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HANDSURGERY

Update TFCC: histology and pathology, classification, examination and diagnostics

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Abstract The TFCC is a crucial stabilizer of the DRUJ. Based on its superficial and deep fibers, the TFCC guarantees unrestricted pronation and supination which is essential for performing sophisticated tasks. The ability to perform complex movements is of uppermost importance for hand function. Therefore, a functional intact TFCC is a prerequisite in this context. The articular disc of the TFCC is a fibrocartilaginous extension of the superficial zone of hyaline articular cartilage which arises from the radius. The peripheral 10–40 % of the TFC is vascularized. Degeneration of the articular disc is common with increasing age. Even though the central part of the articular disc is avascular, potential regeneration of lesions could be detected. The Palmer and Atzei classifications of TFCC lesions are complementary. TFCC innervation is based on different nerves. There is a high variability. A diligent clinical examination facilitates specific tests which help to allocate symptoms to the pathology. Therefore, a thorough clinical examination is not dispensable. Wrist arthroscopy remains the "gold standard" for diagnosing TFCC pathologies despite technical progress in imaging modalities. MR arthrography may have the potential to become a real alternative to wrist arthroscopy for diagnosing TFCC pathologies with technical progress in the future.

Keywords Arthroscopy · Clinical examination · Imaging diagnostics · Histology · TFCC

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Introduction

The triangular fibrocartilage complex (TFCC) consists of the articular disc, the meniscus homologue, the dorsal and palmar radioulnar ligaments, the ulnolunate and ulnotriquetral ligaments and the extensor carpi ulnaris (ECU) tendon sheath. From the ulnar styloid, the ulnolunate and ulnotriquetral ligaments insert into the carpal bones. The articular disc is surrounded by superficial and deep radioulnar fibers; the deep fibers of the triangular fibrocartilage (TFC) are also called the "ligamentum subcruentum" and insert onto the fovea ulnaris and at the basis of the styloid process whereas the superficial fibers insert onto the ulna styloid [1, 2]. The radioulnar ligaments act as stabilizer of the distal radioulnar joint (DRUJ) [3]. Furthermore, the dorsal capsule is tightened by the ECU tendon sheath. The "ligamentum subcruentum" and the wrist ligaments are depicted in Fig. 1.

As a center of forearm rotation, the TFCC plays a key role in stabilization, rotation, translation, loading transmission to the wrist and acts as an essential pivot point [4, 5]. Due to its anatomical location as well as its involvement in the key functions of rotation and load bearing, it is highly prone to injuries and attritional wear [4]. Objective of this article is to review and summarize the recent clinical

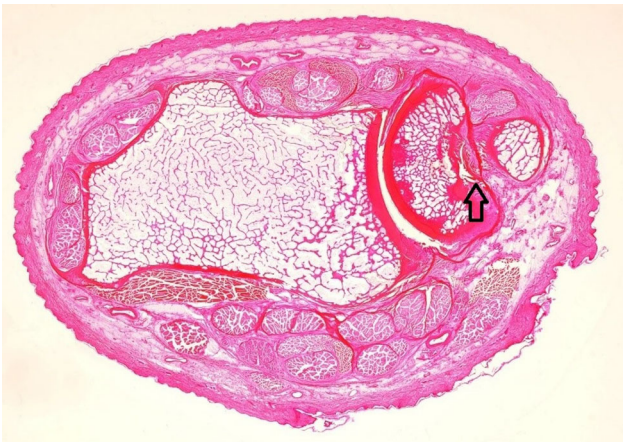


Fig. 1 Axial histological slide (H&E stain, 2× magnification). *Arrow* insertion site of the deep fibers of the radioulnar ligaments (lig. subcruentum)

and experimental research on TFCC regarding histology and pathology, classification, examination and diagnostics.

Histology and pathology

It is generally agreed that the TFCC consists of an articular disc, surrounded by fibrous structures [6–12]. Fibrocartilage cells are typical for the articular disc, particularly at the radial side and its enthesis at the dorsal and palmar regions. The articular disc is a fibrocartilaginous extension of the superficial zone of hyaline articular cartilage, arising from the radius [13]. The articular disc has two laminae, the upper lamina leads towards the styloid process and the head of the ulna, whereas the lower lamina extends beyond the ulna and blends with the ECU tendon sheath and the ulnar collateral ligament (UCL) [14]. The components of the TFCC are further illustrated in Fig. 2.

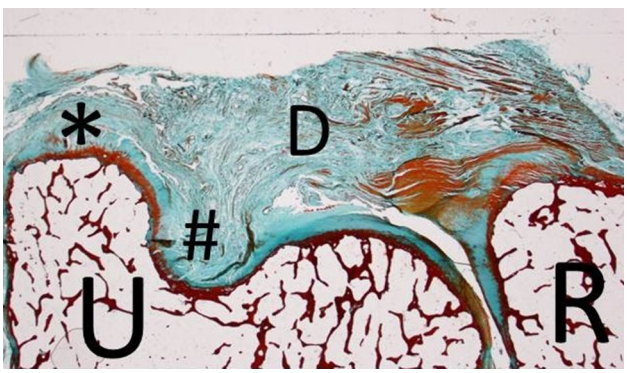


Fig. 2 Coronal histological slide (Masson's trichrome stain, 2× magnification): *U* ulna, *R* radius, *D* disc, *asterisk* styloid insertion of the superficial part, *hash symbol* foveal insertion of the deep part of the TFCC

The anterior and posterior interosseus arteries supply the TFCC with blood. The peripheral 10–40 % of the TFC is vascularized, compared to the inner portion which is avascular [15–18].

Ulnar negative variances are seen with fewer degenerative wear of the articular disc, on the contrary, ulnar positive variance seems to facilitate the degeneration of the TFC [6, 19]. Unglaub et al. [20, 21] correlate ulna positive variance with a greater occurrence of apoptotic cells in degenerative disc lesions compared to articular discs of patients with ulna neutral variance. Tatebe et al. [22] state that a reduction of ulnar loading achieved through ulnar shortening can trigger repair mechanisms and that 50 % of the studied wrists showed a regeneration of cartilage. Reduction of the ulna length may have benefits on the amount of proliferating cells in the articular disc [23]. Nevertheless, the proliferation potential of the cartilage cells of the TFC is unclear, because it has been shown that cell viability is reduced in palmer 1A lesions [24]. Mikić [7] states that this loss of tissue viability, elastic and collagen fibers, is a central feature of articular disc degeneration. The degeneration of the TFC tissue begins in the third decade. In 38 % of the examined specimens in the third decade, Mikić [7] found erosions, ulcerations and perforations. Still, few studies could detect proliferating cell nuclear antigen (PCNA) in several disc lesions, which indicates that there is a possible regeneration, because PCNA acts as an indicator for mitotic processes and regeneration [20, 23, 25].

Classification

Lesions of the TFCC may be of degenerative or traumatic nature. The commonly used Palmer classification categorizes these lesions based on the nature of their formation and their location in the TFCC [26].

Traumatic tears are usually caused by rotational injuries or accidents while the patient is falling upon a pronated or hyperextended wrist [27]. Those lesions are classified as Class 1 and further divided as type A, B, C or D. Class 1A lesion describes a central tear through the horizontal portion of the TFCC (Fig. 3). Traumatic avulsions of the TFCC from its insertion at the distal ulna are referred to as class 1B lesions. These injuries are related to lesions of the ulnar styloid and instabilities regarding the distal radioulnar joint [3]. Palmer classified distal avulsions of the TFCC as class 1C lesions, for instance ruptured ulnolunate or ulnotriquetral ligaments, which lead to ulnar carpal instability. Finally, class 1D lesions represent radial avulsion of the TFCC with or without sigmoid notch fracture (Fig. 4) [26].

In contrast to that, class 2 lesions describe degenerative wear and perforation of the TFCC, that may be associated

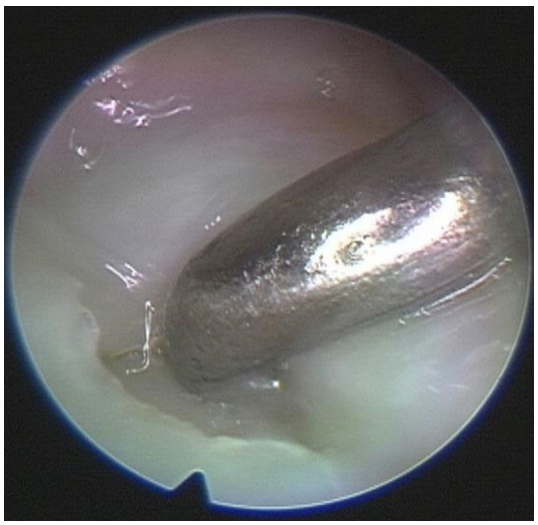


Fig. 3 Arthroscopic view of the disc with a traumatic lesion. Typical longitudinal tear, the probe is inserted into the lesion (Palmer 1A)

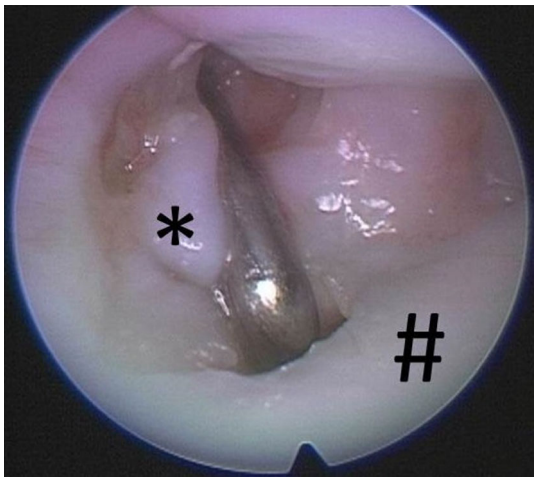


Fig. 4 Arthroscopic view of the disc in a Palmer 1D lesion. The probe is inserted into the lesion. *Hash symbol* radial aspect of the radius with hyaline cartilage at the sigmoid notch. *Asterisk* disc with fibrocartilage tissue

with chronic loading of the ulnocarpal joint, which is also associated with the ulnar impaction syndrome [6]. Those more common degenerative class 2 lesions are subclassified as type A, B, C, D or E. Class 2A stands for wear of the horizontal portion of the TFCC without perforation, the lesion may be located distally, proximally or both. Class 2B lesions resemble 2A with additional chondromalacia of the lunate or ulnar head or both. Progression of the degenerative wear results in perforation of the TFCC, which then is classified as class 2C lesions. Those lesions usually occur in the avascular portion of the TFCC and tend to have an ovoid morphology (Fig. 5). Class 2D lesions describe further advances of the degenerative

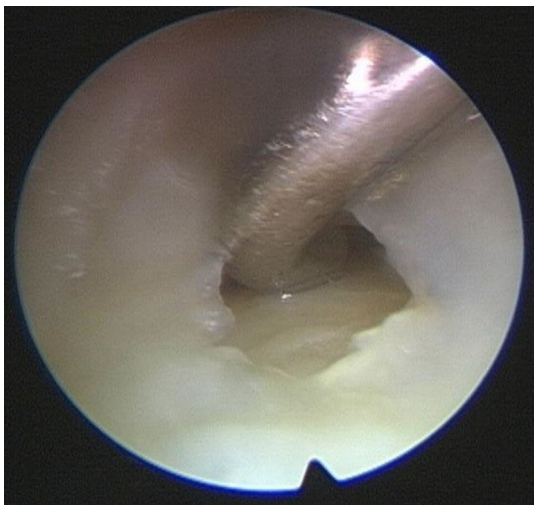


Fig. 5 Arthroscopic view of a degenerative disc lesion (Palmer 2C) with a typical round perforation. The tissue is thinned out. The probe is inserted into the lesion. The ulnar head is visible through the perforation of the disc

process with rupture of the lunotriquetral ligament (LTL) and cartilage abnormalities of the ulnar head and the lunate. Deterioration of class 2D lesions coupled with ulnocarpal arthritis represent class 2E lesions [26].

However, the Palmer classification does not cover all cases of peripheral TFCC tears [28]. Estrella et al. [29] observed several dorsal tears of the TFCC, which could not be categorized with the Palmer classification. Besides, Henry states that class 1B injuries are broadly applied to lesions irrespective of their origin and association with DRUJ instability [30].

Atzei published a new treatment-oriented classification of TFCC peripheral tears, in which he illustrates 5 classes (Fig. 6) [31]. Atzei describes the ulnar-sided TFCC as 3 structures: the proximal triangular ligament which represents the ligamentum subcruentum, the distal hammock structure, and the UCL, which both make up the distal component of the TFCC [31, 32]. Class 1 lesions depict repairable distal tears with intact proximal TFCC component, which he recommends to treat by traditional arthroscopic suture. If there is a complete tear through the distal and proximal component of the TFCC, with DRUJ instability, the lesion is considered as a class 2 injury and requires foveal reattachment of the TFCC. Whereas, a proximal tear with intact distal TFCC component is considered as a class 3 lesion, but also requires foveal reattachment. Class 4 injuries are characterized, similar to class 2 lesions, by a complete tear through the distal and proximal components of the TFCC, but not repairable and associated with a severe DRUJ instability. As a consequence, class 4 needs reconstruction using a tendon craft. Adams described a technique, which treats posttraumatic

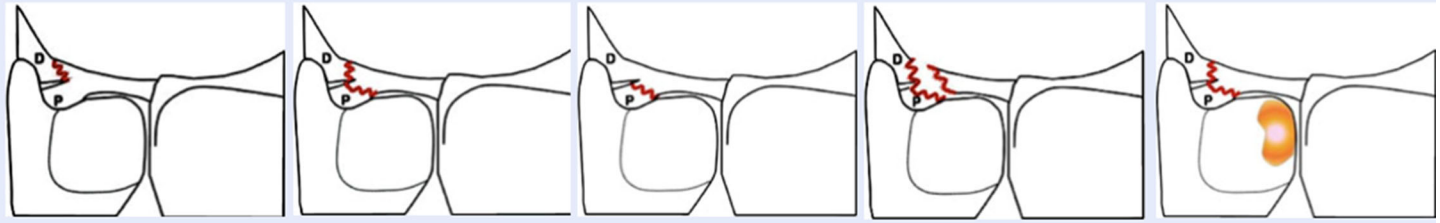
	Class 1: Repairable distal tear	Class 2: Repairable complete tear	Class 3: Repairable proximal tear	Class 4: Non-repairable tear	Class 5: Arthritic DRUJ
					
Clinical DRUJ instability	None/slight	Mild/severe		Severe	Mild/severe
Appearance of TFCC distal component (RC arthroscopy)	Torn	Torn	Intact	Torn	Variable
Status of TFCC proximal component (hook test/ DRUJ arthroscopy)	Intact	Torn	Torn	Torn	
Healing potential of TFCC tear's margins	Good	Good	Good	Poor	
Status of DRUJ cartilage	Good	Good	Good	Good	Poor
Treatment	*Repair* Suture (lig-to-capsule)	*Repair* Foveal refixation		*Reconstruction* Tendon graft	*Salvage* Arthroplasty or joint replacement

Fig. 6 Atzei classification of Palmer 1B lesions [31] (with the friendly permission of Springer Science and Business Media)

DRUJ instability with a reconstruction of the distal radioulnar ligaments using a tendon graft [33, 34]. Furthermore, stabilization of the DRUJ can be performed by the dorsal capsular imbrication [35]. Finally, class 5 lesions stand for an arthritic DRUJ, which should be treated by arthroplasty or joint replacement [31].

Innervation

Gupta et al. [36] dissected ten cadaveric specimens and used the nitric acid maceration technique in nine of those to evaluate the nerves contributing to the innervation of the TFCC. A as result of that, the authors state that the palmar portion of the TFCC is innervated by branches of the ulnar nerve in 100 % of specimens and the dorsal sensory branch of the ulnar nerve in 33 %, whereas the ulnar aspect was innervated by branches of the ulnar nerve in 22 % and the dorsal sensory branch of the ulnar nerve in 33 %. In addition to that, they examined sections of the central and radial parts of the TFCC, which were stained with hematoxylin and eosin, and could not show any nerve fascicles.

Laporte et al. [37] evaluated 11 cadaveric specimens and demonstrated that in the majority the TFCC is innervated by the dorsal sensory branch of the ulnar nerve in 100 % of specimens, the medial antebrachial cutaneous nerve in 91 %, and the palmar branch of the ulnar nerve in 73 %. The TFCC was innervated by the anterior interosseus nerve in 27 % of specimens, the posterior interosseus nerve in 18 %, and the palmar branch of the median nerve in 9 %. Furthermore, the authors pointed out that additionally randomized trials are necessary to evaluate selective TFCC denervation compared to arthroscopic debridement for type 1A injuries.

Published data lack evidence of innervation of the healthy articular disc [36, 38]. To evaluate the hypothesis that traumatic and degenerative lesions may lead to an ingrowth of nerve fibers, which cause ulnar-sided wrist pain, Unglaub et al. [39] investigated the biopsies of 32 patients with Palmer 1A lesions and 17 patients with Palmer 2C lesions and searched for signs of nerve fibers. The biopsies were stained with the primary antibody protein gene product (PGP) 9.5 and none of the specimens showed ingrowth of nerve fibers.

Clinical examination

The patient's history gives information about a degenerative or traumatic pathoetiology of ulnar-sided wrist pain. TFCC lesions often come along with pain during powerful rotatory hand movement, like squeezing a cloth or pushing down a door knob. Ulnar-sided pain with lifting heavy objects might be a hint for a TFCC lesion and/or DRUJ instability [40].

The wrist should be carefully inspected for a prominence of the ulnar head or swelling along the prestyloid recess or the ECU tendon sheath. Points of tenderness are assessed by palpation: A foveal disruption of the TFCC, but also an inflammatory synovitis of the prestyloid recess or a pathology of the meniscus homologue might cause pain in the "ulnar snuff box", which is located ulnopalmar to the ECU tendon, between the triquetrum and ulna head. Such a positive "ulnar fovea sign" was proven to have a sensitivity of 95.2 % in detecting foveal TFCC disruption and/or ulnotriquetral ligament injuries and a specificity of 86.5 % [41]. Palpation might provoke tenderness at the proximal ulnar corner of the lunate, the distal surface of the ulnar head and/or the proximal tip of the hamate in case of an ulnocarpal abutment syndrome indicating a chondromalacia [41, 42].

In functional testing, patients with degenerative TFCC lesions and ulnocarpal abutment syndrome experience ulnar-sided pain during passive maximum ulnar deviation and active forearm rotation against resistance ("screwdriver test") [40]. In addition, a powerful grip might be more painful in supination than in pronation; using the Jamar dynamometer, a difference in grip strength might be assessed ("GRIT test": ratio grip strength in supination versus grip strength in pronation >1.3) [43].

For the "ulno-carpal stress test" ("TFC grind test"), the forearm is brought in a vertical position and the wrist in a maximum ulnar deviation. Applying axial load, the forearm is rotated from full supination to pronation. Ulnar-sided wrist pain occurring during forearm rotation in the mentioned position (but not in neutral or radial deviation), constitutes a positive test, a painless click is considered a negative test. Nakamura et al. found this test positive in patients with ulnocarpal abutment syndrome, traumatic TFCC tear, LTL tear, and wrist arthritis [44].

For the "TFC shear test" ("pisiform boost test", "ulnomenisco-triquetral dorsal glide test"), the pisiform is pushed dorsally with the thumb while the index and middle finger translate the ulna head palmarly. If this maneuver provokes pain, the test is considered positive, which was proven to be the case in two-third of the patients with a pathology of the meniscus homologue and the TFC. LaStayo [45] assessed a specificity of 64 %, a positive predictive value (PPV) of 58 %, and a negative predictive value (NPV) of 69 % for this test.

The "press test", introduced by Lester et al. [46], provokes ulnocarpal pain when a seated patient lifts the body weight up off the chair using the affected wrist.

The "ulnocarpal meniscoid-test" ("waiter's test") creates a local stress to the meniscus homologue by bringing the wrist passively from extension to ulnar deviation and from there to flexion while applying an axial load to the

ulnar carpus [42]. Repeating this test in supination, neutral, and pronation, a TFCC lesion causes more pain in supination than in pronation. Ruston et al. [47] compared the waiter's test to arthroscopic findings and assessed a sensitivity of 40 %, a specificity of 92.7 %, a PPV of 76.9 %, a NPV of 71.7 %, and an accuracy of 72.7 % in detecting a TFCC lesion.

A foveal disruption of the TFCC could cause an instability of the DRUJ [48]. The clinical assessment of DRUJ instability is to some degree influenced by the compliance of the patient and the experience of the examiner [3]. The "piano key sign" is tested with the hand lying flat on the table. If there is a subluxation of the DRUJ, a prominent ulna head can be reduced palmarly by the examiner pushing the ulna down, which re-dislocates passively to the initial position without this maneuver. In some cases, the dorsopalmar translation of the ulna head can be observed if the patient presses the hand actively on the table surface [49].

The "bilateral test for potential subluxation of the DRUJ" investigates the relative movement between radius and ulna at the DRUJ, which is palpated by the index and middle fingers, comparing both sides simultaneously during forearm rotation. The test was proven to be 100 % sensitive compared to the computed tomography (CT) [50].

For the "ballottement-test of the distal ulna" the radius is manipulated in a dorsopalmar direction, while the distal ulna is stabilized. The degree of translation is tested in several positions of forearm rotation and should decrease at the end positions in a stable joint [42].

Imaging diagnostics

X-ray

In case of preceding acute trauma, X-ray may be the first imaging modality. Nevertheless, X-ray is useless in assessing the quality of the articular disc. Still X-ray is useful to determine a patient's ratio between ulna and radius. The neutral position while taking the radiograph is essential, because a pronation of the hand leads to ulna plus variance [51, 52]. To obtain valid radiographic criteria for the wrist, roentgenograms have to be taken with the elbow 90° flexed; using a vertical beam, the upper arm needs to be 90° abducted in the shoulder for the posteroanterior view [53]. Furthermore, radiographs may show signs of fracture and help to distinguish between palmer 1B and 1D lesions (Fig. 7) [26].

Arthrography

Arthrography of the wrist is an invasive imaging modality, which rarely leads to complications [54]. Triple-injection arthrography has been favored for evaluation of TFCC lesions [55]. Nevertheless, arthrography of the wrist has a quite high rate of false-negative findings and is less accurate than arthroscopy, especially in diagnosing injured ligaments [56, 57]. Furthermore, Schers et al. [58] state that arthrography detects only 50 % of the TFCC lesions that arthroscopy identified. If arthrography is combined with magnetic resonance imaging (MRI), a sensitivity of 97 % and specificity of 96 % and an accuracy of 97 % can be achieved, compared with arthroscopy [59].

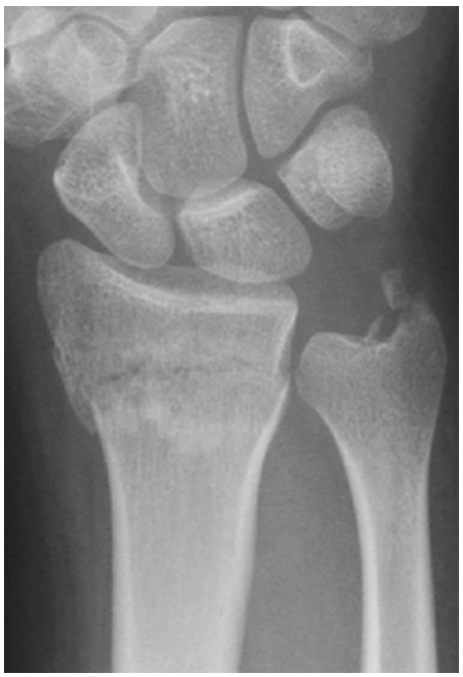


Fig. 7 X-ray, posterior-anterior view, with a distal radius fracture and an avulsion fracture of the superficial and deep part of the ulnar aspect of the TFCC with instability of the DRUJ

MRI and MR arthrography

Damages of the TFCC can be assessed by several imaging diagnostics. MRI is important and useful for non-invasive evaluation of wrist pain. MRI is accurate in visualizing partial tears and central or radial TFCC lesions, but lacks sensitivity in diagnosing peripheral TFCC lesions at the ulnar insertion [60, 61]. This observation is in accordance with Oneson et al. [62], who reported a sensitivity of 91 % for detecting central degenerative perforations, a sensitivity of 86–100 % for detecting radial tears and a sensitivity of 25–50 % for detecting ulnar-sided avulsions compared with arthroscopy. These results correlate with the findings of Haims et al. [63], who stated a sensitivity of 17 % for detecting peripheral TFCC tears. A study by Iordache et al. demonstrated that MRI scans of asymptomatic patients showed lesions of the TFCC in nearly half of the wrists.

Hence, it is essential to view the imaging results in the context of the clinical history. In addition to that the authors described a positive correlation of TFCC degeneration and an increase in age [64].

Since the structures of the wrist are rather small compared to large joints, commonly used 0.2–1.5 T MRI is accompanied by technical limitations of spatial resolution and signal-to-noise ratio. However, 3 T MRI becomes more available in clinical use and recent studies state that 3 T MRI has advantages over 1.5 T MRI, due to an improvement of the contrast-to-noise ratio between bone and cartilage in 3 T MRI [65–67]. Anderson et al. [67] correlated 1.5 and 3 T wrist MRI with wrist arthroscopy findings in patients with ulnar-sided wrist pain and state that 1.5 T wrist MRI had a sensitivity of 85 % and a specificity of 75 % compared with the arthroscopy, whereas 3 T wrist MRI had a sensitivity of 94 % and a specificity of 88 %. On the contrary, the diagnostic improvement of 3 T MRI is still limited and using a dedicated microscopy wrist coil is mostly sufficient enough [49, 68]. However, in clinical reality MRI is often conducted without wrist coils [69].

Nevertheless, 7 T wrist MRI provides excellent images of the wrist and the future of imaging modalities looks promising as seen in Fig. 8. Still at this point, these MRIs are only used for research.

Magnetic resonance arthrography (MRA) of the wrist seems to be superior compared to conventional MRI [70–72]. Schmitt et al. [73] corroborated the advantages of direct MRA and recommended it particularly if the examiner suspects lesions of the scapholunate ligament (SLL) and the TFCC. Nevertheless, Schweitzer et al. [63] stated that indirect MRA improves only the sensitivity in the evaluation of the SLL, but is not superior in evaluating the articular disc of the TFCC. Braun et al. [74] stated that direct MRA is a promising imaging modality and is of equal value compared to diagnostic arthroscopy in detecting complete defects of the intrinsic ligaments and the TFCC. Lee et al. described sensitivity, specificity and accuracy for MRI of 66, 86 and 90 %, and for MRA of 100, 100 and 100 % [72]. Furthermore, Meier et al. stated that the sensitivity of direct MRA approaches that of arthroscopy and, therefore, may avoid invasive diagnostics like arthroscopy in the future, but cannot replace it at the moment [73, 75]. Hahn et al. stated that in clinical routine sensitivities and specificities are rather lower because MRI of the wrist is often performed before a hand surgeon is consulted. Therefore, a detailed clinical examination which is necessary for an appropriate indication for MRI, is missing [69].

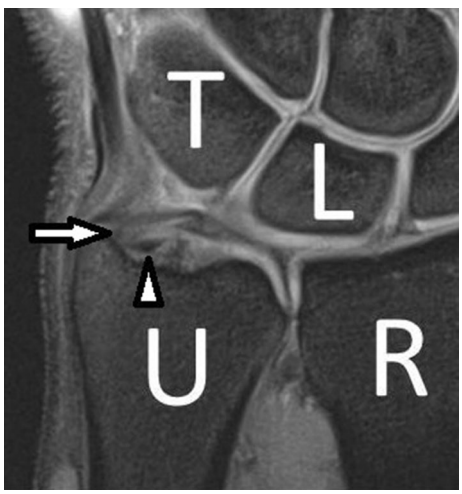


Fig. 8 Seven Tesla MRI of the ulnocarpal region in a healthy wrist (*U* ulna, *R* radius, *L* lunate, *T* triquetrum). The superficial and deep part of the TFCC is visible. The lig. subcruentum inserts onto the fovea of the ulna head and the basis of the styloid (*arrow head*). The superficial part inserts onto the styloid process (*arrow*)

CT Arthrography

Sometimes MRI is not available and CT is used to evaluate unclear carpal trauma or wrist pathologies. The CT exam is generally performed using slices with a thickness of 2 mm and a high resolution algorithm. Native CT is used for detection of fractures, which are difficult to define on plain films. To evaluate the articular cartilage and ligaments injection of contrast agents in the distal radioulnar, radiocarpal and mediocarpal compartments is mandatory. Bille et al. [76] showed that computed tomography arthrography (CTA) is a highly accurate imaging modality at evaluating tears of the SLL, LTL and central TFCC tears, but not peripheral tears. De Filippo et al. [77] stated that multidetector computed tomography (MDCT) shows sensitivity, specificity and accuracy ranging between 92 and 94 % for TFCC lesions. In addition to that Lee et al. assessed a sensitivity, specificity and accuracy for CTA of 100, 100 and 100 % [72].

Ultrasound

Despite the fact that ultrasound has several advantages like noninvasiveness, mobility, lack of ionizing radiation and low costs, its use in diagnosing TFCC lesions is rather uncommon because of its inability to provide enough information on the internal structure of the TFCC to allow a diagnosis [78]. Linear transducers of high frequency of 7.5 and 10 MHz are required to obtain sufficient spatial resolution.

Nevertheless, ultrasound is a valuable imaging modality to diagnose ligament injuries and recent studies demonstrated that its usefulness to detect tears of intrinsic ligaments and the TFCC may be underestimated [79, 80].

Arthroscopy and arthroscopic examination

Wrist arthroscopy is the "gold standard" in diagnosis of TFCC injuries [81–86]. It allows an accurate assessment of the TFCC; lesions can be described precisely and it can be distinguished whether a lesion is traumatic or degenerative. Degenerative lesions are often round perforations with frayed borders, which show a yellowish coloring of the articular disc (Fig. 5) [87]. Traumatic lesions would rather show plain longitudinal tears, which keep the white color of the disc. Furthermore, the assessment of accompanying chondral lesions of the ulnar half of the lunate and the proximal pole of the hamate or tears of the LTL are a hint for an ulnar impaction syndrome.

Löw et al. [88–90] stated that the reproducibility of diagnoses based on photo documents in wrist arthroscopies is limited and intra- and interobserver reliability should be improved by labeling structures in photo documents.

There are several techniques to evaluate the TFCC during wrist arthroscopy. Usually, the TFCC is inspected through the 3–4 portal. By a probe, inserted through the 4–5 or 6-R portal, scanning the TFCC surface for tears. The trampoline test evaluates the tautness of the horizontal part by applying a compressive load across it using a small probe (Fig. 9) [91]. If this structure is wavy and soft, it can indicate a peripheral tear. Furthermore, the hook test may be performed to assess the integrity of the deep fibers of the TFCC [31]. The hook test is accomplished by inserting a probe through the 4–5 or 6-R portal and applying traction to the ulnar-most border of the horizontal part of the TFCC. If the tissue can be pulled distally and radially toward the center of the radiocarpal joint, it is positive.

In addition to that the push-off needle test allows to evaluate if the deep fibers of the radioulnar ligaments are torn [92]. The technique is performed by placing an arthroscope in the 3–4 portal and inserting an 18-gauge Tuohy needle midway between the DRUJ and the ulnar styloid process. The needle can then be advanced distal to the ulna articular surface and radial to the ECU tendon. The tip of the needle faces the distal ulna articular surface during insertion in order to prevent iatrogenic injury to the TFCC. Then the needle is withdrawn out of the ulnocarpal compartment and can be inserted underneath the TFC. If especially the deep fibers of the radioulnar ligaments are torn, the horizontal part of the TFCC can be pushed off the ulna by manipulating the needle up and down against the proximal surface of this structure (Fig. 10).

Progress in the understanding of TFCC biomechanics and anatomy reveal the importance of the proximal part of the TFCC [93, 94] (see "Introduction") facing the ulna head and gave rise to new classification systems [12]. Especially the ligamentum subcruentum and its attachment onto the ulnar fovea are at the center of interest. Both can be visualized via portals to the DRUJ that give insight into the space between TFCC and the ulna head (Fig. 11). The arthroscopy of the DRUJ is still estimated as technical demanding and therefore routineously rarely applied. There are only few larger series reported in the literature [95–98]. Attempts to gain access to the DRUJ can be disappointing [99]. The lack of space within the joint makes interventions more difficult and the insertion of the scope into a stable DRUJ is scarcely possible. This is also reflected by earlier series, where the proximal surface of the TFCC was

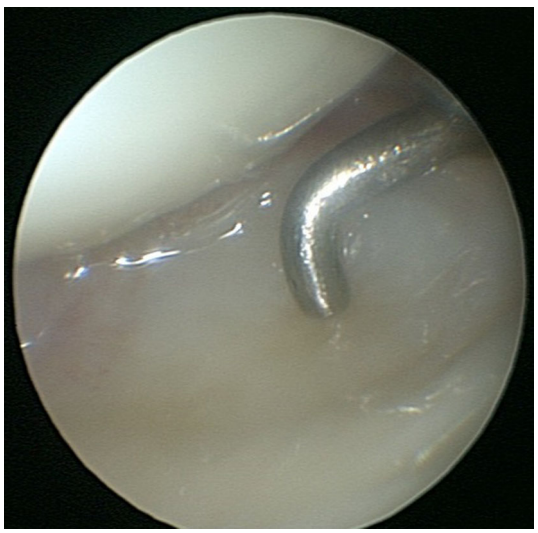


Fig. 9 Arthroscopic view of the trampoline test. The tautness of the horizontal part of the TFCC is evaluated by applying a compressive load using a probe

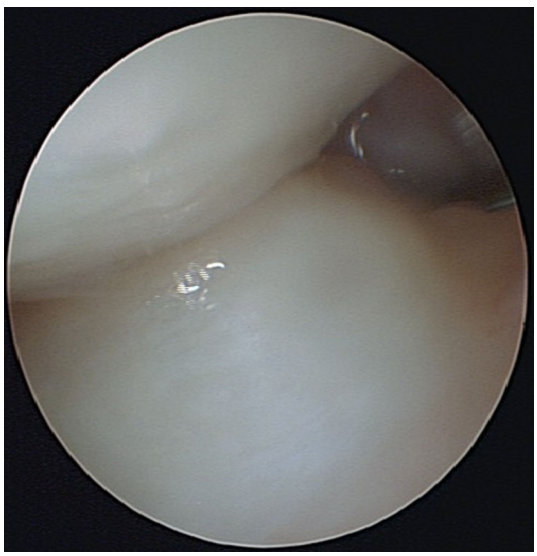


Fig. 10 The needle is inserted underneath the TFC. The horizontal part of the TFCC can be lifted up easily from the foveal insertion, indicating a lig. subcruentum lesion

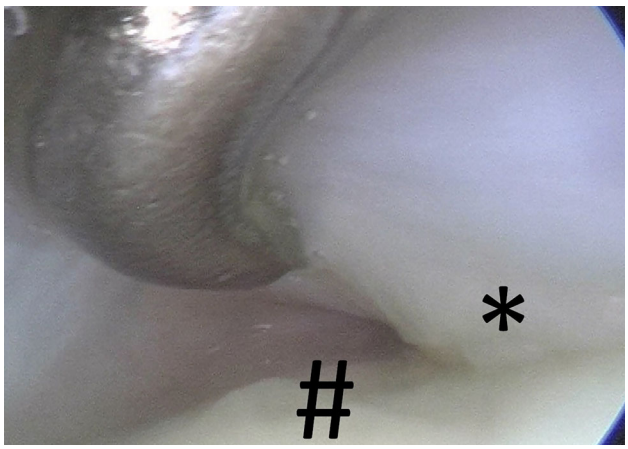


Fig. 11 DRUJ arthroscopy with a probe under the lifted articular disc. The lig. subcruentum (*asterisk*) is visible and tested for stability, *hash symbol* ulna head

visualized in 100 %, but the foveal insertion of the lig. subcruentum only in 57 % of the cases [96]. Some improvement is promised by the introduction of new palmar portals [100] and smaller (1,9 mm diameter) scopes [101]. Nakamura et al. reported a success rate for the visualization of the foveal attachment of 86 % (170 in 196 cases) [101].

Despite all technical difficulties, these aspects of the DRUJ arthroscopy will attract rising attention for an improved diagnosis and classification of TFCC lesions [102].

References

1. Kauer JM (1975) The articular disc of the hand. Acta Anat (Basel) 93:590–605
2. Kleinman WB (2007) Stability of the distal radioulna joint: biomechanics, pathophysiology, physical diagnosis, and restoration of function what we have learned in 25 years. J Hand Surg Am 32:1086–1106
3. Spies CK, Müller LP, Oppermann J, Hahn P, Unglaub F (2014) Instability of the distal radioulnar joint—an overview of clinical and radiological procedures regarding their efficacies. Handchir Mikrochir Plast Chir 46:137–150
4. Trumble TE, Gilbert M, Vedder N (1996) Arthroscopic repair of the triangular fibrocartilage complex. Arthroscopy 12:588–597
5. Sauerbier M, Hahn ME, Berglund LJ, An K-N, Berger RA (2011) Biomechanical evaluation of the dynamic radioulnar convergence after ulnar head resection, two soft tissue stabilization methods of the distal ulna and ulnar head prosthesis implantation. Arch Orthop Trauma Surg 131:15–26
6. Palmer AK, Werner FW (1981) The triangular fibrocartilage complex of the wrist—anatomy and function. J Hand Surg Am 6:153–162
7. Mikić ZD (1978) Age changes in the triangular fibrocartilage of the wrist joint. J Anat 126:367–384
8. Mikić Z, Somer L, Somer T (1992) Histologic structure of the articular disk of the human distal radioulnar joint. Clin Orthop Relat Res 275:29–36
9. Chidgey LK, Dell PC, Bittar ES, Spanier SS (1991) Histologic anatomy of the triangular fibrocartilage. J Hand Surg Am 16:1084–1100
10. Garcia-Elias M, Domènech-Mateu JM (1987) The articular disc of the wrist. Limits and relations. Acta Anat 128:51–54
11. Nakamura T, Yabe Y (2000) Histological anatomy of the triangular fibrocartilage complex of the human wrist. Ann Anat 182:567–572
12. Schmidt H-M (2004) The anatomy of the ulnocarpal complex. Orthopade 33:628–637
13. Milz S, Sicking B, Sprecher CM, Putz R, Benjamin M (2007) An immunohistochemical study of the triangular fibrocartilage complex of the wrist: regional variations in cartilage phenotype. J Anat 211:1–7
14. Benjamin M, Evans EJ, Pemberton DJ (1990) Histological studies on the triangular fibrocartilage complex of the wrist. J Anat 172:59–67
15. Bednar MS, Arnoczky SP, Weiland AJ (1991) The microvasculature of the triangular fibrocartilage complex: its clinical significance. J Hand Surg Am 16:1101–1105
16. Mikić Z (1992) The blood supply of the human distal radioulnar joint and the microvasculature of its articular disk. Clin Orthop Relat Res 275:19–28
17. Thiru RG, Ferlic DC, Clayton ML, McClure DC (1986) Arterial anatomy of the triangular fibrocartilage of the wrist and its surgical significance. J Hand Surg Am 11:258–263
18. Unglaub F, Kroeber MW, Thomas SB, Wolf MB, Arkudas A, Dragu A et al (2009) Incidence and distribution of blood vessels in punch biopsies of Palmer 1A disc lesions in the wrist. Arch Orthop Trauma Surg 129:631–634
19. Palmer AK, Werner FW, Glisson RR, Murphy DJ (1988) Partial excision of the triangular fibrocartilage complex. J Hand Surg Am 13:391–394
20. Unglaub F, Wolf MB, Thome MA, Germann G, Sauerbier M, Reiter A (2008) Correlation of ulnar length and apoptotic cell death in degenerative lesions of the triangular fibrocartilage. Arthroscopy 24:299–304
21. Unglaub F, Thomas SB, Kroeber MW, Dragu A, Fellenberg J, Wolf MB et al (2009) Apoptotic pathways in degenerative disk lesions in the wrist. Arthroscopy 25:1380–1386
22. Tatebe M, Horii E, Nakao E, Shinohara T, Imaeda T, Nakamura R et al (2007) Repair of the triangular fibrocartilage complex after ulnar-shortening osteotomy: second-look arthroscopy. J Hand Surg Am 32:445–449
23. Unglaub F, Thomas SB, Wolf MB, Dragu A, Kroeber MW, Mittlmeier T et al (2010) Cartilage cell proliferation in degenerative TFCC wrist lesions. Arch Orthop Trauma Surg 130:953–956
24. Unglaub F, Fellenberg J, Germann G, Bickert B, Sauerbier M, Richter W (2007) Detection of apoptotic cartilage cells in symptomatic central tears of the triangular fibrocartilage. J Hand Surg Am 32:618–622
25. Pfander D, Körtje D, Weseloh G, Swoboda B (2001) Cell proliferation in human arthrotic joint cartilage. Z Orthop Ihre Grenzgeb 139:375–381
26. Palmer AK (1989) Triangular fibrocartilage complex lesions: a classification. J Hand Surg Am 14:594–606
27. Palmer AK (1990) Triangular fibrocartilage disorders: injury patterns and treatment. Arthrosc J Arthrosc Relat Surg 6:125–132
28. Van Schoonhoven J (2014) Arthroscopy of the wrist and hand. Oper Orthop Traumatol 26:537–538
29. Estrella EP, Hung L-K, Ho P-C, Tse WL (2007) Arthroscopic repair of triangular fibrocartilage complex tears. Arthroscopy 23:729–737, 737.e1
30. Henry MH (2008) Management of acute triangular fibrocartilage complex injury of the wrist. J Am Acad Orthop Surg 16:320–329

31. Atzei A (2009) New trends in arthroscopic management of type 1-B TFCC injuries with DRUJ instability. J Hand Surg Eur 34:582–591
32. Atzei A, Luchetti R (2011) Foveal TFCC tear classification and treatment. Hand Clin 27:263–272
33. Adams BD (2000) Anatomic reconstruction of the distal radioulnar ligaments for DRUJ instability. Tech Hand Up Extrem Surg 4:154–160
34. Adams BD, Berger RA (2002) An anatomic reconstruction of the distal radioulnar ligaments for posttraumatic distal radioulnar joint instability. J Hand Surg Am 27:243–251
35. Unglaub F, Manz S, Bruckner T, Leclère FM, Hahn P, Wolf MB (2013) Dorsal capsular imbrication for dorsal instability of the distal radioulnar joint. Oper Orthop Traumatol 25:609–614
36. Gupta R, Nelson SD, Baker J, Jones NF, Meals RA (2001) The innervation of the triangular fibrocartilage complex: nitric acid maceration rediscovered. Plast Reconstr Surg 107:135–139
37. Laporte DM, Hashemi SS, Dellon AL (2014) Sensory innervation of the triangular fibrocartilage complex: a cadaveric study. J Hand Surg Am 39:1122–1124
38. Shigemitsu T, Tobe M, Mizutani K, Murakami K, Ishikawa Y, Sato F (2007) Innervation of the triangular fibrocartilage complex of the human wrist: quantitative immunohistochemical study. Anat Sci Int 82:127–132
39. Unglaub F, Wolf MB, Dragu A, Schwarz S, Kroeber MW, Horch RE (2011) Nerve fiber staining investigations in traumatic and degenerative disc lesions of the wrist. J Hand Surg Am 36:843–846
40. Berger RA, Dobyns JH (1996) Physical examination and provocative maneuvers of the wrist. In: Gilula LA, Yin Y (eds) Imaging wrist hand. WB Saunders, Philadelphia
41. Tay SC, Tomita K, Berger RA (2007) The "ulnar fovea sign" for defining ulnar wrist pain: an analysis of sensitivity and specificity. J Hand Surg Am 32:438–444
42. Garcia-Elias M (2012) Clinical examination of the ulnar-sided painful wrist. In: del Pinal F (ed) Arthroscopic management of ulnar pain. Springer, Berlin, pp 24–44
43. LaStayo P, Weiss S (2001) The GRIT: a quantitative measure of ulnar impaction syndrome. J Hand Ther 14:173–179
44. Nakamura R, Horii E, Imaeda T, Nakao E, Kato H, Watanabe K (1997) The ulnocarpal stress test in the diagnosis of ulnar-sided wrist pain. J Hand Surg Br 22:719–723
45. LaStayo P, Howell J (1995) Clinical provocative tests used in evaluating wrist pain: a descriptive study. J Hand Ther 8:10–17
46. Lester B, Halbrecht J, Levy IM, Gaudinez R (1995) "Press test" for office diagnosis of triangular fibrocartilage complex tears of the wrist. Ann Plast Surg 35:41–45
47. Ruston J, Konan S, Rubinraut E, Sorene E (2013) Diagnostic accuracy of clinical examination and magnetic resonance imaging for common articular wrist pathology. Acta Orthop Belg 79:375–380
48. Spies CK, Müller LP, Unglaub F, Hahn P, Klum M, Oppermann J (2014) Anatomical transosseous fixation of the deep and superficial fibers of the radioulnar ligaments. Arch Orthop Trauma Surg 134:1783–1788
49. Sachar K (2012) Ulnar-sided wrist pain: evaluation and treatment of triangular fibrocartilage complex tears, ulnocarpal impaction syndrome, and lunotriquetral ligament tears. J Hand Surg Am 37:1489–1500
50. Hahn P, Wolf MB, Unglaub F (2013) Bilateral test for potential subluxation of the DRUJ. Arch Orthop Trauma Surg 133:1459–1461
51. Epner RA, Bowers WH, Guilford WB (1982) Ulnar variance—the effect of wrist positioning and roentgen filming technique. J Hand Surg Am 7:298–305
52. Tomaino MM (2000) The importance of the pronated grip X-ray view in evaluating ulnar variance. J Hand Surg Am 25:352–357
53. Schernberg F (1990) Roentgenographic examination of the wrist: a systematic study of the normal, lax and injured wrist. Part 1: the standard and positional views. J Hand Surg Br 15:210–219
54. Hugo PC, Newberg AH, Newman JS, Wetzner SM (1998) Complications of arthrography. Semin Musculoskelet Radiol 2:345–348
55. Loredo RA, Sorge DG, Garcia G (2005) Radiographic evaluation of the wrist: a vanishing art. Semin Roentgenol 40:248–289
56. Nagle DJ, Benson LS (1992) Wrist arthroscopy: indications and results. Arthroscopy 8:198–203
57. Chung KC, Zimmerman NB, Travis MT (1996) Wrist arthrography versus arthroscopy: a comparative study of 150 cases. J Hand Surg Am 21:591–594
58. Schers TJ, van Heusden HA (1995) Evaluation of chronic wrist pain. Arthroscopy superior to arthrography: comparison in 39 patients. Acta Orthop Scand 66:540–542
59. Schmitt R, Christopoulos G, Meier R, Coblenz G, Fröhner S, Lanz U et al (2003) Direct MR arthrography of the wrist in comparison with arthroscopy: a prospective study on 125 patients. Rofo 175:911–919
60. Potter HG, Asnis-Ernberg L, Weiland AJ, Hotchkiss RN, Peterson MG, McCormack RR (1997) The utility of high-resolution magnetic resonance imaging in the evaluation of the triangular fibrocartilage complex of the wrist. J Bone Joint Surg Am 79:1675–1684
61. Zanetti M, Saupe N, Nagy L (2007) Role of MR imaging in chronic wrist pain. Eur Radiol 17:927–938
62. Oneson SR, Timins ME, Scales LM, Erickson SJ, Chamoy L (1997) MR imaging diagnosis of triangular fibrocartilage pathology with arthroscopic correlation. AJR Am J Roentgenol 168:1513–1518
63. Haims AH, Schweitzer ME, Morrison WB, Deely D, Lange RC, Osterman AL et al (2003) Internal derangement of the wrist: indirect MR arthrography versus unenhanced MR imaging. Radiology 227:701–707
64. Iordache SD, Rowan R, Garvin GJ, Osman S, Grewal R, Faber KJ (2012) Prevalence of triangular fibrocartilage complex abnormalities on MRI scans of asymptomatic wrists. J Hand Surg Am 37:98–103
65. Saupe N, Prüssmann KP, Luechinger R, Bösiger P, Marincek B, Weishaupt D (2005) MR imaging of the wrist: comparison between 1.5- and 3-T MR imaging—preliminary experience. Radiology 234:256–264
66. Bittersohl B, Huang T, Schneider E, Blazar P, Winalski C, Lang P et al (2007) High-resolution MRI of the triangular fibrocartilage complex (TFCC) at 3T: comparison of surface coil and volume coil. J Magn Reson Imaging 26:701–707
67. Anderson ML, Skinner JA, Felmlee JP, Berger RA, Amrami KK (2008) Diagnostic comparison of 1.5 Tesla and 3.0 Tesla preoperative MRI of the wrist in patients with ulnar-sided wrist pain. J Hand Surg Am 33:1153–1159
68. Tanaka T, Yoshioka H, Ueno T, Shindo M, Ochiai N (2006) Comparison between high-resolution MRI with a microscopy coil and arthroscopy in triangular fibrocartilage complex injury. J Hand Surg Am 31:1308–1314
69. Hahn P, Häusler A, Bruckner T, Unglaub F (2012) Quality rating of MRI regarding TFCC lesions in the clinical practice. Handchir Mikrochir Plast Chir 44:310–313
70. Abdelsattar MH, Hassaan MA, Kamal HA (2012) Conventional magnetic resonance imaging versus MR arthrography (MRA) of the wrist in the evaluation of triangular fibrocartilage lesions. Egypt J Radiol Nucl Med 43:235–244
71. Schweitzer ME, Natale P, Winalski CS, Culp R (2000) Indirect wrist MR arthrography: the effects of passive motion versus active exercise. Skelet Radiol 29:10–14

72. Lee RKL, Ng AWH, Tong CSL, Griffith JF, Tse WL, Wong C et al (2013) Intrinsic ligament and triangular fibrocartilage complex tears of the wrist: comparison of MDCT arthrography, conventional 3-T MRI, and MR arthrography. Skelet Radiol 42:1277–1285
73. Meier R, Schmitt R, Krimmer H (2005) Wrist lesions in MRI arthrography compared with wrist arthroscopy. Handchir Mikrochir Plast Chir 37:85–89
74. Braun H, Kenn W, Schneider S, Graf M, Sandstede J, Hahn D (2003) Direct MR arthrography of the wrist- value in detecting complete and partial defects of intrinsic ligaments and the TFCC in comparison with arthroscopy. Rofo 175:1515–1524
75. Meier R, Schmitt R, Christopoulos G, Krimmer H (2003) TFCC-lesion. MR arthrography vs. arthroscopy of the wrist. Unfallchirurg 106:190–194
76. Bille B, Harley B, Cohen H (2007) A comparison of CT arthrography of the wrist to findings during wrist arthroscopy. J Hand Surg Am 32:834–841
77. De Filippo M, Pogliacomi F, Bertellini A, Araoz PA, Averna R, Sverzellati N et al (2010) MDCT arthrography of the wrist: diagnostic accuracy and indications. Eur J Radiol 74:221–225
78. Heuck A, Bonél H, Stäbler A, Schmitt R (1997) Imaging in sports medicine: hand and wrist. Eur J Radiol 26:2–15
79. Keogh CF, Wong AD, Wells NJ, Barbarie JE, Cooperberg PL (2004) High-resolution sonography of the triangular fibrocartilage: initial experience and correlation with MRI and arthroscopic findings. AJR Am J Roentgenol 182:333–336
80. Taljanovic MS, Sheppard JE, Jones MD, Switlick DN, Hunter TB, Rogers LF (2008) Sonography and sonoarthrography of the scapholunate and lunotriquetral ligaments and triangular fibrocartilage disk: initial experience and correlation with arthrography and magnetic resonance arthrography. J Ultrasound Med 27:179–191
81. Chloros GD, Wiesler ER, Poehling GG (2008) Current concepts in wrist arthroscopy. Arthroscopy 24:343–354
82. Bain GI, Munt J, Turner PC (2008) New advances in wrist arthroscopy. Arthroscopy 24:355–367
83. Slutsky DJ, Nagle DJ (2008) Wrist arthroscopy: current concepts. J Hand Surg Am 33:1228–1244
84. Slutsky DJ (2012) Current innovations in wrist arthroscopy. J Hand Surg Am 37:1932–1941
85. Whipple T (1992) Arthroscopic surgery: the wrist. Lippincott, Philadelphia
86. Haefeli M, Schaefer DJ, Kalbermatten DF, Honigmann P (2013) Endoscopy in hand surgery. Obere Extrem 8:103–110
87. Unglaub F, Wolf MB, Dragu A, Schwarz S, Kroeber MW, Horch RE (2011) Nerve fiber staining investigations in traumatic and degenerative disc lesions of the wrist. J Hand Surg Am 36:843–846
88. Löw S, Pillukat T, Prommersberger K-J, van Schoonhoven J (2013) The effect of additional video documentation to photo documentation in wrist arthroscopies on intra- and interobserver reliability. Arch Orthop Trauma Surg 133:433–438
89. Löw S, Herold D, Mühldorfer-Fodor M, Pillukat T (2012) The effect of labeling photo documents in wrist arthroscopies on intra- and interobserver reliability. Arch Orthop Trauma Surg 132:1813–1818
90. Löw S, Herold A, Eingartner C (2014) Standard wrist arthroscopy : technique and documentation. Oper Orthop Traumatol 26:539–546
91. Hermansdorfer JD, Kleinman WB (1991) Management of chronic peripheral tears of the triangular fibrocartilage complex. J Hand Surg Am 16:340–346
92. Unglaub F, Müller LP, Oppermann J, Hahn P, Spies CK (2014) Push-off needle test for traumatic triangular fibrocartilage complex lesions. J Hand Surg Am 39:1448–1449
93. Shen J, Papadonikolakis A, Garrett JP, Davis SM, Ruch DS (2005) Ulnar-positive variance as a predictor of distal radioulnar joint ligament disruption. J Hand Surg Am 30:1172–1177
94. Haugstvedt J-R, Berger RA, Nakamura T, Neale P, Berglund L, An K-N (2006) Relative contributions of the ulnar attachments of the triangular fibrocartilage complex to the dynamic stability of the distal radioulnar joint. J Hand Surg Am 31:445–451
95. Luchetti R, Atzei A, Fairplay T (2007) Arthroscopic wrist arthrolysis after wrist fracture. Arthroscopy 23:255–260
96. Yamamoto M, Koh S, Tatebe M, Shinohara T, Shionoya K, Nakamura R et al (2008) Arthroscopic visualisation of the distal radioulnar joint. Hand Surg 13:133–138
97. Yamamoto M, Koh S, Tatebe M, Shinohara T, Shionoya K, Hirata H et al (2010) Importance of distal radioulnar joint arthroscopy for evaluating the triangular fibrocartilage complex. J Orthop Sci 15:210–215
98. Nakamura T, Iwamoto T, Matsumura N, Sato K, Toyama Y (2014) Radiographic and arthroscopic assessment of DRUJ instability due to foveal avulsion of the radioulnar ligament in distal radius fractures. J Wrist Surg 3:12–17
99. Zelouf DS, Bowers WH (1999) Arthroscopy of the distal radioulnar joint. Hand Clin 15:475–477
100. Slutsky DJ (2007) Distal radioulnar joint arthroscopy and the volar ulnar portal. Tech Hand Up Extrem Surg 11:38–44
101. Nakamura T, Matsumura N, Iwamoto T, Sato K, Toyama Y (2014) Arthroscopy of the distal radioulnar joint. Handchir Mikrochir Plast Chir 46:295–299
102. Pillukat T, Fuhrmann R, Windolf J, van Schoonhoven J (2014) Arthroscopy of the distal radioulnar joint. Oper Orthop Traumatol 26:547–555