The Distal Radioulnar Joint: Problems and Solutions

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Abstract

Disorders of the distal radioulnar joint are a major source of ulnar-sided wrist pain. Fortunately, our understanding of the anatomy, joint mechanics, and pathophysiology of this area has increased greatly in recent years, making resolution of many of these problems feasible. In most cases, an accurate diagnosis can be made, and successful treatment can then be prescribed. This review covers various problems affecting the distal radioulnar joint, including fractures and dislocations, triangular fibrocartilage pathology, arthritis, and other disorders.

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Disorders of the distal radioulnar joint (DRUJ) are a common source of ulnar-sided wrist pain. The ulnar side of the wrist has often been likened to the lower back because of the difficulties involved in establishing a specific diagnosis for pain at both sites and therefore in prescribing an effective treatment plan. Fortunately, increased research interest during the past two decades has improved our understanding of both the anatomy and the pathology of this area of the wrist. As a result, accurate diagnosis has been facilitated, making possible the appropriate treatment that will yield a satisfactory outcome in most cases.

Anatomy

The articulation of the distal radius and ulna is through the sigmoid notch of the radius and the ulnar head (Fig. 1). The arc of curvature of the sigmoid notch ranges from 47 to 80 degrees. Articular cartilage covers a much greater arc of the ulnar head, ranging from 90 to 135 degrees. The radius of curvature of the sigmoid notch is 15 mm, compared with 10 mm for the ulna, resulting in both rotational and sliding motions in the normal joint.

The DRUJ is one part of the forearm joint. During forearm motion, the entire length of the radius and ulna, the interosseous membrane, and the proximal radioulnar articulation interplay with the DRUJ. In certain pathologic conditions, this critical interplay is compromised.

The DRUJ is normally separated from the radiocarpal joint by the triangular fibrocartilage complex (TFCC). The term “TFCC” was coined by Palmer and Werner[1] in 1981. The complex includes the articular disk, or triangular fibrocartilage proper; the dorsal and palmar radioulnar ligaments; the meniscus homologue; and the extensor carpi ulnaris sheath (the floor of which is often called the ulnar collateral ligament) (Fig. 2). Although neither included in the TFCC nor a part of the DRUJ, the ulnotriquetral and ulnolunate ligaments play an important functional role in this area of the wrist.

Examination of the histology of the TFCC helps in understanding its anatomy.[2] Because collagen fibers are oriented along lines of stress, microscopic observation of the fiber arrangement provides insight into the stresses within the TFCC. The dorsal and palmar radioulnar ligaments are composed of longitudinally oriented bundles of collagen fibers that originate and insert directly into bone, as they do in ligaments elsewhere in the body.

The central articular disk is composed of fibrocartilage that originates from the hyaline cartilage of the distal radiolunate fossa. The hyaline cartilage of the lunate fossa continues around the edge of the distal radius and is continuous with the hyaline cartilage of the sigmoid notch. The continuous layer of hyaline cartilage has a different signal intensity on magnetic resonance (MR) imaging than the adjacent articular disk fibrocartilage. This difference in signal intensity should

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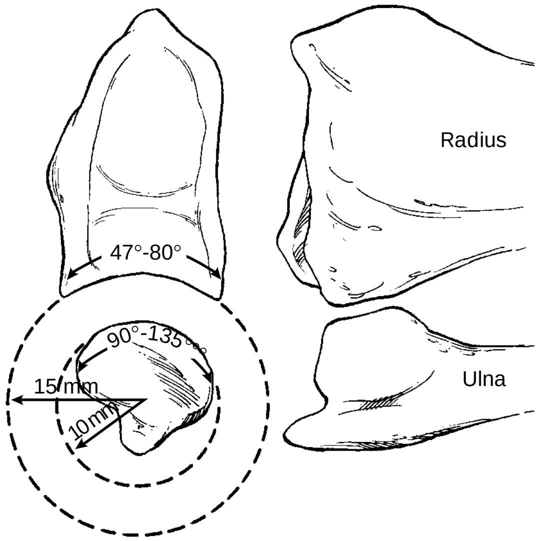


Fig. 1 Articulation between the sigmoid notch of the radius and the ulnar head, viewed both end-on **(left)** and dorsally **(right)**. The arc covered with articular cartilage is greater for the ulnar head than for the sigmoid notch, while the radius of curvature is greater for the sigmoid notch. This results in both rotational and sliding motions during supination and pronation.

not be misinterpreted as a tear in the articular disk.

The site of origin of the articular disk fibrocartilage from the hyaline cartilage is reinforced by thick collagen bundles projecting 1 to 2 mm from the radius into the articular disk. A common tear of the articular disk is oriented in the sagittal plane at the junction of these thick bundles with the remainder of the disk (a subtype of class 1A in Palmer's classification of TFCC injuries[3] [Table 1]).

In the central portion of the disk, the collagen fibers are oriented at oblique angles to each other, forming a wave pattern. The interweaving of these waves produces a basket-weave configuration well suited for both compressive and tensile stresses. On the ulnar side, the collagen fibers coalesce into two main bundles, one inserting into the styloid and one into the foveal area. These two fiber bundles are separated by loose vascular connective tissue, which occupies the floor of the prestyloid recess and is frequently involved in early rheumatoid arthritis of the wrist, producing a lytic lesion on radiographs of this area.

The extrinsic vascularity of the DRUJ is supplied from the dorsal and palmar branches of the anterior interosseous artery and the dorsal and palmar radiocarpal branches of the ulnar artery. Interosseous vessels from the ulnar head also enter the TFCC through the foveal area. The dorsal and palmar radioulnar ligaments are well vascularized, as is the peripheral 15% to 20% of the articular disk. The central 80% to 85% is avascular, with no vessels entering the articular disk from the radius. Therefore, traumatic peripheral tears and avulsions from the ulna have the vascular potential to heal, while traumatic tears located centrally and along the origin from the radius do not. Interestingly, however, a recent study in dogs has shown some healing capability of traumatic articular-disk tears in the avascular region.[4] In contrast, there is no evidence that central degenerative perforations are capable of healing.

Joint Mechanics

Compressive loads across the wrist not only are borne by the distal radius but also are transmitted through the TFCC to the ulnar head. In a human cadaver study, Palmer and Werner[5] found that 82% of the compressive load across the wrist is transmitted through the radiocarpal

Table 1
Palmer's Classification of TFCC Injuries[3]*

Class 1: Traumatic	
Type A:	Central perforation
Type B:	Medial avulsion (ulnar attachment)
	With distal ulnar fracture
	Without distal ulnar fracture
Type C:	Distal avulsion (carpal attachment)
Type D:	Lateral avulsion (radial attachment)
	With sigmoid-notch fracture
	Without sigmoid-notch fracture
Class 2: Degenerative (ulnocarpal impaction syndrome)	
Stage A:	TFCC wear
Stage B:	TFCC wear with lunate and / or ulnar chondromalacia
Stage C:	TFCC perforation with lunate and / or ulnar chondromalacia
Stage D:	TFCC perforation with lunate and / or ulnar chondromalacia and lunotriquetral-ligament perforation
Stage E:	TFCC perforation with lunate and / or ulnar chondromalacia, lunotriquetral-ligament perforation, and ulnocarpal arthritis

*Adapted with permission from Palmer AK: Triangular fibrocartilage complex lesions: A classification. *J Hand Surg [Am]* 1989;14:594-606.

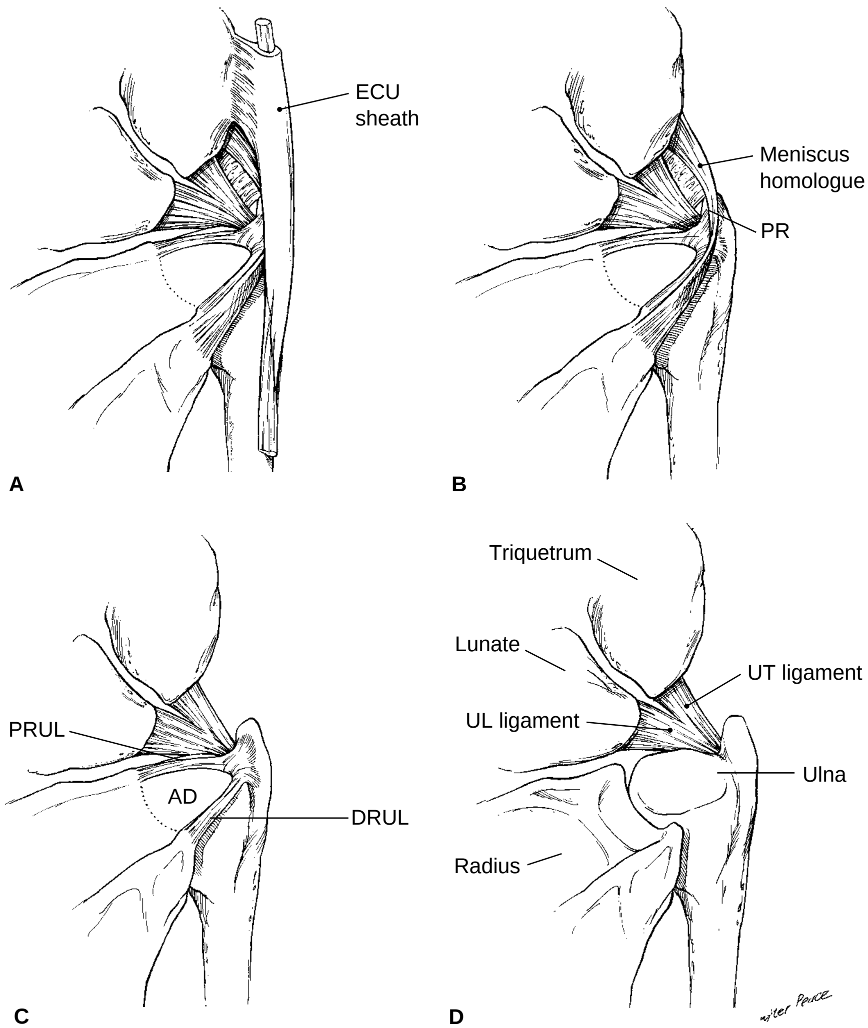


Fig. 2 Dorsal views of the TFCC, looking from radial to ulnar. **A,** All components are shown in an intact TFCC. The sheath of the extensor carpi ulnaris (ECU) extends farther than drawn, reaching the fifth metacarpal with connections to the triquetrum and hamate. **B,** The sheath has been removed along with its thickened floor, called by some the "ulnar collateral ligament." The meniscus homologue (MH) originates from the dorsal margin of the radius and sweeps palmarly and ulnarly to insert into the palmar / ulnar aspect of the triquetrum. Along its course, fibers insert into the ulnar styloid. As the MH sweeps past the palmar radioulnar ligament, it forms the dorsal roof of the prestyloid recess (PR), a synovium-lined recess that variably connects to the palmar aspect of the ulnar styloid. **C,** The MH has been removed to show the articular disk (AD), palmar radioulnar ligament (PRUL), and dorsal radioulnar ligament (DRUL). **D,** The TFCC has been removed. The ulnolunate (UL) and ulnotriquetral (UT) ligaments extend from the palmar aspect of the respective carpal bones and lunotriquetral ligament to the ulna, inserting into the foveal area and the base of the ulnar styloid.

articulation, and 18% is transmitted through the ulnocarpal articulation with a neutral ulnar variance. Small changes in ulnar variance can alter this force distribution markedly. (Figure 3 illustrates the radiographic technique of measuring ulnar variance.) A 2.5-mm increase in variance raises the ulnocarpal articular load to 42%. A 2.5-mm decline in ulnar variance from the neutral position lowers the ulnocarpal compressive load to 4.3%. Ulnar variance is not static; changes in forearm position and power grip continually alter it. Full forearm pronation increases ulnar variance, while full forearm supination decreases it. Ulnar variance also becomes more positive with power grip. Variance changes related to forearm rotation and grip may be as much as 2 to 3 mm. Changes of this magnitude demonstrate the large load alterations across the ulnocarpal articulation during daily activities involving rotation of the forearm and grip.

The structures contributing to stability of the DRUJ include the TFCC, the extensor carpi ulnaris and its sheath, the interosseous membrane, the pronator quadratus, the forearm muscles that cross the supination-pronation axis, and the osseous architecture of the joint. The exact

Fig. 3 Ulnar variance is measured on a standardized PA radiograph. A line perpendicular to the longitudinal axis of the radius is drawn at the level of the subchondral bone of the palmar lip of the lunate fossa. The distance the ulnar head extends above or below this line is the ulnar variance. In this case there is 1 mm of positive ulnar variance.

contribution of each to DRUJ stability has yet to be fully defined, but clearly primary and secondary stabilizers are involved.

Palmer and Werner[1] concluded from their study of cadavers that the TFCC is the major stabilizer of the DRUJ. As the authors sequentially sectioned the pronator quadratus, the capsule of the DRUJ, and the TFCC, the distal ulna was loaded dorsally, palmarly, or laterally at various forearm positions. The pronator quadratus and the capsule of the DRUJ contributed minimally to stability, while sectioning of the TFCC resulted in complete dislocation of the DRUJ except in full pronation. In this position, the ulna displaced dorsally after TFCC sectioning, with incomplete palmar displacement. Complete palmar displacement was prevented by the interosseous membrane and the osseous architecture.

The role played by individual components of the TFCC in maintaining stability remains controversial. The central two thirds of the articular disk can be resected without affecting joint stability. Using a stereophotogrammetric method in cadavers, Schuind et al[6] demonstrated that the palmar radioulnar ligament is taut during normal supination, while the dorsal radioulnar ligament is taut during pronation.

In another study of cadavers, Ekenstam and Hagert[7] assessed DRUJ stability after sectioning either the dorsal or the palmar radioulnar ligament. After division of the palmar ligament alone, the DRUJ was stable during supination, but during pronation the ulnar head would dislocate dorsally in relation to the radius. In full supination, the ulnar head slid palmarly and the still-intact dorsal radioulnar ligament became tight. Stability was provided by the interaction between the tight dorsal radioulnar ligament and the palmar lip of the sigmoid notch. Division of only the dorsal ligament caused DRUJ instability with supination, but the joint was stable with pronation. In full pronation, the ulnar head slid dorsally, and the intact palmar radioulnar ligament became tight. The interaction between the tight palmar ligament and the dorsal lip of the sigmoid notch provided stability.

The studies by Schuind et al[6] and Ekenstam and Hagert[7] suggest contradictory conclusions regarding tension in the dorsal and palmar radioulnar ligaments during supination and pronation. However, Schuind et al believe that the two different observations may actually be compatible; that is, the tension pattern may change in the ligaments, progressing from normal motion to the extreme positions where dislocation takes place (Fig. 4).

Diagnostic Evaluation

History and Physical Examination

The histories of patients with DRUJ problems, including the onset of symptoms, vary widely. By developing an orderly approach to the history and physical examination based on full knowledge of the possible injuries to and disorders of the DRUJ, the clinician can avoid oversights in diagnosis (Table 2). Important aspects of the history and physical examination will be reviewed below as specific problems of the DRUJ are discussed. As with many musculoskeletal conditions, the choice of treatment will be influenced by the age of the patient, hand dominance, and vocational and recreational demands. Thus, this is important information to obtain from all patients.

During the physical examination, it is essential to compare the upper extremities, particularly because the normal range of motion and laxity of the DRUJ vary considerably among individuals. Range of motion can vary anywhere from 75 to over 100 degrees of supination and pronation.

Imaging Studies

Standard Radiography

Standard radiographs should include a posteroanterior (PA) and a

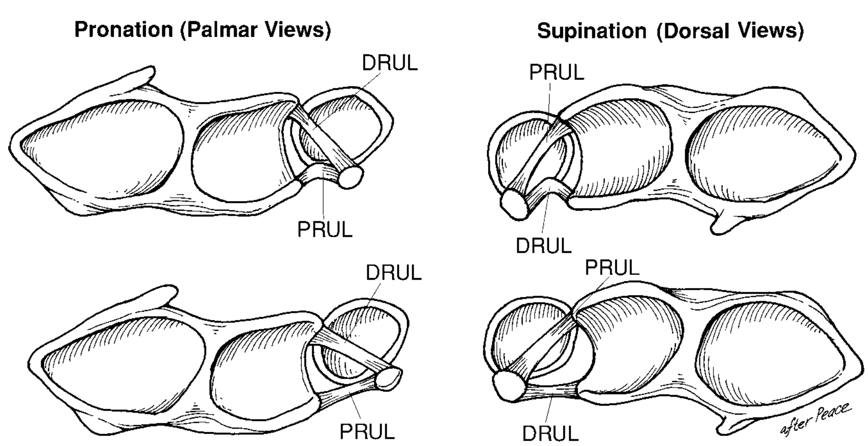


Fig. 4 Tension patterns in the dorsal radioulnar ligament (DRUL) and the palmar radioulnar ligament (PRUL). **Top,** Studies have shown that during normal motion the DRUL is tight in pronation and the PRUL is tight in supination.[6] **Bottom,** In apparent contradiction to the findings in normal motion studies, Ekenstam and Hagert[7] have shown that in pronation the PRUL is the important ligament in preventing dorsal dislocation and that in supination the DRUL prevents palmar dislocation.

Table 2
Injuries and Disorders of the DRUJ

- Intra-articular fractures without instability
  - Sigmoid notch (intra-articular distal radial fractures)
  - Ulnar head (including chondral fractures)
  - Ulnar styloid
- TFCC injuries without instability
  - Traumatic (some of Palmer's class 1 injuries will be associated with dislocation / instability)
  - Degenerative (ulnocarpal impaction syndrome [Palmer's class 2 injuries])
    - Idiopathic positive ulnar variance
    - Acquired positive ulnar variance
- Dislocations and instability
  - Acute
    - Dorsal with or without fracture
    - Palmar with or without fracture
    - Multidirectional with or without fracture
    - Proximal-distal instability (Essex-Lopresti)
  - Chronic (with or without arthritic changes)
    - Dorsal with or without malunion or nonunion
    - Palmar with or without malunion or nonunion
    - Multidirectional with or without malunion or nonunion
    - Proximal / distal instability
  - Chronic instability after DRUJ resectional arthroplasty
- Arthritis (e.g., osteo-, posttraumatic, or rheumatoid arthritis, gout, pseudogout)
- Other disorders
  - Congenital (Madelung's deformity)
  - Unstable extensor carpi ulnaris tendon
  - Fixed forearm rotational contracture
  - Tumor (hereditary multiple exostosis involvement of DRUJ)

lateral view. Hardy et al[8] have pointed out several advantages of obtaining the PA view in the "standard ulnar variance position" (Fig. 4), in which the forearm is positioned in neutral pronation / supination, the shoulder is abducted 90 degrees from the side, the elbow is flexed 90 degrees, and the wrist is maintained in neutral flexion / extension. In this position, the ulnar styloid process projects along the ulnar edge of the ulna, and the fovea at the base of the ulnar styloid is clearly profiled. This standard PA view enables one to measure the ulnar variance consistently over time.

Epner et al[9] feel that additional information may be obtained by taking the standard ulnar variance PA view with the wrist in full ulnar deviation. The scaphoid is rotated into a more horizontal position, which facilitates the search for a possible scaphoid fracture. The movement of the lunate can also be assessed with ulnar deviation. In the neutral position, the lunate is half on and half off the ulnar border of the radius. Normally, the lunate moves entirely over the radius with ulnar deviation. The lack of lunate movement radially with ulnar deviation has been associated with radiocarpal arthritis.

The lateral view is obtained with the patient's shoulder adducted to the side, the elbow flexed 90 degrees, and the forearm in neutral supination / pronation. On a true lateral view, the pisiform should overlie the distal third to fourth of the distal pole of the scaphoid. The variable shape of the distal ulna makes alignment of the dorsal cortex of the radius and ulna an unreliable determinant of a true lateral view. Comparison lateral views taken with identical rotation of both forearms may show DRUJ subluxation or dislocation. However, one must be cautious about overinterpreting a single lateral view, as this can be a pitfall in diagnosing DRUJ subluxation. A few degrees of rotation can make the normal ulnar head appear dorsally or palmarly subluxated.

Oblique views in the semipronated and semisupinated positions may be used to profile the dorsal and palmar ulnar aspects of the wrist, respectively. The semisupinated view is especially helpful when visualizing the pisotriquetral joint and the hook of the hamate. A metal marker over the specific site of tenderness may be helpful in identifying the source of pain.

Stress views with a subluxating force applied to the ulna may reveal patterns of instability. When evaluating pain due to suspected ulnocarpal impaction syndrome, it is helpful to obtain a PA view with the forearm fully pronated while the patient makes a tight fist. In patients with ulnocarpal impaction syndrome, symptoms are usually most pronounced in this position. Both grip and pronation of the forearm increase (i.e., make more positive) ulnar variance.

Computed Tomography

Computed tomography (CT) is the study of choice for evaluating patients with clinically suspected DRUJ subluxation and dislocation. The modality is also helpful in evaluating the congruity of the DRUJ articular surface in fractures. The patient is positioned prone with both arms extended overhead. The forearms are maintained parallel to each other, and imaging sections are obtained through the area of Lister's tubercle. When the two sides are compared, frank dislocation is obvious.

For more subtle subluxation, several CT scan measurement methods have been described (Fig. 5). In an evaluation of three of these methods, Wechsler et al[10] deemed it essential to obtain scans in the neutral, fully pronated, and fully supinated positions. The distal-radioulnar-line method was found to be less reliable than either the epicenter method or the congruity method. Pirela-Cruz et al[11] have suggested a stress CT method for visualization of even more subtle signs of subluxation. With forced attempts at subluxating the DRUJ, they observed a translational difference of no more than 3 mm between the upper extremities of normal subjects.

Arthrography

Triple-injection arthrography of the wrist is currently the diagnostic study of choice in patients with suspected TFCC tears. Three hours after the initial injection of contrast material into the radiocarpal joint, the patient returns for injections into the DRUJ and the midcarpal row. Several studies have shown the importance of triple-injection arthrography compared with single-injection arthrography of the radiocarpal joint or DRUJ.[12-14] When only a radiocarpal injection is performed, approximately one fourth of tears may be overlooked.

Digital subtraction arthrography has been proposed as a method to better visualize the area of a tear,[13] but the arm must be kept absolutely still throughout this procedure. Stressing the wrist during an arthrographic study by moving the hand around and having the patient clench the fist is important since as many as 14% of TFCC tears become evident only when the wrist is stressed.[14]

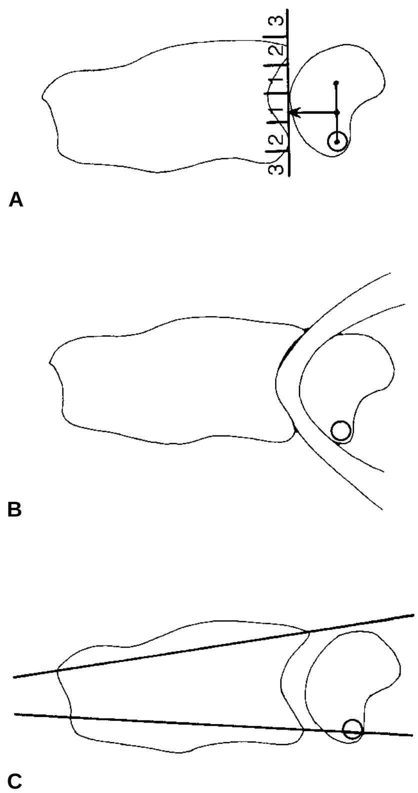


Fig. 5 Methods for using CT scan measurements to assess DRUJ subluxation. **A,** Epicenter method. A perpendicular line is drawn from the halfway point of a line drawn between the center of the ulnar head and the center of the ulnar styloid. The joint is not subluxated if this perpendicular line points to the middle of the sigmoid notch. **B,** Congruity method. The joint is normal if the arc of the ulnar head is congruent with the arc of the sigmoid notch. **C,** Radioulnar-line method. The joint is normal if the head falls between the two lines. This method is the least reliable.

Herbert et al[15] have questioned the usefulness of unilateral arthrograms in diagnosing wrist pathology. They used arthrography to examine 60 patients with traumatic wrist pain, 70% of whom were less than 40 years old. In each case, both the painful wrist and the asymptomatic opposite wrist were examined. In 74% of patients, communications were found in the contralateral asymptomatic wrist.

MR Imaging

Magnetic resonance imaging is rapidly approaching arthrography in its ability to demonstrate TFCC tears. A wrist coil is required. Traumatic tears are best diagnosed on T2-weighted images in the coronal plane. Areas of degenerative change and traumatic tears both display intermediate signal intensity on T1-weighted images, making differentiation between the conditions difficult. Also, the normal continuation of the articular cartilage of the distal radius with the articular cartilage of the sigmoid notch may be misinterpreted as a tear on a T1-weighted image. On T2-weighted images, synovial fluid has a high signal intensity; therefore, it can act as an endogenous contrast agent when it fills a tear.

Several studies have compared the sensitivity and specificity of arthrography with those of MR imaging.[16-19] Both imaging techniques have a sensitivity of approximately 80% and a specificity approaching 100%. Perforations of the articular disk seen on these studies must be correlated with the clinical history and symptoms. Degenerative tears are a normal part of aging[20-22]; in fact, by 50 to 60 years of age, more than half of asymptomatic persons have perforations of the articular disk.

Arthroscopy

Arthroscopy is an excellent diagnostic tool in evaluating the TFCC from the radiocarpal side. However, arthroscopy of the DRUJ itself is difficult and has limited usefulness.

Intra-articular Fractures Without Instability

The most common intra-articular fractures of the DRUJ are distal radial fractures that extend into the sigmoid notch. These fractures may also be associated with fractures of the ulnar styloid or the ulnar head. Isolated ulnar styloid fractures are less common, and isolated fractures involving the ulnar head are rare.

Perhaps because of their frequency, distal radial fractures are often treated with less respect than they deserve. Attention is often directed primarily at the radiocarpal joint, and the clinician may fail to address the importance of fracture displacement extending into the sigmoid notch. Also, the index of suspicion is often low for associated DRUJ instability or dislocation. Findings on standard radiographs that should alert the clinician to possible instability are displaced sigmoid-notch fractures involving the dorsal or palmar rim and displaced ulnar-styloid fractures.

The clinician should also pay particular attention to restoring radial length and achieving adequate reduction of the sigmoid-notch articular surface. A high proportion of unsatisfactory treatment outcomes following malunion of the distal radius result from shortening of the radius, with an associated acquired positive ulnar variance. Ulnocarpal impaction syndrome may result. Knirk and Jupiter[23] have documented poor results in distal radial fractures when displacement of the radiocarpal articular surface is greater than 1 mm. No data are yet available that indicate whether the DRUJ articular surface is any more tolerant of articular surface displacement. Computed tomography may be needed to fully assess the sigmoid-notch articular surface and DRUJ subluxation or dislocation in cases in which plain radiographs are suggestive but not diagnostic.

Adequate reduction of the distal radius and DRUJ may require external fixation and / or internal fixation. For less complex ulnar-styloid fractures that are isolated and nondisplaced, application of a Muenster cast for 6 weeks, with the forearm in neutral rotation and the wrist in slight ulnar deviation, is usually sufficient.

TFCC Injuries Without Instability

The TFCC is a major stabilizer of the DRUJ, and injury to this structure may lead to DRUJ instability. However, many injuries to the TFCC that produce no instability can still cause the patient pain. In the classification scheme for TFCC injuries developed by Palmer[3] (Table 1, Fig. 6), injuries that do or do not result in instability are not categorized separately; rather, injuries are separated into two broad categories, traumatic and degenerative.

Traumatic Injuries

Traumatic tears of the articular disk usually occur along the avascular origin from the radius. They are class 1A injuries, according to Palmer's classification, not to be confused with the less common radial avulsion of the entire TFCC from the radius (class 1D). The most common subtype of class 1A injuries is a tear in the sagittal plane approximately 1 to 2 mm from the articular surface of the radius. This site occurs at the junction of the thick collagen bundles protruding from the radial articular surface and the fibrocartilage of the central articular disk. Bowers[24] has suggested that the palmar-radial corner of the articular disk is especially vulnerable to injury in full pronation. The ulna slides dorsally in the sigmoid notch with full pronation, and the palmar-radial aspect of the articular disk is unsupported by the ulnar head.

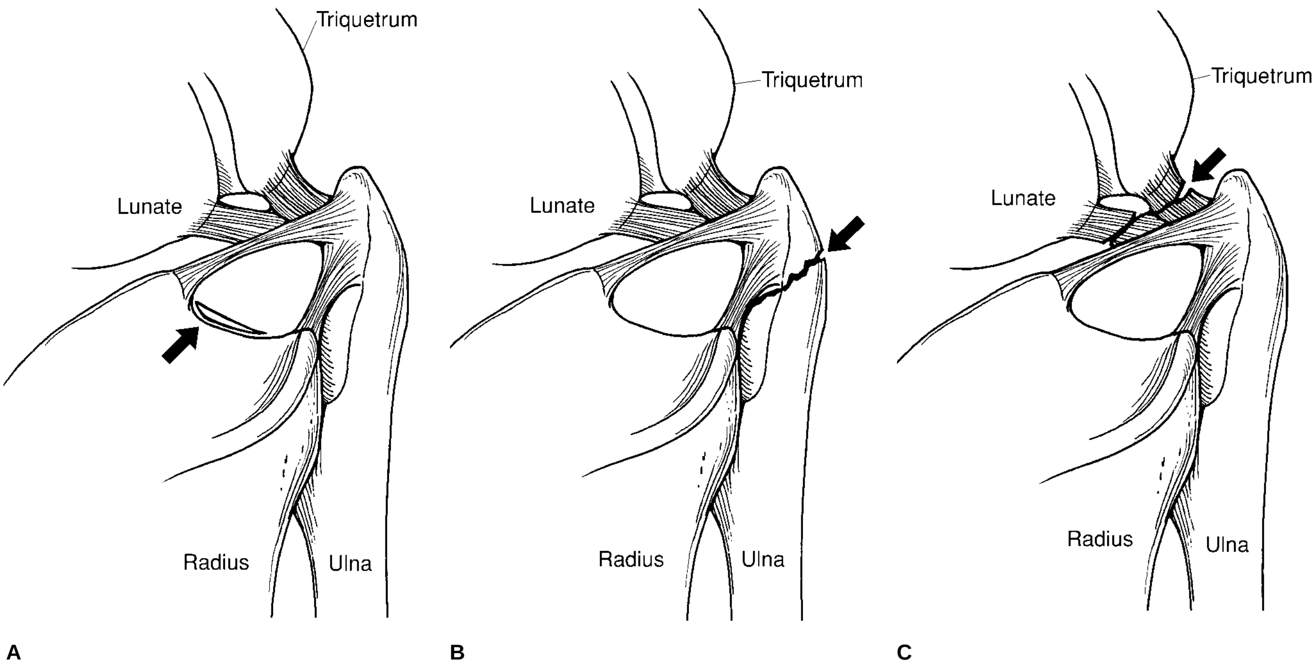
Arthroscopic debridement of these articular disk lesions has become the treatment of choice for many clinicians. The central two thirds of the articular disk can be excised without affecting the stability of the DRUJ as long as the dorsal and palmar radioulnar ligaments are preserved. Osterman[25] reported that 73% of 52 patients had complete resolution of their ulnar wrist pain after arthroscopic debridement of an articular disk tear. Stokes et al[26] reported that of 23 patients who underwent arthroscopic debridement of articular disk tears, 77% remained asymptomatic an average of 21 months after surgery. In my unpublished experience with arthroscopic debridement of articular disk tears, the results have been generally satisfactory in patients with no or negative ulnar variance. However, in patients with positive ulnar variance, debridement alone has yielded poor results, and an ulnar head recession has also been required to avoid persistent postoperative symptoms of impaction.

Peripheral rim tears of the articular disk are less common than central and radial tears and lend themselves to surgical repair because they occur in the vascular portion of the articular disk. Cooney et al[27] achieved good to excellent results in 26 of 33 patients treated with an open repair technique. Arthroscopic suturing techniques have also been used in the TFCC.[28]

Avulsions of the TFCC ulnar attachment are more common than distal or radial TFCC avulsions. These injuries are often associated with DRUJ instability and frank dislocation and will be discussed in the section on dislocations and instability.

Degenerative Problems

Degenerative changes of the TFCC (Palmer's class 2 injuries, or ulnocarpal impaction syndrome) progress through five stages. The first stage involves wear of the central articular disk region, which may



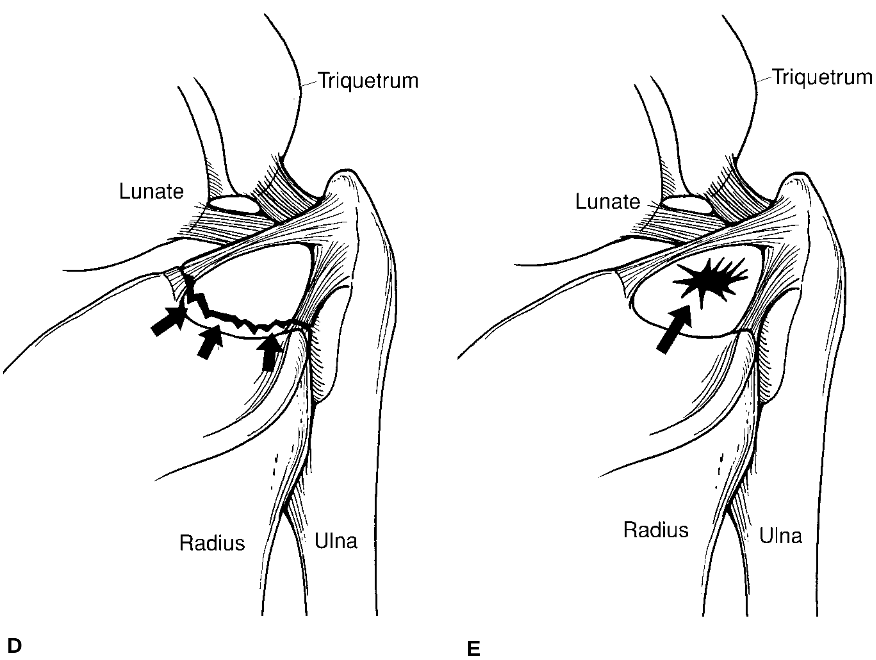


Fig. 6 Diagrammatic representation of the different classes of TFCC injuries, as described by Palmer.[3] **A,** Class 1A central traumatic tear, usually in the sagittal plane 1 to 2 mm from the articular surface of the radius. **B,** Class 1B medial avulsion may or may not be associated with an ulnar styloid fracture. **C,** Class 1C distal avulsions involve disruption of the ulnocarpal ligaments. **D,** Class 1D lateral avulsions involve disruption of the radioulnar-ligament and articular-disk attachments to the radius. This injury may or may not be associated with a sigmoid-notch fracture. **E,** Class 2 degenerative perforations occur centrally.

later be associated with lunate and ulnar head chondromalacia. Ultimately, degeneration leads to perforation of the disk and then perforation of the lunotriquetral ligament. The last stage is associated with ulnocarpal arthritic changes (Fig. 7).

Ulnocarpal impaction syndrome is associated with positive ulnar variance. In persons born with positive ulnar variance, impaction may occur with repetitive overload. The thickness of the central portion of the articular disk has been found to be inversely related to the ulnar variance.[29] Therefore, individuals born with a long ulna have a thinner central articular disk. Positive ulnar variance may also be acquired, as, for example, when a distal radial fracture heals in a shortened position or physeal growth arrest occurs, involving the distal radius with con-

Fig. 7 A PA radiograph of a patient with ulnocarpal impaction syndrome. In this late stage, arthritic changes are present at both the ulnar head and the lunate (arrowheads).

tinued growth of the ulna. Longitudinal instability between the radius and ulna after a radial head resection or radial head fracture (especially related to an Essex-Lopresti injury) can also lead to ulnocarpal impaction syndrome.

The onset of symptoms in patients with ulnocarpal impaction syndrome may be insidious or abrupt (i.e., due directly to a traumatic event). If, for example, positive ulnar variance was acquired secondary to distal radial malunion, the patient may have had persistent symptoms following the initial fracture. Other patients, such as those born with positive ulnar variance, may report a gradual onset of ulnar wrist pain exacerbated by activities, especially repetitive forearm rotation and gripping. Physical examination may reveal tenderness over the TFCC area and the lunotriquetral joint. Having the patient pronate and supinate the forearm with simultaneous clenching of the fist and ulnar deviation of the wrist should exacerbate symptoms. Pain and crepitus produced by compressing the radius and ulna together as the patient supinates and pronates the hand can be useful in helping the clinician distinguish DRUJ articular surface changes. This information is important because if ulnocarpal impaction syndrome is associated with DRUJ surface changes, treatment must address both problems.

Radiographs are essential to characterize ulnar variance and to identify any associated distal radial deformity. Cystic changes in the ulnar head and lunate are evident in later stages. An arthrogram may show perforation of the articular disk and lunotriquetral ligament. In the radiographic examination, as in the physical examination, attention should be directed to the appearance of the DRUJ articular surfaces. The finding of surface incongruities will influence treatment options. Diagnostic arthroscopy has been especially helpful, not only in examining the articular disk of the TFCC and the lunotriquetral ligament, but also in detecting chondromalacic changes in the lunate and ulnar head.

If conservative measures, such as activity modification and the use of anti-inflammatory drugs and splints, fail to resolve the problem and no evidence can be found of DRUJ surface incongruity, surgical treatment should be directed at correcting the disparity between the radial and ulnar lengths. If ulnocarpal impaction is secondary to a radial malunion, corrective osteotomy of the radius may be sufficient to correct the radioulnar length discrepancy (Fig. 8).

For other causes of ulnocarpal impaction, correction of length discrepancy is by means of ulnar shortening. Whether an accompanying TFCC articular disk perforation should also be debrided is unclear. Ulnar shortening may be accomplished by a formal diaphyseal osteotomy and plate fixation, which is a modification of an osteotomy originally described by Milch.[30] Alternatively, a wafer procedure (either open or arthroscopic), as originally described by Feldon et al,[31] may be performed. With the arthroscopic technique, debridement of a TFCC central perforation is followed by burring of the ulnar head through the perforation. The wafer procedure, whether open or arthroscopic, involves resecting only 2 to 3 mm of the distal ulnar head, leaving the styloid process intact. It is recommended in patients with a positive ulnar variance of only 2 to 4 mm. Feldon et al[31] reported good to excellent outcomes in a review of the results in 12 patients.

Some clinicians believe that a formal ulna-shortening osteotomy is advantageous because patients with ulnocarpal impaction have a loose ulnar ligamentous complex, and ulnar shortening tightens those ligaments.[32] No experimental or clinical data have been published to confirm this opinion, however.

When planning a shortening osteotomy, one should pay particular attention to the slope of the DRUJ articular surface. In physeal growth arrest of the distal radius, accommodation to these injuries may be made over time. The DRUJ may be abnormally shaped, but the articular surfaces may be congruent. Shortening of the ulna may result in incongruity of the surfaces and persistent postoperative pain. Also, the sigmoid notch may have a reverse slope in some individuals. Substantial shortening may cause the articular surface of the ulnar head to ride up on the proximal rim of the sigmoid notch, resulting in persistent pain and progression of arthritic changes. Ulnocarpal

A B

Fig. 8 **A,** Preoperative PA **(left)** and lateral **(right)** radiographs of a patient with a distal radial malunion. The patient reported pain primarily on the ulnar side of the wrist secondary to ulnocarpal impaction. **B,** Posteroanterior **(left)** and lateral **(right)** radiographs obtained after the patient underwent an opening-wedge osteotomy of the distal radius and an ulna-shortening osteotomy.

impaction syndrome associated with incongruity of the DRUJ articular surface will be dealt with in the section on arthritis.

Dislocations and Instability

Dislocations, subluxations, and instabilities of the DRUJ have classically been defined on the basis of the direction the ulnar head moves in relation to the radius. By this definition, if the ulnar head is dorsal to the radius, the condition is described as a dorsal DRUJ dislocation, implying that the radius is the stable unit, while the ulna moves in a dorsal or palmar direction. In reality, the ulna is the stationary bone of the forearm, and the radius, wrist, and hand rotate around it. However, the convention of describing dislocations and instabilities on the basis of the direction of the ulnar head has been long established in the literature and will probably remain in use.

Acute Dislocations and Instability

While dislocation of the DRUJ may occur as an isolated injury, more often it is associated with a concomitant forearm fracture. The more common dorsal dislocation occurs with forced hyperpronation. Physical examination reveals limitation of supination with a dorsal prominence of the ulnar head. Palmar dislocation of the ulnar head occurs with forced hypersupination, and pronation is markedly limited, with a dimple in the skin seen dorsally. Because of the overlying soft tissues, the ulnar head may not form an obvious prominence palmarly.

Subluxation and instability are more difficult to diagnose on physical examination than frank dislocation is. Each of the forearm bones must be stabilized in the examiner's hands. The two bones are then "shucked" past each other to determine the amount of dorsal/palmar laxity. There is normally more laxity in neutral forearm rotation than in either supination or pronation. The joint should "tighten up" in full supination and full pronation. Comparison with the opposite side is essential.

Dorsal dislocations are reduced in supination, while palmar dislocations are reduced in pronation. If a congruent reduction can be achieved, immobilization for 6 weeks in a long-arm cast is sufficient for healing. If a congruent reduction cannot be achieved, open reduction is required. Interposed structures, such as the tendon and sheath of the extensor carpi ulnaris, may prevent reduction. Such interposition should be suspected when reduction cannot be accomplished.

Acute DRUJ instability associated with a forearm fracture is more frequent than previously assumed. In a review of forearm injuries, Goldberg et al[33] reported that two or more sites of injury are routine and that the DRUJ is affected in 60% of patients. Complex distal radial fractures may be associated directly with TFCC injury or may render the DRUJ unstable because of an associated fracture of the sigmoid notch, as described by Bowers.[24] Galeazzi fracture-dislocations and their variants may be associated with either palmar or dorsal dislocation. Longitudinal instability may accompany radial-head fractures and disruption of the central portion of the interosseous membrane (Essex-Lopresti injuries).

Anatomic reduction of distal radial fractures and Galeazzi fracture-dislocations may by itself render the DRUJ stable. A review of DRUJ function after Galeazzi fracture-dislocations treated by open reduction and internal fixation showed that with anatomic reduction of the radius, DRUJ function usually returned to normal without the need for direct open repair of the TFCC.[34] However, this result cannot be assumed; after anatomic reduction and fixation of the fracture, DRUJ stability needs to be assessed intraoperatively. This should ideally be done with the arm in the neutral position and in supination and pronation. The forearm can then be positioned postoperatively in its most stable position (usually somewhere between neutral and full supination), so that adequate soft-tissue healing can occur. If the DRUJ is unstable in all forearm positions (after adequate reduction of the radius has been confirmed), reduction can be maintained with a Kirschner wire inserted from the ulna to the radius just proximal to the joint.

In cases of radial head fracture, especially those associated with pain over the DRUJ, every effort should be made to retain the radial head. Geel and Palmer[35] reported good results in 18 of 19 patients treated with open reduction and internal fixation, avoiding radial head excision and the possibility of DRUJ dysfunction.

Chronic Joint Instability

Chronic instability may develop as a residuum of an injury to DRUJ-stabilizing structures or in association with malunion or nonunion of a forearm fracture. In either case, initial assessment should focus on the joint surface of the DRUJ. Incongruity of the joint surface or arthritic changes will influence the treatment plan. Instability associated with arthritic changes or incongruity of the joint will be discussed in the section on arthritis.

Chronic instability without associated forearm bone malunion may be treated by soft-tissue reconstruction. Many techniques have been used, with mixed results.[36,37] Bowers[38] has pointed out the prerequisites and components of the stabilizing structures involved in successful soft-tissue reconstructive efforts. These procedures are contraindicated if arthritic changes, bone malunion, or bone-length discrepancies are present. To fully deal with the problem of instability, the following components should be present: (1) smooth articular surfaces, (2) a flexible rotational tether between the radius and the ulna, (3) suspension of the ulnar carpus to the radius, (4) an ulnocarpal cushion, and (5) an ulnar shaft–ulnar carpus connection. No technique that meets all these requirements has yet been described. In patients with only minor degrees of subluxation, Hermansdorfer and Kleinman[39] have reported success with reattachment of the TFCC to the fovea, even in chronic cases. With associated ulnar styloid nonunion, reduction and fixation of large styloid fragments can be successful. Smaller styloid fragments can be excised, and the TFCC can then be reattached into the cancellous bone defect.

With gross instability, further soft-tissue augmentation is warranted. Bach[40] recently described a technique in which reattachment of the TFCC is augmented with a distally based strip of the extensor carpi ulnaris tendon woven through drill holes in the distal ulna and radius. All 24 patients in his series had objective improvement of their instability, and 23 had subjective improvement. Scheker et al[41] reported improvement in 9 of 14 patients who underwent reconstruction of the dorsal radioulnar ligament with use of a tendon graft woven through drill holes in the radius and ulna. Petersen and Adams[42] studied the biomechanics of numerous reconstructive procedures in a cadaver model and found that procedures that created a tether between the radius and the ulna reestablished stability better than those that created a tether between the distal ulna and the ulnar carpus.

Chronic DRUJ instability may be associated with angulatory or rotational malunion of the forearm bones. Angular deformities are usually obvious on standard radiographs, but axial CT scans of both upper extremities may be required to help define rotational deformities. Attempts at soft-tissue reconstruction alone in the face of an instability that has resulted from a malunion will be doomed to failure. Indeed, a congruent reduction may not even be possible unless a corrective osteotomy is performed.

Chronic Instability After Resectional Arthroplasty

Chronic instability of the distal ulnar shaft after DRUJ resectional arthroplasty is among the most difficult DRUJ problems to solve. Instability of the distal ulnar shaft has most commonly been associated with the Darrach procedure, but it has also occurred after hemiresectional arthroplasty and the Sauvé-Kapandji procedure (Fig. 9). Breen and Jupiter[43] have reported some success in resolving the instability by creating a tenodesis with a distally based slip of the extensor carpi ulnaris and flexor carpi ulnaris woven through the distal ulnar shaft.

In our institution, we have had limited success with a modification of the pronator quadratus advancement described by Johnson[44] and reported by Ruby et al.[45] The pronator quadratus is pulled up into the defect left by the ulnar head and sutured through a drill hole to the distal ulnar shaft. Kapandji[46] has reported using this technique as a supplement to the Sauvé-Kapandji procedure. Pulling the pronator quadratus into the gap of the resected ulnar shaft may prevent bone bridging across the pseudarthrosis.

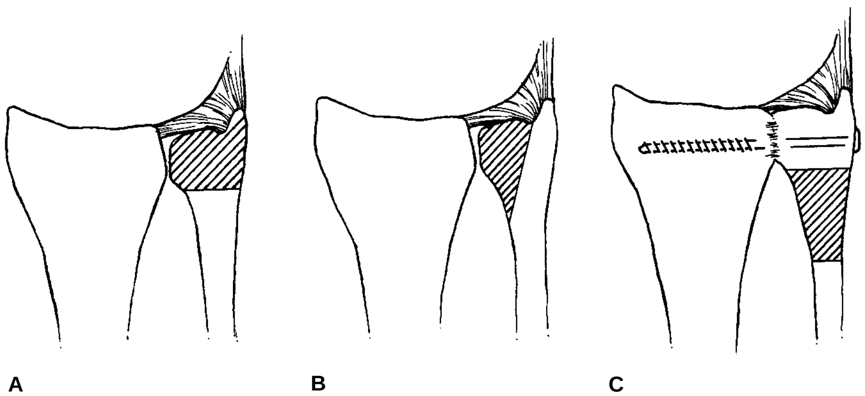


Fig. 9 Techniques for treatment of the arthritic DRUJ. The cross-hatched area represents the bone resected in each procedure. **A,** Darrach excisional arthroplasty. **B,** Hemiresection-interposition technique. **C,** Sauvé-Kapandji procedure.

No way of resolving the problem of chronic proximal / distal instability secondary to an Essex-Lopresti injury is currently known. Patients with this condition often undergo multiple procedures without resolution of the persistent instability between the radius and the ulna. The creation of a one-bone forearm is a viable salvage procedure. Union between the radius and the ulna may be difficult to achieve; experience at our institution has shown that a formal transposition of the radius to the ulna with plate fixation is an effective solution to the problem.

Arthritis

Patients with rheumatoid arthritis frequently have DRUJ involvement early in the course of the disease. Osteoarthritis and posttraumatic arthritis may also involve the DRUJ. Less commonly, gout and pseudogout involve the joint.

One hallmark of articular surface involvement of the DRUJ is pain associated with forearm rotation. The pain becomes more severe if the examiner exerts a compressive force across the DRUJ by squeezing the radius and ulna together. Evaluation of associated instability of the DRUJ is important during the examination. Treatment options are altered by associated instability. Destruction of the joint surfaces is usually evident on standard radiographs.

Resectional Arthroplasty Techniques

Several techniques for resectional arthroplasty of the arthritic DRUJ have been described. In the Darrach procedure (Fig. 9, A), the ulnar head is totally excised, although the ulnar styloid may be left intact. Stability of the distal ulnar shaft has been unpredictable following this procedure, especially in younger patients with posttraumatic arthritis or osteoarthritis of the DRUJ. Modifications of the Darrach procedure have included variations in the amount of bone resected, the addition of soft-tissue reconstruction to enhance stability, and the use of silicone capping of the remaining ulnar stump. Silicone capping has been largely abandoned due to concerns about silicone-induced synovitis, persistent instability, and cap fracture.

In a review of factors influencing the results of the Darrach procedure, Dingman[47] found that the most important prognostic factor was the amount of bone resected. According to his review, better results were achieved when very little bone was removed or when substantial bone regenerated between the ulnar shaft and the styloid. In a recent study of 33 patients who underwent the Darrach procedure, Tulipan et al[48] reported good or excellent results at an average follow-up of 4 years in the 30 patients (91%) in whom the procedure had been modified to involve minimal bone resection and associated soft-tissue reconstruction.

In 1985, Bowers[49] reported the use of a hemiresection-interposition technique (Fig. 9, B) on 38 patients, 27 of whom had rheumatoid arthritis. In 1986, Watson et al[50] described a similar “matched resection” of the distal ulna in 44 patients, 34 of whom had rheumatoid disease. When the cases of other authors are added, the total number of reported cases comes to 152. In these cases, 42% of the patients had rheumatoid arthritis; 29%, joint instability; 21%, ulnocarpal impingement; 5%, osteoarthritis; and 3%, various other traumatic problems. After hemiresectional arthroplasty, 76% were pain-free. The remaining 24% reported mild pain but described it as less severe than the pain they had experienced preoperatively. No patient had a poor postoperative result. Of the patients who had mild postoperative pain after a hemiresectional arthroplasty, 2% had pain that was secondary to persistent stylocarpal impingement, which was corrected by a secondary shortening osteotomy. Of the patients who did not have preoperative instability, none had postoperative distal ulnar instability. In the patients who did have preoperative instability, hemiresectional arthroplasty resulted in less painful instability.

In patients with rheumatoid arthritis, hemiresectional arthroplasty has value in the early stages of the disease, when the TFCC is still reconstructible.

Patients with late disease usually have radiocarpal translocation in addition to DRUJ involvement; they are better treated with a radiolunate arthrodesis combined with either a Darrach procedure or a Sauvé-Kapandji procedure (described below). A contraindication to the hemiresection-interposition technique is the presence of an incompetent or nonreconstructible TFCC. The stability of the ulnocarpal axis is dependent on this complex. Most of the cases in which the TFCC is not reconstructible occur in patients with late rheumatoid arthritis.

Sauvé-Kapandji Procedure

An alternative to resectional arthroplasty for patients with an arthritic DRUJ is the Sauvé-Kapandji procedure (Fig. 9, C). In this operation, the DRUJ is fused, and a pseudarthrosis is created just proximal to the DRUJ by resecting part of the ulnar shaft. Sanders et al[51] reported that all 10 of their patients who underwent the procedure had excellent or good postoperative outcomes. Nine of the patients had a diagnosis of posttraumatic arthritis. Vincent et al[52] achieved good results in 21 wrists in 17 patients with rheumatoid arthritis. They suggested that the surgery may prevent ulnar and palmar translocation of the carpus by providing a stable ulnar-sided support.

Other Disorders

Involvement of the DRUJ is always found in Madelung's deformity, which is characterized by palmar subluxation of the hand, a long distal ulna, and ulnar / palmar angulation of the distal radius. The condition can usually be treated conservatively, without operative intervention. When surgery is required, one can choose from a number of procedures,[53,54] among them corrective osteotomy of the distal radius combined with ulnar shortening and / or angular osteotomy, epiphysiodesis of the distal ulna, the Darrach procedure, and the Sauvé-Kapandji procedure. No comparative studies have been published to show whether one procedure is superior to another, however. Results have, in general, been satisfactory.

Acute disruption of the tendon sheath of the extensor carpi ulnaris occurs when the forearm is supinated while the wrist is held forcibly in ulnar deviation. An external force pushes the wrist radially, with resultant tearing of the sheath. The tendon typically reduces back into the groove, and manipulation is required to subluxate the tendon and confirm the diagnosis. Inspection will reveal that during supination and ulnar deviation against resistance, the unstable extensor carpi ulnaris pops out of its tunnel. Acute disruption of the tendon sheath can be treated by casting the forearm in full pronation with the wrist slightly extended and radially deviated. Six weeks of immobilization is required for healing. Successful treatment of chronic instability can be achieved by surgical reconstruction of the sheath.[55]

Contractures of the DRUJ without associated bone deformities or arthritic changes may follow direct trauma to the joint, often with an associated distal radial fracture. They may also result from prolonged immobilization for other problems. More common are pronation contractures in which supination is limited or nonexistent. Dynamic splinting and serial casting are often successful in correcting the condition. Surgical release of the joint for pronation contractures may be done through a palmar approach in which the capsule is resected.[38] The distal radioulnar ligaments must be preserved.

Hereditary multiple exostosis can involve the DRUJ. In a review of 50 patients with hereditary multiple exostosis, Wood et al[56] found that 30 had significant involvement of the upper extremity; the degree of involvement depended on the location of the osteochondromas. Osteochondromas on the radius caused minimal deformity, while those on the distal end of the ulna usually caused physeal growth arrest. In this situation, the TFCC acted as a tether as the radius continued to grow, resulting in deformity of the radius and / or dislocation of the radial head at the elbow. In 10 patients in the series of Wood et al,[56] corrective surgery had good results. The procedure consisted of sectioning of the TFCC tether, lengthening of the ulna, a corrective osteotomy and epiphysiodesis of the radius, and removal of the offending osteochondroma.

Summary

Problems with the DRUJ are a major source of ulnar-sided wrist pain. As our understanding of the anatomy and kinematics of this joint has progressed, so has our ability to diagnose specific problems and prescribe successful treatment. Expanding the differential diagnosis to include pathologic conditions in the entire forearm gives one a more extensive understanding of the processes involved. A systematic approach to the history and physical examination is strengthened by mentally working through a complete differential diagnosis. If conservative measures fail in patients whose conditions have been correctly diagnosed, a number of operative techniques are available that can lead to a successful outcome.

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