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IN-DEPTH REVIEW

Ulnar peripheral tears of the triangular fibrocartilage complex: multiplanar approach of injury patterns with a focus on CT arthrography

Gonzalo A. Serrano-Belmar

Department of Radiology, Clinica Alemana de Santiago, Vitacura, Chile

ABSTRACT

The triangular fibrocartilage complex (TFCC), specifically the distal radioulnar ligaments (DRULs) are the main stabilizing components of the distal radioulnar joint. These ligaments are formed by superficial and deep fibers that are inserted into the distal ulna in the styloid process and fovea, respectively. Therefore, four arms are inserted into the ulna, two superficial and two deep arms. The deep foveal arms are biomechanically more advantageous in maintaining joint stability. For this reason, determining the injury to these fibers is the most critical parameter to define when planning an eventual surgery. Different forces acting on the distal radioulnar joint stretch each of these DRUL components differently. If the various forces acting on these structures are excessive, it can determine an avulsion of the bone insertion. Which components may tear will depend on the predominant mechanism of injury, magnitude, and direction of the traumatic forces acting on the ulnar wrist. The CT arthrography, in case of an injury, can clearly define which component is involved. The purpose of this review was to demonstrate the detailed description of the different components affected and the tear patterns of peripheral ulnar TFCC that can be defined through a multiplanar approach in CT arthrography. This approach has not been previously exposed in the literature. The various injuries described utilizing the multiplanar approach could lead to a better clinical-radiological correlation and a change in patient management.

Keywords: *Triangular fibrocartilage complex. Distal radioulnar ligaments. Deep foveal arms. CT arthrography.*

INTRODUCTION

The triangular fibrocartilage complex (TFCC) has seven distinct components: the articular disc, the dorsal and palmar radioulnar ligaments, the ulnocarpal ligaments (ulnolunate and ulnotriquetral), the sub-sheath of the extensor carpi ulnaris tendon (ECU-ss), and the meniscus homologue[1] (Figure 1). Accurate diagnosis of peripheral tears of the TFCC has been a relevant topic in recent years[2]. TFCC injuries are typically categorized within the Palmer classification[3]. Palmer 1B lesions correspond to distal avulsions of the proximal or distal lamina. This type of injury is the one that most often goes unnoticed in imaging studies[4,5].

Palmer's classification has several limitations. Distal radioulnar ligament (DRUL) injuries are not categorized. Class 1B lesions have not been subclassified, depending on which component is specifically affected[3,6]. Except for class 1C injuries (ulnocarpal ligament injury), all other peripheral injuries fall within class 1B injuries,

Corresponding author:
Gonzalo A. Serrano-Belmar
E-mail: serrano.gonzo@gmail.com

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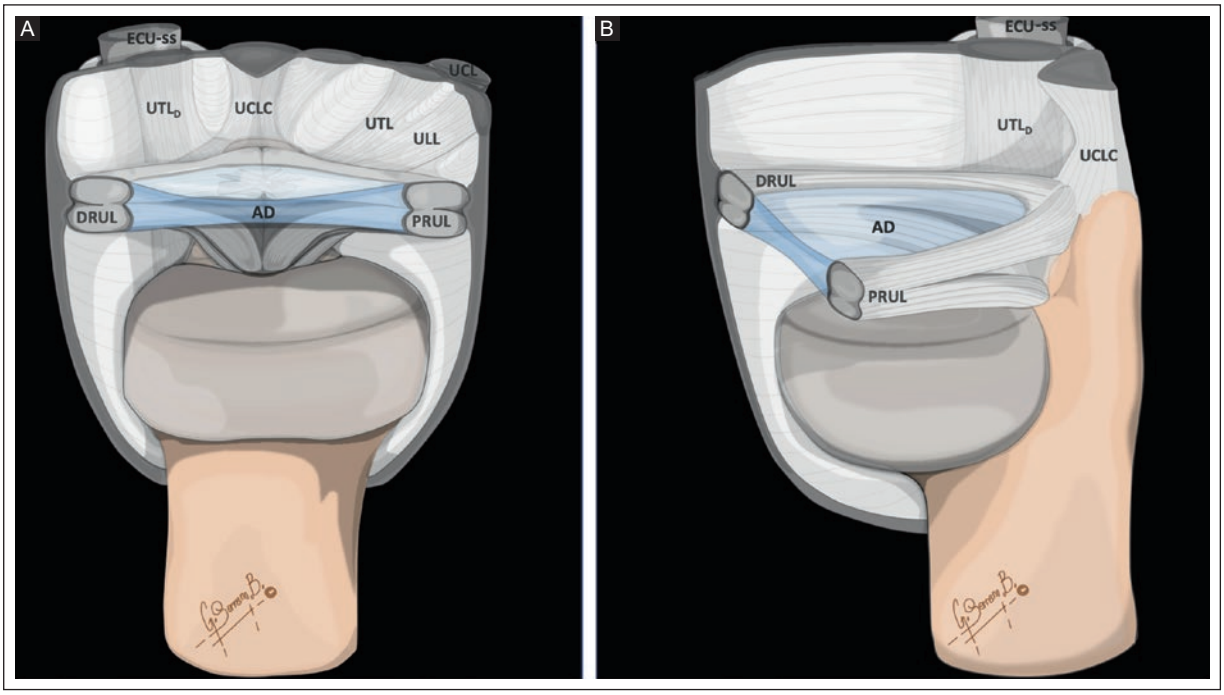


Figure 1. TFCC components. **A and B:** articular disc (AD), dorsal (DRUL), and palmar (PRUL) radioulnar ligaments, ulnocarpal ligaments (ulnolunate [ULL], ulnotriquetral [UTL], and ulnocapitate [UCL]), ECU tendon and sub-sheath (ECU-ss), dorsal ulnotriquetal ligament (UTLd), and meniscus homologue/ulnar colateral complex (UCLC).

TFCC: triangular fibrocartilage complex.

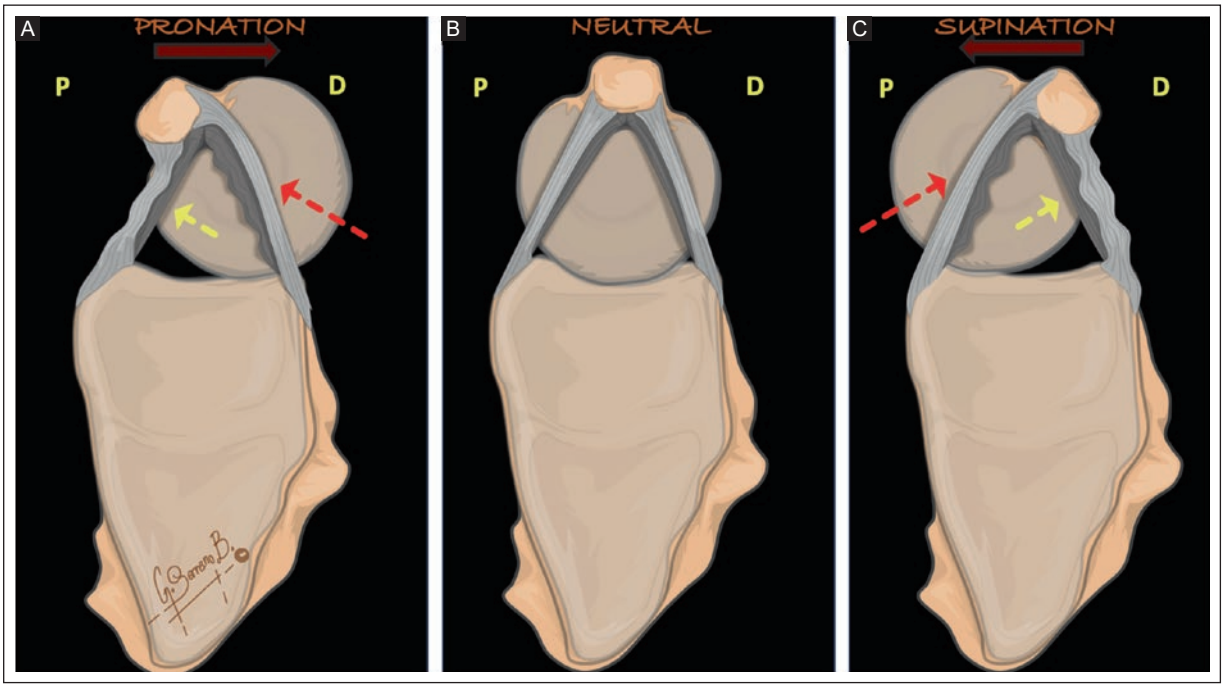


Figure 2. Anatomy and biomechanics of the peripheral ulnar TFCC. **A:** during pronation, the superficial dorsal (red arrow) and deep palmar (yellow arrow) fibers tighten. **B:** neutral position. **C:** in supination, the superficial palmar (red arrow) and deep dorsal (yellow arrow) fibers stretch. The obtuse orientation of the deep foveal fibers becomes mechanically more advantageous to stabilize the joint.

TFCC: triangular fibrocartilage complex.

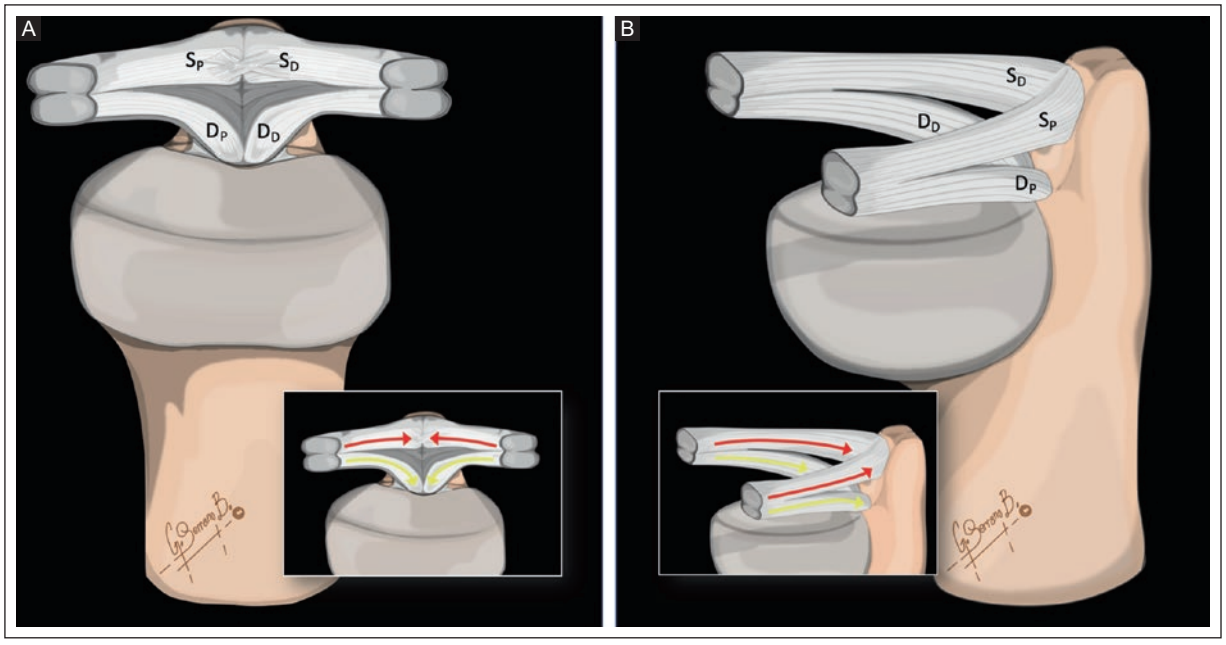


Figure 3. TFCC peripheral insertion. **A and B:** each distal radioulnar ligament is composed of a deep and superficial component; halfway between the radius and ulna, each ligament divides to extend peripherally toward the ulnar styloid and fovea. Therefore, the ulnar peripheral insertion has four arms: a deep palmar arm (D_P), a deep dorsal arm (D_D), a superficial palmar arm (S_P), and a superficial dorsal arm (S_D).
TFCC: triangular fibrocartilage complex.

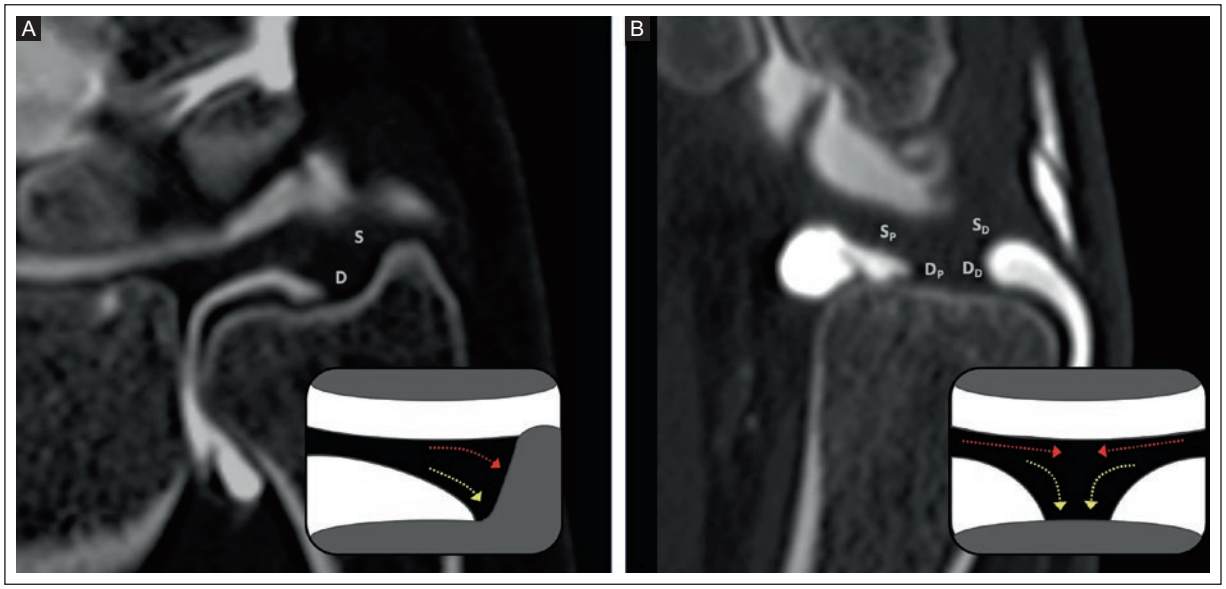


Figure 4. Ulnar insertional anatomy of the TFCC on CT arthrography. **A:** coronal plane. The peripheral ulnar insertion is observed as a single structure with the superficial styloid fibers (S) going toward the base and radial edge of the styloid process of the ulna (red arrow). The deep foveal fibers (D) are directed toward the ulnar fovea, which is a recess devoid of cartilage that lies between the ulnar styloid and the articular cartilage of the distal pole of the ulna. It is a richly vascularized area (yellow arrow). **B:** sagittal plane. Both superficial arms (red arrow) converge toward the ulnar styloid and appear as thickening zones on the periphery of the distal portion of the TFCC (S_P and S_D). The deep arms converge toward the ulnar fovea in an almost vertical orientation (yellow arrow), adopting a "fan morphology" with well-defined edges (D_P and D_D).
CT: computed tomography; D_D: deep dorsal; D_P: deep palmar; S_P: superficial palmar; S_D: superficial dorsal; TFCC: triangular fibrocartilage complex.

Table 1. Different ulnar injury patterns detected on CT arthrography

Tear patterns of the proximal foveal fibers
Tear of the deep palmar or dorsal foveal arm
Tear of both deep foveal arms
Tear patterns of the distal styloid fibers
Tear of the superficial palmar or dorsal styloid arm
Tear of both superficial styloid arms
Tear patterns of the proximal foveal and distal styloid fibers
Tear of the deep and superficial arms on the palmar or dorsal side (complete unilateral)
Tear of both deep foveal arms and one of the superficial styloid arms (palmar or dorsal)
Tear of the four arms of the ulnar insertion of the DRULs

CT: computed tomography; DRULs: dorsal radioulnar ligaments.

although they require different treatments[7]. Combined injuries are also not included, despite being frequently found[6]. Due to these limitations, in 2011, Atzei introduced a specifically targeted classification for ulnar side injuries, suggesting different therapeutic options for each one[8]. Radiologists face the difficult task of providing an adequate description of TFCC peripheral ulnar lesions, to estimate an injury that eventually requires surgical treatment[3].

CT arthrography diagnostic role in TFCC injuries

Usually, in TFCC injuries, an imaging test's diagnostic performance is compared with arthroscopy, which has diagnostic and therapeutic capabilities[9]. The categorization of TFCC injuries is essential when deciding to perform surgery. Considering the limited applicability of DRUJ arthroscopy when the foveal fibers are intact, it is crucial to have a less invasive technique capable of providing diagnostic information before surgical exploration[3]. Palmer 1B injuries are one of the main reasons for requesting a wrist CT arthrography to precisely define the injury characteristics[4].

CT arthrography has not been widely used despite its high spatial resolution[10]. This technique has shown an accuracy greater or at least equal to MR arthrography for the diagnosis of intrinsic ligament and TFCC injuries, with sensitivity, specificity, and precision close to 100%[11,12]. It is a much faster technique, making it virtually devoid of motion artifacts[4,9]. It allows high accuracy to determine injuries, with practically perfect intra and interobserver agreement[2,3,11,13]. Distension with contrast facilitates the differentiation of the distinct components of the TFCC, especially the foveal fibers, helping avoid performing unnecessary arthroscopies of the DRUJ[2,14]. The ability to perform multi-planar reconstructions makes it even more valuable[2,11,13,15]. Most patients tolerate the procedure well, and radiation exposure is not a significant concern with appropriate protocols[16,17].

Anatomy and biomechanics of the peripheral ulnar TFCC

The peripheral ulnar insertion of the TFCC is usually referred to as a styloid and foveal insertion through a distal and proximal lamina, respectively[18]. However, in a more detailed anatomic view, each DRUL is composed of a deep and superficial component, which divides halfway between the radius and ulna. The superficial arms on each side follow an almost horizontal direction toward the ulnar styloid, while the deep arms take a more vertical orientation toward the fovea[19,20]. The superficial and deep arms on each side interdigitate at their distal insertion to form a conjoined ligament with two laminae[4]. Each arm can usually be individually followed on images. Some authors even describe an intermediate layer with crosslinked fibers[21].

Different forces acting on the distal radioulnar joint stretch each of these DRUL components differently. During pronation and supination, the radius rotates around a fixed ulna, as well as some translation. The center of rotation passes through the ulnar fovea. During pronation, the superficial dorsal and deep palmar fibers are tightened, providing stability to the DRUJ. In supination, the superficial palmar and the deep dorsal fibers are stretched[22] (Figure 2). The centric insertion of the deep fibers in the fovea and the epicentric insertion of the superficial fibers in the styloid allow a smooth transition between the structures[21]. Foveal fibers have a more advantageous position, playing a more significant role in the stability of the DRUJ compared with styloid fibers[22].

Palmar instability of the radius, where the radius shows a palmar displacement relative to the ulna, is a form of DRUJ instability much more frequent than dorsal. In this sense, the deep palmar arm provides higher restriction to the palmar instability of the radius than the deep dorsal arm[23]. These facts demonstrate a significant part of the importance of being able to differentiate which specific component of the ulnar TFCC is injured.

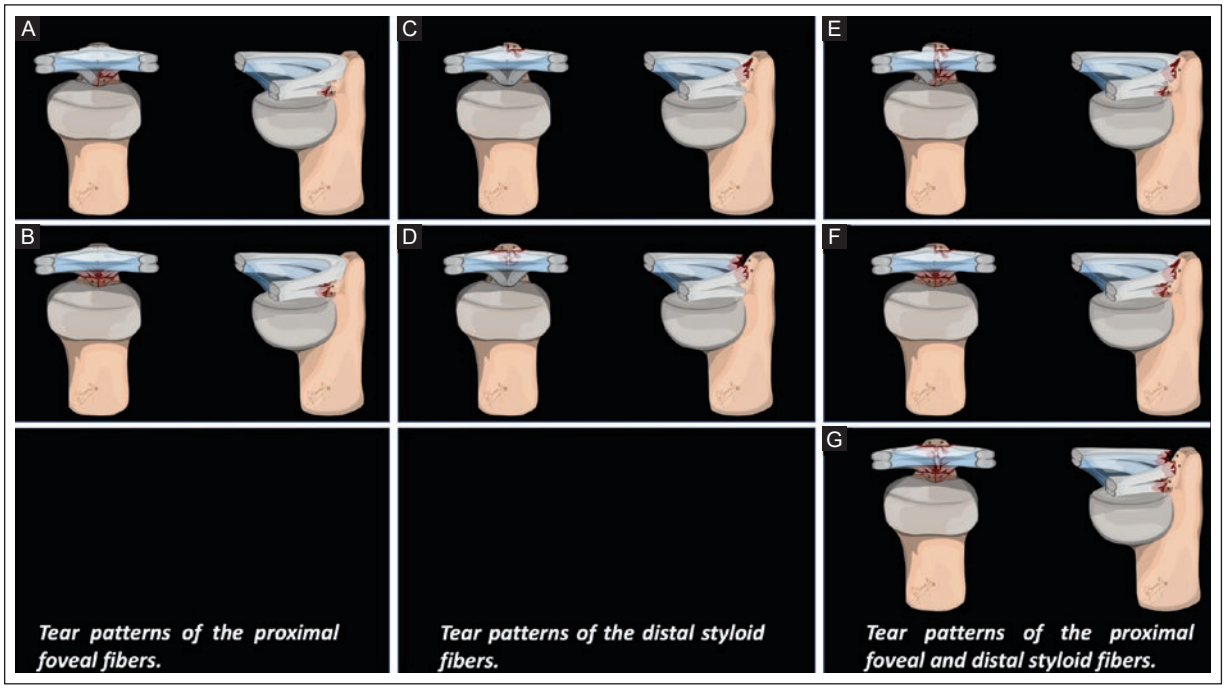


Figure 5. Schematic representation of the different ulnar injury patterns detected on CT arthrography. **A:** tear of the deep palmar or dorsal foveal arm. **B:** tear of both deep foveal arms. **C**: tear of the superficial palmar or dorsal styloid arm. **D:** tear of both superficial styloid arms. **E:** tear of the deep and superficial arms on the palmar or dorsal side (complete unilateral). **F:** tear of both deep foveal arms and one of the superficial styloid arms (palmar or dorsal). **G:** tear of the four arms of the ulnar insertion of the DRULs.

CT: computed tomography; DRULs: distal radioulnar ligaments.

Additionally, the ulnocarpal ligaments have a close relationship with the superficial and deep palmar arms at their distal insertion. The ulnotriquetral ligament attaches to the ulnar styloid along with the superficial palmar arm and the ulnocapitate ligament together with the deep palmar arm[24]. Biomechanical studies have shown that the ulnocapitate ligament and the deep palmar arm become taut during extension and radial deviation of the wrist[25,26]. For this reason, it could also be related to the injury mechanism of foveal avulsions. If the different forces acting on these structures are excessive, it may determine an avulsion from the bony insertion. Which components may tear will depend on the predominant mechanism of injury, magnitude, and direction of the traumatic forces acting on the ulnar wrist[8].

Less attention has been paid to the relationship between the mechanism of injury and the specific anatomical characteristics of the peripheral insertion of the TFCC. Taking this into account, Moritomo et al.[27] hypothesized four basic mechanisms for foveal avulsions: (1) forced wrist extension with forearm pronation, tearing first the foveal insertion, and then the superficial dorsal arm; (2) forced extension of the wrist with the forearm in supination, tearing first the foveal insertion, and then the superficial palmar arm; (3) forced pronation of the forearm, first tearing the superficial dorsal arm, and then the foveal insertion; and (4) forced supination of the forearm, first tearing the superficial palmar arm and then the foveal insertion. For them, this differentiation could change the surgical approach.

Therefore, in the context of the detailed information that can be provided and to better understand the different injury patterns identified in the CT arthrography, it might be convenient to consider the ulnar peripheral insertion as four insertions: a deep palmar arm, a deep dorsal arm, a superficial palmar arm, and a superficial dorsal arm[28] (Figure 3). Each of these can be injured individually or in association, as previously noted.

Ulnar peripheral insertion anatomy of the TFCC on CT arthrography

In both the coronal and sagittal planes, the different components of the peripheral ulnar insertion of the TFCC can be adequately evaluated with proper distension of the articular compartments by contrast. In coronal images, both the superficial styloid fibers and the deep

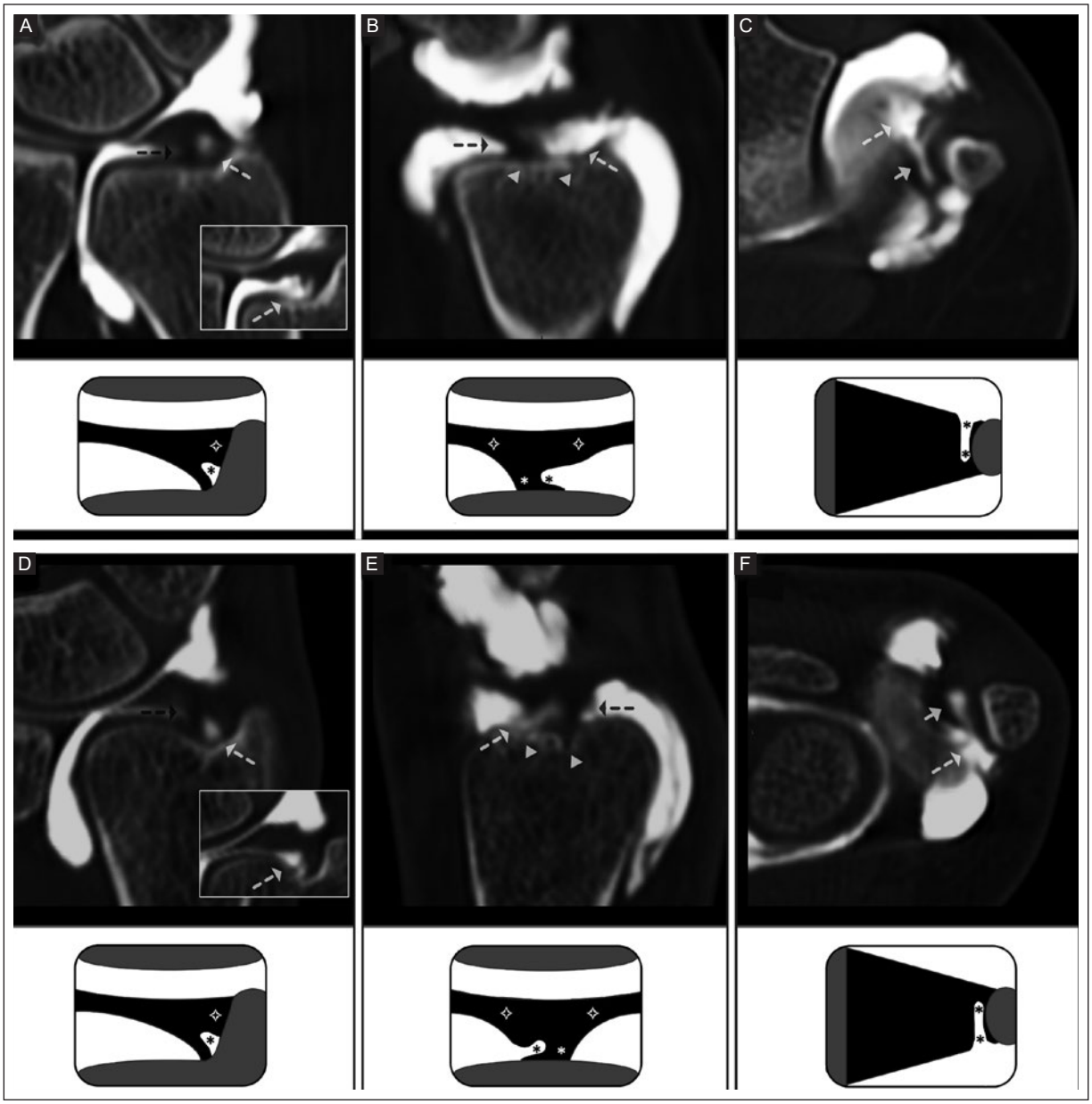


Figure 6. Tear of the deep palmar or dorsal foveal arm. *Upper panel*: **A:** coronal plane. Intraarticular contrast (white arrow) between the fibers at the base of the styloid and the deep foveal fibers (black arrow) is a completely abnormal finding. The coronal section plane is in a more dorsal position with the absence of the dorsal foveal deep fibers (the magnified view is shown). **B:** sagittal plane. Partial loss of the deep fibers "fan morphology" with contrast filtering the dorsal margin (white arrow) with preservation of the palmar margin (black arrow), confirming the tear of the deep dorsal arm. Vascular channels in the fovea (arrowheads). **C:** axial plane. Palmar-dorsal extension of the contrast, at the level of the defect (white long arrow) and extension between the superficial and deep arms in the palmar aspect (white short arrow). *Lower panel:* **D:** coronal, **E:** sagittal, and **F:** axial planes. Defect in this case involving the deep palmar arm (white arrows) is clearly demonstrated in the CT arthrography.

CT: computed tomography.

foveal fibers are seen as a unique hypodense structure. They can be individualized by their anatomical location depending on their insertion site in the radial margin of the ulnar styloid and toward the base of the ulnar styloid and fovea, respectively. On sagittal images, both superficial arms converge toward the ulnar styloid and appear as thickening areas on the periphery of the distal portion of the TFCC. The distal lamina is the term used to describe the confluence and blending of the superficial palmar and dorsal fibers in their styloid insertion.

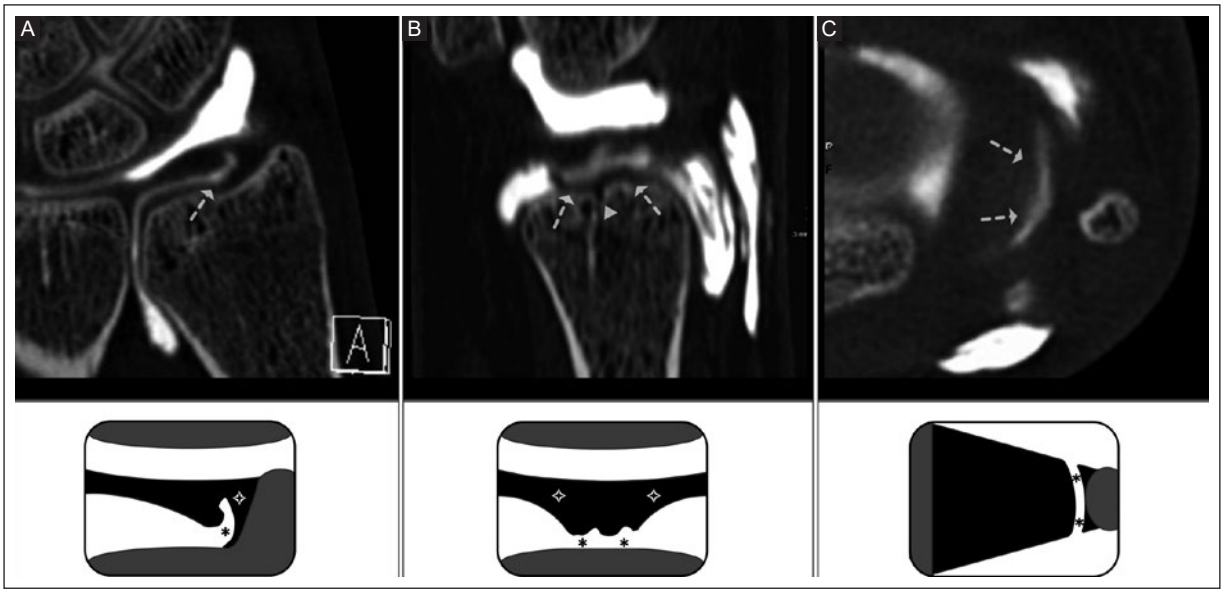


Figure 7. Tear of both deep foveal arms. **A:** coronal plane. Roundish defect involving the deep foveal fibers and those oriented to the base of the ulnar styloid (arrow). **B:** sagittal plane. Disruption of both deep arms with loss of "fan morphology" (white arrows). Vascular channel (arrowhead). **C:** axial plane. Palmar-dorsal extension of the defect (white arrows).

In contrast, the fibers of the deep arms of both radioulnar ligaments converge toward the ulnar fovea, in an almost vertical orientation, forming the proximal lamina. These fibers adopt a "fan morphology" with well-defined edges in the sagittal plane. This fan morphology must always be preserved; otherwise, loss of its expected appearance may represent a tear of the components of the foveal insertion (Figure 4). The axial plane is quite useful to demonstrate the dorsal palmar extension of the ulnar tears, as well as the longitudinal extension of the peripheral non-Palmer injuries frequently associated with these injuries.

Different ulnar injury patterns detected by CT arthrography

Table 1 and Figure 5 show the ulnar injury patterns detected by CT arthrography**.** The characteristics of these patterns are described below.

Tear patterns of the proximal foveal fibers

– **Tear of the deep palmar or dorsal foveal arm**

Foveal fibers (proximal lamina) are the main contributor to the stability of the DRUJ. When deciding on appropriate surgical treatment for repairable injuries of the ulnar insertion of the TFCC, the most important parameter is to define the tear of the foveal fibers[29].

A frequent mechanism of foveal injuries is hyperextension, usually preserving the dorsal superficial fibers. Tearing of the foveal fibers could represent an early stage of the injury, with later tearing of the remaining components[27].

In this tear pattern, it is essential to know the normal configuration of the fibers that run toward the ulnar fovea and not to confuse them with the nearby fibers at the base of the styloid process. In the coronal plane, contrast demarcates the ulnar fovea in the defect area, and a linear or roundish morphology of the defect is identified. The latter has shown high specificity (but low sensibility) for foveal tears in one study, with hand surgeons as exam readers[13]. The typical "fan morphology" is partially lost in the sagittal plane, with contrast filtering one of its margins representing the tear of the deep arm, either palmar or dorsal (Figure 6).

– **Tear of both deep foveal arms**

The approach is the same as for injuries to one of the deep arms. The sagittal plane (and axial) at the fovea level corroborates the dorsal-palmar extension of the tear, clarifying the tear of both deep arms. Linear or roundish (Figure 7) defects are found[13]. These roundish defects are more prominent. Based on the findings of the imaging exams, they also usually seem to involve the fibers directed toward the base of the styloid, probably assuming a higher degree of clinical

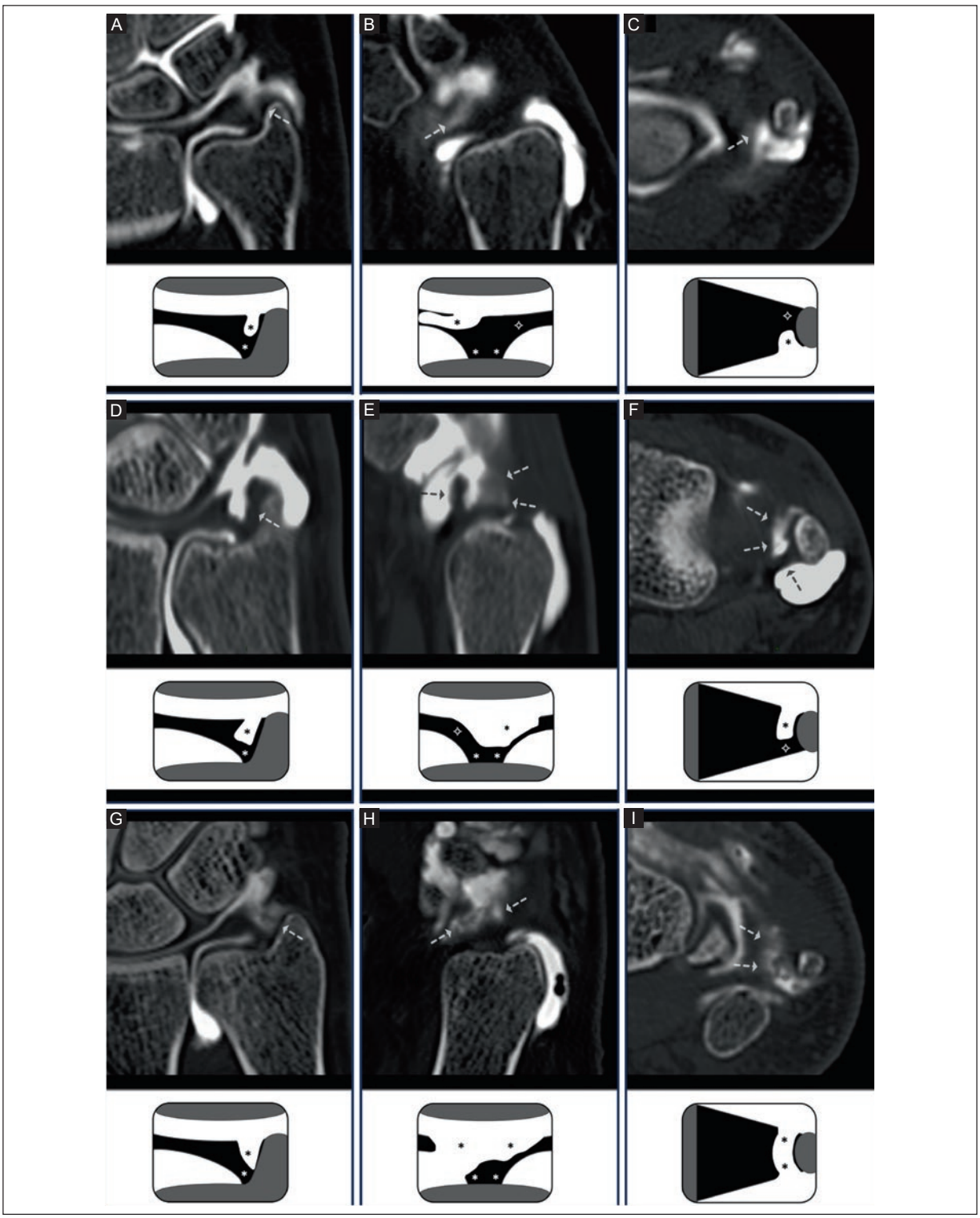


Figure 8. Tear of the superficial palmar or dorsal styloid arm. *Upper panel:* **A:** superficial fibers defect (white arrow), with frondiform grayish tissue partially occupying the tear, representing synovitis. **B:** sagittal plane. Defect is located in the anatomical site of the superficial palmar arm (white arrow). Preservation of "fan morphology." **C:** axial plane. The defect location is confirmed at the level of the palmar fibers (white arrow). *Middle panel:* **D:** coronal plane. A prominent defect involves the superficial fibers, with contrast filling the tear (white arrow). **E:** sagittal plane. Extensive defect of the superficial fibers (white arrows) with at least partial preservation of the superficial palmar fibers (black arrow). **F:** axial plane. Continuity of the superficial palmar fibers inserting into the ulnar styloid (black arrow). Central and dorsal defect with wide contrast passage (white arrows). *Lower panel:* **G:** superficial fibers defect (white arrow), with frondiform grayish tissue representing synovitis. **H:** sagittal plane. Defect involving both superficial arms, with partial preservation of the dorsal arm (white arrows). Preservation of deep fibers "fan morphology." **I:** axial plane. Palmar-dorsal extension of the defect (white arrows).

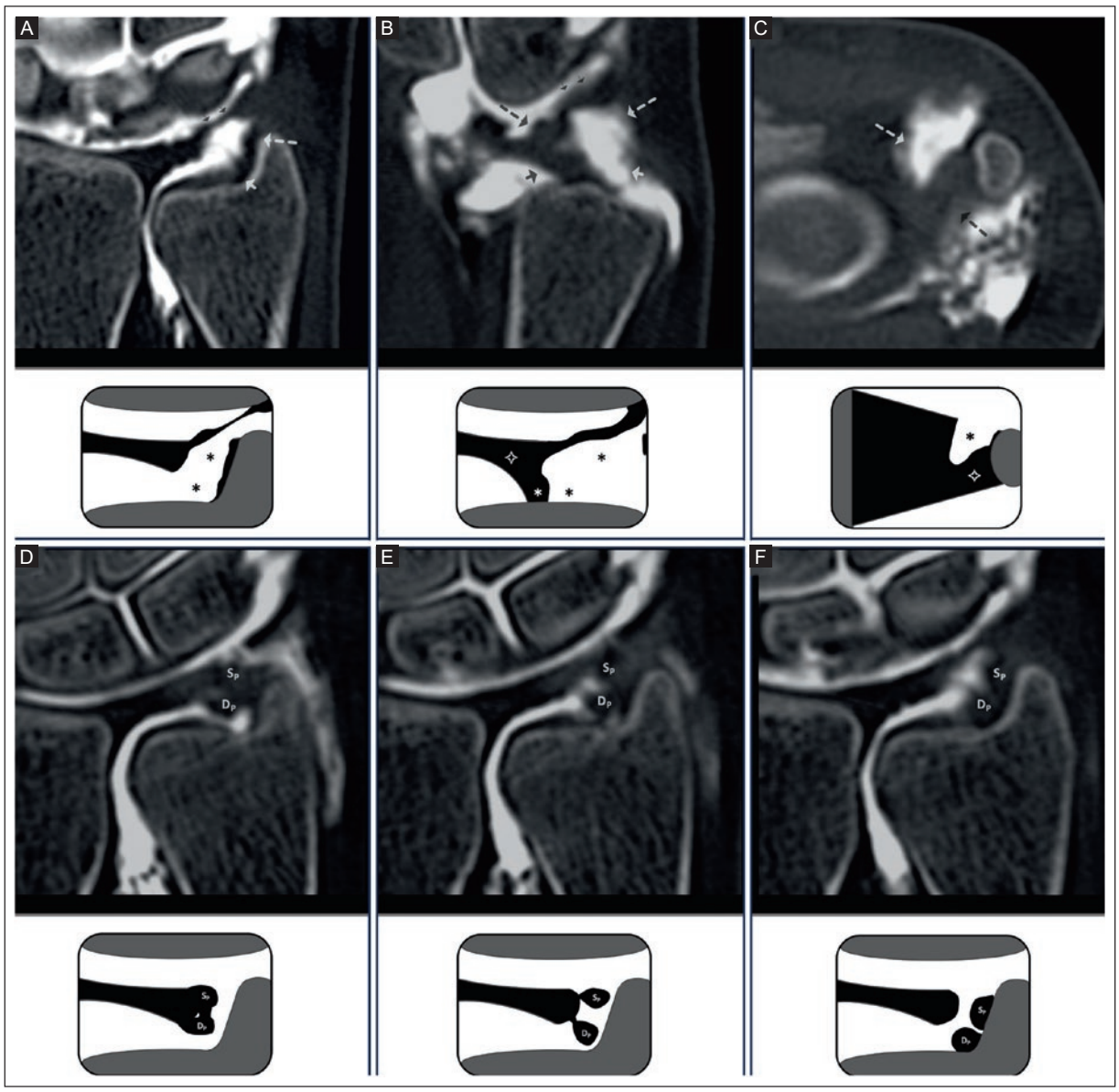


Figure 9. Tear of the deep and superficial arms on the palmar or dorsal side (complete unilateral tear). *Upper panel:* **A:** coronal plane. Complete defect of the superficial (long white arrow) and deep (short white arrow) fibers. Preservation of some thin superficial distal fibers (small black arrows). **B:** sagittal plane. The injury involves the superficial and deep dorsal arms (long and short white arrows) and maintaining the palmar arms (long and short black arrows). Thin superficial distal fibers are preserved, determining a non-communicating injury (small black arrows). **C:** axial plane. Extension of the dorsal defect (white arrow) with uninjured palmar fibers (black arrow). Variant of the Atzei class 2 lesion. *Lower panel:* **D-F:** in the sequential coronal slices from palmar to dorsal, the uninjured superficial palmar (S_P) and deep palmar (D_P) arms can be followed, directed toward their distal insertion in the styloid and fovea, respectively.

D_P: deep palmar; S_P: superficial palmar.

instability. Some remnant fibers may persist at the periphery of the defect. The same findings are made and corroborated in the axial plane.

In the case of a foveal tear (especially the palmar arm) with preservation of the superficial dorsal arm, visualization of the fovea can be difficult from an open dorsal approach, as it is necessary to section the floor of the ECU sheath and the superficial dorsal arm to gain access to the fovea. This procedure leads to unnecessary iatrogenic sectioning of a distal radioulnar stabilizer to repair the fovea (the deep palmar and superficial dorsal arms stabilize the DRUJ in pronation). In these cases, some authors suggest using a palmar approach to access and repair the palmar foveal fibers[30]. Therefore, the detailed information provided by the CT arthrography can eventually modify the surgical approach.

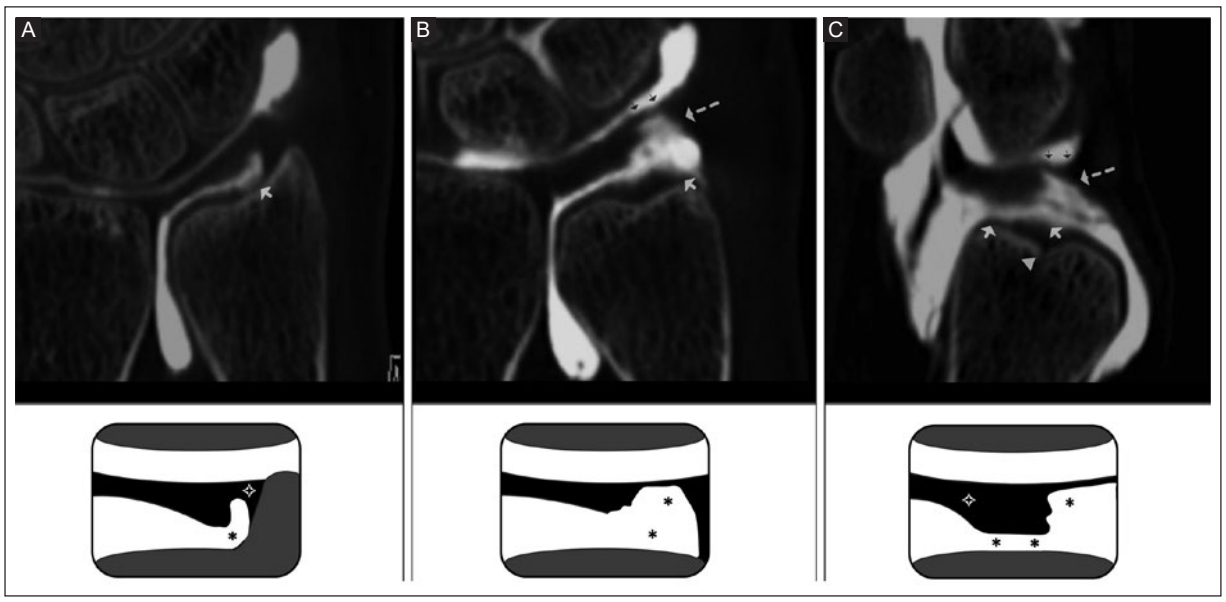


Figure 10. Tear of both deep foveal arms and one of the superficial styloid arms (palmar or dorsal). **A:** palmar coronal plane. Deep fibers defect (short white arrow). **B:** dorsal coronal plane. Complete defect of the superficial (long white arrow) and deep (short white arrow) fibers. Preservation of some thin superficial distal fibers (small black arrows). **C:** sagittal Plane. Defect of both deep arms (short white arrows) with loss of "fan morphology." Tear of the dorsal superficial fibers (long white arrow), with preservation of thin distal fibers, determining a non-communicating injury (small black arrows). Vascular channel (arrowhead). As some distal fibers remain intact, these injuries will not be directly visualized during wrist arthroscopy through the radiocarpal portals.

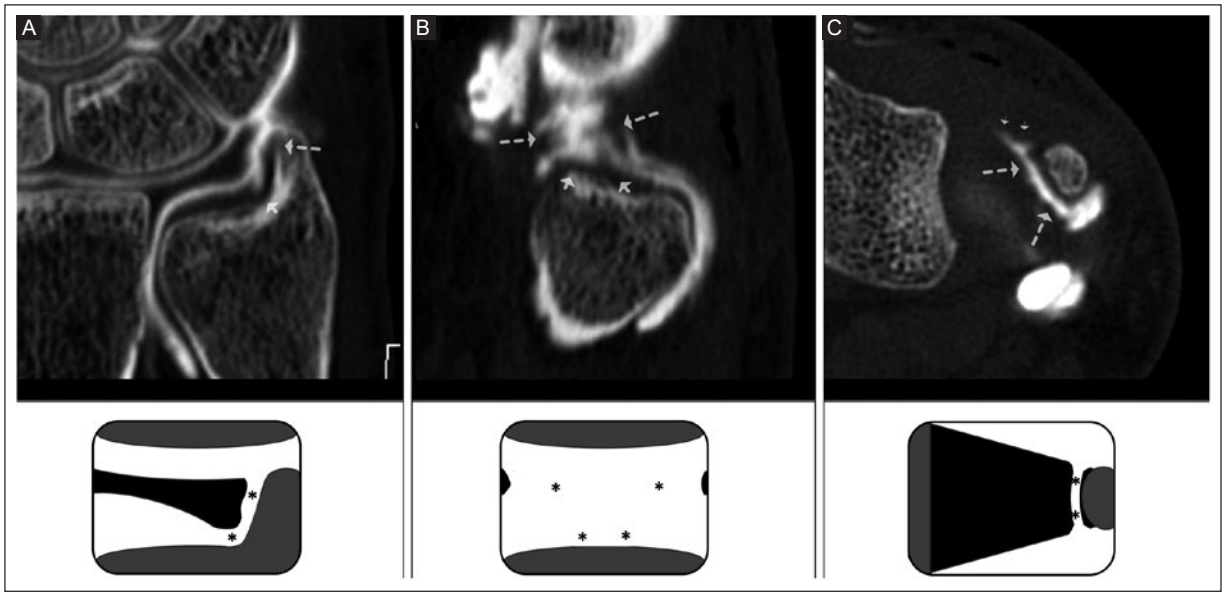


Figure 11. Tear of the four arms of the ulnar insertion of the DRULs. **A:** coronal plane. Complete defect of superficial (long white arrow) and deep (short white arrow) fibers with communication of the compartments, with slight retraction. **B:** sagittal plane. Defect of all four arms (long and short white arrows), with complete loss of peripheral attachment morphology. **C:** axial plane. Complete tear from dorsal to palmar (long white arrows), with an extension to the dorsal ulnar fibrocapsular junction (small white arrows).

DRULs: distal radioulnar ligaments.

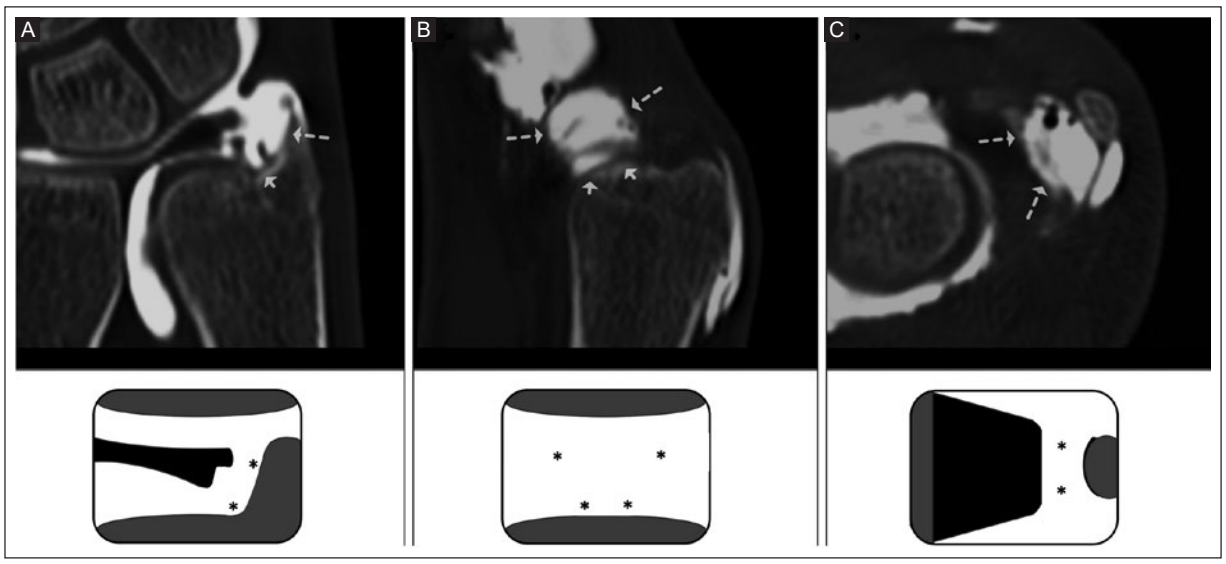


Figure 12. Tear of the four arms of the ulnar insertion of the DRULs with poor margins. **A:** coronal plane. Complete defect of both arms (long and short arrow), with retracted margin. Note the separation of the radioulnar joint, as a sign of joint instability. **B and C:** sagittal and axial planes. Extensive defect of the ulnar peripheral insertion can be clearly quantified.
DRULs: distal radioulnar ligaments.

Tear patterns of the distal styloid fibers

– **Tear of the superficial palmar or dorsal styloid arm**

The superficial arms (distal lamina) are inserted at the ulnar styloid's radial edge and can occupy its entire extension from the base to the tip[31]. The tear is frequently covered by synovitis in arthroscopies, requiring synovectomy for visualization[6,7]. Although it does not necessarily cause significant instability when torn in isolation, it can cause ulnar wrist pain highly symptomatic[6]. In the multiplanar examination, the interruption of one of the superficial arms' fibers is observed with the same clarity as in tears of the foveal fibers. It is necessary to take into consideration that they may not fill homogeneously with contrast, partially occupied by a grayish frondiform tissue representing synovitis (Figure 8). The tear can be quite prominent and give the impression of compromising both arms. However, in the multiplanar approach, at least partial indemnity of one of the arms can be precisely identified.

– **Tear of both superficial styloid arms**

The defect of both superficial arms is confirmed by carefully examining all the imaging planes. It is only necessary to be careful with the abundant synovitis that frequently occupies them, making their identification sometimes tricky (Figure 8). Synovitis and the tear may extend to the pre-styloid recess[7].

Tear patterns of the proximal foveal and distal styloid fibers

– **Tear of the deep and superficial arms on the palmar or dorsal side (complete unilateral)**

In this variety of injury patterns, a superficial analysis of the images in the coronal plane can be interpreted as a complete tear of the ulnar peripheral insertion of the TFCC; in the Atzei classification[8], it might seem like a pure class 2 lesion. However, in a detailed multiplanar evaluation, preservation of the superficial and deep fibers of one of the sides will be confirmed, whether palmar or dorsal depending on the predominant mechanism of injury (Figure 9). This exceptionally detailed assessment of the components that are torn and preserved may perhaps explain in part why in class 2 injuries in the Atzei classification, the degree of instability of the distal radioulnar joint ranges from mild to severe. Probably, as we can demonstrate in the CT arthrography, there may be at least partial preservation of the fibers on one side, actually representing a variant of the Atzei class 2 lesion.

– **Tear of both deep foveal arms and one of the superficial styloid arms (palmar or dorsal)**

The excellent spatial resolution of the CT arthrography allows for quantifying the extent of a lesion quite accurately and corroborates the specific components of the peripheral insertion that are compromised and

preserved. Together with any of the superficial arms, either palmar or dorsal, injury to the foveal fibers can occur quite frequently in the context of peripheral ulnar tears. As proposed by Moritomo et al.[27], the combination of these could represent a mechanism of injury with an extension of the wrist, either in supination (injury to the foveal fibers first and then the superficial palmar arm) or in pronation (injury to the foveal fibers first and later the superficial dorsal arm). It is not uncommon that the injury to the superficial arms, which may be a high-grade tear, leaves some undamaged fibers on the ligament's distal surface that faces the radiocarpal compartment (Figure 10). This injury represents a non-communicating tear; therefore, there are some essential facts to emphasize. The first is the importance of always injecting contrast into the distal radioulnar compartment[4]. Otherwise, these lesions will go unnoticed. As some distal fibers remain intact, these injuries will not be visualized directly during wrist arthroscopy through the radiocarpal portals. In other words, according to Atzei's concept of the Iceberg[8], we could be facing a significant tear from the biomechanical point of view, completely submerged underwater for the orthopedic surgeon's eyes. With an adequate description of the injury, this valuable information can become essential during surgical planning.

– **Tear of the four arms of the ulnar insertion of the DRUL's**

These injuries are usually, but not always, communicating injuries, with contrast passing between the radiocarpal and the distal radioulnar compartment[13]. They combine the findings of the previously mentioned patterns, with loss of continuity of the deep and superficial fibers in the coronal plane in the ulnar insertion. In the sagittal plane at the tear level, a complete distortion of the expected morphology will be seen in the peripheral ulnar portion of the TFCC, with the defect involving the four arms of the DRULs (Figure 11). These injuries are the ones that most commonly require surgical repair, given the degree of instability they produce[7,32]. As with repairs elsewhere, they must be stress-free. Therefore, the description of the defect is essential, as substantial defects with poor-quality retracted segments will be more likely to be reconstructed than repaired with reinsertion[7] (Figure 12).

CONCLUSION

CT arthrography is a highly capable imaging technique to evaluate TFCC injuries. When evaluating ulnar peripheral tears, the multiplanar approach allows a detailed description of the different components affected. This approach to assessing ulnar TFCC injuries in imaging studies has not been described in the literature to the best of the author's knowledge. This information could be quite valuable to carry out a more reliable clinical-radiological correlation and become the starting point for future research studies. Furthermore, it may have implications at the time of surgical planning, even changing the surgical approach. Radiologists face the difficult task of providing an adequate description of the ulnar peripheral TFCC tears, and the approach presented in this article can significantly facilitate this task.

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Conflicts of interest

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Ethical disclosures

Protection of individuals. The author declares that no experiments were performed on humans or animals.

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