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In Focus

Arthroscopic-Assisted Repair of the Triangular Fibrocartilage Complex

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A R T I C L E I N F O

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Triangular fibrocartilage complex (TFCC) injuries are a common cause of ulnar-side wrist pain and may progress to persistent pain, instability of the distal radioulnar joint, and arthritis if left untreated. Diagnosis and management of these injuries requires a nuanced understanding of features pertinent to the clinical presentation, imaging, and arthroscopic findings for accurate management. Arthroscopic-assisted repair techniques have revolutionized surgical management, providing detailed visualization and facilitating the repair of TFCC injuries and associated pathologies with minimally invasive techniques. In this review, we discuss the anatomy of the TFCC, history and examination of ulnar-sided pathology, imaging findings, and classification schemes and review surgical techniques for the treatment of TFCC injuries. We also touch on pearls and pitfalls of the techniques, complications, and results of treatment.

Triangular fibrocartilage complex (TFCC) injuries are a common cause of ulnar-sided wrist pain and may lead to persistent pain, distal radioulnar joint (DRUJ) instability, and arthritis when untreated. The TFCC stabilizes the carpus and DRUJ and buffers the wrist during axial load and ulnar deviation.[1] A thorough understanding of the nuances of TFCC anatomy, vascularization, physical examination findings, and the use of imaging is essential for accurate diagnosis and treatment. Accurate diagnosis is essential for a good outcome as TFCC pathology is only one diagnosis of a long list of differential diagnoses of ulnar-sided wrist pain (Table).[2,3] Associated pathologies should be recognized and addressed, such as DRUJ instability, extensor carpi ulnaris (ECU) tendinopathy and/or subluxation, lunotriquetral (LT) pathology, pisotriquetral pathology, and ulnar impaction syndrome.[4]

Anatomy

Both acute trauma and repetitive ulnar loading and impaction may lead to TFCC pathology. A provider should associate any traumatic extension–pronation force to the axially loaded wrist with acute injury, although long-standing ulnar-sided pain of insidious onset raises suspicion for a chronic, degenerative process. We focus on the treatment of traumatic TFCC lesions in this chapter. The classification system described by Palmer distinguishes between traumatic (type I) and degenerative (type II) TFCC injuries.[5] Traumatic lesions are subcategorized according to their location (Fig. 1).[5,6]

The TFCC is comprised of six major components: the distal radioulnar ligaments (dorsal and volar), central articular disk, meniscus homolog, ulnar collateral ligament, ECU subsheath, and the ulnolunate (UL)/ulnotriquetral (UT) ligaments.[7] Biomechanical analysis of the DRUJ has revealed that the distal ulna, through its articulation with the medial carpus via the TFCC, carries approximately 20% of the axial load of the forearm.[8] The TFCC is centrally avascular and peripherally vascularized by the ulnar artery and the palmar and dorsal branches of the anterior interosseous artery (Fig. 2).[9–12] Similar to the knee meniscus, tears in the peripheral aspect of the TFCC have the potential to heal, whereas central tears may not.

More recently, there has been increasing emphasis on the foveal insertion of the TFCC. Atzei and Luchetti[13] divide the TFCC into three principal structures: (1) the proximal triangular ligament (proximal component of TFCC [pc-TFCC]), (2) the distal hammock structure (distal component of TFCC [dc-TFCC], or the superficial radioulnar ligaments that insert on the ulnar styloid), and (3) the ulnar collateral ligament. In the iceberg model described by Atzei

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Table
Physical Examination Maneuvers for Evaluating the TFCC and Related Pathology*

Anatomy	Name	Technique	Significance
DRUJ	DRUJ stress (piano key test)	Passive translation of the ulna in the dorsal-volar direction compared with the radius in pronation, supination, and neutral	Increased passive translation of the ulna relative to the contralateral side
DRUJ	Piano key sign	Patient's hand and pronated forearm rest on a table; patient applies an active palmar force into the table	Dorsal prominence of the ulnar head reduces with palmar force, but quickly returns dorsally when released
TFCC	Fovea sign	Examiner compresses between the ECU and FCU distal to the ulnar styloid	Focal tenderness at this point suggests longitudinal split tear of UT ligament or foveal avulsion of TFCC
TFCC	TFCC compression test	Examiner applies an axial load in simultaneous rotation on the ulnarly deviated wrist	Pain or a painful click
TFCC	"Frying pan" sign	Examiner places a heavy object into the wrist to simulate the weight of a frying pan with a long lever arm placing the wrist into in hypersupination	Pain is reproduced with hypersupination. Patients may also complain of pain with carrying a "frying pain"
TFCC	Hypersupination/hyperpronation	Patient's elbows positioned at the side of their body with their thumb up. The patient is asked to supinate and pronate their forearm	Pain is elicited with hypersupination or hyperpronation compared to the contralateral side
ECU subsheath	ECU synergy test	Patient's forearm fully supinated, the examiner resists the patient's abducted and radially deviated thumb through long finger in full extension	If positive, the patient reports pain or subluxation along the ECU tendon
Pisotriquetral arthritis	Pisiform boost	Place index finger on ulnar styloid and thumb on pisiform; apply pressure to both	Pain with TFCC tear, ulnar impaction, pisotriquetral arthritis, sigmoid notch arthritis
Ulnar impaction	Ulnar styloid impaction	Forearm in neutral, extend wrist, then rotate forearm into supination	Pain with ulnar impingement syndrome
Ulnar impaction	Ulnocarpal stress test	Forearm with ulnar deviation and pronate and supinate forearm	Pain with ulnar impingement syndrome
LT pathology	LT compression test	Wrist is stabilized with one hand, opposite thumb used to compress triquetrum into lunate	Pain or instability suggests LT ligament injury
LT pathology	Kleinman shear test	Examiner maintain lunate and radiocarpal joint stationary with one hand, then uses other hand to move the triquetrum with the thumb and index finger	Positive test elicits pain and suggests LT ligament injury
LT pathology	LT ballottement test	The lunate is stabilized with thumb and index finger, and triquetrum and pisiform are translated dorsally and palmarly	Pain or increased laxity with this maneuver suggests possible LT ligament injury
Triquetrohamate instability	Triquetrohamate shear test	Wrist is ulnarly deviated, pisotriquetral joint is stabilized, and the remainder of the carpus is translated palmarly and dorsally	Pain and crepitus suggest degenerative changes in the joint, laxity indicates instability of the triquetrohamate joint
Guyon canal	Tinel's sign at Guyon canal	Percussion of the ulnar nerve over the Guyon canal	Resultant paresthesias in the fourth and fifth digits support the diagnosis of ulnar neuropathy at the Guyon canal
Guyon canal	2-point discrimination	Assessment of minimal distance required to distinguish two sharp points	If decreased along the dorsal ulnar aspect of the hand only, consider pathology of dorsal sensory branch of the ulnar nerve or the ulnar nerve more proximally such as cubital tunnel syndrome; if patients have normal sensation of the dorsal ulnar hand but reduced on the palmar aspect, consider Guyon canal pathology
Ulnar artery	Allen's test	Patient makes a fist to pump out blood from the hand; examiner then occludes the radial and ulnar arteries with direct compression	Reperfusion of the hand with release of either artery signals a patent arch; persistent ischemia suggests an occluded or incomplete arch (eg, hypothenar hammer syndrome with an occluded ulnar artery)

* Adapted with permission from Brogan et al.[3]

and Luchetti,[13] arthroscopy of the radiocarpal joint visualizes the "emerged" styloid insertion, which functions as a shock absorber (Fig. 3). The larger size of the "submerged" portion of the iceberg corresponds to the proximal triangular ligament (also known as the ligamentum subcruentum, which includes the deep volar and dorsal DRUJ ligaments and palmar ulnocarpal ligaments) that functions as the major stabilizer of the DRUJ and ulnar carpus and attaches to the ulnar fovea.

History

Patients presenting with acute TFCC injuries will often complain of pain and clicking on the ulnar side of the wrist after a traumatic injury, commonly an extension–pronation force to an axially loaded wrist. Symptoms are exacerbated with ulnar deviation of the wrist, twisting maneuvers, power grip, and axial compression or weight-bearing.

During history taking, it is important to clarify if the patient experiences pain alone, pain with instability, or degenerative pain.[3] Although the specificity of symptoms is not always high, certain clues may exist. Pain alone could be indicative of a tear of the central or peripheral insertion of the superficial dorsal radioulnar and palmar radioulnar ligaments, a split tear of the UT and UL ligaments, a capsular stretch injury, a LT interosseous ligament tear or sprain, ulnocarpal synovitis, or pisotriquetral joint pathology.[3] Pain with some instability should cue the provider toward a possible

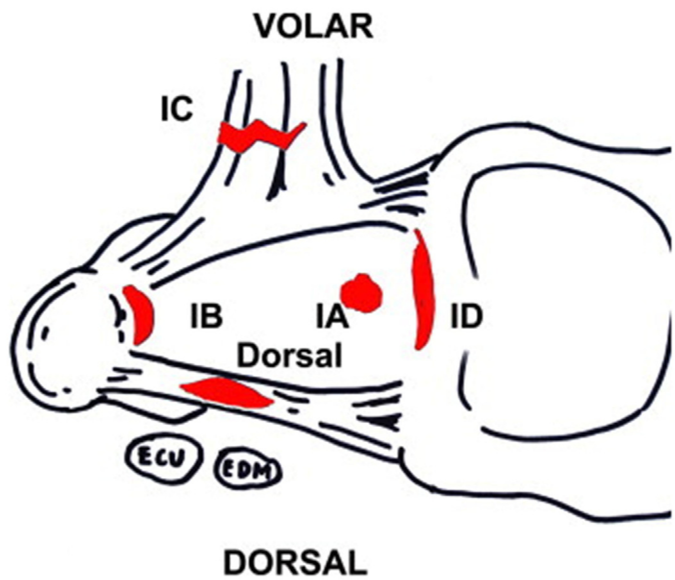

Figure 1. Palmer classification of traumatic TFCC lesions. Class IA: perforation in the central portion of the TFCC, usually 2–3 mm ulnar to the TFCC's radial attachment. A flap of cartilage may be attached to the ulnar border. Class IB: traumatic avulsion of the TFCC from its insertion into the distal ulna or fracture of ulnar styloid base and may also be associated with DRUJ instability. Class IC: avulsion of the TFCC via the UL and UT ligaments, which may result in ulnar carpal instability with palmar translocation of the carpus. Class ID: traumatic avulsion of the TFCC from its attachment onto the sigmoid notch of the distal radius. EDM, extensor digiti minimi. From Estrella et al,[6] with permission.

tear or avulsion of the deep dorsal radioulnar and palmar radioulnar ligaments (ulnar or radial), a transverse tear of the UT and UL ligaments, an ECU subsheath tear, or a LT interosseous ligament injury.[3] Arthritic pain presents typically with load bearing and range of motion that is better with rest and worst at night and should cue the provider toward chronic ulnar impaction syndrome, pisotriquetral arthritis, or DRUJ arthritis.[3]

A meticulous history and physical examination should rule out other causes for ulnar-sided wrist pain, such as DRUJ or pisotriquetral degenerative changes, LT ligament pathology, ulnar impaction syndrome, instability of the DRUJ or dynamic soft tissue structures such as the ECU and flexor carpi ulnaris (FCU) tendons, triquetrohamate instability, and hypothenar hammer syndrome.[4]

Physical Examination

It is important to use the physical examination to try to help delineate between a pc-TFCC or dc-TFCC injury and any concomitant pathology.[13] When there is an isolated rupture of the dc-TFCC, DRUJ stability is preserved. However, when a TFCC tear involves disruption of the pc-TFCC, the DRUJ may be unstable.

The examiner should inspect the wrist and observe a supination or palmar sag deformity and perform DRUJ examination maneuvers. In the DRUJ stress test, increased passive translation of the ulna is present in the injured wrist in the dorsal-volar direction in pronation, supination, or neutral compared with the contralateral wrist. With the piano key sign, the subluxated ulnar head reduces with downward pressure but resubluxates when released. When positive, the deep radioulnar ligaments are likely disrupted and should be repaired or reconstructed acutely. Each examination maneuver should also be compared with the patient's contralateral side to obtain a baseline. Additional maneuvers used to thoroughly assess the TFCC include a series of specific tests: the fovea sign, the compression test, the "frying pan" sign, and pain with hypersupination and hyperpronation. Performing these maneuvers requires that the patient's elbow be flexed at a 90° angle while resting on the examination table (unless otherwise stated). A positive test result is reproduction of the patient's symptomatic pain. The fovea sign is positive with focal tenderness between the ECU and FCU distal to the ulnar styloid. Compression of the TFCC will reveal pain or a painful click, particularly with axial load in pronosupination and ulnar deviation. The "frying pan sign" involves having the patient hold a heavy object to mimic the action of holding a frying pan with an extended handle. A positive sign induces pain via forced hypersupination. Finally, hypersupination and hyperpronation tests involve asking a patient to supinate and pronate their forearm with elbows at the side of their body with their thumb up. These movements are contrasted with the unaffected limb to check for discrepancies, particularly pain elicited at the extreme end ranges of pronation and supination (Table).

Additionally, a peripheral TFCC tear may be associated with the disruption of the ECU subsheath. To evaluate this, the ECU synergy test is indicated. With the patient's forearm fully supinated, the examiner applies resistance to the patient's abducted and radially deviated thumb and long finger in full extension. A positive result is noted if the patient reports experiencing pain or subluxation along the ECU tendon. It is critical to conduct further tests to rule out conditions such as hypothenar hammer syndrome, triquetrohamate instability, and LT ligament pathology (Table).[3]

Imaging

To evaluate ulnar variance, basic x-rays should be performed with neutral rotation posteroanterior and lateral views. Dynamic changes in ulnar variance can be observed with a pronated, clenched-fist posteroanterior view of the wrist.[14] Bernstein et al[15] highlighted that the lateral wrist x-rays may be most accurate for ulnar variance assessment, whereas dynamic posteroanterior x-rays may be best suited for simulating daily activities that may lead to ulnocarpal impaction. Additionally, x-rays can detect fracture or malunion in the distal radius, ulnar styloid fractures, DRUJ arthritis, and DRUJ widening, influencing the treatment approach.

Advanced three-dimensional imaging, such as computed tomography or magnetic resonance imaging (MRI), is crucial for a detailed evaluation of the DRUJ, particularly the shape of the sigmoid notch and the ulnar fovea recess and groove for signs of dysplasia.[16] Jung et al[17] found that a flat-face sigmoid notch was more frequently observed in patients with TFCC foveal tears than C-, S-, and ski-slope tear types. Additionally, computed tomography imaging of both patients' wrists in supination, neutral, and pronation may be beneficial in evaluating DRUJ incongruency particularly when the DRUJ stability is in question.[18]

Magnetic resonance imaging has become the primary imaging modality for assessing injuries to the TFCC, with the image with the highest diagnostic value being a T2-weighted image in the coronal plane.[19] Sensitivity and specificity for diagnosis of TFCC lesions have been found to be the highest with computed tomography arthrography (0.89 and 0.89), followed by magnetic resonance arthrography (0.89 and 0.78) and then MRI (0.76 and 0.82).[20] The accuracy of the imaging modalities was higher for central TFCC tears (0.92 sensitivity and 0.93 specificity) compared with peripheral tears (0.71 sensitivity and 0.98 specificity).[20] The introduction of 3-Tesla MRI and three-dimensional reconstruction has improved the diagnostic accuracy of MRI. Magee[21] found that a 3-Tesla MRI can detect TFCC tears with 89% sensitivity and 100% specificity, which increased to 100% sensitivity with the use of MR arthrography. However, they also found that MR arthrography was less specific, with three false positives (6%), likely resulting from

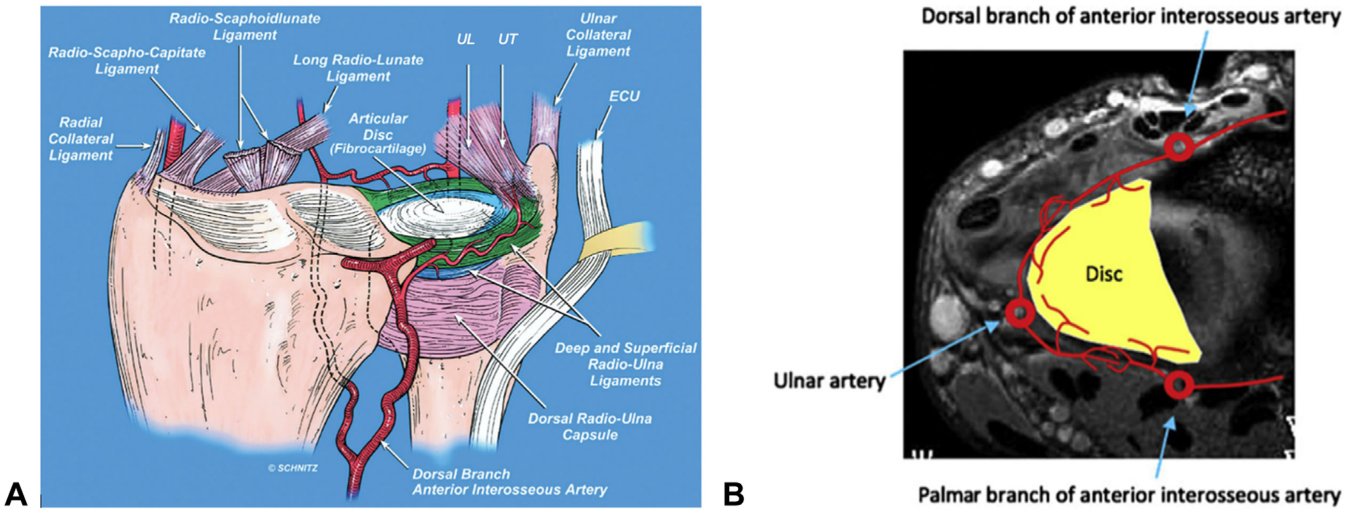

Figure 2. **A** Anatomy of the TFCC. Extensor carpi ulnaris, UL ligament, and UT ligament. Adapted with permission from Kleinman.[11] **B** Illustration of the vascular supply of the TFCC. From Vezeridis et al,[12] with permission.

microperforations in baseline anatomical TFCC structures.[21] Eladawi et al[22] demonstrated that unenhanced 3-Tesla MRI, when used with dedicated true plane reformats of 3D T2 Dual Echo Steady State, can achieve 100% sensitivity for the detection of TFCC tears compared with arthroscopy. It is imperative to recognize that imaging may often reveal TFCC abnormalities in asymptomatic patients. One study revealed MRI evidence of TFCC tears in 38% of asymptomatic wrists, with the rate increasing in individuals aged >50 years.[23] Therefore, corroborating imaging results with a physical examination is essential for ensuring accurate diagnosis.

Recent advances in high-resolution ultrasound technology have facilitated the development of an ultrasound scanning protocol for the assessment of TFCC injury and guidance in delivering diagnostic and therapeutic injections.[24] Ultrasound may have an advantage in evaluating dynamic changes of the ulnar wrist throughout the range of motion or painful activities, but its efficacy compared with existing imaging modalities requires further study.

Wrist arthrography is helpful in diagnosing intercarpal ligament or TFCC tears. When wrist arthrography is performed, the triple injection technique is recommended. This method helps ensure that one-way flaps are not missed. Weiss et al[25] compared the results of triple injection cinearthrography with arthroscopy. The sensitivity, specificity, and accuracy in detecting tears of the TFCC were 60%, 100%, and 76%, respectively.[25]

Arthroscopy remains the gold standard for assessing the size, stability, and location of a TFCC tear. In a cadaveric study, Trehan et al[26] evaluated the accuracy and reliability of two arthroscopic tests for TFCC injuries. The “trampoline test,” a technique for assessing the TFCC tension, was found to have poor sensitivity, specificity, and reliability for TFCC foveal injuries.[26] The “hook test” was found to be 90% specific and sensitive for identifying TFCC foveal disruption and subsequent return to baseline tension after TFCC foveal repair with a higher rate of agreement among observers.[26] A complete diagnostic wrist arthroscopy, which would include midcarpal arthroscopy, should be performed so that any synovitis, lunate chondromalacia, LT tear, ulnar extrinsic ligament tear, or proximal hamate chondromalacia can also be diagnosed and addressed.

Nonsurgical Treatment

In patients with a stable DRUJ, conservative measures (nonsteroidal anti-inflammatory drugs, immobilization for 4 weeks, hand therapy, and steroid injections) are the first line of treatment for dc-TFCC injuries (superficial radioulnar ligaments).[3] Previous studies have found that about 60% of patients with dc-TFCC injury may experience an improvement in symptoms after conservative measures.[3,13] Even patients with central tears may be treated with conservative measures. Although the healing potential is poor, they may become asymptomatic.

Surgical Indications

Instability attributed to an acute pc-TFCC injury and subacute peripheral dc-TFCC tear that has failed conservative measures for 3–6 months is an indication for surgical intervention.[14] Reconstruction is indicated for irreparable TFCC tears due to poor tissue quality or large irreparable tears with evidence of DRUJ instability.

Arthroscopic and open repair have largely equivalent outcomes.[15] Advantages of arthroscopy include visualization of the entire joint for concomitant pathology and decreased soft tissue trauma, potentially resulting in a more rapid recovery.[6,27–31] Surgeon training and experience should dictate the ideal treatment technique.

Contraindications and Considerations

Patients with DRUJ or radiocarpal arthritis, patients who are minimally symptomatic, and low demand and medically unfit patients should not be indicated for surgery. Arthroscopic repair of central- or radial-sided TFCC tears is contraindicated due to avascularity and the limited ability to heal.

Although ulnar-positive variance (2 mm or greater) is more commonly associated with degenerative-type tears, it may also be present in the setting of an acute peripheral tear. An ulnar shortening osteotomy may be considered at the time of repair to avoid repetitive loading across the repair.[22,23]

Wrist Arthroscopy Technique

Setup and positioning

The setup involves having the patient under regional or general anesthesia, with the patient in the supine position, with a well-padded pneumatic tourniquet on the upper arm. Alternatively, wrist arthroscopy may be performed under wide awake, local

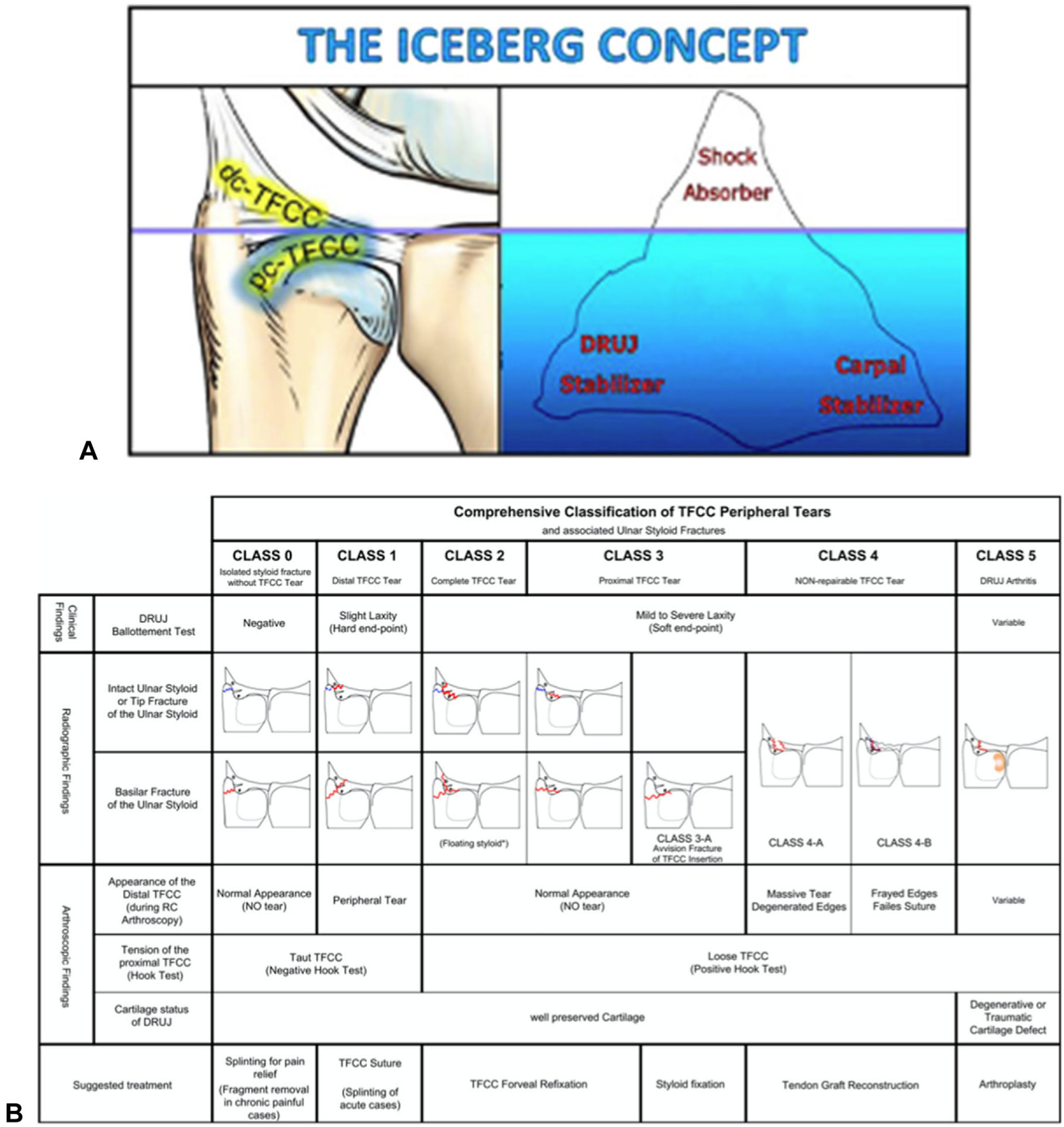

Figure 3. A Atzei classification of foveal tears. The "iceberg" concept of the ulnar portion of the TFCC, separated into the distal component (dc-TFCC) formed by the ulnar collateral ligament and the distal hammock structure which can be visualized during radiocarpal arthroscopy, and the proximal component (pc-TFCC), represented by the proximal triangular ligament, or ligamentum subcruentum, which originates from the ulnar fovea and the proximal styloid and stabilizes the DRUJ. From Atzei and Luchetti,[13] with permission. **B** Atzei and Luchetti classification schema describing TFCC injuries with corresponding clinical, imaging, arthroscopic findings, and treatment recommendations. From Atzei and Luchetti,[13] with permission.

anesthesia, no tourniquet. We recommend using a hand table in case open repair or reconstruction is needed. Perform an examination under anesthesia. Evaluate for instability of the DRUJ and the ulnar side of the wrist. Place finger traps over the index and long fingers. Using a standard arthroscopic traction device, pad and secure the arm to provide for countertraction force and then place the wrist in about 5.4 kg (12 lb) of traction with the wrist in 10° to 15° of flexion. We typically use a 2.7–3.5 mm 30° arthroscope. Mark out surface landmarks including Lister's tubercle, ECU, extensor pollicis longus, ulnar head, and the radiocarpal joint line (Fig. 4A).

Radiocarpal diagnostic arthroscopy

Create the 3–4 portal 1 cm distal to Lister's tubercle. Inspect the integrity of the radial side of the radiocarpal joint systematically.

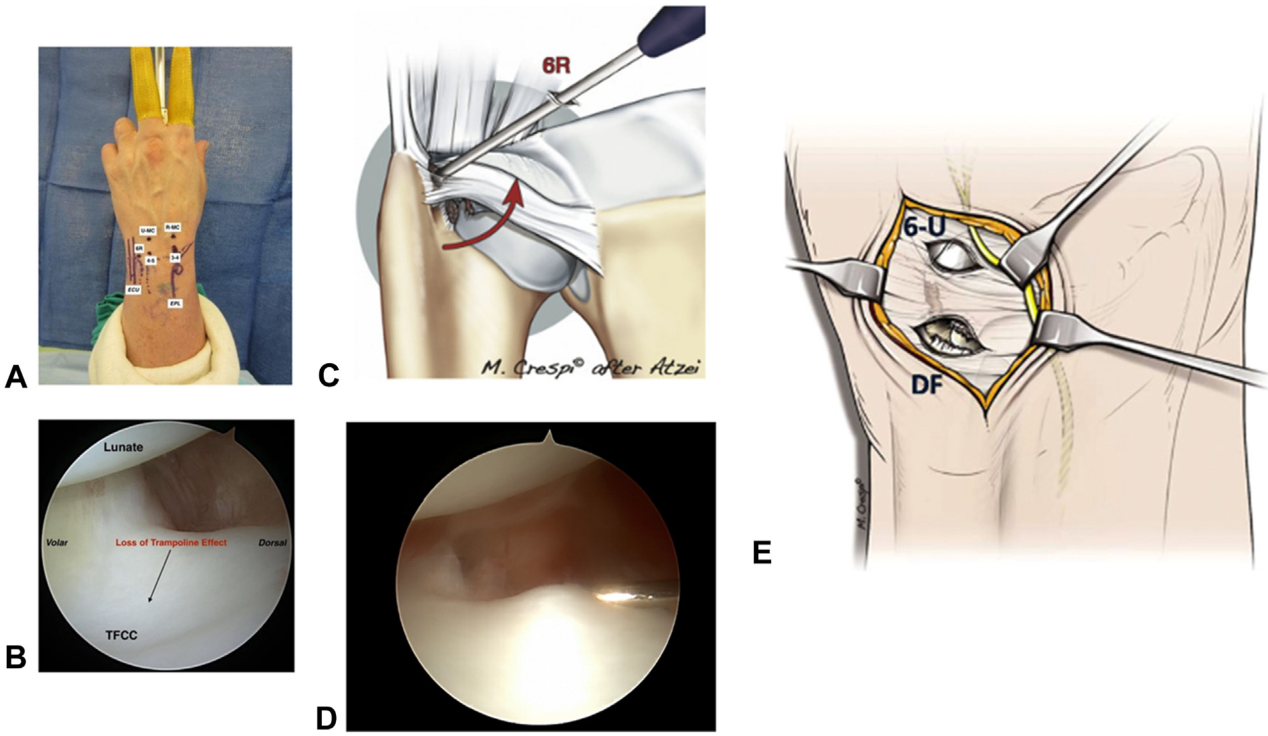

Figure 4. **A** Wrist arthroscopy set up and portals with marked landmarks. Personal image courtesy of Jeffrey Yao, MD. **B** Loss of trampoline effect. Personal image courtesy of Jeffrey Yao, MD. **C** Positive hook test. Arrow indicates the direction of force applied by the probe. From Atzei et al,[32] with permission. **D** View of the dorsal ulnar periphery of the TFCC. Note that the tip of the probe is obscured by redundant tissue from a peripheral TFCC tear (class IB). Personal image courtesy of Jeffrey Yao, MD. **E** The direct foveal (DF) portal is located 1cm proximal to the 6U portal and allows exposure of the basi-styloid and foveal area. It can also be prepared as a mini open approach through an incision between the ECU and FCU tendons. From Atzei and Luchetti,[13] with permission. EPL, extensor pollicis longus; 6U, 6U portal; U-MC, ulnar midcarpal portal; R-MC, radial midcarpal portal.

Under direct visualization, triangulate an 18-gauge needle from the 6R portal site, directly radial to the ECU tendon. Accurate placement of the 6R portal allows sufficient reach of instruments to evaluate and debride any nonviable TFCC tissue and synovitis for adequate visualization. Perform the trampoline test through the 6R portal by using a probe to apply gentle pressure to the central aspect of the disc. If the "trampoline effect" is lost and the broad end of the tip of the probe is obscured within the central aspect of the TFCC proper, then suspicion should be raised for TFCC or ulnar-carpal ligament injury. A central TFCC tear (class IA) would be evident within the substance of the articular disc while testing for the trampoline effect. It is usually located 2–3 mm medial from its radial attachment (Fig. 4B).

Perform the hook test through the 6R portal to evaluate the foveal attachment of the TFCC by using a probe to apply a radially directed force to the TFCC periphery in the prestyloid recess. A positive finding is when the TFCC translates off the ulnar head (distally and radially) (Fig. 4C).[32] Inspect the dorsal ulnar aspect of the TFCC for a peripheral, superficial tear (Palmer type IB or Atzei class 1). A frank tear may not always be obvious because healing of the tear may have occurred with the TFCC in an unreduced position (Fig. 4D). Test for tension at the periphery using the probe. Again, the broad tip of the probe should not be obscured when the disc is of normal integrity.

Next, evaluate the ulnar extrinsic ligament complex. The torn edges of the UL and UT ligaments may be appreciated without laxity in palmar class IC or Atzei class 1 (dc-TFCC) tears. The torn edges of the UL and UT ligaments may be appreciated with or without evidence of laxity in Atzei class 2 (complete TFCC) and Atzei class 3 (pc-TFCC) tears. Radial-sided tears (palmar class ID) are seen as a detachment of the disc from the sigmoid notch of the distal radius. Insert the arthroscope into the 6R portal. This allows for better visualization of the LT ligament and chondral surface of the ulnar side of the lunate. An LT ligament tear and/or chondromalacia of the lunate may be signs of ulnar impaction syndrome. Insert the arthroscope into the radial midcarpal portal and probe into the ulnar midcarpal portal (each 1 cm distal to the 3–4 and 4–5 portals, respectively). Examine the LT interval and proximal pole of the hamate. Lunotriquetral dissociation can lead to chondromalacia of the hamate, depending on its chronicity.

DRUJ diagnostic arthroscopy

Distal radioulnar joint arthroscopy (typically performed with a smaller, 1.9 mm arthroscope) allows for direct visualization of any ligamentous tear of the pc-TFCC or avulsion from the fovea. A normal DRUJ is narrow and congruent, and DRUJ arthroscopy may be difficult to perform when the pc-TFCC is still intact. When the pc-TFCC is torn, the articular disk becomes loose and more space is available for DRUJ arthroscopy.

Use an 18-gauge needle through the dorsal DRUJ portal to localize the joint. Probe the pc-TFCC through the direct foveal portal, located 1 cm proximal to the 6U portal (Fig. 4E).[13] The direct foveal portal is less technically difficult than establishing a volar portal, but its use is limited due to the introduction of working instruments in the area of the ulnar styloid and fovea (34).[33] Advance the probe into the ulnar fovea to lift the articular disk and palpate the foveal insertion of the pc-TFCC. In the authors' experience, there is a high correlation between the positive hook test and a disruption of TFCC foveal insertion. As such, confirmatory DRUJ arthroscopy is not always considered necessary. Distal radioulnar joint arthroscopy may still be used to evaluate for posttraumatic chondromalacia or cartilage loss of the distal ulna or sigmoid notch.

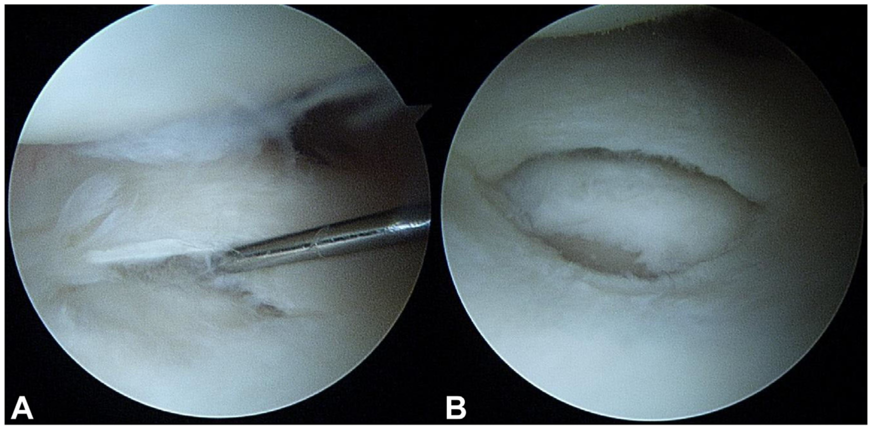

Figure 5. Central TFCC tear before and after debridement. Personal image courtesy of Jeffrey Yao, MD.

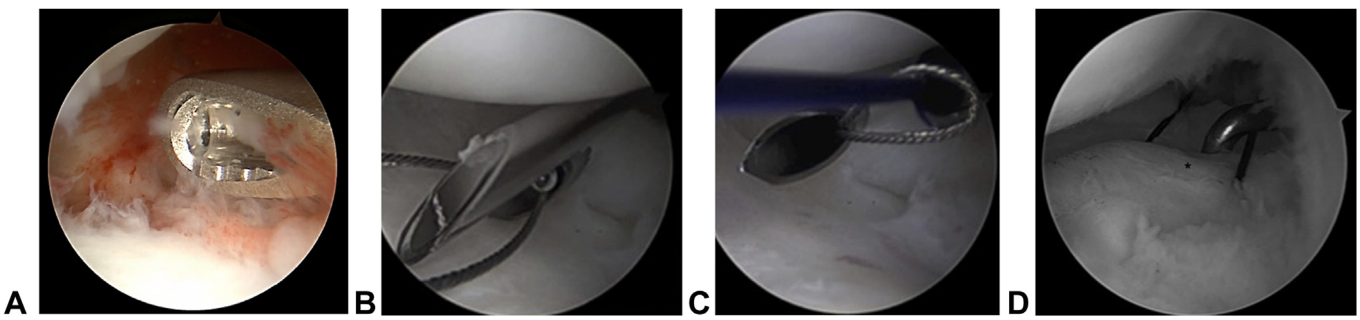

Figure 6. Outside-in arthroscopic-assisted repair. **A** Introduce a shaver into the 6R portal to debride the unstable and frayed edges of the periphery of the TFCC. Personal image courtesy of Jeffrey Yao, MD. **B** Eighteen-gauge needle with stylette seen penetrating dorsal capsule. Next, it is repositioned beneath the TFCC so that it penetrates from its undersurface. Place the second needle with stylette so that the distance between the needles spans most of the tear and the beveled ends face each other. Remove one stylette and pass a wire loop in its place. **C** Push the other needle through the wire loop, pull out the stylette, and pass the 2-0 PDS suture through the needle. Pull back on the needle through which the suture has been passed. Firmly grasp the suture with the wire loop, but do not attempt to pull it through the needle. With a firm grasp on the suture with the wire loop, pull back on the needle and loop as a unit and the suture will follow. **D** Reduction of the TFCC periphery to the dorsal ulnar capsule is done by pulling traction on the suture from the outside of the wrist. Asterisk indicates the location of the peripheral fibrocartilage complex tear. From Frank et al,[44] with permission.

Arthroscopic debridement of central TFCC tears (Palmer class 1A)

Central TFCC tears lack the vascularity required to mount a healing response to attempted repair. Therefore, arthroscopic debridement of the unstable portion of the tear is recommended. It has been found to provide good relief of symptoms.[34]

With the arthroscope in the 3–4 portal and a 3.5-mm full radius shaver or 2.5-mm suction punch in the 6R portal, debride the edges of the tear until they are stable. It may be necessary to alternate instruments between portals to achieve adequate debridement (Fig. 5). It has been demonstrated that the central two-thirds of the disc may be resected with no effect on forearm axial load transmission or stability.[7] Adams stressed that 2 mm of the periphery of the TFCC must be maintained to avoid instability.[34] Class IA lesions may also be associated with ulnar-positive variance when ulnar impaction lesions are identified. Consider an ulnar shortening osteotomy or wafer procedure in these cases. Once the debridement is complete, re-examine the wrist. Any preoperative click that was appreciated preoperatively should be resolved.

Arthroscopic technique for capsular repair (Palmer class 1B and Atzei class 1 peripheral tears)

Capsular repair is indicated for Palmer class 1B tears without DRUJ instability and Atzei class 1 peripheral tears. These lesions result from an avulsion of the TFCC from the ulnar styloid. Acute peripheral tears that fail conservative treatment should undergo arthroscopic repair. Methods for arthroscopic repair include inside-out, outside-in, and all-inside techniques.[27,29,30,35–42]

Outside-in arthroscopic-assisted repair

Special equipment required includes long spinal or Tuohy needles.[29,43] Our preference is to use the Meniscus Mender II kit (Smith & Nephew). Alternatively, repair could be performed using a suture anchor placed into the fovea of the ulna. After creating the 3–4 and 6R portals, identify and debride the peripheral tear to allow vascular ingrowth and potentiate the healing response (Fig. 6A).[44] Extend the 6R portal incision 1 cm and bluntly dissect to extensor retinaculum over the sixth compartment to avoid injury to the dorsal sensory branch of the ulnar nerve.

Incise the retinaculum over the ECU up to 50% of its longitudinal width. With the ECU retracted, insert a straight spinal needle or one of the needles from the Meniscus Mender II kit through the floor of the sixth extensor compartment, starting proximal to the disc and penetrating the disc from proximal to distal under arthroscopic visualization 1–2 mm central to the tear. Insert the next needle just radial or ulnar to the first. The beveled ends of the needles should be facing each other (Fig. 6B). Remove one of the stylettes and insert a wire loop in its place so that the loop is visible through the arthroscope. Place the other needle through the wire loop and pull on the loop so that the loop grasps the shaft of the needle. Remove the stylette from the needle and pass a 2-0 polydioxanone (PDS)

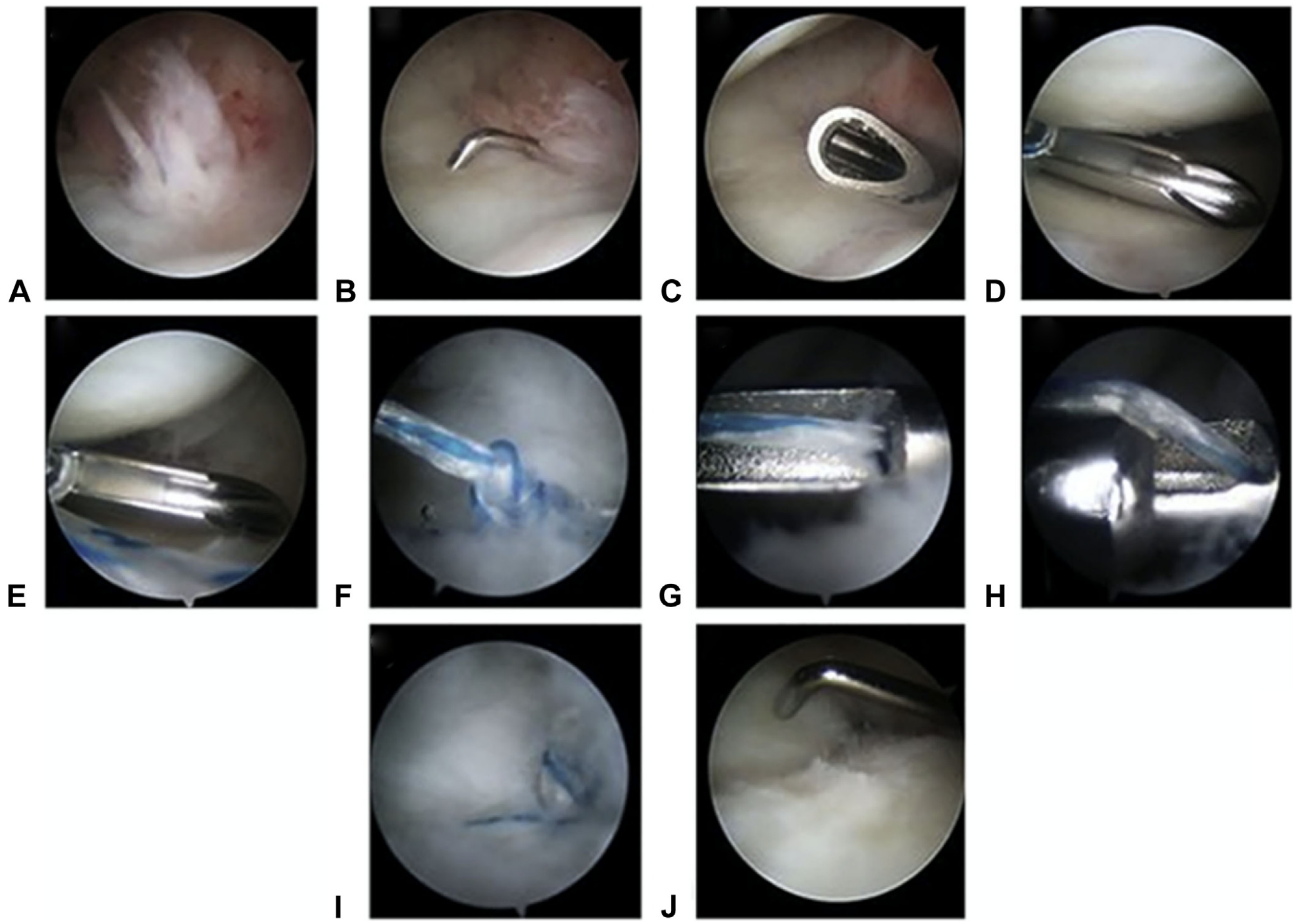

Figure 7. All-inside arthroscopic repair of peripheral TFCC tear to capsule. **A** Tear identification. **B** Positive trampoline effect shown. **C** Debrided tear. **D** FasT-Fix suture inserted through the 3–4 portal. **E** Second FasT-Fix suture inserted. **F** Needle introducer is removed revealing the pretied suture. **G** Knot pusher used to tighten the suture. **H** Suture is cut with knot cutter. **I** Final construct after repair. **J** Negative trampoline effect. From Yao,[27] with permission.

suture through it so that it is visible in the wrist (Fig. 6C). We recommend stopping the arthroscopic inflow before passing the suture to prevent encountered resistance.

Carefully pull back on the needle through which the suture was passed and grasp the suture with the wire loop. Pull back on the wire loop and suture so that the end of the wire loop is just visible through the end of the needle. Do not attempt to pull the wire loop and suture through the needle because this will likely cut the suture along the sharp end of the needle. With a firm grasp of the suture with the wire loop, pull the needle and wire loop out as a unit. The suture should follow and holding tension on the suture should reduce the peripheral tear, which can be checked arthroscopicaly (Fig. 6D).

Both ends of the PDS suture should now be visible from the dorsal–ulnar aspect of the wrist. Place the forearm in slight supination to reduce tension and pull the sutures taught to reduce the articular disc to the dorsal capsule. An additional one to two more sutures may be placed for larger tears. If an ulnar shortening osteotomy is planned, it should be performed before tying the sutures to the capsule so that there is no tension placed on the repair. For ulnar shortening osteotomies, we prefer the distal metaphyseal ulnar shortening technique.[45,46] The sutures may be tied over the dorsal capsule by extending the incision for the 6R portal between the sutures as they exit the wrist and pulling the sutures through the wound.

An alternative fixation technique involves inserting the PDS sutures into the eyelet of the suture anchor, drilling for the anchor approximately 1.5–2 cm proximal to the ulnar styloid, and inserting the anchor, keeping tension on the sutures during insertion. One additional option here is to suture the most distal edge of the TFCC to the adjacent capsule or periosteum to further reduce the dc-TFCC with an absorbable suture.

All-inside arthroscopic repair

Our preferred technique of repair is the all-inside repair (Fig. 7) technique using a pretied suture device such as FasT-Fix (Smith and Nephew Endoscopy).[27] With the arthroscope in the 6R portal, insert a curved FasT-Fix into the 3–4 portal with the assistance of the blue cannula. Advance the introducer needle with the first block of the FasT-Fix (the poly-L-lactate) through the articular disc, traversing the tear, and then advancing through the ulnar capsule. A decrease in resistance indicates penetration of the ulnar capsule.

Using the trigger, deploy the needle introducer to release the first poly-L-lactate block onto the outside of the ulnar capsule. The block will flip 90° and catch on the outside of the ulnar capsule. Withdraw the needle back into the radiocarpal joint and readvance on the ulnar side of the tear. Deploy the second poly-L-lactate block just ulnar to the tear in a vertical mattress configuration. Remove the introducer and use a knot pusher/cutter to tighten the 2-0 pretied braided polyester suture. Once the knot is tight, use the pusher/cutter to cut the knot. Use an arthroscopic punch to remove any excess suture. Repeat these steps to deploy a second TFCC FasT-Fix as needed.

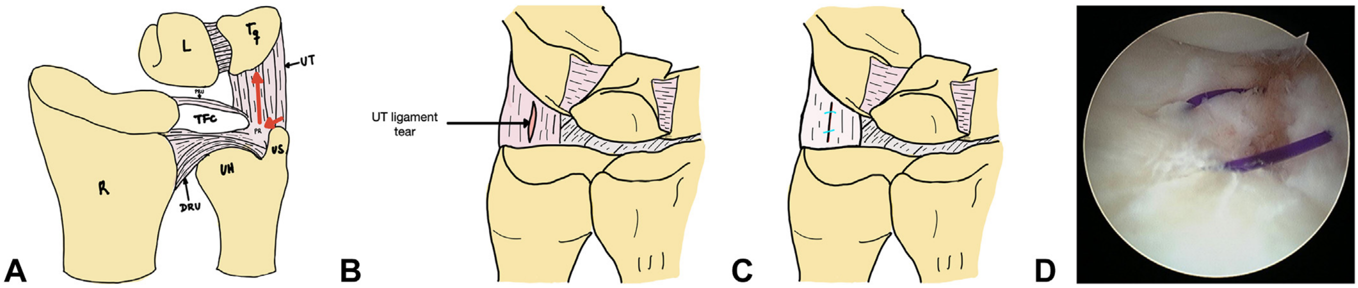

Figure 8. Technique for repair of palmar class IC tear or UT/UL ligament tears without disruption of proximal TFCC (Atzei class 1). **A** Red arrows illustrate the direction of avulsion of UT/UL ligaments when loaded under maximal traction: wrist extension/radial extension, and forearm supination. Prestyloid recess (PR), ulnar styloid (US), ulnar head (UH), DRU (dorsal radial ulnar), palmar radioulnar (proximal radial ulnar), lunate (L), triquetrum (Tq). From Sasao et al,[47] with permission. **B** Illustration of UT ligament tear. **C** Illustration of repair construct. **D** Arthroscopic image of the repair of a longitudinal UT split tear using two strands of 2-0 PDS sutures. R, radius. From Tay et al,[48] with permission.

Arthroscopic technique for repair of palmar class IC tear or UT/UL ligament tears without disruption of proximal TFCC (Atzei class 1)

Suspicion should be raised for an ulnar extrinsic avulsion from the ulnar carpus when the ulnar side of the wrist appears palmarly translated or supinated.[47,48] In the presence of DRUJ instability, a foveal repair or distal radioulnar ligament reconstruction is indicated. The technique described here addresses a UT/UL tear without DRUJ instability using the Meniscus Mender II kit (Smith & Nephew) (Fig. 8).

The volar or palmar radioulnar ligament forms the proximal attachment of the UL and UL ligaments, which attach to the palmar and ulnar aspects of the triquetrum. Arthroscopically, these ligaments can be visualized on the volar margin of the TFCC from the 3–4 or 6R portal. There is no clear demarcation between the UL and UT ligaments, and the ligaments can only be recognized by their distal attachments. Although the pisotriquetral joint can occasionally be visualized from the 6R portal under normal conditions, it is consistently identified in the presence of an ulnar extrinsic ligament disruption.

We recommend an arthroscopically assisted outside-in repair. Make a 1 cm longitudinal incision just anterior to the ECU tendon from just distal to the ulnar styloid extended proximally. Bluntly dissect to protect the dorsal sensory branch of the ulnar nerve down to the ulnar extrinsic ligaments, and identify and protect the ulnar neurovascular bundle. Identify the tear and, using the arthroscope to guide suture placement from within the joint, pass the Meniscus Mender II with 2-0 PDS across the split tear. Use a similar technique for passing the PDS suture as detailed in the outside-in repair described above. Pass the suture around bundles of the UT/UL ligaments for repair. When these sutures are tied, the split tear is anatomically closed.

Arthroscopic technique for foveal repair (Palmer type 1B deep or complete tear and Atzei class 2 or 3 peripheral tears) via the ulnar tunnel arthroscopic technique

There have been many techniques of foveal repair of the TFCC that have been described.[49–51] The authors prefer the ulnar tunnel technique (Fig. 9).[52] Special equipment for repair includes the FiberStick, 2.5 mm Mini PushLock, TFCC aiming guide, and suture passer (Arthrex). Tear of the pc-TFCC or Atzei class 2/3 injuries involves complete TFCC injuries, including the peripheral and deep portions with instability or a soft end point of the DRUJ on examination. Distal radioulnar joint arthroscopy can help visualize the proximal TFCC tear in the setting of a normal-appearing TFCC on radiocarpal arthroscopy with a positive hook test.

With the exception of a class 3 injury associated with a basilar ulnar styloid fracture (avulsion injury of the TFCC insertion, subclassified as 3A), treatment of Atzei class 2/3 injuries involves reinsertion of the TFCC into the ulnar fovea. In Atzei class 3A injuries, ulnar styloid fixation is recommended with cannulated screws, tension band wiring, or K-wires. We will focus on the arthroscopic technique for foveal repairs here.

Create 3–4 portals and 6R portals to visualize and debride the foveal tear. In the authors' experience, there is a high correlation between the positive hook test and a disruption of TFCC foveal insertion. As such, confirmatory DRUJ arthroscopy is not always considered necessary but may be completed at this step to confirm the foveal injury.

The authors prefer to use a c-clamp aiming guide through the 6R portal to pinpoint guidewire placement arthroscopically at the level of the articular disc. We then make a 3 mm incision proximal and volar to the ECU tendon for the cannulated c-clamp guide to sit flush on bone. Insert a 2.0-mm guidewire starting 1.5 cm proximal to the ulnar neck exiting through the fovea, underneath the articular disc. This step is done under arthroscopic (viewing from the 3–4 portal) and fluoroscopic visualization and guidance. Drill over this wire with a cannulated 3.0-mm drill, taking care not to drill through the articular disc itself. Through the drilled tunnel, a 4-0 FiberStick (Arthrex) suture on a suture passer (Arthrex) is passed through the articular disc of the TFCC while visualizing from the 3–4 portal. Instrumenting through the 6R portal, pull the end of the suture through the articular disc of the TFCC using a suture loop that is passed through the articular disc via the same tunnel a second time and pass the suture back into the osseous tunnel. This will create a mattress suture. Pull the repair suture taught, evaluate the reduction arthroscopically, and insert the ends of the repair suture through the eyelet of the knotless suture anchor (Arthrex PushLock) embedded into a drill hole created in the proximal ulna about 1.5 cm proximal to the ulnar tunnel. Take care to tie the sutures away from the ECU or dorsal sensory branch of the ulnar nerve. Repeat this technique to place additional sutures as needed.

Arthroscopic technique for repair of Palmer class ID tears

Avulsion of the TFCC from the sigmoid notch of the distal radius can occur in isolation or in association with a distal radius fracture.[53] The poor vascular supply of the TFCC in its radial periphery suggests a poor potential for healing. Therefore, simple debridement of the radial tear has led to satisfactory results. Nevertheless, arthroscopic repair has been described (Fig. 10), and this is the preferred technique of repair only if the DRUJ is unstable.[54–57] A bony avulsion of the TFCC from the sigmoid notch

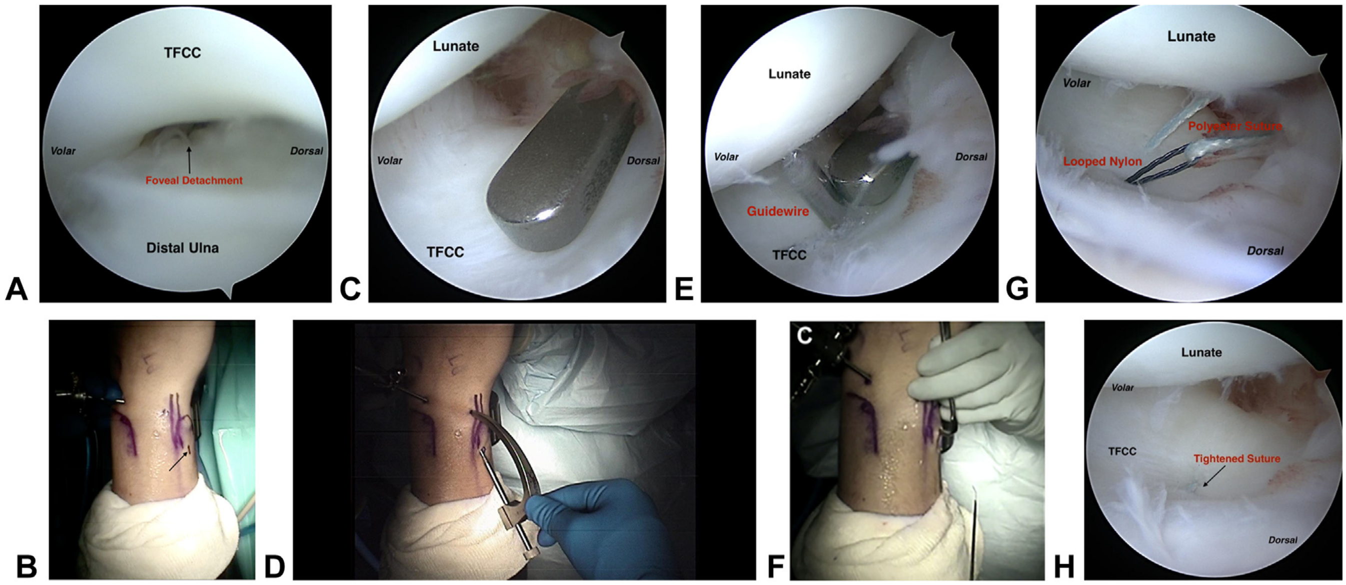

Figure 9. Technique for foveal repair (Palmer type 1b deep or complete tear [Atzei Class 2 or 3 peripheral tears]). **A** Arthroscopic view of the foveal detachment. **B** Recommended incisions for the aiming guide placement. Arrow indicates incision for trochar. **C** Arthroscopic view of the aiming guide in the radiocarpal joint. **D** Clinical photo with aiming guide and trochar placement. **E** Arthroscopic view of the guidewire drilled into the radiocarpal joint. **F** Visualization of the FiberStick suture and **G** passage of the looped nylon FiberStick passing suture. **H** Final arthroscopic view of the foveal repair. From Shapiro and Yao,[52] with permission.

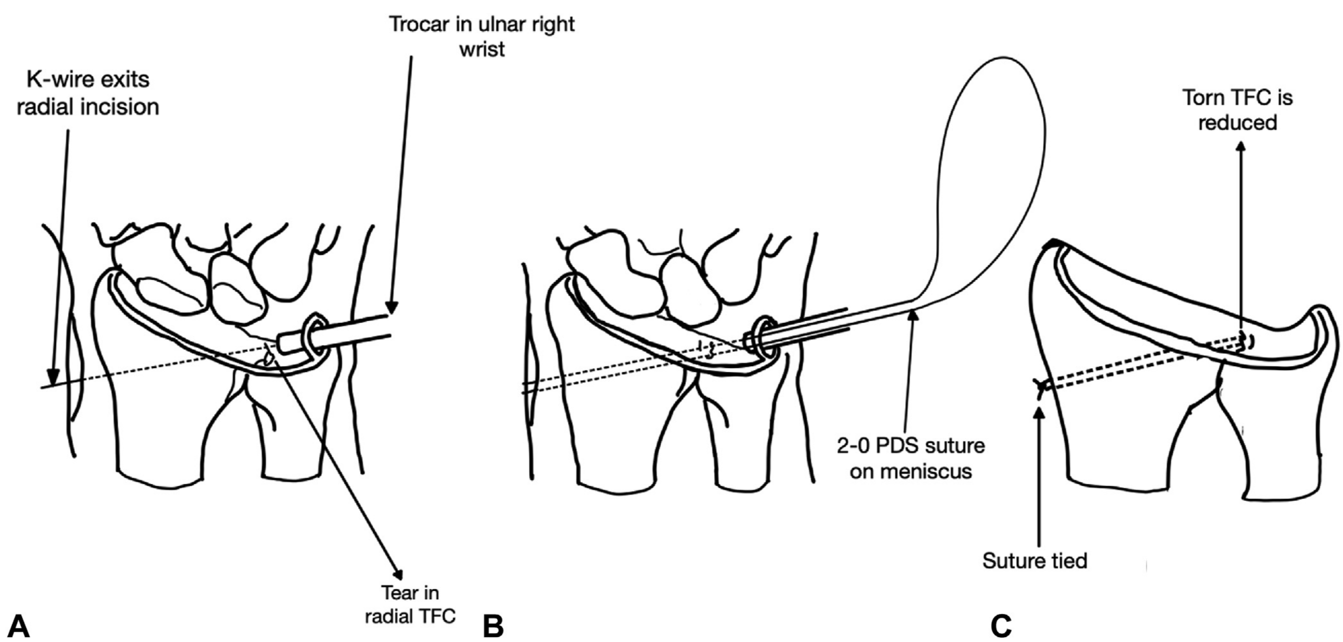

Figure 10. Arthroscopic repair of radial-sided TFCC tear. **A** K-wire followed by meniscus needle advanced through an intra-articular cannula out the radial wrist incision. **B** A second K-wire and meniscus needle are passed in a similar fashion 2 mm from the first pass. **C** Final repair construct. TFC, triangular fibrocartilage. From McAdams et al.[53]

of the radius will increase the likelihood of healing if appropriately reduced. Introduce a shaver/burr through the 3–4 or 4–5 portal and debride the TFCC attachment site to the sigmoid notch to bleeding bone to encourage healing of the TFCC to the radial sigmoid notch. Insert a trochar in the ulnar wrist via the 6U portal and aim for the tear in the radial TFCC. Place a 1.4-mm (0.045-in) Kirschner wire (K-wire) through the detached portion of TFCC and into the abraded sigmoid notch, exiting out through the radial cortex of the radius.

Make a longitudinal incision between the first and second extensor compartments at the exit site of K-wire radially, protecting the superficial branch of the superficial radial nerve through blunt dissection to the extensor retinaculum. Insert a folded 2-0 PDS suture on two meniscal needles (Meniscus Mender II kit [Smith & Nephew]) with the free ends exiting radially and the loop kept ulnar. If needed, use a wire loop passed from the other spinal needle to retrieve the suture. Arthroscopically visualize the reduction of the TFCC onto the sigmoid notch as traction is applied to the suture ends. Tie the suture over the bone bridge on the radius or insert it into the eyelet of a knotless suture anchor (Arthrex PushLock) embedded into a drill hole on the radial distal radius, 1–2 cm proximal to the radial styloid.

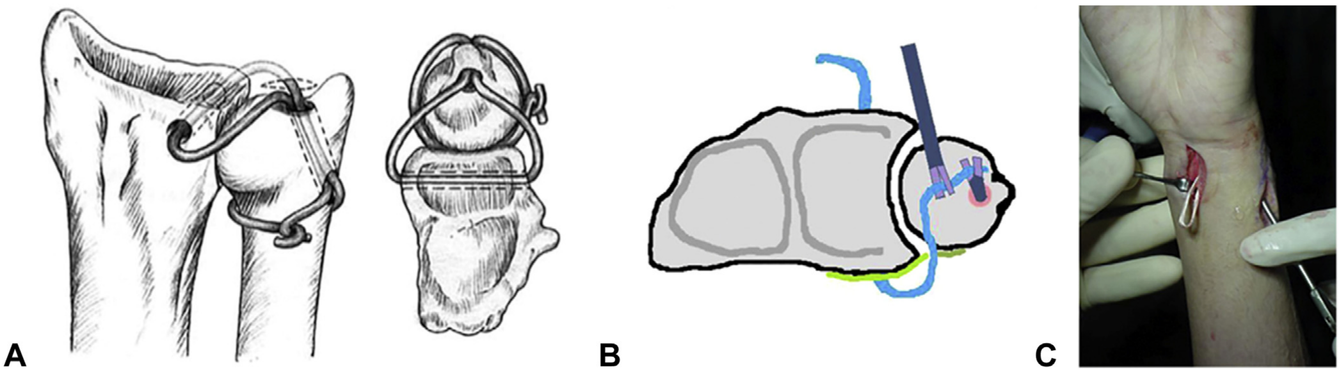

Figure 11. Arthroscopic technique for TFCC reconstruction (Atzei class 4). **A** Construct of ligament reconstruction for DRUJ instability. From Adams and Berger,[58] with permission. **B, C** Demonstration of a key step of arthroscopic ligament reconstruction using palmaris longus autograft. Volar and dorsal limbs of graft are passed intra-articularly through to the ulnar tunnel. From Tse et al,[59] with permission.

Arthroscopic technique for TFCC reconstruction (Atzei class 4)

Arthroscopic TFCC reconstruction is indicated for persistent DRUJ instability with a TFCC that is no longer reparable primarily.[58,59] Chronicity of the injury is not as important as the quality of the tissue when considering TFCC repair or reconstruction. Repair may be utilized as long as the tissue quality is sufficient for repair. In the case where the tissue quality is not sufficient for repair, reconstruction should be employed.

The technique described below is based on that of Tse et al,[59] which delivers the tendon autograft arthroscopically (Fig. 11). Start with creating a 3−4 portal, 6R working portal, and 4−5 portal (for passage of the graft). Then, confirm the nonviability of the native TFCC tissue. Multiple graft options may be used, including palmaris longus or, if not present, a strip of the FCU. Harvest the palmaris longus using a 5 mm distal incision and a proximal stab incision using the Saeed and Kay[60] technique. Elevate the fourth extensor compartment from the dorsal margin of the sigmoid notch. Place a guidewire through the radius parallel to the articular surface, 1 cm proximal to the joint surface, and 5 mm radial to the sigmoid notch. Overdrill the guidewire with a 3.5-mm cannulated drill. Drill a second tunnel in the ulna from the ulnar neck to the fovea as described above for the arthroscopic foveal repair. Pass the tendon autograft (palmaris longus or slip of FCU) through the radial tunnel from dorsal to palmar and pull back one end of the graft through the ulnar tunnel.

After the graft is placed in the radial tunnel, introduce an arthroscopic trochar from the 4−5 portal to the volar capsule between the UL ligament and short radiolunate ligament to create a window in the volar capsule through which the arthroscopic gasper can be used to retrieve the volar limb of the graft into the joint. Use a second grasper through the ulnar tunnel to bring the graft back through the ulna. The dorsal limb of the graft is placed into the joint through the 4−5 portal and retrieved through the ulnar tunnel using an arthroscopic grasper. Both ends of the graft are then passed through the ulnar tunnel (with one passing volarly and the other passing radially and deep into the ECU sheath). Position the forearm in neutral rotation and tie the ends of the graft around the ulnar neck to tension the DRUJ. Alternatively, an interference screw placed into the tunnel or placement of a suture anchor can be used for securing the tendon graft.

Pearls

Perform a thorough examination in the office and under anesthesia to rule out other causes of the patient's presenting ulnar-sided wrist symptoms. Distal radioulnar joint instability should undergo early surgical foveal TFCC repair. In the absence of DRUJ instability, conservative management can be attempted with 4 weeks of immobilization. If conservative measures fail, TFCC injuries may be successfully treated arthroscopically. When utilizing arthroscopy, place the forearm in 4.5 kg (12 lb) of traction and slight flexion to allow for adequate visualization and maneuvering of instruments within the wrist. Pass sutures and needles at least 2 mm radial to the tear so that the suture does not pull through the TFCC periphery when traction is applied. If ulnar shortening is also performed, tension and tie the suture after the osteotomy is completed to avoid placing tension on the repair.

Pitfalls

Do not attempt to pull the suture through the needle with a wire loop; the suture may be cut from the sharp edge of the needle. After the wire loop has a firm grasp of the suture, pull the loop and needle as a unit. Patients with ulnar-positive variance who engage in daily activities or sports requiring weight-bearing of the wrist may have a poor result after TFCC repair; in these situations, consider performing a concomitant ulnar shortening osteotomy. Be wary of DRUJ instability. A positive hook test in the setting of an otherwise normal radiocarpal arthroscopy should cue the provider to a proximal TFCC injury, and foveal repair is indicated.

Postoperative Management

In patients who undergo debridement alone or arthroscopic capsular repairs using the FasT-Fix, we recommend immobilization in a short arm splint for 2 weeks. Hand therapy for wrist and elbow motion can be initiated at 2 weeks, with progression to strengthening at 4 weeks. Activity restrictions are lifted at 6−12 weeks, depending on the patient's progression with therapy.

In patients who undergo an arthroscopic foveal repair or reconstruction, we recommend a sugar tong splint for 2 weeks and transition to a Munster cast for 4 weeks to allow for elbow flexion and extension without forearm pronosupination. Hand therapy is initiated at 6 weeks and strengthening at 8 weeks. Return to sport or work is determined on a case-by-case basis but typically occurs at 3−4 months.

Complications

The most likely complication following arthroscopic treatment of TFCC tears is postoperative wrist stiffness. It is essential to encourage digital motion in the perioperative period despite the application of a wrist-based or sugar tong splint. Wrist stiffness after a long period of immobilization following TFCC repair is expected. Therapy consisting of gentle wrist motion followed by strengthening exercises is instituted after the appropriate period of immobilization.

Ulnar-sided wrist pain and DRUJ instability that recurs or does not resolve after surgery and appropriate rehabilitation should raise suspicion for insufficient repair, retear, or the failed diagnosis of other causes of ulnar-sided pain. In particular, for TFCC repairs, DRUJ stability should be assessed via intraoperative physical examination with comparison to the contralateral extremity before wound closure and splint placement. The possibility of concomitant ECU subluxation, DRUJ instability, or ulnar impaction syndrome should be considered. Failure to heal a repair may also occur, especially in the setting of central and radial tears. Pain with paresthesias on the ulnar side of the wrist and hand should raise concern for injury to the dorsal cutaneous branch of the ulnar nerve, especially if care is not taken to identify the nerve when any sutures are tied down directly to the dorsal capsule. Previous studies have found nerve injury to be less frequent in arthroscopic versus open TFCC repair.[61] Irritation of the ECU tendon may also occur with symptomatic knots on the ulnar aspect of the wrist. Less commonly, infection or fracture from multiple passes of the guidewire in foveal, DRUJ reconstruction, or outside-in repairs may occur.

Results

With accurate indications, arthroscopic or arthroscopically assisted dc-TFCC repair results have satisfactory to excellent results in the literature with regards to grip strength and patient-reported outcomes.[6,30,31,34,38]

Outcomes of DRUJ reconstruction are also excellent with regards to return to native DRUJ stability and ulnar translation in pronation and supination, pain relief, and grip strength.[49] Of note, decreased pronosupination after DRUJ reconstruction has been reported, averaging 20° of loss of pronosupination arc.[62] Although technique differences vary and may continue to be modified, the outcomes of TFCC repair and reconstruction are encouraging.

Conclusion

Diagnosis and treatment of TFCC injuries is nuanced and requires a thorough understanding of concomitant injuries and pathophysiology of TFCC injuries. A complaint of pain exacerbated with ulnar deviation of the wrist, twisting maneuvers, power grip, and axial compression or weight-bearing should clue the clinician to complete a thorough examination for ulnar-sided wrist disorders. Advanced imaging including MRI and diagnostic arthroscopy can greatly aid in the diagnosis of the tear. It is important to be on the lookout for not only dc-TFCC injuries but also injuries of the ulnar extrinsic ligaments (UT/UL), and the proximal triangular ligament (deep volar and dorsal DRUJ ligaments and palmar ulnocarpal ligaments). There are many methods to treat these injuries based on their location. Classifications including the Palmer classification and the Atzei classification are helpful in delineating management. Current techniques are directed toward eliminating pain and restoring stability and function to the injured TFCC. Choosing a technique depends on the stage and characteristics of the TFCC injury and DRUJ stability. Surgeon experience, as well as patient characteristics, may guide the decision for arthroscopic or open management. In this manuscript, we describe our preferred techniques for surgical management based on injury location and discuss the pearls and pitfalls of arthroscopic-assisted techniques.

Conflicts of Interest

No benefits in any form have been received or will be received related directly to this article.

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