



# Interdisciplinary consensus statements on imaging of DRUJ instability and TFCC injuries

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## Abstract

**Objectives** The purpose of this agreement was to establish evidence-based consensus statements on imaging of distal radioulnar joint (DRUJ) instability and triangular fibrocartilage complex (TFCC) injuries by an expert group using the Delphi technique.

**Methods** Nineteen hand surgeons developed a preliminary list of questions on DRUJ instability and TFCC injuries. Radiologists created statements based on the literature and the authors' clinical experience. Questions and statements were revised during three iterative Delphi rounds. Delphi panelists consisted of twenty-seven musculoskeletal radiologists. The panelists scored their degree of agreement to each statement on an 11-item numeric scale. Scores of "0," "5," and "10" reflected complete disagreement, indeterminate agreement, and complete agreement, respectively. Group consensus was defined as a score of "8" or higher for 80% or more of the panelists.

**Results** Three of fourteen statements achieved group consensus in the first Delphi round and ten statements achieved group consensus in the second Delphi round. The third and final Delphi round was limited to the one question that did not achieve group consensus in the previous rounds.

**Conclusions** Delphi-based agreements suggest that CT with static axial slices in neutral rotation, pronation, and supination is the most useful and accurate imaging technique for the work-up of DRUJ instability. MRI is the most valuable technique in the diagnosis of TFCC lesions. The main indication for MR arthrography and CT arthrography are Palmer 1B foveal lesions of the TFCC.

**Clinical relevance statement** MRI is the method of choice for assessing TFCC lesions, with higher accuracy for central than peripheral abnormalities. The main indication for MR arthrography is the evaluation of TFCC foveal insertion lesions and peripheral non-Palmer injuries.

## Key points

- Conventional radiography should be the initial imaging technique in the assessment of DRUJ instability. CT with static axial slices in neutral rotation, pronation, and supination is the most accurate method for evaluating DRUJ instability.
- MRI is the most useful technique in diagnosing soft-tissue injuries causing DRUJ instability, especially TFCC lesions.
- The main indications for MR arthrography and CT arthrography are foveal lesions of the TFCC.

**Keywords** Wrist injuries · Delphi technique · Guidelines · Distal radioulnar joint · Triangular fibrocartilage complex

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Iwona Sudoł-Szopińska and Tobias Johannes Dietrich contributed equally to this work.

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## Abbreviations

CT	Computed tomography
DOB	Distal oblique band of the interosseous membrane
DRUJ	Distal radioulnar joint
ECU	Extensor carpi ulnaris
IQR	Interquartile range
I-WRIST 2021	International Wrist Radiologic evaluation for the Instability of the Scapholunate and DRUJ/TFCC
MRI	Magnetic resonance imaging
TFCC	Triangular fibrocartilage complex

## Introduction

Distal radioulnar joint (DRUJ) instability and triangular fibrocartilage complex (TFCC) lesions are frequent clinical conditions that are often misdiagnosed and cause ulnar-sided wrist pain and dysfunction [1–6].

The critical function of the DRUJ is the pronosupination of the forearm through a complex interaction of the bones and soft tissue stabilizers with the proximal radioulnar joint, radiocapitellar joint, and interosseous membrane [1–4].

The etiology of DRUJ instability is multifactorial, and distal radius fractures, ulnar styloid fractures, and TFCC injuries are the leading causes. TFCC lesions are the primary cause of ulnar-sided wrist pain, and if the insertion of the distal radioulnar ligaments is injured, DRUJ instability can develop [1–4].

Imaging is key to the diagnostic workup for DRUJ instability and TFCC injuries. A variety of static and dynamic diagnostic imaging techniques are being proposed for the work-up of DRUJ instability and TFCC injuries, including radiography, computed tomography (CT), magnetic resonance imaging (MRI), CT arthrography, and MR arthrography [7–10]. Although there is increasing research, there are substantial uncertainties regarding the optimal diagnostic imaging work-up of wrist instability in clinical practice [1, 2, 11, 12].

The I-WRIST 2021 group of radiologists and hand surgeons was established to provide interdisciplinary consensus statements on imaging of post-traumatic wrist instability. The current work belongs to a two-part series. The first part was focused on scapholunate joint instability [13].

The purpose of this research was to establish evidence-based consensus statements on the imaging of DRUJ instability and TFCC injuries by experts using the Delphi technique for consensus building.

## Materials and methods

Methods of the present article were identical and simultaneous to the first part of this project [13]. Panelist selection, questions to hand surgeons, literature research, literature database distribution to the panelists, project leader and task group nomination, Delphi process, and statistical analysis were performed at the same time as the first project. Details are provided in the appendix.

## Questions

In the first step, hand surgeons were asked to submit questions to the radiologists on potentially problematic or controversial issues related to the imaging of DRUJ instability and TFCC injuries.

The surgeons were also asked to select the most relevant clinical classifications to illustrate to radiologists the clinical relevance of imaging in the surgical decision-making process.

A preliminary list of nine questions regarding DRUJ instability and TFCC injuries was developed (Table 1). The selected classifications were the Palmer classification of TFCC lesions [14] (Table 2), the Atzei classification of peripheral tears of the TFCC [15–17] (Table 3), and the del Piñal classification of Palmer class 1B injuries [18] (Table 4).

## Bibliographic search strategy

A word search of MEDLINE and the Cochrane Library using the terms “imaging,” “radiographs,” “magnetic resonance imaging,” “computed tomography,” “ultrasonography,” “TFCC injury,” “TFCC tear,” “DRUJ instability,” and “DRUJ injury” revealed 894 articles published between January 2010 and January 2020. Subsequently, radiologists were asked to supplement the literature database with additional publications.

This left three meta-analyses, 90 articles, and 6 book chapters that formed the evidence base for the Delphi process and were archived in a cloud-based directory accessible to radiologists.

## Task groups

The project leaders (T.D., I.S.S.) nominated experts into separate task groups. For consecutive Delphi rounds, each task group developed one statement as an answer to the assigned question in Table 1, followed by a short discussion and a list of references. The scientific evidence level

**Table 1** Preliminary list of nine questions on distal radioulnar joint instability and triangular fibrocartilage complex injuries proposed by hand surgeons

No	Question
1	Which imaging techniques provide information on DRUJ stability?
2	Which imaging technique provides reliable information on the shape of sigmoid notch?
3	Which imaging technique provides reliable information on the ulnar variance?
4	Can imaging techniques differentiate class 1 (traumatic) of TFCC lesions (central, ulnar, ulnocarpal, radial) based on Palmer classification?
5	Can imaging techniques differentiate type IB of TFCC lesions (distal, proximal, both, nonrepairable) based on Atzei classification?
6	Can imaging techniques provide information on DRUJ arthritis based on Atzei classification?
7	Can imaging techniques provide information on volar and dorsal capsular tear described by del Piñal F, Mathoulin C, Nakamura T. (Arthroscopic Management of Ulnar Pain. Chapter 6 Springer Heidelberg New York Dordrecht London 2013)
8	Which imaging techniques provide information if distal oblique bundle is intact, incompetent or torn?
9	Which imaging techniques provide information on ECU stability?

TFCC triangular fibrocartilage complex, DRUJ distal radioulnar joint, ECU extensor carpi ulnaris tendon

according to the 5-point scale developed by the Oxford Centre for Evidence-Based Medicine was assigned to every article of the discussion by the experts of each task group [19].

The panelists were asked to classify their degree of agreement with each statement according to an 11-point Likert-type scale, in which 0 reflects complete disagreement, 5 reflects neither agreement nor disagreement, greater than or equal to 8 ( $\geq 8$ ) reflects agreement, and 10 reflects complete agreement.

The end of the Delphi process was predetermined at a maximum of three rounds or achievement of group consensus for each statement, whichever came first [13, 20].

In the first Delphi round, the panelists were invited to comment on the phrasing or content of the thirteen preliminary questions and statements listed in Table 1, particularly if their rating did not reflect full agreement (scoring  $\leq 7$ ). The feedback of the panelists was used to insert additional questions and rephrase the statements for the next Delphi rounds [20]. The second and third Delphi rounds included the revised and extended questions and statements and the corresponding questions and statements of the former round.

Questions and statements nos. 7–11 were added in the second Delphi round in response to panelists' feedback to elaborate on the initial questions and statements. The final fourteen questions and statements (no. 1–no. 14) of the second and third Delphi rounds are listed in Table 5. The third and final Delphi round was limited to one question that did not achieve group consensus in the previous rounds.

## Statistical analysis

Threshold values for consensus of the Delphi method have not been established [21]. A systematic review showed a broad range between 50 and 97% as the threshold for consensus in various Delphi studies, the median was 75% [22]. In general,

a higher level of agreement implicates more powerful statements. Therefore, the 80% threshold value for group consensus was also used in previous ESSR-associated consensus statements on femoroacetabular impingement [23].

Group consensus of the present survey was defined as 80% or more of the panelists rating their agreement level as “8,” “9,” or “10” [13, 22]. Median and interquartile range (IQR) values are provided as measures of polarization among the panelists [21].

## Results




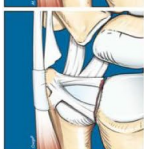
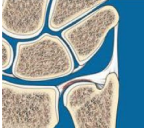
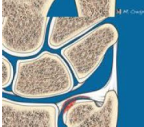

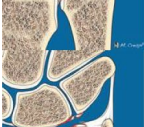
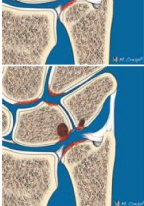
Literature research on diagnostic imaging of DRUJ instability and TFCC injuries revealed a heterogeneous spread of scientific evidence between level 1 and level 5 according to criteria of the Oxford Centre for Evidence-Based Medicine (Table 5) [19]. Three statements achieved group consensus in the first Delphi round (statement no. 3, no. 9, no. 10), and ten in the second Delphi round (statement no. 1, no. 2, no. 4, no. 5, no. 6, no. 7, no. 8, no. 11, no. 12, no. 14). The remaining statement achieved group consensus in the third Delphi round (statement no. 13). The final questions and statements including the percentages, medians, and IQRs of agreement of the Delphi panelists are provided in Table 5.

## Discussion

### DRUJ instability


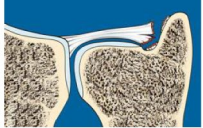
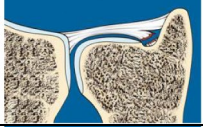
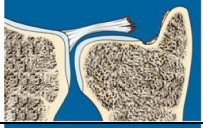

*Statement no. 1: The most useful imaging technique in DRUJ instability is CT (axial CT slices of the DRUJ in neutral, pronation, and supination positions). Conventional radiography, although generally used as an initial assessment method, has significant limitations in DRUJ*

**Table 2** Palmer’s classification of triangular fibrocartilage complex injuries

Palmer class 1 traumatic lesions of the TFCC	Graphics	Lesion description
A		Central perforation
B		Ulnar avulsion: 1. With styloid fracture 2. Without styloid fracture
C		Distal avulsion (from carpus)
D		Radial avulsion: 1. With sigmoid notch fracture 2. Without sigmoid notch fracture
Palmer class 2 degenerative lesions of the TFCC		Lesion description
A		TFCC wear
B		TFCC wear plus lunate or ulnar head chondromalacia
C		TFCC perforation
D		TFCC perforation plus lunate or ulnar head chondromalacia plus lunotriquetral ligament perforation
E		TFCC perforation plus lunate or ulnar head chondromalacia plus lunotriquetral ligament perforation plus ulnocarpal arthritis

TFCC triangular fibrocartilage complex, DRUJ distal radioulnar joint, ECU extensor carpi ulnaris tendon

**Table 3** Atzei classification of triangular fibrocartilage complex peripheral tear

Type	Graphics	Clinical DRUJ Instability	Involved TFCC Component	TFCC healing potential	Status of DRUJ cartilage	Treatment
Class 1 Repairable distal tear		None or slight	Distal - torn Proximal - intact	Good	Good	Repair Suture ligament to capsule or debridement
Class 2 Repairable complete tear		Mild or severe	Distal - torn Proximal - torn	Good	Good	Repair Foveal refixation
Class 3 Repairable proximal tear		Mild or severe	Distal - intact Proximal - torn	Good	Good	Repair Foveal refixation
Class 4 Non-repairable		Severe	Distal - torn Proximal - torn	Poor	Good	Reconstruction Tendon graft
Class 5 Arthritic DRUJ		Mild or severe	Variable	Variable	Poor	Salvage Arthroplasty or Joint Replacement

instability. MRI, especially MR arthrography and CT arthrography, allows the assessment of TFCC injuries causing DRUJ instability.

*Statement no. 2: CT is the most appropriate imaging technique for providing reliable information on the shape of the sigmoid notch of the radius at the DRUJ. MRI also facilitates the evaluation of the radial sigmoid notch morphology despite limited evidence.*

The DRUJ is an incongruent joint with different radii of curvature of the articular surfaces that allow rotation of the sigmoid notch of the radius on the head of the ulna and anteroposterior sliding of the articular surfaces [1, 4]. In extreme pronosupination movements, contact of the articular surfaces is limited to the volar and dorsal margins of the radial sigmoid notch, contributing significantly to DRUJ stability [24, 25]. The dorsal bone margin typically forms an acute angle, while the volar margin is more rounded, although augmented by a fibrocartilaginous ridge. In post-traumatic fractures or deficiencies of the DRUJ margins, joint stability is significantly compromised [26].

The main stabilizers of the DRUJ are soft tissues such as the joint capsule, ECU tendon, pronator quadratus muscle, and interosseous membrane, in contrast to osseous structures that contribute to only 20% of its stability [1–4, 25, 27].

Conventional radiography with two standardized projections (PA and lateral) is the initial imaging method of the DRUJ. It helps assess fractures, DRUJ joint space, degenerative changes of the DRUJ, alignment of articular surfaces, and ulnar variance [1, 2, 4].

CT is the imaging method of choice for the diagnosis of DRUJ instability (Fig. 1). CT allows evaluation of the articular surface morphology [1, 2, 28]. Dynamic assessment is the most useful technique and can be performed using static positions in neutral rotation, pronation, or supination [1, 2, 28].

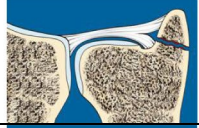


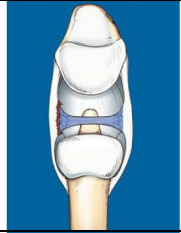
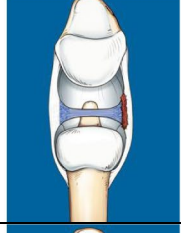
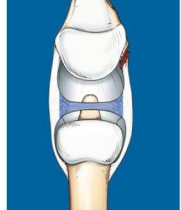
A real-time dynamic four-dimensional CT study with variable loads makes it possible to study the movement of the joint and the interaction of its bony and soft tissue components, although its actual role needs to be better defined [1, 29].

Ultrasound assessment of DRUJ instability under load has been described but has not yet reached a significant spread [30].

The primary role of MRI, CT arthrography, and MR arthrography in DRUJ instability is the evaluation of soft tissue injuries, especially of the TFCC [1, 2].

*Statement no. 3: Plain radiography with an appropriate measuring method and positioning provides reliable information on the ulnar variance.*

**Table 4** Del Piñal classification of Palmer class 1B injuries

Type	Graphics	Clinical DRUJ instability	Involved TFCC component	TFCC healing potential	Status DRUJ cartilage	Treatment
Ulnar styloid fracture without TFCC tear		None	None	Not applicable	Good	None
Ulnar styloid fracture with TFCC tear		Mild or severe	Proximal	Good	Good	Repair Foveal refixation Non-union ulnar styloid resection
Ulnar styloid fracture without TFCC tear		None	None	Not applicable	Good	Non-union ulnar styloid resection
Volar capsule tear		None	Volar capsule	Good	Good	Repair Volar capsule suture
Dorsal capsule tear		None	Dorsal component detachment from the capsule	Good	Good	Repair Dorsal capsule suture
Dorsal synovitis		None	Dorsal synovitis	No data	Good	Debridement, Mobilization

The term ulnar variance refers to the relative length of the distal articular surfaces of the ulna and radius [31]. The standardized posteroanterior wrist radiograph is the reference standard method for determining ulnar variance [32, 33]. However, this measurement can usually be reliably performed in CT and MRI studies, with minor differences that are not clinically significant [32, 33].

### TFCC injuries

*Statement no. 4: High-resolution MRI, MR arthrography, and CT arthrography allow an accurate assessment of the location and extent of full-thickness Palmer class 1*

*TFCC injuries. MR arthrography and high-resolution CT 3D arthrography techniques with radial reconstruction centered on the ulnar styloid process provide a precise evaluation of the different types of noncommunicating partial thickness lesions of the TFCC.*

Palmer classification of TFCC lesions (Table 2) divides TFCC injuries into traumatic (class 1) and degenerative (class 2) injuries. Traumatic injuries are subdivided based on the anatomical location of the injury into four subtypes (A–D) [14]. Class 1A and 1B injuries are the most frequent subtypes of traumatic injuries [34], although class 2 derangements become particularly frequent in older adults [35].

**Table 5** Consensus statements: questions, statements and agreement of 27 panelist

No	Questions and statements	Scientific evidence level*	Agreement [median] (IQR)
1	Which imaging techniques provide information on DRUJ stability? #The most useful imaging technique in DRUJ instability is CT (axial CT slices of the DRUJ in neutral, pronation, and supination positions). Conventional radiography, although generally used as an initial assessment method, has significant limitations in DRUJ instability. MRI, and especially MR arthrography and CT arthrography, allow the assessment of TFCC injuries causing DRUJ instability	2	100% [10] (9–10)
2	Which imaging techniques provide reliable information on the sigmoid notch of the radius? #CT is the most appropriate imaging technique for providing reliable information on the shape of the sigmoid notch of the radius at the DRUJ. MRI also facilitates the evaluation of the sigmoid notch morphology despite limited evidence	3	96% [10] (9–10)
3	Which imaging technique provides reliable information on the ulnar variance? #Conventional radiography with appropriate measuring method and positioning provides reliable information on the ulnar variance	2	96% [10] (10–10)
4	Can imaging techniques distinguish between the various types of Palmer class 1 injuries by providing information on the location and extent of TFCC tears? #High-resolution MRI, MR arthrography, and CT arthrography allow an accurate assessment of the location and extent of full-thickness Palmer's class 1 TFCC injuries. MR arthrography and high-resolution CT 3D techniques with radial reconstruction centered on the ulnar styloid process provide a precise evaluation of the different types of non-communicating partial thickness lesions of TFCC	1	89% [9] (8–9)
5	Can MR or MR arthrography accurately diagnose Palmer 1B injuries affecting ulnar foveal attachment (proximal TFCC injuries class 3 of Atzei classification)? #Conventional MRI has a low accuracy in the diagnosis of foveal partial tears of TFCC (Atzei class 3). MR arthrography, with an injection of the distal radioulnar compartment, shows only moderate diagnostic accuracy in these injuries. The arthroscopic correlation of imaging findings of the foveal tears of the TFCC is limited because their direct visualization is not possible with conventional arthroscopic portals. Future research is needed	MRI 3 MR arthrography 2	85% [9] (8–9)
6	Can imaging techniques provide information on DRUJ osteoarthritis based on Atzei classification? #Both conventional radiography and CT detect DRUJ osteoarthritis in advanced stages with subchondral remodeling. MRI and especially MR arthrography and CT arthrography allow the evaluation of OA in early stages	5	96% [9] (9–10)
7	Can imaging techniques provide information on the quality (blood supply/avascular scar) of the edge of a peripheral TFCC tear? #There is currently no evidence that imaging can assess vascularisation of the peripheral TFCC or provide information on the vascularisation/quality of peripheral TFCC tears	5	100% [10] (10–10)
8	What are the main indications for direct MR arthrography in suspected TFCC injuries? I# The main indications for direct MR arthrography in suspected TFCC injuries are to delineate central and peripheral tears (foveal vs styloid attachment) of the TFCC and differentiate between partial and full-thickness tears	2	100% [10] (9–10)
9	Can imaging techniques provide information regarding the ulnotriquetral ligament injuries, including horizontal tear (Palmer class 1C tear) and the longitudinal split tear? #The diagnosis of horizontal and longitudinal split tears of the ulnotriquetral ligament remains challenging. On conventional MRI and on MR arthrography they are usually not detected. The diagnostic accuracy of imaging methods for Palmer class 1C lesions needs to be established	3	81% [9] (8–10)
10	Can imaging techniques diagnose the detachment of the volar and dorsal distal radioulnar ligaments from their insertion in the sigmoid notch, with or without associated avulsion fracture? #MRI and MR arthrography demonstrate partial- and full-thickness injury of the radial attachment of the volar and dorsal distal radioulnar ligaments. Associated fracture avulsion of the radial sigmoid is quite uncommon and is better demonstrated on CT or CT arthrography	4	81% [8] (8–10)
11	Can imaging techniques adequately address TFCC injuries not included in Palmer classification (non-Palmer injuries) such as horizontal “flap” tears, bucket handle tears, and carpal detachment injury described by Nishikawa? #Although MRI and especially MR arthrography and CT arthrography have the potential to detect and characterize TFCC injuries not included in Palmer classification, more studies are needed to determine their real efficacy and future role	5	96% [9] (9–9)
12	Can imaging techniques provide information on volar and dorsal capsular tear of the TFCC? #MRI and MR arthrography allow evaluation of capsular lesions of TFCC, although imaging accuracy has not been established	5	81% [8] (8–9)

**Table 5** (continued)

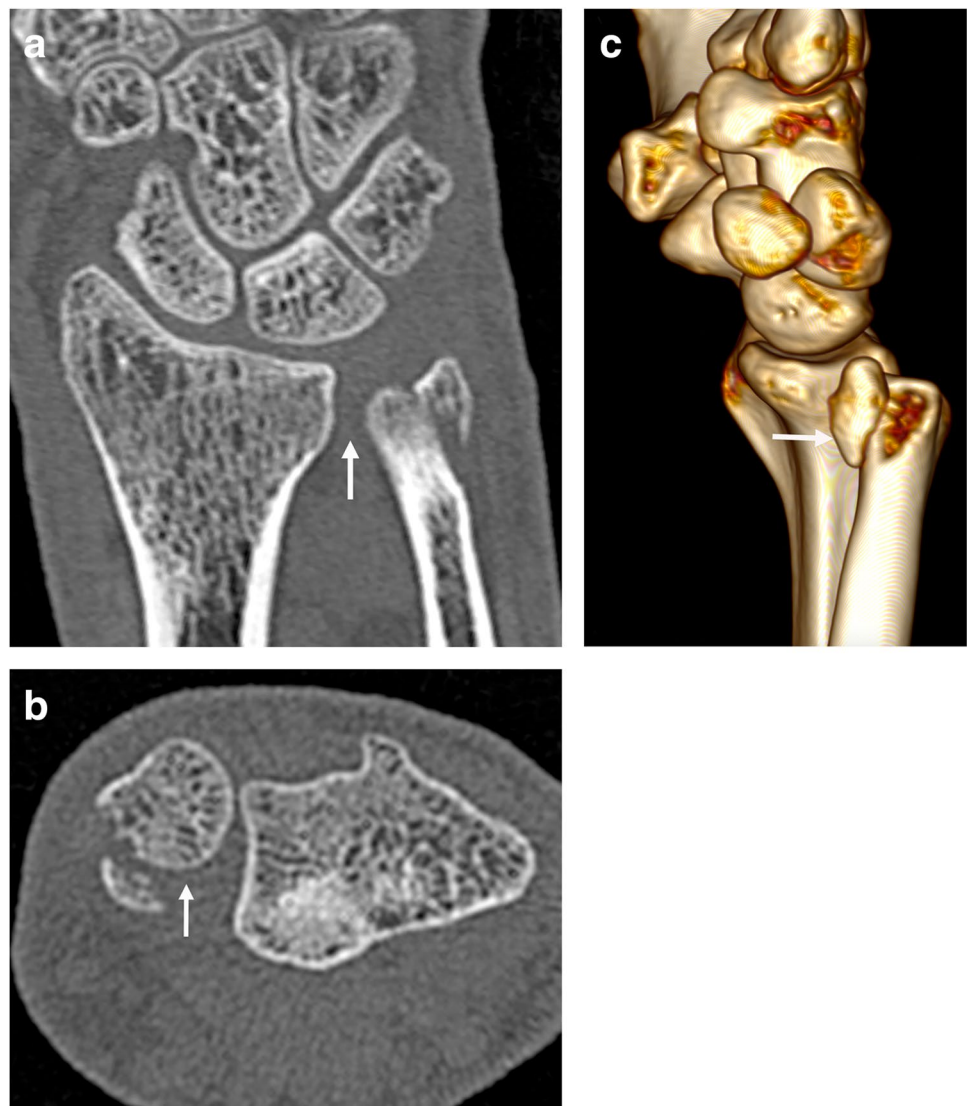
No	Questions and statements	Scientific evidence level*	Agreement [median] (IQR)
13	Which imaging techniques identify the distal oblique band of the distal interosseous membrane and its injuries? #High-resolution studies of both ultrasound and MRI have the potential to assess the normal anatomy of the distal oblique bundle of the distal interosseous membrane. However, the two published studies about this topic have major methodological biases that limit the validity of their conclusions	4	89% [9] (8–9)
14	Which imaging techniques provide information on extensor carpi ulnaris tendon stability? #Dynamic ultrasound and MRI with stress maneuvers (e.g., maximum supination) provide information about extensor carpi ulnaris tendon stability	4	96% [10] (10–10)

*TFCC* triangular fibrocartilage complex, *DRUJ* distal radioulnar joint, *ECU* extensor carpi ulnaris tendon, *MRI* magnetic resonance imaging, *CT* computed tomography. Asterisk (\*) indicates scientific evidence level according to the 5-item scale of the Oxford Centre for evidence-based Medicine [24]

Traumatic lesions of the TFCC might be stable or unstable, causing instability of DRUJ. Palmer class 1A injuries are stable. Complete or partial foveal Palmer 1B lesions, 1C

lesions, and 1D lesions, when they affect the insertion of the distal radioulnar ligaments, with or without fracture, produce DRUJ instability to a greater or lesser degree [3, 5] (Fig. 2).

**Fig. 1** A 24-year-old male with ulnar wrist pain after a motorcycle crash. **a–c** CT reconstructions in the coronal, axial, and 3D planes showing a fracture of the base of the ulnar styloid process with static distal radioulnar instability. Note the joint space widening (arrow in **a**) and the dorsal subluxation of the ulnar head (arrows in **b** and **c**)





Few studies have analyzed the diagnostic efficacy of MRI, MR arthrography, and CT arthrography in traumatic injuries of the TFCC with arthroscopic or surgical correlation as a “gold standard” [35–42]. Three published meta-analyses [11, 12, 42] and one systematic review [43] show significant methodological shortcomings in most of the studies reviewed and generally lack robust analysis of the diagnostic accuracy of the different subtypes of TFCC lesions.

The most recent meta-analysis by Treiser et al [12] included 28 studies comparing the diagnostic accuracy of MRI, MR arthrography, and CT arthrography in assessing TFCC lesions with arthroscopic or open surgical findings as the gold standard. This meta-analysis demonstrated MRI, MR arthrography, and CT arthrography sensitivities of 0.76, 0.78, and 0.89, respectively, with specificities of 0.82, 0.85, and 0.89. CT arthrography and MR arthrography had statistically equivalent sensitivity and specificity for diagnosing TFCC lesions. In all imaging modalities, diagnostic accuracy was higher in central TFCC lesions than in peripheral lesions [12].

*Statement no. 5: Conventional MRI has a low accuracy in the diagnosis of foveal tears of TFCC (Atzei class 3). MR arthrography, with an injection of the distal radioulnar compartment, shows only moderate diagnostic accuracy in these injuries. Future research is needed.*

*Statement no. 6: Both conventional radiography and CT detect DRUJ osteoarthritis in advanced stages with subchondral remodeling. MRI and especially MR arthrography and CT arthrography allow the evaluation of osteoarthritis in early stages.*

*Statement no. 7: There is currently no evidence that imaging can assess vascularization of the peripheral TFCC or provide information on the vascularization/quality of peripheral TFCC tears.*

*Statement no. 8: The main indications for direct MR arthrography in suspected TFCC injuries are to delineate central and peripheral tears (foveal vs styloid attachment) of the TFCC and differentiate between partial- and full-thickness tears.*

The ulnar insertion of the TFCC has a vertical proximal lamina inserted in the ulnar fovea and a horizontal distal

**Fig. 2** Diagrams illustrating the primary unstable lesions of the TFCC: Palmer class 1B lesion unstable subtypes (a–d). **a** Foveal TFCC tear. **b** Foveal TFCC tear associated with ulnar styloid process fracture or pseudoarthrosis. **c** Complete TFCC ulnar detachment. **d** Complete TFCC ulnar detachment associated with styloid fracture or pseudoarthrosis. Palmer class 1D lesion unstable subtypes (e–h). **e** Radial avulsion of the dorsal distal radioulnar ligament. **f** Radial avulsion of the volar distal radioulnar ligament. **g** Avulsion of the distal radioulnar ligament (volar or dorsal) with associated fracture. **h** Complete radial detachment of the TFCC (so-called floating styloid)

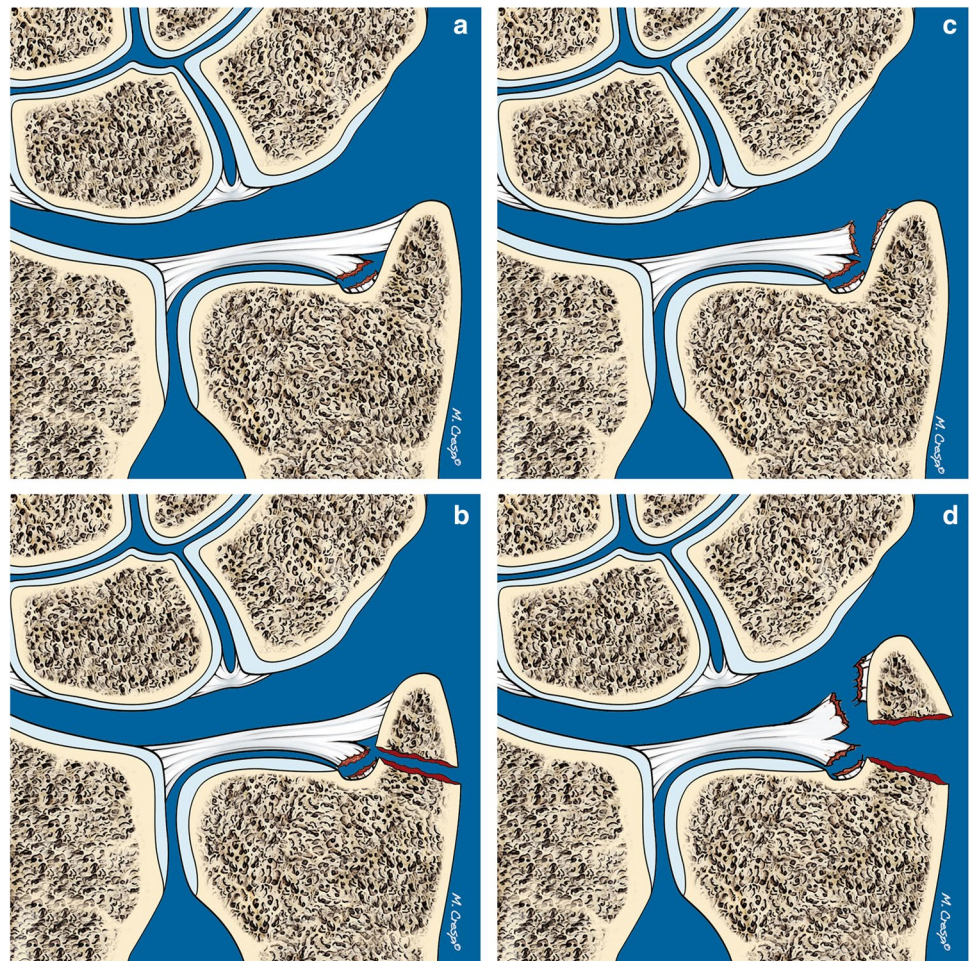
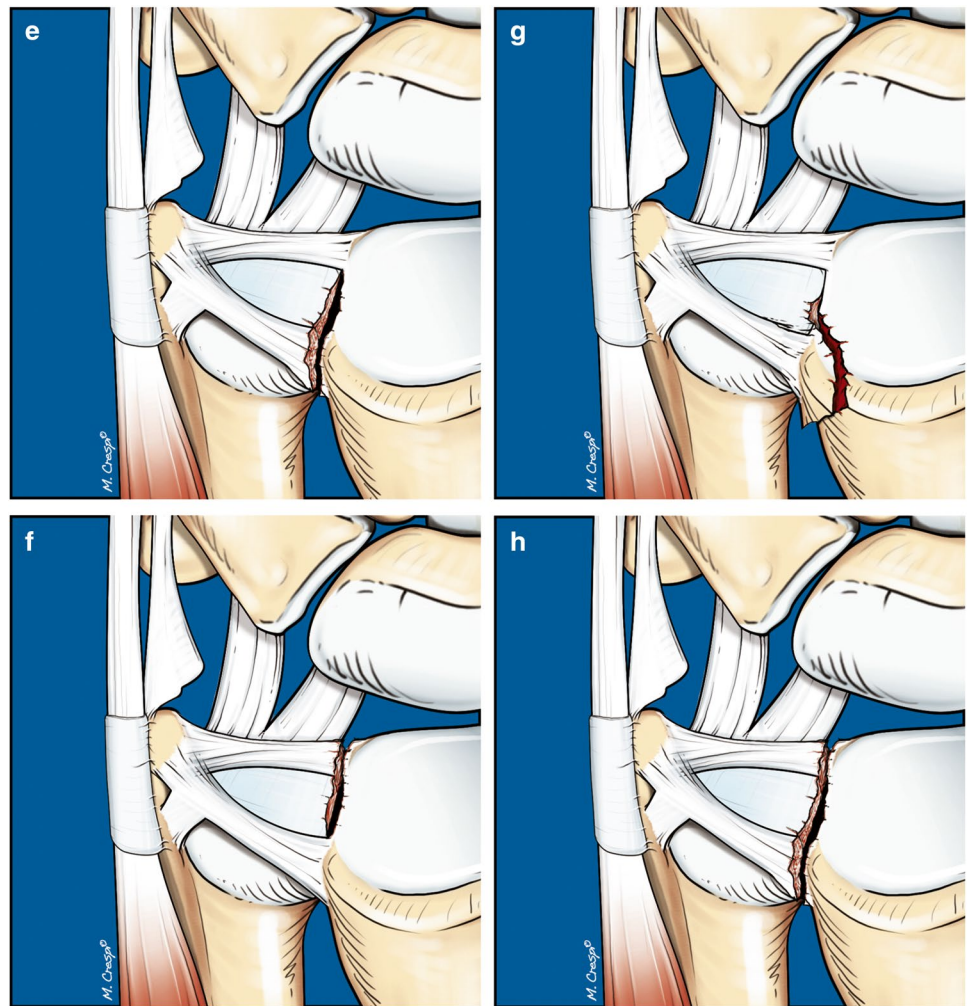


Fig. 2 (continued)



lamina inserted in the ulnar styloid process [44]. Foveal insertion is the most important biomechanically. It represents the convergent point of insertion of the distal radioulnar and ulnocarpal ligaments, critical stabilizers of both the DRUJ and the ulnocarpal joint [44, 45].

Atzei has classified Palmer class 1B lesions into five subtypes, depending on which structures are affected, providing a guide for their therapeutic management (Table 3) [15–17]. Complete (Atzei class 2) and foveal (Atzei class 3) tears of the TFCC ulnar attachment lead to DRUJ instability and DRUJ osteoarthritis (Atzei class 5) [15–17].

Palmer class 1B lesions affecting the foveal insertion (Atzei class 3) are unstable lesions in which the DRUJ and radiocarpal compartments do not communicate due to the integrity of the styloid lamina [15, 46].

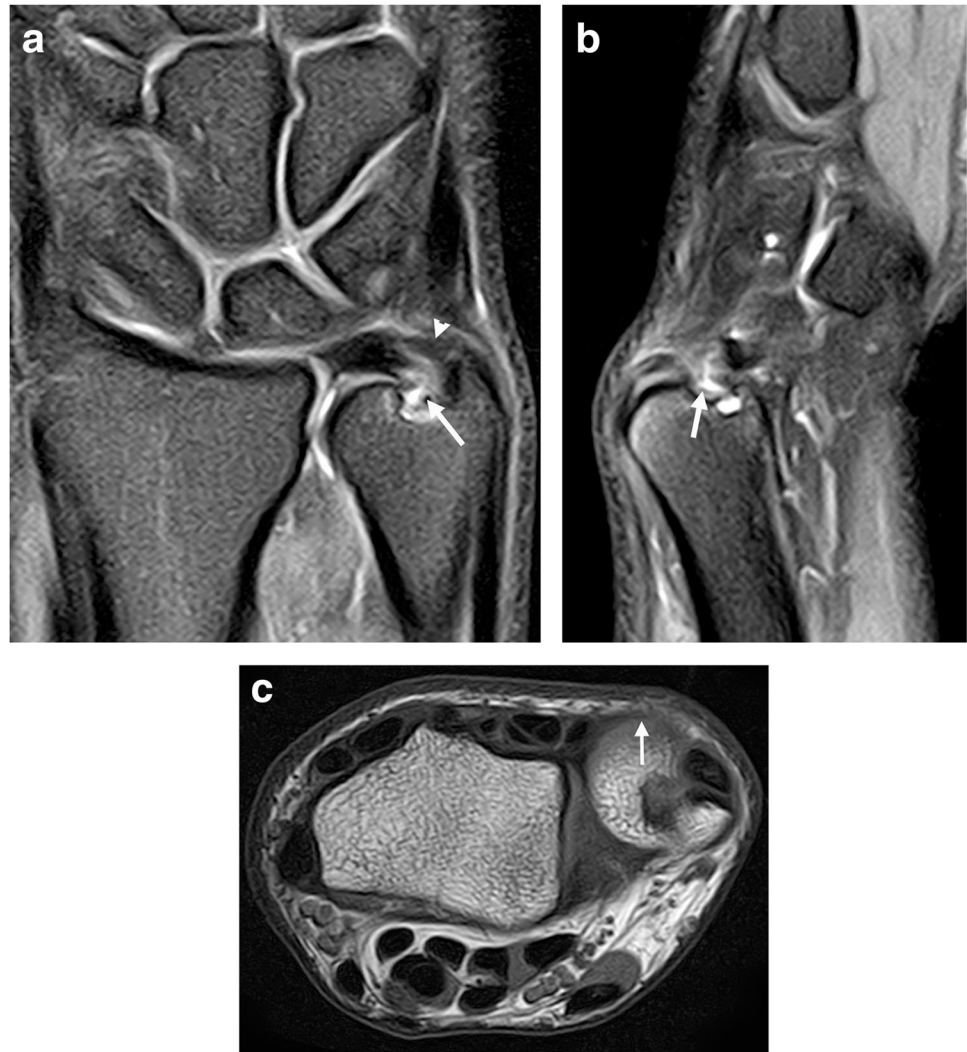
The MRI assessment of the foveal insertion of the TFCC requires high-quality studies [5, 46–48] (Fig. 3). Proper wrist positioning is key to assessing foveal attachment on MRI. The MRI study should be performed either with the patient

prone in the “superman” position with the wrist pronated or with the patient supine, the arm at the patient’s side, and the wrist coil in a horizontal position with the wrist pronated and the palm down [5].

No studies specifically analyze the diagnostic accuracy of MRI in class 1B foveal lesions in a significant number of patients. The actual usefulness of MRI in foveal tears of TFCC still needs to be determined [34, 49]. Detection of foveal lesions is the main indication for MR arthrography. It requires injection of the DRUJ compartment, with a reported sensitivity of 85% and a specificity of 76% [50] (Fig. 4). The assessment of the foveal lamina of the TFCC could be improved with 3D sequences and radial reconstructions centered on the ulnar fovea in both MR arthrography and CT arthrography [36, 51, 52].

The peripheral 10–40% of the TFCC is vascularized, with the central area being avascular [53], which has important therapeutic implications. MRI, MR arthrography, and CT arthrography can demonstrate retraction of Palmer 1B

**Fig. 3** A 28-year-old male paddle tennis player with ulnar wrist pain. **a, b** Coronal and sagittal PD fat-suppressed images showing a tear of the foveal lamina of the TFCC (arrow), respecting the styloid insertion (arrowhead in **a**). **c** Axial T1 image reveals a static distal radioulnar joint instability. The ulnar head is dorsally subluxated (arrow)



injuries (Atzei class 4) but do not allow assessment of vascularity or viability of TFCC lesions [17].

*Statement no. 9: The diagnosis of horizontal and longitudinal split tears of the ulnotriquetral ligament remains challenging. On conventional MRI and MR arthrography, they are usually undetected. The diagnostic accuracy of imaging methods for Palmer class 1C lesions needs to be established.*

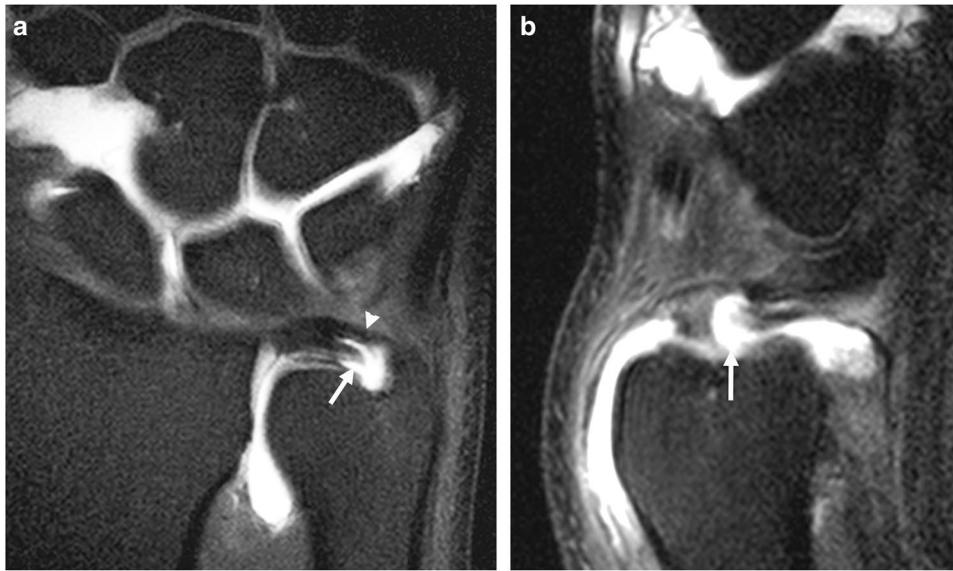
Palmer class 1C injury (carpal avulsion of the ulnocarpal ligaments) or longitudinal tears of the ulnotriquetral ligament are rare injuries [18, 54, 55]. These lesions cause pain and possibly a component of instability of the ulnocarpal joint and, to a lesser degree, of the DRUJ [5, 18].

MRI shows poor sensitivity and specificity for detecting the longitudinal split type of ulnotriquetral ligament tear, with an overall sensitivity of 44% and specificity of

60% [55]. The diagnostic accuracy of imaging methods for Palmer class 1C lesions needs to be established [34, 54].

*Statement no. 10: MRI and MR arthrography demonstrate partial- and full-thickness injury of the radial attachment of the volar and dorsal distal radioulnar ligaments. Associated fracture avulsion of the sigmoid notch of the radius is quite uncommon and is better demonstrated on CT or CT arthrography.*

Palmer's original description of class 1D lesions was complete avulsion of the TFCC from the radial attachment. Nakamura subdivided these 1D lesions into four subtypes [56]. Most 1D lesions are ruptures of the TFC proper attachment in the hyaline cartilage of the radial sigmoid notch (stable lesions). Less frequently, 1D lesions could extend to the dorsal or volar radioulnar ligaments, with or without avulsion fracture (unstable lesions) [56, 57].



**Fig. 4** A 29-year-old male professional tennis player with ulnar wrist pain. Conventional MRI studies are not conclusive. **a, b** Coronal and sagittal T1 fat-suppressed MR arthrography images (bicompartamental MR arthrography with distal radioulnar and midcarpal joint injection) show a rupture of the foveal insertion of the TFCC (arrows). The sty-

loid lamina is respected (arrowhead in **a**). This is a noncommunicating lesion without contrast passage from the distal radioulnar joint to the radiocarpal compartment. Accurate assessment of Palmer 1B noncommunicating foveal tear is one of the main indications for MR arthrography of the wrist

MRI and MR arthrography facilitate an accurate diagnosis of distal radioulnar ligament tears. CT and CT arthrography better demonstrate radial avulsion fractures of these ligaments [5, 57].

*Statement no. 11: MRI, MR arthrography, and CT arthrography can delineate and characterize additional TFCC injuries not included in Palmer's classification (non-Palmer injuries); however, as of now, the diagnostic accuracy for these types of TFCC injuries has only been validated for MRI.*

*Statement no. 12: MRI and MR arthrography allow evaluation of capsular lesions of TFCC, although imaging accuracy has not been established.*

Recent advances in arthroscopy and imaging methods have led to the description of new TFCC lesion patterns not included in the Palmer classification. These non-Palmer injuries include traumatic, degenerative, and combined injuries, such as capsular, horizontal, flap, or bucket-handle tears [18, 34, 58–62]. Del Piñal [18] described and systematized capsular lesions for the first time, differentiating between dorsal capsular detachment, volar capsular detachment, and dorsal capsular detachment from the triquetrum with focal synovitis (Nishikawa lesion) (Table 5). Dorsal capsular lesions affecting the capsular insertion of the dorsal radioulnar ligament and/or the ECU subsheath are the most common non-Palmer lesions [18, 63, 64]. Volar capsular detachments and Nishikawa's lesions are rare [18].

Few studies with a small number of cases have analyzed the diagnostic capacity of MRI in diagnosing lesions not included in Palmer's classification. MRI, MR arthrography, and CT arthrography could facilitate the diagnosis of these lesions, although more studies are needed to demonstrate this [34].

### Other soft-tissue stabilizers of the DRUJ

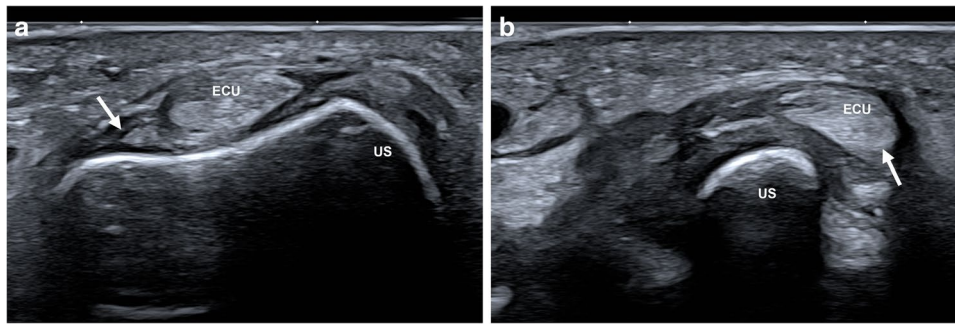
*Statement no. 13: None of the imaging techniques have been shown to be reliable at assessing the interosseous membrane.*

*Statement no. 14: Dynamic ultrasound and MRI with stress maneuvers (e.g., maximum supination) provide information about extensor carpi ulnaris tendon stability.*

Injury to secondary stabilizing soft tissue structures, such as the DRUJ joint capsule, distal oblique band of the forearm interosseous membrane (DOB), ECU, and pronator quadratus muscle, may contribute to DRUJ instability [1–4, 27].

The DOB is a secondary stabilizer of the DRUJ with an anatomical and functional relationship to the TFCC [1–4]. The DOB can be visualized with ultrasound and MRI [65, 66]. However, the accuracy of imaging methods to assess the DOB lesion in patients with DRUJ instability has not been studied.

ECU subluxation is secondary to rupture or attenuation of the infratendinous extensor retinaculum or subsheath of the ECU [67, 68]. The diagnosis of ECU instability is initially clinical. ECU instability can be constitutional and, if



**Fig. 5** A 25-year-old recreational tennis player with painful dynamic snapping. **a** Axial ultrasound image of the dorsal aspect of the wrist showing a slight irregularity of the radial aspect of the subsheath of the extensor carpi ulnaris tendon (arrow in **a**). The extensor carpi

ulnaris tendon maintains a normal position in the sigmoid notch with the wrist in pronation. **b** Corresponding axial ultrasound image in supination and flexion of the wrist showing dynamic dislocation of the extensor carpi ulnaris tendon (arrow in **b**)

asymptomatic, does not require treatment [69, 70]. Symptomatic patients present with ulnar wrist pain and/or painful dynamic snapping. Ultrasound is the imaging method of choice in diagnosing ECU instability allowing dynamic examination in pronosupination. ECU displacement is maximal in supination, especially if combined with wrist flexion [71] (Fig. 5). MRI can accurately show ECU subsheath injuries and associated injuries [68]. Real-time dynamic MRI or static MRI in fixed positions could be useful in diagnosing ECU and DRUJ instability but is infrequently performed [69].

There are limitations to this study that are inherent to the Delphi process. Empirical peer-reviewed evidence is preferred whenever diagnostic and management pathways are being considered but when this is absent then expert opinion must be substituted. Opinion may vary from clinician to clinician, and between institutes, countries, and healthcare systems. The Delphi method, when properly applied, provides a systematic, structured process to aggregate, evaluate, and summarize limited scientific evidence in which a majority of experts can converge towards an optimal answer [20]. The process reduces the impact of marginal opinions on the final consensus statements. The large number of panelists ( $n=27$ ) from eleven different countries including the USA and most of Europe ensured that the consensus statements were based on broad expert opinions and that the opinion is likely to be generalizable across these medical communities. However, most musculoskeletal radiologists with an academic background were from Europe. Therefore, the expert panel may bias against the perspective of non-academic radiologists, particularly outside Europe.

## Conclusions

Conventional radiography should be the initial imaging method to assess DRUJ instability. CT with static axial slices in neutral rotation, pronation, and supination is the method of choice in

evaluating DRUJ instability. MRI is the most useful technique in the diagnosis of soft-tissue injuries, especially TFCC lesions. The main indication for MR arthrography and CT arthrography are the suspicion of noncommunicating foveal lesions.

Imaging studies with arthroscopy correlation as the standard of reference are needed to determine the actual diagnostic performance of MRI, MR arthrography, and CT arthrography for the detection of Palmer 1B noncommunicating injuries, injuries at the radial attachments of the distal radioulnar ligaments, capsular injuries, and other non-Palmer injuries.

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## Declarations

**Guarantor** The scientific guarantor of this publication is Luis Cerezal (first author), Iwona Sudoł-Szopińska and Tobias Dietrich (senior authors).

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**Informed consent** Written informed consent was not required for this study because neither patients nor volunteers were directly included as participants.

**Ethical approval** Institutional Review Board approval was not required because patients nor volunteers were directly included as participants. Thus, Institutional Review Board approval was not required because the present study fulfills the conditions for not requiring official approval for operation according the Swiss Federal Act on Research Involving Human Beings (Human Research Act).

## Methodology

- prospective
- not applicable
- multicenter study

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