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REVIEW ARTICLE

Imaging evaluation of traumatic carpal instability

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Abstract

Purpose To review the epidemiology, pertinent wrist anatomy, classification system, and emergent imaging evaluation of carpal instability with a focus on radiographic assessment of instability.

Methods A review of current literature on carpal instability was performed with summary presentation of carpal instability epidemiology, carpal anatomy, imaging evaluation, and classification with imaging evaluation focused on diagnosis in the emergency setting.

Results Carpal instability is a common pathology in falls on outstretched hand and is likely underdiagnosed due to instability being occult or demonstrating subtle malalignment on static imaging of the wrist. While there is a complex network of intrinsic and extrinsic ligaments contributing to carpal instability, a detailed knowledge of these ligaments is not necessary for radiologists to make an accurate diagnosis in the emergency setting, as identification and classification of carpal instability is based on identification of carpal malalignment patterns on radiography as opposed to identification of specific ligament injuries on advanced imaging. The Mayo classification is the most widely used classification system, which divides carpal instability into four categories: dissociative, non-dissociative, complex, and adaptive. Understanding this classification system allows radiologists to successfully classify almost all carpal instability injuries they will encounter, even in the setting of unusual or rare instability patterns.

Conclusion In working with the treating clinician, it is essential that the emergency radiologist is comfortable with identifying and classifying carpal instability. This will ensure prompt treatment of seemingly benign injuries and those that require intervention, surgical or otherwise, improving the likelihood of a good outcome.

Keywords Wrist · Carpal · Instability · Trauma · Musculoskeletal

Introduction

The wrist is a unique conglomeration of joints working together to produce a wide arc of motion in multiple planes. In order to provide this wide range of mobility, the wrist must have minimal constraint, or impediment, of motion from the bony articulations of the carpal bones. Bony constraint of a joint is related to the proportion of stability of a joint provided by the bony anatomy [1]; therefore, the more mobile a joint, the more the joint must rely on soft tissue structures to provide joint stability. This is certainly true for the wrist, where a large majority of carpal stability is provided by the intrinsic and extrinsic carpal ligaments [2]. Stretching or tearing of these carpal ligaments can result in carpal instability, which can result in significant morbidity due to pain and diminished function [3].

Carpal instability is probably much more common than clinicians realize. Fall on outstretched hand (FOOSH) is among the most common causes of carpal instability with a reported incidence of carpal instability after FOOSH of 22–44% [4–6]. In a study of FOOSH patients with carpal instability by O-Brien et al., 24% had scapholunate instability, 24% had lunotriquetral instability, 14% had midcarpal instability, and 28% had two or more instabilities [4]. In addition to FOOSH, other potential causes of carpal instability include sports related injuries, motor vehicle accidents, and repetitive

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overuse activities [4, 6, 7]. Carpal ligament injuries are also commonly found in conjunction with other wrist injuries, such as scaphoid waist and distal radius fractures [8, 9], and can be easily missed due to the presence of these distracting injuries.

The true incidence of carpal instability is difficult to determine as carpal instability is frequently missed on both clinical exam and imaging. Perilunate instability patterns have been reported to be missed in up to 25% of cases [10]. It is easy to understand how carpal instability can be missed as the clinical findings can be nonspecific and the imaging diagnosis often relies on recognizing malalignment of the carpal bones, which can be difficult to judge due to inappropriate positioning of radiographs and/or lack of experience in diagnosing carpal instability by the interpreting radiologist. Furthermore, the terminology for carpal instability is often confusing with most of the literature focused on specific components of carpal instability and not offering a global perspective on carpal instability that could be applied to a radiology practice.

Delays in diagnosis of carpal instability can result in chronic pain, decreased grip strength, and mobility [11]. Therefore, it is imperative that physicians working in emergency centers are aware of the fundamental patterns of carpal instability and the imaging approach to diagnosing these difficult injuries in order to make a timely diagnosis. This paper aims to educate readers as to the imaging approach and imaging criteria used to identify carpal instability with emphasis on radiographic imaging. We also describe the most commonly used classification of carpal instability, the Mayo classification, in a clear and concise method that can be applied by clinicians in an emergency setting, even if they do not routinely encounter wrist trauma in their practice.

Anatomy

The carpal bones can be considered as existing in two rows: the proximal carpal row (scaphoid, lunate, triquetrum, and pisiform) and the distal carpal row (trapezium, trapezoid, capitate, and hamate) with the scaphoid serving as a bridge between the proximal and distal rows. The proximal carpal row can further be considered as an "intercalated segment," meaning the proximal carpal row serves as a link between the radius/ulna and distal carpal row onto which no tendons directly attach [12]. Since no tendons directly insert on the proximal carpal row, the proximal row functions as a chain bridging the forces exerted on the proximal, ulnar side of the wrist at the radioulnar joint with the forces exerted on the distal, radial side of the wrist at the distal carpal row. This chain consists of three osseous and three ligament "links": the triquetrum, lunotriquetral ligament, lunate, scapholunate ligament, scaphoid, and scaphotrapeziotrapezoid ligament. Disruption of any of these links can result in instability of the proximal carpal row, which often presents as changes in carpal bone alignment on imaging.

Ligaments of the wrist can be broadly separated into two groups: the intrinsic carpal ligaments, which connect the carpal bones to each other, and the extrinsic ligaments, which connect the carpal bones to the metacarpals and distal radius/ulna. There are many intrinsic and extrinsic carpal ligaments; however, a few ligaments have been identified to serve primary roles in maintaining carpal stability. By far the two most important intrinsic ligaments for carpal stability are the scapholunate and lunotriquetral ligaments (Fig. 1) [2]. The scapholunate ligament connects the scaphoid and lunate bones, and it has dorsal, volar, and interosseus aspects. The dorsal component is the most robust component of the ligament and is the most important for carpal stability [13]. Like the scapholunate ligament, the lunotriquetral ligament has three components with the dorsal component being the most robust and important for carpal stability [13]. While not as frequently discussed, the scaphotrapeziotrapezoid ligament (Fig. 1) is another intrinsic ligament worth mentioning as it serves as a bridge between the scaphoid and the distal carpal row, and injuries to the scaphotrapeziotrapezoid ligament have been linked to intercalated carpal instability [14].

Several additional ligaments have been identified as playing a significant role in carpal stability (Fig. 2). The dorsal radiotriquetral (a.k.a the radiolunotriquetral or long radiolunate) ligament is probably the most important extrinsic ligament for scapholunate stability. The dorsal radiotriquetral ligament contributes significantly to lunotriquetral stability, and injuries to this ligament can result in volar intercalated segmental instability (VISI)-type carpal instability, which is a type of carpal instability resulting in abnormal volar tilt of the lunate, even in the absence of other ligament injuries [15, 16]. The dorsal intercarpal ligaments (triquetroscaphoidal and triquetro-trapezoido-trapezial ligaments) and the volar arcuate (scaphocapitate and triquetrohamocapitate) ligaments are the

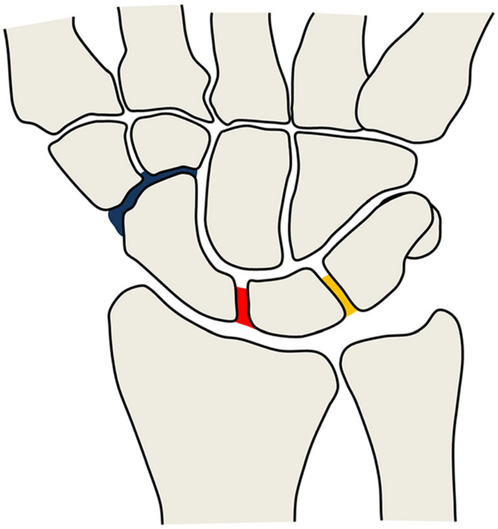

Fig. 1 Major intrinsic carpal ligaments: scapholunate (red), lunotriquetral (yellow), and scaphotrapeziotrapezoid (blue) ligaments

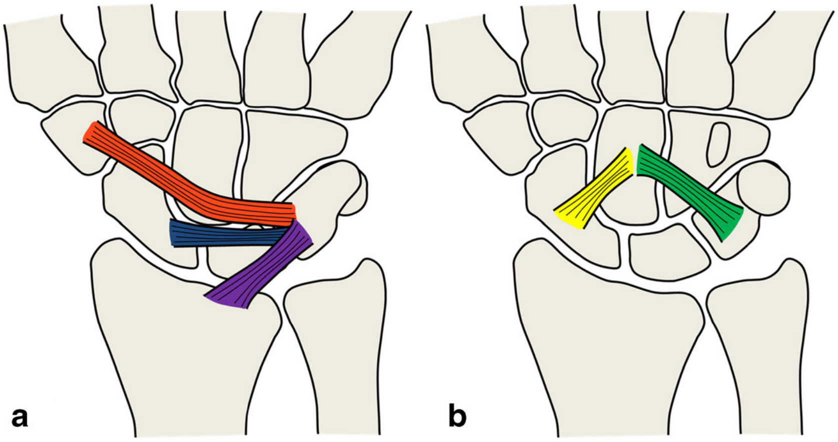

Fig. 2 Additional primary carpal stabilizing ligaments. **a** Dorsal ligaments: radiotriquetral (purple), triquetroscaphoid (blue), and triquetro-trapezoid-trapezial (orange). **b** Volar ligaments: scaphocapitate (yellow), triquetrohamocapitate (green)

major ligaments preventing instability between the proximal and distal carpal rows (i.e., midcarpal instability) [17, 18].

Some forms of carpal instability can occur with tearing of a single ligament. However, most carpal instability occurs as the result of multiple ligament disruptions, and multiple different ligament disruption patterns may produce the same type of carpal instability [19, 20]. Fortunately for radiologists, while the integrity of the previously described intrinsic and extrinsic carpal ligaments may be relevant for surgical repair, the role of the radiologist is not to predict which ligaments are injured but rather to recognize and report the instability pattern which can direct patient management.

Imaging

Radiograph assessment

A standard radiograph series of the wrist is comprised of PA, lateral, and oblique views. These three views are usually adequate for identifying most clinically significant wrist fractures, but they can have low sensitivity for identifying carpal instability [21]. To help identify carpal instability, additional stress views of the wrist can be obtained. Two commonly obtained stress views are the clenched fist and the PA radial/ulnar deviated views. In the clenched fist view, the patient clenches their fist, while a PA or AP image is obtained. If there is instability, the capitate will move proximally towards the lunate with concomitant widening of the scapholunate interval. In the PA radial and ulnar deviation views, PA views of the wrist are performed during both radial and ulnar deviation. The ulnar deviated view highlights injuries to the scapholunate ligament, while the radial deviated view highlights injuries to the lunotriquetral ligament. There is significant variability between patients, but in general, a scapholunate interval of greater than 4 mm is considered indicative of scapholunate ligament disruption [22, 23]. A normal lunotriquetral distance is less well defined [24]. Because there is significant variability in normal scapholunate and lunotriquetral distances between patients, obtaining stress views of the contralateral uninjured wrist can be helpful for comparison. Less commonly used stress radiographs are lateral views of the wrist in flexion and extension. The lateral flexion/extension views allow for detection of dynamic and static scapholunate instability [25]. During flexion, if the lunate does not touch the 0 degree line during flexion, it is likely that dynamic scapholunate instability is present [25]. If it remains extended during flexion, then there is static scapholunate instability [25].

The carpal bones can be considered to consist of two groups of arcs on a PA view. The first group of arcs is called the arcs of Gilula (Fig. 3a), which is composed of a set of three arcs that delineate the normal boundaries of the proximal and distal carpal rows. Normally, these arcs exhibit a smooth contour, and an abrupt contour change of any of these arcs is suggestive of carpal malalignment. The other set of arcs is the greater and lesser arcs of the wrist (Fig. 3b). The greater and lesser arcs are the arcs of ligaments and bone surrounding the lunate [26]. These arcs represent a zone of vulnerability of the wrist where a vast majority of carpal injuries occur [26]. The lesser arc is composed of the ligaments immediately surrounding the lunate. The greater arc is composed of bony structures that surround the lunate: the radial styloid, scaphoid, capitate, triquetrum, and ulnar styloid. Disruption of one or both of these arcs is seen in perilunate instability patterns.

Two angles are commonly assessed on lateral radiographs to identify carpal instability. The lunocapitate angle is created by a line drawn along the long axis of the capitate and a line drawn through the midpoint of the proximal and distal surfaces of the lunate (Fig. 4a). A normal lunocapitate angle is between 0 and 30° [27]. The scapholunate angle is created by a line drawn along the long axis of the scaphoid and a line drawn through the midpoint of the proximal and distal surfaces of the lunate (Fig. 4b). A normal scapholunate angle is between 30 and 60° [28]. Abnormal scapholunate and lunocapitate measurements are suggestive of carpal

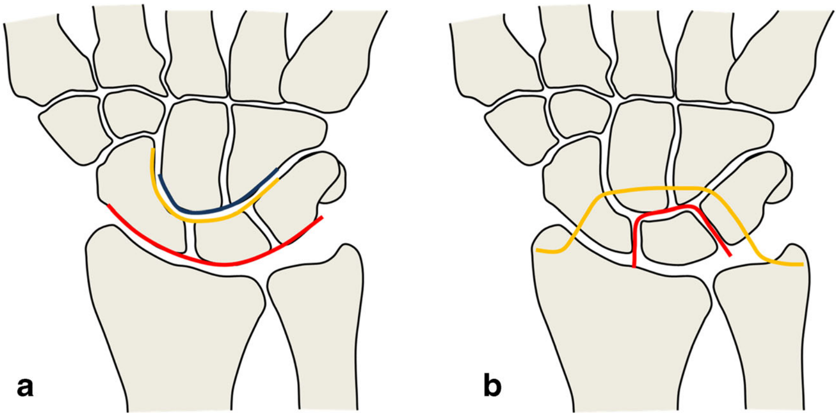

Fig. 3 **a** Arcs of Gilula. Smooth curved lines can be drawn along the proximal (arc I, red) and distal (arc II, orange) aspect of the proximal carpal row as well as along the proximal aspect of the distal carpal row (arc III, blue). **b** Greater arc (yellow) and Lesser arc (red) of the wrist

instability. Another useful geographic assessment on a lateral radiograph is the radio-luno-capitate alignment. A line drawn through the center of the radius articular surface along the long axis of the radius should pass through the mid portion of lunate and capitate (Fig. 4c). Displacement of the lunate or capitate away from this line is another sign of carpal instability. It is important to note that assessment of alignment on a lateral radiograph relies heavily on a true lateral radiograph being obtained. In the absence of a true lateral projection, care should be exercised in diagnosing carpal malalignment on the lateral radiograph.

CT and MRI assessment

Dynamic and static radiographs are the primary method for identifying carpal instability, and a large majority of carpal instability injuries are managed without advanced imaging. However, CT or MRI can be utilized to ensure greater diagnostic accuracy and to detect occult ligament tears and fractures. CT is useful to identify occult fractures and completely characterizing fracture patterns in complex fracture–dislocations. According to a 2007 study, plain radiographs were found to have 69.7% sensitivity for detecting carpal fractures, while CT was found to have 100% sensitivity when using clinical assessment including radiographs, CT, and physical exam as the reference standard [29]. CT should be performed from the level of the distal radial metaphysis through the level of the proximal metacarpal shafts with triplanar reformats in both soft tissue and bone kernels. In general, a reformatted slice thickness of 2 mm is adequate for identifying fractures. Three-dimensional volume rendered reformats can be helpful for identifying carpal instability patterns, but have poor sensitivity for identifying fractures compared with standard two-dimensional imaging. MRI can be used to directly visualize ligament tears, and MR arthrography is particularly useful for assessing suspected tears of the scapholunate (Fig. 5a, b) or lunotriquetral (Fig. 5c, d) ligaments [30].

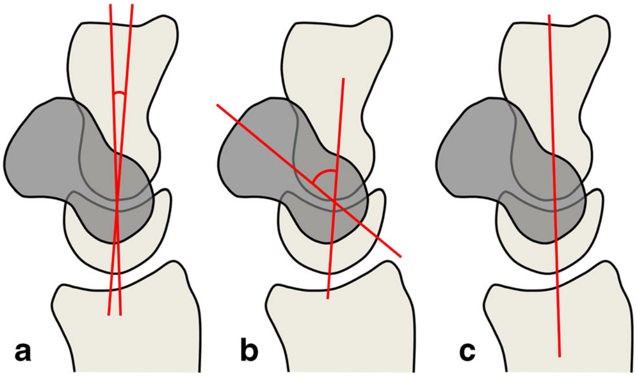

Fig. 4 Lateral wrist alignment. **a** Lunocapitate angle. **b** Scapholunate angle. **c** Radio-luno-capitate axis

Carpal instability patterns

Static and dynamic instability

One particularly useful way of considering carpal instability is in terms of static versus dynamic instability. Static instability refers to abnormal alignment of the carpal bones that is present on standard, non-stress wrist imaging. Dynamic instability is carpal malalignment that either only occurs during stressed imaging or worsens during stress imaging. Differentiating between static and dynamic instability can have treatment implications [31]. Static instability may require a more invasive approach such as surgery to correct the malalignment, while dynamic instability may only require a splint or cast. Although, from a radiologist standpoint, dynamic instability is most important to be aware of because standard, non-stress imaging will miss some cases of dynamic carpal instability injuries. At our institution, we routinely preform a PA ulnar deviated view to help identify dynamic instability of the scapholunate ligament, which is the most common traumatic ligament injury in the wrist. We do not routinely perform other stress imaging in the setting of wrist trauma; however, stress imaging is routinely performed by our orthopedic surgeons in trauma patients with persistent wrist pain or evidence of carpal instability and normal static wrist radiographs.

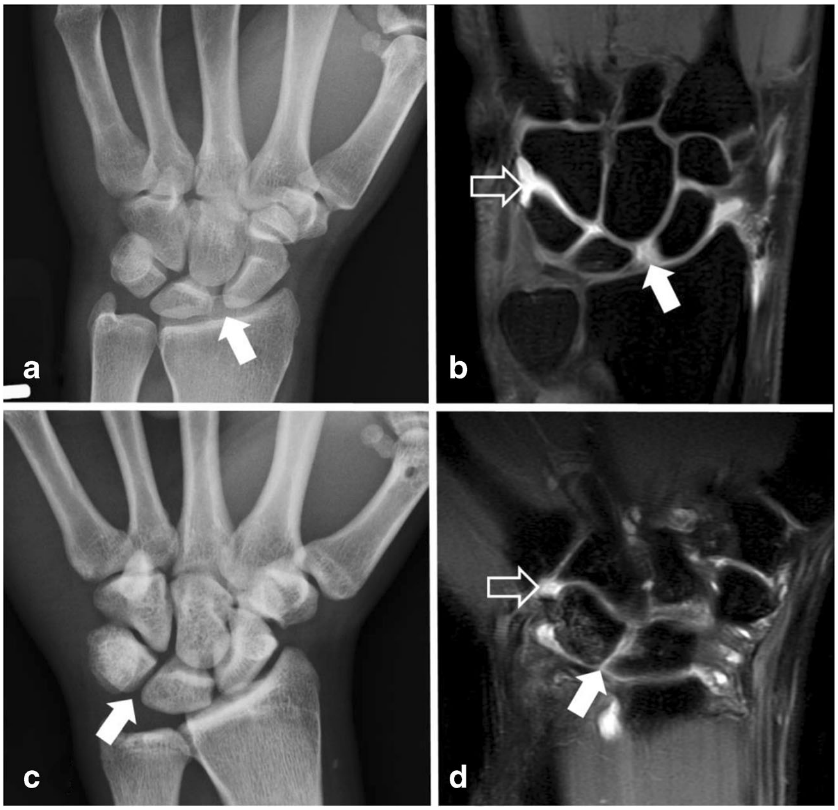

Fig. 5 Intrinsic carpal ligament injuries on MRI. **a** PA wrist radiograph shows normal alignment of scapholunate interval (arrow). **b** MR arthrography of the same patient as in figure **A** shows high signal in the scapholunate interval (solid arrow) with contrast in the midcarpal joint (silhouette arrow), consistent with full-thickness scapholunate ligament tear. **c** PA wrist radiograph shows normal alignment of the lunotriquetral interval (arrow). **d** MR arthrography of the same patient as in figure C shows high signal in the lunotriquetral interval (solid arrow) with contrast in the midcarpal joint (silhouette arrow), consistent with full-thickness lunotriquetral ligament tear

Mayo classification

There are some carpal instability patterns that are known to most radiologists. Perilunate and lunate dislocations along with volar intercalated segmental instability (VISI) and dorsal intercalated segmental instability (DISI) are described in many radiology review books due to their relatively easy to recognize (and test) imaging characteristics. However, these carpal instabilities represent just portions of larger instability patterns. Just being familiar with these few types of carpal instability can cause confusion and misdiagnosis when radiologists are confronted with instability patterns outside these well-known instability types.

One of the most commonly used classification systems for carpal instability is the Mayo classification [32]. The foundations of the Mayo classification date back to 1972 when the concepts of DISI and VISI were first introduced [28]. Over time, the Mayo classification has matured into a more comprehensive system for describing carpal instability. In the Mayo classification, carpal instability can be placed in four broad categories: carpal instability dissociative, carpal instability non-dissociative, carpal instability complex, and carpal instability adaptive. The titles of these categories sound complex and intimidating, but the concepts underlying the categories are simple. Understanding these simple concepts allows radiologists to classify a wide range of carpal instability patterns without requiring much memorization.

CID

Carpal instability dissociative is carpal instability that occurs between carpal bones within the same carpal row. This is the most common category of carpal instability and can be subcategorized based on whether the instability involves the proximal or distal carpal row. Most commonly, this injury pattern occurs when the wrist is in an extended position [33].

Proximal row CID

Proximal row carpal instability dissociative (CID) can be caused by a wide range of injuries, including scapholunate ligament rupture, scaphoid fracture, lunotriquetral ligament rupture, and inflammatory/crystalline arthritis. We will focus on the two most common traumatic ligament etiologies of proximal CID: scapholunate and lunotriquetral ligament disruption.

Scapholunate injuries are the most common type of proximal row CID [34]. They may occur as isolated injuries or as part of a perilunate instability pattern, which will be discussed later. There are three stages of severity [35]. In the first stage, there is an incomplete tear of the scapholunate ligament, which can be categorized as "occult" scapholunate instability. The alignment of the proximal row may be normal on both standard and stress views. An MRI or MR arthrogram may be necessary for diagnosis. In the second stage, there is a full tear of the ligament with secondary stabilizer intact. This typically produces dynamic scapholunate instability where the standard views are normal but the scapholunate interval widens on stress imaging. In the third stage of injury, there is a complete tear of the scapholunate ligament along with injury to the secondary stabilizers. This results in static scapholunate instability, which can be seen on standard radiographs. This final stage of injury represents dorsal intercalated segmental instability (DISI). In DISI, the scaphoid rotates volar, while the lunate rotates dorsal.

On PA radiographs, DISI due to scapholunate ligament injury (Fig. 6a) can be recognized by widening of the scapholunate interval, disruption of Gilula's arcs I and II, and the "signet-ring" sign (a circle of cortical bone overlying the scaphoid representing the scaphoid waist seen en face due to increased tilt of the scaphoid) [36]. On lateral radiographs, DISI appears as an increase in the scapholunate angle (> 60–70°) [37] and increase in the lunocapitate angle to > 30° (Fig. 6b) [38].

Over time, chronic scapholunate instability can progress to scapholunate advanced collapse (SLAC). In a SLAC wrist, the capitate migrates proximally into the gap between the scaphoid and lunate. This migration can progress to the point the capitate forms an articulation with the radius. The severity of SLAC wrist instability is graded based on the extent of secondary osteoarthrosis that has occurred as a result of carpal malalignment [39]. The osteoarthritis initially affects the radial-styloid part of the radioscaphoid joint (SLAC I), progressing to the whole of the radioscaphoid joint (SLAC II), the scaphocapitate, and/or lunocapitate joints (SLAC III), and finally, the entirety of the carpus (SLAC IV) [39]. Carpal instability arising from nonunion of a scaphoid fracture can undergo similar proximal migration of the capitate with secondary osteoarthrosis of the wrist. This similar process has been termed scaphoid nonunion advanced collapse (SNAC).

Lunotriquetral ligament injuries can occur in isolation or as part of a perilunate instability pattern. However, unlike scapholunate injuries, traumatic isolated lunotriquetral ligament ruptures are rare. Also, unlike scapholunate injuries, isolated lunotriquetral ligament injuries are often difficult to diagnosis on PA radiographs as the secondary stabilizers of the lunotriquetral joint hold the lunate and triquetrum in close proximity. Therefore, stress views can be helpful in identifying occult lunotriquetral ligament injuries. On PA radiographs, lunotriquetral instability can present as subtle disruptions of Gilula's arcs I and II, proximal migration of the triquetrum, and/or overlap of the lunate and triquetrum.

In more severe injuries of the lunotriquetral interval where the lunotriquetral ligament tears in conjunction with the secondary support ligaments, a volar intercalated segmental instability (VISI) pattern can be seen on static radiographs. In VISI, the lunate may have a triangular shape (Fig. 7a), instead of the normal trapezoidal shape on a PA radiograph. On a lateral radiograph, the lunate will rotation into flexion, the capitate will rotate into extension, which will result in an increase in the lunocapitate angle to >30° and a decrease in the scapholunate angle to < 30° (Fig. 7b).

Distal row CID

Distal row carpal instability dissociative patterns are much less common than proximal carpal row injuries. These injuries are usually the result of high energy trauma such as blast injuries or motor vehicle collisions [40, 41]. There are two types of distal carpal row CID: radial side dissociation (Fig. 8a) and ulnar side dissociation (Fig. 8b). In both types, there is an axial detachment of the carpus in a longitudinal manner. This results in two columns being created. One column is stable, meaning it remains attached to the proximal carpal row, and the other column is separated from the proximal carpal row. In radial side distal row CID, the distal carpal row on the radial side of the wrist is separated from the proximal carpal row and the converse is true for ulnar side distal row CID. Very rarely, both columns can become separated from the proximal carpal row in what is termed a combined distal row CID. These injuries can be further described based on the bones involved with the prefixes of "trans-" used if a fracture has occurred through the separated bone and "peri-" used if a fracture has not occurred.

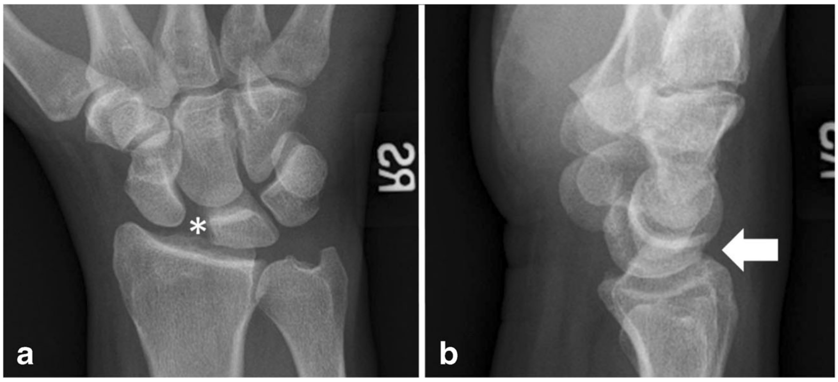

Fig. 6 DISI due to scapholunate ligament rupture. **a** PA radiograph showing widening of the scapholunate interval (asterisk) with disruption of Gilula's arcs I and II. **b** Lateral radiograph showing dorsal tilt of the lunate (arrow) with increase the scapholunate and lunocapitate angles

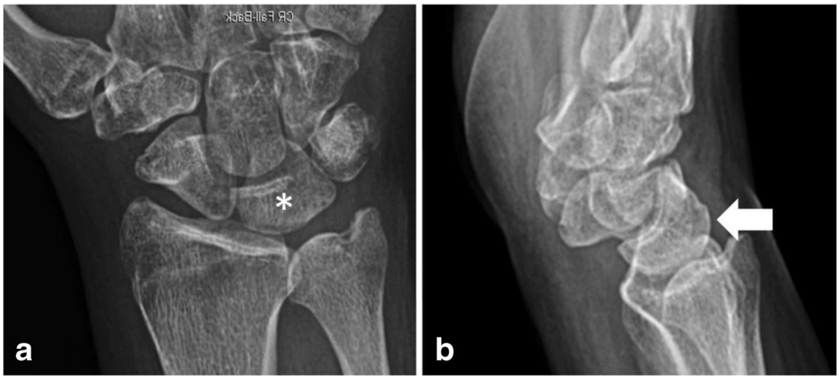

Fig. 7 VISI due to lunotriquetral ligament rupture. **a** PA radiograph shows tilt of the lunate creating a triangular shape (asterisk) with disruption of Gilula's arcs I and II. **b** Lateral radiograph showing volar tilt of the lunate (arrow) with decrease in the scapholunate angle and increase in lunocapitate angle

CIND

Carpal instability non-dissociative (CIND) is carpal instability occurring between the radius/ulna and proximal carpal row or between the proximal and distal carpal rows. These injury patterns are usually the result of damage to the extrinsic carpal ligaments, which can be due to trauma, inflammatory arthropathy, and congenital deficiency (e.g., Madelung deformity). CIND is typically subcategorized as either radiocarpal or midcarpal depending on whether the instability occurs between the radius and proximal carpal row or between the proximal and distal carpal rows, respectively.

Radiocarpal CIND can be further subdivided based on the direction of carpal displacement. Radiocarpal CIND that occurs in the ulnar direction is described as *ulnar translocation* and is most commonly seen in advanced rheumatoid arthritis, trauma, or Madelung deformities. Ulnar translocation can be further divided into type I injuries in which the entire carpus is displaced in the ulnar direction or type II injuries where a portion of the carpus remains linked to the radius (Fig. 9a) [42]. Radiocarpal CIND occurring in the radial direction is *radial translocation* and can also be seen in advanced rheumatoid arthritis or trauma, but is less common than ulnar translocation. Radiocarpal CIND also encompasses *radiocarpal dislocation* (Fig. 9b), which is a rare result of high-energy wrist trauma.

Midcarpal CIND is a complex and confusing pattern of carpal instability. While midcarpal CIND always involves instability between the proximal and distal carpal rows, there is often a component of radiocarpal instability as well. Midcarpal instabilities can be subcategorized as palmar, dorsal, combined, and extrinsic instability patterns. Midcarpal instability can be challenging to diagnose on radiographs because the instability patterns may be occult on static imaging, and when present, midcarpal injuries can exhibit imaging characteristics similar to VISI and DISI injury patterns. Palmar CIND can be detected radiographically by observing a palmarly tilted lunate [43]. Plain radiography is usually inadequate for the diagnosis of dorsal CIND, but dorsal CIND can be identified by dorsal capitate displacement during stress testing under fluoroscopy [43]. For combined CIND, an increased radial inclination of the distal radius and increased ulnaminus variance may be seen on plain radiographs; however, fluoroscopy is the most reliable method of diagnosis [43]. For comparison purposes, bilateral radiographs must be taken due to the ligamentous laxity of female teenagers, the population that most often presents with this injury pattern [43].

CIC

In carpal instability complex (CIC), there are combined disruptions of the intrinsic and extrinsic ligaments, resulting in

Fig. 8 Distal row CID injuries. **a** Peri-trapeziotrapezoidal dislocation. Rupture of the scaphotrapeziotrapezoidal ligament with dislocation of the radial side of the distal carpal row (arrow). **b** Trans-triquetral fracture-dislocation. Fracture through the triquetrum (arrow) with dislocation of the ulnar side of the distal carpal row. An intra-articular distal radius fracture is also present

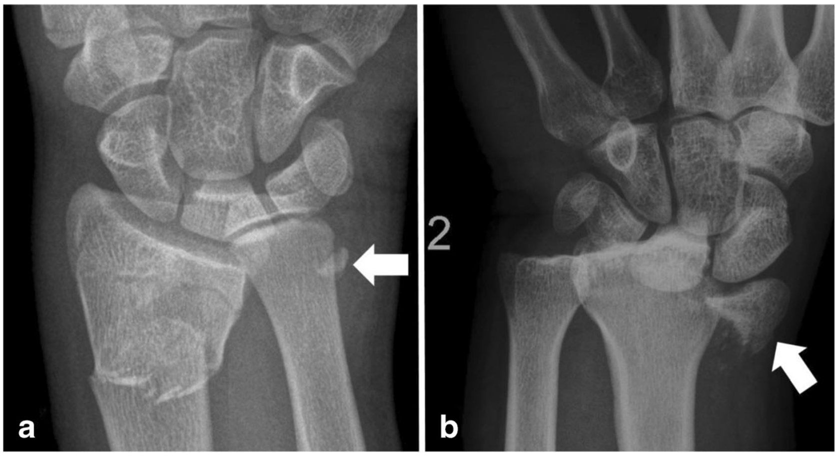

Fig. 9 Carpal Instability Non-dissociative injures. **a** Fracture of the ulnar styloid (arrow) with ulnocarpal dislocation representing a type II ulnar translation CIND injury. An extra-articular distal radius fracture is also present. **b** Fracture through the radial styloid (arrow) with radiocarpal dislocation representing a radial translation CIND injury

instability both within a row and between rows. CIC injuries can generally be classified into four patterns of instability: perilunate instability (lesser arc injuries), perilunate fracture–dislocations (greater arc injuries), axial dislocations, and isolated carpal bone dislocations. Perilunate injuries can be further described as occurring in the palmar or dorsal direction.

In perilunate instability, there is disruption of the ligaments immediately surrounding the lunate. This typically begins along the radial side of the lunate and progresses around the lunate in a circular pattern. Four stages of perilunate instability have been described [44]. Stage 1 injuries are isolated injuries to the scapholunate ligament and are analogous to the scapholunate ligament injuries previously described in the proximal row CID injury patterns. Stage 2 injuries involve tearing of the scapholunate ligament as well as the lunocapitate capsular ligaments. Stage 2 injuries result in what is commonly called a perilunate dislocation, which can be recognized on lateral radiographs by disarticulation of the lunocapitate joint with the lunate remaining in alignment with the normal radio-luno-capitate axis while the remaining carpus displaces either dorsal to volar to the normal axis (Fig. 10a). In perilunate dislocations dorsal displacement of the carpus is much more common than volar displacement. In stage 3 injuries there is disruption of the scapholunate, lunocapitate capsular, and lunotriquetral ligaments. This results in a radiographic appearance similar to stage 2 injuries and can be difficult to differentiate from stage 2 injuries. However, widening of the lunotriquetral interval, when present, is a clear indicator for distinguishing between stage 2 and stage 3 injuries. Stage 4 injuries represent complete or near complete disruption of the ligaments surrounding the lunate. Stage 4 injuries are also called lunate dislocations because the lunate is freely dissociated from the remaining carpal bones. On a lateral radiograph, the lunate will displace into the volar or dorsal soft tissues while the remaining carpus remains in normal alignment with the radius (Fig. 10b). Volar dislocation of the lunate is much more common than dorsal dislocation.

Just like perilunate instability, perilunate fracture–dislocations typically begin along the radial side of the wrist and progress in a circular fashion around the lunate to the ulnar side [45]. However, unlike perilunate instability, which is defined as injury exclusively involving the ligaments immediately adjacent to the lunate, perilunate fracture–dislocations involve an injury pattern in a wider arc around the lunate with fracture of one or more of the carpal bones along the greater arc of the wrist (Fig. 10c). Perilunate fracture–dislocations often do not purely involve the greater arc of the wrist. Instead, these injury patterns will usually involve portions of both the greater and lesser arcs. Perilunate fracture–dislocations are described in a similar manner as perilunate instability with the addition of any fractured bones contributing to the instability pattern being included in the description with the prefix "trans-" added to the name of the fractured bone. For example, a perilunate fracture–dislocation with fracture through the scaphoid would be termed a "trans-scaphoid perilunate dislocation" and a lunate dislocation with fractures through the scaphoid and capitate would be termed a "trans-scaphoid, trans-capitate lunate dislocation." Unlike perilunate instability, which relies completely on carpal malalignment for radiographic diagnosis, identification of multiple carpal bone fractures in the expected distribution of perilunate fracture–dislocation (i.e., along the greater arc of the wrist) is suspicious for carpal instability even in the absence of carpal malalignment on static imaging.

Axial dislocations are injuries created by a strong force transmitted down the length of the hand, wrist, and forearm. These injuries almost always occur as the result of a high-energy mechanism of injury. Axial dislocations are similar to distal row CID in that these injuries result in the creation of two columns, a stable column that remains anchored to the radius/ulna and an unstable column that is dissociated from the remaining carpal bones. Also, just like in distal row CID, the unstable column can be on either the ulnar or radial side of the wrist. The distinction between axial dislocations and distal row CID is the dissociated column of bone seen in axial dislocations that span the proximal and distal carpal rows, while in distal row CID the dissociated column of bone is confined to the distal carpal row (Fig. 10d). Axial dislocations have a high association with additional soft tissue injuries such as the neurovascular structures.

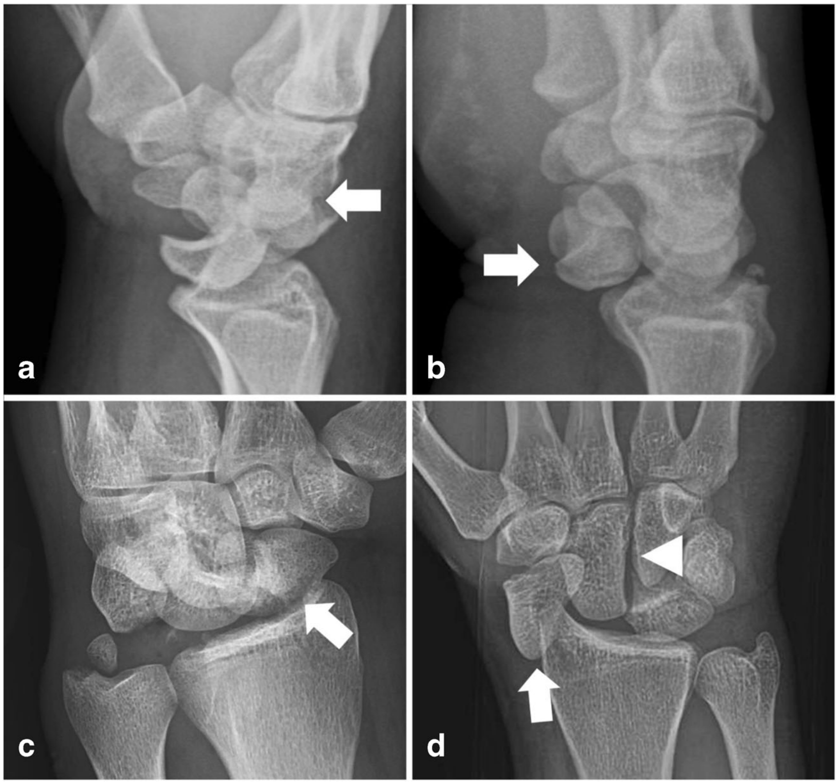

Fig. 10 Carpal Instability Complex injuries. **a** Perilunate dislocation. Dorsal displacement of all carpal bones (arrow) except for the lunate. **b** Lunate dislocation. Volar displacement of the lunate (arrow) with normal alignment of remaining carpus. **c** Trans-scaphoid lunate dislocation. Scaphoid waist fracture (arrow) with dislocation and rotation of the lunate disrupting all 3 arcs of Gilula. **d** Axial dislocation. Dislocation along the radial side of both the proximal (arrow) and distal (arrowhead) carpal rows

Isolated carpal dislocations are a rare phenomenon in wrist trauma. The lunate is by far the most common carpal bone to dislocate. Other carpal bones that have been reported to dislocate in isolation include the scaphoid, pisiform, triquetrum, and the trapezoid, although these dislocations are exceedingly rare [46–49].

CIA

In adaptive CIND, the carpal bones are arranged in such a way that the ligaments are forced to stretch, resulting in a deformity such as DISI or VISI. When the wrist is ulnarly deviated, the smooth transition of the proximal carpal row from flexion to extension is interrupted, resulting in clunking or snapping [33]. This is an adaptive arrangement of the carpus secondary to congenital malformation or trauma. The most common cause of adaptive CIND is distal radius fracture malunion [33]. Typically, there is dorsal tilt of the malunited distal radius articular surface with the lunate in extension and capitate in flexion creating a DISI configuration of the wrist [43].

Conclusion

In working with the treating clinician, it is essential that the emergency radiologist is comfortable with identifying and classifying carpal instability. This will ensure prompt treatment of seemingly benign injuries and those that require intervention, surgical or otherwise, improving the likelihood of a good outcome. In order to minimize missed diagnoses, it is critical for the emergency radiologist to have a strong understanding of the various categories of carpal instability and methods for evaluating soft tissue injuries of the wrist.

Code availability Not applicable.

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Data availability Not applicable.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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