears and can reliably be used as a secondary sign of a TFCC lesion [57, 58]. In the distal section, dorsal capsular injuries at the triquetral insertion are considered typical. In the acute stage, these are referred to as “Nishikawa injuries” [59], in the chronic stage with interposed synovial tissue as a “triquetral impingement ligament tear” (TILT syndrome) [60]. P1 lesions are most reliably detected on the sagittal MRI plane [46, 61].

P2 lesions (► Fig. 6c)

In the case of the P2 lesion type, the ulnolunate and/or ulnotriquetral ligaments are torn. There is either ligament detachment from the lunate and/or triquetrum [62] or a longitudinal tear of the ulnotriquetral ligament [63, 64]. These palmar ligament injuries, which correspond to lesion type I C according to Palmer [7], can lead to ulnocarpal instability.

P3 lesions (► Fig. 6d and 6e)

These lesions comprise ruptures of the radial and middle segments of the radioulnar ligaments, i.e., the ligament sections beyond the ulnar insertion (see U-lesions). Besides ruptures, delamination of the ligaments from the articular disc can also occur. Typical locations of P3 lesions are either radial, involving the dor-

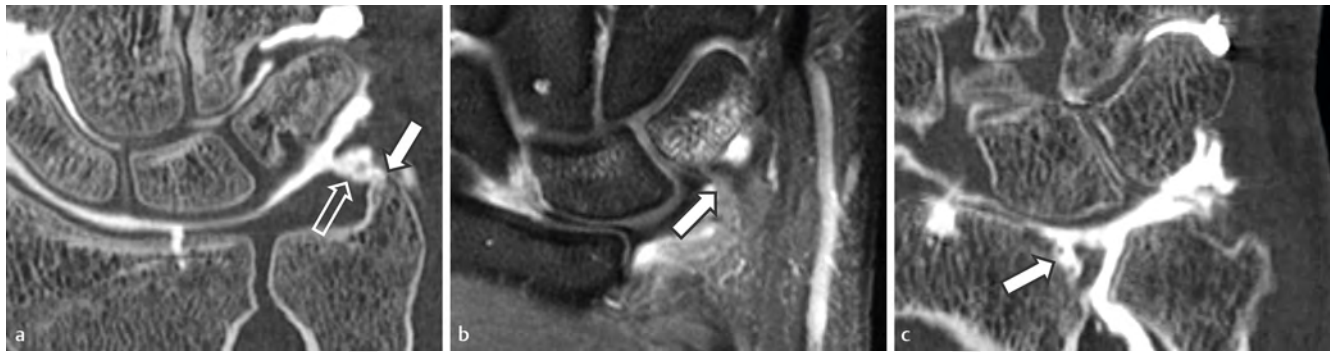
sal or palmar radioulnar ligament torn from the sigmoid notch, or dorsal, where the dorsal radioulnar ligament is torn between the ECU and extensor digiti minimi tendons [62, 65]. MRI and MR arthrography facilitate the diagnosis of radioulnar ligament tears [25]. The suffixes “p” (palmar) and “d” (dorsal) indicate whether the P3 lesion is located on the palmar or dorsal side.

Osseous P lesions (► Fig. 7a–7c)

Like U lesions, P lesions can also be associated with fractures. A bony avulsion at the styloid tip together with a tear in the meniscus homologue (type P1#, ► Fig. 7a) is the least severe injury and does not lead to instability. In contrast, osteoligamentous avulsion fractures of the ulnolunate and/or ulnotriquetral ligament at the lunate or triquetrum (type P2#, ► Fig. 7b) can cause ulnocarpal instability. Fractures at the palmar or dorsal edge of the sigmoid notch (type P3p# or P3d#, ► Fig. 7c), which are occasionally seen with distal radius fractures, are more severe [66]. They are best depicted using CT or CT arthrography [25].

Combined TFCC lesions (► Fig. 8a and 8b)

These are lesions at two or more sites of the TFCC. There are different etiological and chronological patterns. For example, a perforation of the articular disc (type C3) may already exist before a trauma causes a complete tear of the ulnar laminae (type U3). A



► **Fig. 7** Osseous variants of peripheral TFCC lesions (P# lesions). **a** P1# lesion (CT arthrography without contrast-filled DRUJ): Small bony avulsion at the tip of the ulnar styloid process (arrow) and tear in the meniscus homologue (open arrow) in a non-displaced radius fracture. Fracture-associated chondral fissure in the lunate surface of the radius. **b** P2# lesion (fat-saturated PD-w FSE): Osteoligamentous avulsion of the ulnotriquetral ligament at the triquetrum. The ligament (arrow) is partially edematous. Additionally, there is a fissure and bone marrow edema in the triquetrum. **c** P3# lesion (CT arthrography): Intra-articular radius fracture passing through the sigmoid notch. From its palmar corner, a cortical fragment (arrow) with the radioulnar ligament is detached.



► **Fig. 8** Combined TFCC lesions of different ages. **a** Coronal and **b** transaxial CT arthrography. Probably, a preexisting 3.5 mm wide perforation of the articular disc (arrows) is present. Following acute trauma, there are tears of the foveal and styloid laminae (open arrows). These lesions are categorized as C3U3 according to the CUP classification.

C3U3 type pattern is then present (► **Fig. 8a** and **8b**). An acute trauma can also cause simultaneous injuries at two TFCC sites. Examples include the combination of a pinhole lesion of the articular disc (type C2) and a rupture of the styloid lamina (type U1) or, in the case of an intra-articular radius fracture, the combination of a degenerative articular disc (type C1) and an avulsion fracture at the palmar edge of the sigmoid notch (type P3#p). Combined TFCC lesions are also considered in the Herzberg classification [9].

Conclusion

Due to its size, the articular disc is the most prominent portion of the TFCC on imaging, although its functional significance is limited to that of a cushion-like shock absorber [11, 14]. More important is the ligamentous fixation of the TFCC to the ulnar head (including the ulnar styloid process). In particular, the foveal lamina is crucial for DRUJ stability [17]. As the size of the foveal lamina is only a few millimeters, the requirements for imaging are high. The slice thickness on MRI should not exceed 2 mm, slice gaps should be avoided, and an in-plane resolution of about 0.2 mm should be favored [4, 23, 28]. Plain MRI is dependent on soft-tissue edema and local effusion at the rupture site for the detection of TFCC le-

sions and is therefore limited [4, 25, 29]. Contrast-enhanced MRI provides additional information in the first few months following trauma, when fibrovascular repair leads to local hyperemia and thus to contrast enhancement [31]. Therefore, contrast-enhanced MRI is more suitable as a baseline examination. However, direct MRI and CT arthrography remain the reference standard for more focused questions, as both procedures induce structural distension and an improved contrast-to-noise ratio at the rupture site and thus provide superior imaging results at the TFCC [32, 33, 34, 35].

A comprehensive classification is important for interdisciplinary communication at the anatomically challenging TFCC. The previous classifications are either incomplete [6, 7] or difficult due to their complexity [8, 9]. The presented CUP classification attempts to summarize all anatomical aspects by describing the disc as the center (class C), the important ulnar insertions (class U), and the periphery of the TFCC (class P), with an innovative integration of peripheral TFCC lesions [10].

Conflict of Interest

The authors declare that they have no conflict of interest.

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