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Carpal Instability

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Anatomy

The intracapsular ligaments of the wrist are divided into intrinsic and extrinsic components1-9. The two most important intrinsic (interosseous) ligaments, the scapholunate and lunotriquetral ligaments, are divided into dorsal, proximal, and palmar regions (Fig. 1)10. The thickest and strongest region of the scapholunate ligament is located dorsally10, and that of the lunotriquetral ligament is located palmarly10.

There are three strong palmar extrinsic radiocarpal ligaments: the radioscaphocapitate, long radiolunate, and short radiolunate ligaments2. The radioscaphocapitate ligament, which extends from the radial styloid process through a groove in the waist of the scaphoid to the palmar aspect of the capitate, acts as a fulcrum around which the scaphoid rotates (Fig. 2). The long radiolunate ligament, which lies parallel to the radioscaphocapitate ligament, extends from the palmar rim of the distal part of the radius to the palmar horn of the lunate. The long radiolunate ligament and the palmar region of the lunotriquetral interosseous ligament, thought to be in continuity in earlier studies, were previously labeled the radiotriquetral ligament7. Located between the radioscaphocapitate and long radiolunate ligaments, at the level of the midcarpal joint, is an area of capsular weakness known as the space of Poirier. The short radiolunate ligament, which is contiguous with palmar fibers of the triangular fibrocartilage complex, originates from the palmar margin of the distal part of the radius and inserts into the proximal part of the palmar surface of the lunate. The radioscapholunate ligament (the ligament of Testut), previously thought to be an important stabilizer of the scaphoid,
The dorsal intercarpal ligament originates from the triquetrum and extends radially to insert into the lunate, the dorsal groove of the scaphoid, and the trapezium. Kinematics

There are two prevailing theories, the columnar and oval ring concepts, that have been used to characterize carpal kinematics. The columnar carpus concept, introduced by Navarro in 1921, describes the carpus as a series of three longitudinal columns (the central [flexion-extension], lateral [mobile], and medial [rotational] columns) (Fig. 4). Taleisnik modified Navarro’s theory, adding the trapezium and trapezoid to the central column and eliminating the pisiform from the medial column. The scaphoid is considered to be the stabilizing link for the midcarpal joint, and the triquetrum is thought to be the pivot point for carpal rotation. Flexion and extension occur through the central column, and radial and ulnar deviation occur by rotation of the scaphoid laterally and the triquetrum medially. With the proximal row independence and oval ring concepts, Linscheid and Lichtman et al. characterized the carpus as a ring that allows reciprocal motion during radial and ulnar deviation and flexion and extension of the wrist (Fig. 6). Central to this concept is the observation that radial and ulnar deviation and flexion and extension occur reciprocally between the radiocarpal and midcarpal joints (that is, movement by one row is in the opposite direction from that by the other). An interruption of the proximal carpal row at any point in the ring results in carpal instability.

Terminology

The carpus is considered clinically unstable if it exhibits symptomatic malalignment, is not able to bear loads, and does not have normal kinematics during any portion of its arc of motion. Static instability refers to carpal malalignment that can be detected on standard posteroanterior and lateral radiographs. Dynamic instability refers to carpal malalignment that is reproduced with physical examination maneuvers and when stress radiographs are made. With dynamic instability, there is no evidence of carpal bone malalignment on plain radiographs. The terms dorsal intercalated instability and volar intercalated instability refer to the appearance of the lunate, the intercalated segment, on the...
lateral radiograph. In dorsal intercalated instability, the lunate is angulated dorsally in the sagittal plane and the capitate is displaced dorsal to the radiometacarpal axis (radiolunate angle, more than 10 degrees) (Fig. 7).

In volar intercalated instability, the lunate angulates palmarly (radiolunate angle, 10 degrees in a palmar direction), which causes the capitate to become displaced palmar to the radiometacarpal axis.

Other terms have been introduced to clarify various patterns of carpal instability. Carpal instability dissociative connotes an injury to one of the major intrinsic carpal ligaments, such as that seen in scapholunate dissociation and perilunate dislocation. Carpal instability nondissociative indicates an injury to a major extrinsic ligament, such as occurs in dorsal carpal subluxation, midcarpal instability, volar carpal subluxation, or capitate-lunate instability. Carpal instability adaptive refers to carpal instability resulting from an external cause, such as that seen at the radiocarpal or midcarpal joint following severe malunion of the distal part of the radius.

Mechanisms of Injury

In an experimental study, Mayfield et al. determined that the mechanism of injury for most carpal dislocations is a fall on the outstretched hand causing wrist extension, ulnar deviation, and intercarpal supination. Sequential ligamentous injury, called progressive perilunar instability, was noted to be initiated on the radial aspect of the wrist and to extend across the perilunate ligaments to the ulnar aspect of the wrist. Four stages of progressive perilunar instability were defined, including scapholunate dissociation caused by injury to the scapholunate interosseous and palmar radioscaphocapitate ligaments (stage I), dislocation of the capitolunate joint through the space of Poirier (stage II), separation of the triquetrum...
Carpal instability 581

from the lunate with associated injury to the lunotriquetral and lunotriquetral ligaments (stage III), and palmar lunate dislocation due to injury to the dorsal radiocarpal ligament (stage IV). Transradial styloid, transscaphoid, and transcapitate fractures are associated with perilunate injuries that progress from lateral to medial, ultimately involving the lunotriquetral ligament, the volar ulnocarpal ligaments, and the ulnar styloid process.

Radiographic and Other Diagnostic Studies

Six radiographs are made for wrists with suspected carpal instability. These include posteroanterior, lateral, radial and ulnar deviation, and flexion and extension views. An additional posteroanterior radiograph of the wrist with a clenched and loaded fist is made to rule out scapholunate instability. The alignment of the proximal and distal carpal rows is measured with Gilula’s method. The midcarpal joint is visualized as an acetabulum or cup where the capitate and hamate articulate with the proximal carpal row. Interruption of the normal carpal arc of either the proximal or the distal carpal row indicates an instability pattern.

The use of radionuclide bone scans as screening tools is indicated for the localization of the cause of obscure wrist pain such as that due to a chondral fracture. While a positive bone scan provides information on the location of a wrist abnormality, it is rarely diagnostic. A negative bone scan, which suggests that a serious injury has not occurred, does not rule out carpal instability, especially in the early stages when reactive bone changes have not yet taken place. Overall, bone-scanning is not as helpful as other studies in the evaluation of wrists with suspected carpal instability.

Arthrogram of the wrist, performed alone or with videofluoroscopy, is a useful study in the evaluation of a wrist with carpal instability. While wrist dynamics are best assessed with fluoroscopy, arthrography remains the standard study for the carpal ligaments and the triangular fibrocartilage complex. Midcarpal, radiocarpal, and distal radioulnar arthrography (triple-phase injection) provides valuable definitive data on the integ-

**Fig. 8-A**

Figs. 8-A, 8-B, and 8-C: Midcarpal arthrograms diagnostic for a lunotriquetral ligament tear.

Fig. 8-A: Contrast material is injected into the midcarpal joint.

Contrast material is noted to extend across the lunotriquetral joint (arrow).

Contrast material fills the scapholunate interval but does not cross at this location into the radiocarpal joint.
Contrast material injected into the midcarpal joint does not extend into the radiocarpal joint unless there is either an acute or a degenerative intrinsic ligament tear (Figs. 8-A, 8-B, and 8-C). For injuries of the triangular fibrocartilage complex, selective injection of the distal radioulnar joint is carried out. However, in some cases, both the radiocarpal and the distal radioulnar joint must be inspected to show a communicating defect. While false-positive and false-negative arthrograms have been reported, arthrography is of considerable value as a primary study for intrinsic carpal ligament injury.

Tomography of the wrist (polytomography or computed tomography), which is useful for evaluating the alignment of the carpal bones, is most helpful for assessing the fractures and fracture-dislocations that are frequently associated with carpal instability. Complex motion polytomography is of special value for obtaining biplanar images of the carpus. Computed axial tomography, which provides useful cross-sectional images, is particularly helpful if three-dimensional reconstruction is performed. In the evaluation of wrist injuries, tomography is generally limited to cases in which a carpal fracture is suspected.

Magnetic resonance imaging, used frequently for the evaluation of wrist pain, is less helpful than other studies for the assessment of a wrist with carpal instability. Magnetic resonance imaging is most useful for evaluating suspected cases of osteonecrosis of bone and tumors of bone or soft tissue. While it can be helpful for visualizing the triangular fibrocartilage complex, it is not particularly useful for the evaluation of carpal ligament injuries unless gadolinium enhancement is performed. The consistency with which both the radiocarpal and the interosseous ligaments are demonstrated, however, is not sufficient for this to be a primary method of evaluation.

Arthroscopy has replaced arthrography in many centers as the definitive diagnostic study for wrists with
CARPAL INSTABILITY

suspected carpal instability. Recent reports have indicated that arthroscopic evaluation of the wrist is more accurate and specific than arthrography in detecting the site and extent of ligament injury\textsuperscript{21,32}. Diagnostic wrist arthroscopy includes an examination of both the radiocarpal and midcarpal joint. In the radiocarpal joint, triangulation probing of the scapholunate interosseous ligament, the lunotriquetral interosseous ligament, and the triangular fibrocartilage complex is carried out. The volar carpal ligaments are assessed in a radial-to-ulnar direction to determine whether extrinsic ligament injury has occurred. Midcarpal arthroscopy, with use of a triangulation probe, is performed routinely. The space between the scaphoid and lunate bones is assessed for evidence of ligamentous laxity. A diagnosis of partial or complete carpal ligament injury is established on the basis of the ease of separation of the scaphoid from the lunate and of the lunate from the triquetrum. If the probe can be rotated within the joint, a tear of the scapholunate or lunotriquetral interosseous ligament is suggested. If either the probe or the arthroscope can be passed from the midcarpal to the radiocarpal joint, rotatory subluxation of the scaphoid (a complete scapholunate ligament tear with extrinsic ligament laxity) is confirmed. Within the radiocarpal joint, a triangulation probe assists in the assessment of the size, location, and extent of tears of the triangular fibrocartilage complex. Associated osseous injuries (fractures of the proximal pole of the scaphoid or dorsal triquetral chip fractures) can be visualized also. Wrist arthrography and arthroscopy may be carried out in sequence within the operating room. Comprehensive intraoperative assessment currently includes fluoroscopy of the wrist with the patient under anesthesia in the operating room, followed by wrist arthrography and then by wrist arthroscopy, if indicated. Dynamic fluoroscopic imaging studies and arthroscopy are particularly useful when performed sequentially in the operating room to confirm the presence of a ligamentous injury and to plan the appropriate operative approach.

**Acute Static Scapholunate Dissociation**

Acute static scapholunate dissociation, which may occur as an isolated entity or as a late sequela of a peri-

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**Fig. 11**

Figs. 11 through 14: A wrist with acute stage-III dorsal perilunate dislocation according to the system of Mayfield et al.\textsuperscript{18,19}.

Fig. 11: Preoperative posteroanterior radiograph demonstrating overlap of the carpal bones (normally only the trapezium and the trapezoid, and the triquetrum and the pisiform, overlap on the posteroanterior radiograph), a triangular shape to the lunate, and a scapholunate gap of seven millimeters.

Preoperative lateral radiograph demonstrating that while the lunate is palmar flexed it rests in the lunate fossa of the radius. The scaphoid and the capitate are displaced dorsal to the longitudinal axis of the radius.
lunate dislocation, results from injury to the scapholunate interosseous and palmar radioscaphoid ligaments. Depending on the extent of ligamentous injury, there is either diffuse tenderness of the carpus or point tenderness over the scapholunate interval. Radiographs reveal all five key features of rotatory subluxation of the scaphoid (Figs. 9 and 10). While ligamentous repair within three weeks after the injury is preferred, delayed repair can be carried out as long as four to six months from the time of the injury. Several factors govern the feasibility of delayed ligamentous repair (repair later than three weeks after the time of the injury); these factors include the identification of a substantial, reparable scapholunate interosseous ligament and the isolation of a palmar flexed scaphoid that can be reduced without the necessity for extensive circumferential dissection. The extent to which the scaphoid becomes fixed in palmar flexion is dependent on the magnitude of the initial capsular injury, with scarring and capsular contracture increasing over time.

Neither closed reduction alone nor closed reduction and percutaneous pin fixation is uniformly successful in maintaining carpal alignment and in achieving satisfactory long-term outcomes in wrists with acute scapholunate instability. The preferred method of treatment is open reduction of the carpus through a dorsal approach, pinning of the scaphoid to the lunate and to the capitae with two 0.045-inch (0.114-centimeter) Kirschner wires, and direct repair of the scapholunate ligament. Ligament repair is carried out either with direct suture for ligaments torn in their midsubstance or with pull-out sutures or suture anchors for ligaments avulsed from bone. The wrist is immobilized in neutral position in an above-the-elbow thumb-spica cast for eight weeks, following which time the pins are removed and active motion is initiated.

Chronic Scapholunate Dissociation

For wrists in which the scapholunate interosseous ligament cannot be repaired primarily, attempts to reconstruct the dorsal and palmar ligaments of the scaphoid with any combination of late ligamentous repair, tendon-grafting, and capsulodesis, while feasible, have not provided consistent pain relief and have not maintained the alignment of the carpus over the long term. Either scaphotrapeziotrapezoid or scaphocapitate intercarpal arthrodesis is effective operative management. Each has been shown to produce similar reductions in the global range of motion of the wrist and comparable effects on relative intercarpal motion. While some experimental studies have shown that these intercarpal arthrodeses cause increased loads across the radioscpaphoid joint, increased shear stresses on the lunate, and increased tension on the surrounding ligaments, others have indicated that the long-term functional results are satisfactory. Most authors have recommended that radial styloidectomy be carried out at the time of scaphotrapeziotrapezoid and scaphocapitate arthrodeses to avoid radial styloid-scaphoid impingement. Following both of these limited intercarpal arthrodeses, residual flexion and extension of the wrist is 50 to 60 percent of that on the contralateral side and residual radial and ulnar deviation is 60 to 70 percent of that on the contralateral side. The most common complications are nonunion, which is seen in as many as 30 percent of patients, and radioscpaphoid impingement.

Acute Perilunate Dislocation

With acute perilunate dislocation, the typical findings on physical examination are swelling, pain, and deformity of the wrist and the typical finding on radiographic examination is gross disturbance of the intercarpal relationships (Fig. 11). With dorsal perilunate dislocation, lateral radiographs demonstrate that the longitudinal axis of the capitate is displaced dorsal to the longitudinal axis of the radius (Fig. 12). With lunate dislocation, the longitudinal axis of the capitate is co-
linear with the axis of the radius and the lunate is displaced palmarly\(^7\). Distortion of the concentric arcs of the proximal and distal rows indicates that the injury has extended to the ulnar side of the carpus. If initial radiographs are confusing, it is helpful to make distraction radiographs with ten to fifteen pounds (4.5 to 6.8 kilograms) of fingertrap traction. Radiographs of the contralateral wrist in neutral alignment are made, and measurements are made from reference points on the lunate and scaphoid.

Previous investigators have noted that there is a low likelihood of achieving long-term success with closed reduction of an acute perilunate dislocation, with or without percutaneous pin fixation\(^{58}\). Currently, the treatment of choice is immediate closed reduction followed by open ligamentous repair through a dorsal approach. Closed reduction is carried out in the emergency room with traction (ten pounds [4.5 kilograms] for ten minutes) applied to the hand with fingertraps. The fingertraps are removed, and manual longitudinal traction is applied. As the wrist is extended, the lunate is stabilized by the examiner’s thumb. With traction maintained, the wrist is gradually palmar flexed and the capitate is reduced into the concavity of the lunate\(^5\). The patient is then taken to the laboratory for further evaluation.

FIG. 14
Postoperative lateral radiograph demonstrating that the capitate and the lunate are colinear with the radius and that the capitate is concentric with the articular surface of the lunate.

FIG. 15
Photograph demonstrating how point tenderness over the scapholunate interval is elicited in wrists with dynamic scapholunate instability.
Figs. 16-A, 16-B, and 16-C: Photographs demonstrating the scaphoid shift maneuver.
Figs. 16-A and 16-B: Volar and lateral views showing how the maneuver is performed by applying pressure over the scaphoid while the wrist is held in ulnar deviation.
Fig. 16-C: As the wrist is brought from ulnar to radial deviation, the scaphoid’s proximal pole returns to its position in the scaphoid fossa of the radius. The patient notes wrist pain with the maneuver, and both the patient and the examiner note a clunking sensation.
operating room, and regional or general anesthesia is administered. A longitudinal dorsal incision is made from the base of the index and long metacarpals, over Lister’s tubercle to the distal aspect of the forearm. Dissection of the carpus is carried out beneath the infratendinous retinaculum of the fourth dorsal compartment. The scapholunate and lunotriquetral interosseous ligaments are inspected. After reduction of the scapholunate joint, three to four 0.045-inch (0.114-centimeter) Kirschner wires are inserted, extending from the scaphoid to the lunate, from the scaphoid to the capitate, and on occasion from the radius to the lunate. If the lunotriquetral ligament is torn, the lunotriquetral joint is reduced and pinned with an additional 0.045-inch Kirschner wire (Figs. 13 and 14). The scapholunate and lunotriquetral interosseous ligaments are repaired with direct suture with 4.0 braided Dacron or with suture anchors. Currently, a palmar incision is made in addition, particularly if there is a palmar lunate (stage-IV) dislocation that cannot be reduced closed or if there are findings indicative of acute carpal tunnel syndrome.

Postoperatively, the wrist is immobilized in an above-the-elbow plaster-reinforced compression dressing for fourteen days. A below-the-elbow thumb-spica cast is then applied and is maintained for an additional six weeks. Eight weeks postoperatively, the cast is removed, the pins are removed, and active motion is initiated. In a recent multicenter study of perilunate dislocations and fracture-dislocations, the authors noted that both open injury and a delay in treatment had adverse effects on outcomes and that postoperative arthritis was common (seen in as many as 56 percent of cases).

**Transscaphoid Perilunate Dislocation**

Initial evaluation and treatment is similar to that carried out for perilunate dislocation. Internal fixation of the scaphoid is performed with insertion of a compression screw through a dorsal incision. Injury to the dorsolateral branches of the radial artery, which enter the scaphoid through the dorsal ridge, can be avoided by direct visualization and protection of the dorsolateral vascular leash. An additional Kirschner
wire may be placed in the scaphoid to provide rotational stability. Immobilization in a thumb-spica cast is maintained until there are clinical and radiographic signs of scaphoid union as evidenced by the absence of tenderness in the anatomical snuffbox on physical examination and the appearance of trabeculae extending across the fracture site on plain radiographs.

**Scaphoid Dislocation**

Palmar radial displacement of the proximal pole of the scaphoid from the scaphoid fossa of the distal part of the radius is diagnostic of a scaphoid rather than a perilunate dislocation. The interposition of capsular or ligamentous tissue may prevent closed reduction. Treatment, which is similar to that recommended for acute scapholunate dissociation, consists of open reduction of the scapholunate joint, insertion of two 0.045-inch (0.114-centimeter) Kirschner wires extending from the scaphoid to the lunate and from the scaphoid to the capitate, and direct repair of the scapholunate interosseous ligament. Immobilization in a below-the-elbow thumb-spica cast is maintained for eight weeks, after which time active motion is initiated.

**Dynamic Scapholunate Instability**

Initially described by Taleisnik in 1980, dynamic scapholunate instability is the most common cause of wrist pain and instability in adolescents and young adults. Although a precise anatomical cause has not been determined, it is likely that attenuation of the palmar radioscaphoid and scapholunate interosseous ligaments is the basis for this instability pattern. While radiographic findings are frequently normal, consistent findings on physical examination confirm the diagnosis. There is point tenderness over the scapholunate interval (Fig. 15), and provocative tests reproduce symptoms of instability. The scaphoid shift maneuver, performed as described by Watson et al., is the most useful clinical test. To perform this maneuver, pressure is applied to the palmar tubercle of the scaphoid by the examiner’s thumb with the wrist in ulnar deviation (Figs. 16-A and 16-B). In wrists with instability, the scaphoid is displaced dorsally over the lip of the radius. As the wrist is brought from ulnar to radial deviation, the scaphoid's proximal pole returns to its position in the scaphoid fossa of the radius (Fig. 16-C). As the scaphoid reduces, a clunking sensation and wrist pain are noted. Although 110 (11 percent) of 1000 randomly examined wrists were found to have unilateral, asymptomatic increased scaphoid mobility on the scaphoid shift test, patients with dynamic instability are distinguished by their symptoms of instability and pain with this maneuver. The unaffected wrist is examined, and an assessment for generalized ligamentous laxity is carried out. Additional studies, such as three-portal wrist arthrography and wrist arthroscopy, have not been found to be helpful in confirming the diagnosis.

In a recent study, nineteen patients (twenty wrists) with dynamic instability were treated nonoperatively with splinting of the wrist, oral administration of nonsteroidal anti-inflammatory medication, and modification of activities. No patient in that study, however, had a substantial reduction in symptoms, even after twelve weeks and longer durations of nonoperative treatment.

For wrists with persistent incapacitating pain and instability after a trial of nonoperative care, dorsal capsulodesis, as described by Blatt and as modified by Wintman et al., is the treatment of choice (Figs. 17 and 18). Results, reported in three recent studies, have been consistent with regard to the effectiveness of this procedure in eliminating symptoms of instability and pain in more than 90 percent of patients and in the achievement of high levels of satisfaction as reported on questionnaires. Patients reported that substantial improvements occurred in activities such as brushing teeth, opening automobile doors, shoveling, sweeping, throwing, and using a screwdriver. While dorsal capsulodesis has been shown to cause a mean loss of wrist flexion of 15°.
Dorsal Wrist Ganglia and Dynamic Carpal Instability

Dorsal wrist ganglia, which most often originate from the scapholunate interosseous ligament in young adults, have been shown to be associated with symptoms and signs of dynamic scapholunate instability. In a recent study of eighteen patients (nineteen wrists) with a dorsal wrist ganglion and dynamic scapholunate instability, treatment consisted of excision of the ganglion to the level of the scapholunate interosseous ligament and postoperative immobilization of the wrist in 20 degrees of extension for two weeks. On follow-up evaluation, two patients had continued wrist pain and one had a recurrent ganglion. All but one patient in this series, including two who had signs of generalized ligamentous laxity, had a stable nontender wrist on follow-up physical examination at one year. It appears that postoperative dorsal capsular scarring following ganglion excision and two weeks of wrist immobilization stabilizes the scaphoid sufficiently to alleviate symptoms and signs of dynamic scapholunate instability.

Scapholunate Advanced Collapse

The most common form of wrist arthritis, scapholunate advanced collapse, evolves in a predictable sequence. Injury to the scapholunate interosseous and palmar radioscaphoid ligaments has been shown to lead to a progressive shift of the pressure centroid of the scaphoid, resulting in a change in the regions of peak intra-articular contact between the scaphoid and the distal part of the radius. Three distinct time-related degenerative changes occur in scapholunate advanced collapse; these consist of joint-space narrowing between the tip of the styloid process of the radius and the distal outer aspect of the scaphoid in stage I, degenerative

such as triscaphoid arthrodesis, which causes a far greater loss of wrist motion in all planes.

FIG. 20-A

Figs. 20-A and 20-B: Posteroanterior and lateral radiographs showing a malunion of the distal part of the radius. Dorsal lunate subluxation occurs secondary to increased dorsal tilt. There is evidence of a zigzag collapse pattern of the lunate and the capitate.

degrees, this procedure appears to provide superior outcomes when compared with the alternative methods that have been used for the treatment of dynamic instability,
changes along the entire articular surface between the radius and the scaphoid in stage II, and narrowing of the capitolunate joint space in stage III (Fig. 19). The observation that the radiolunate joint is spared consistently in wrists with scapholunate advanced collapse has served as the anatomical basis for several of the most widely used treatment methods over the past two decades.

Initial treatment consists of oral administration of nonsteroidal anti-inflammatory medication, application of a wrist splint, and modification of activities. For wrists with stage-I scapholunate advanced collapse that are resistant to nonoperative measures, operative treatment designed to stabilize the carpus so that compressive and shear forces are transmitted through the normal radiosapholunate articulation is recommended. As ligament reconstruction has not proved to be consistently effective in maintaining correction of the excessively flexed scaphoid, intercarpal arthrodesis has become the operative procedure of choice. Either scaphotrapeziotrapezoid or scaphocapitate arthrodesis achieves the goal of maintaining the scaphoid in an alignment that is 50 to 55 degrees to the longitudinal axis of the radius when the wrist is in neutral position, and each is effective in reducing pain and slowing the progression of degenerative arthritis. Radial styloidectomy, performed simultaneously and consisting of removal of seven millimeters of the radial styloid process dorsally and four millimeters palmarly, consistently minimizes symptoms due to abutment and eliminates pain due to arthritis at the distal aspect of the radioscaphoid joint.

For wrists with degenerative arthritis involving the entire radioscapohoid joint (stage II) or the radioscapohoid and capitolunate joints (stage III), a motion-preserving reconstructive procedure, either capitale-lunate-hamate-triquetrum (four-corner) arthrodesis with scaphoid excision or proximal row carpectomy, is recommended.

Studies by Imbriglia et al. and by Neviaser on proximal row carpectomy have indicated that, while high levels of wrist motion and grip strength are maintained, there is persistent pain, a failure to return to strenuous work, and a recommendation for conversion to arthrodesis in as many as 15 percent of patients. While carefully performed four-corner arthrodesis with scaphoid excision provides levels of patient satisfaction and grip strength that are similar to those seen with proximal row carpectomy, values for the range of motion of the wrist are 15 to 20 degrees lower. Attempts to limit the arthrodesis to the capitale-lunate joint in order to achieve a higher postoperative range of motion of the wrist have been unsuccessful because of high rates of nonunion.

Recent studies have confirmed that proximal row carpectomy maintains an arc of wrist flexion and extension that is approximately 20 degrees greater than the motion arc that is achieved with four-corner arthrodesis. While grip-strength values and overall patient-satisfaction scores have been similar, specific complications have been noted with each procedure. Proximal row carpectomy appears to be particularly unpredictable in laborers and in wrists with stage-III scapholunate advanced collapse. Four-corner arthrodesis has been associated with
failure rates of as high as 30 percent\textsuperscript{79}, and isolated capitolunate arthrodesis has been associated with a nonunion rate of 50 percent (four of eight)\textsuperscript{80}. Studies have indicated that either scaphotrapeziotrapezoid or scaphocapitate arthrodesis with radial styloidectomy is indicated for stage-I scapholunate advanced collapse\textsuperscript{52,73}. For stage II, either four-corner arthrodesis with scaphoid excision or proximal row carpectomy is an effective reconstructive procedure. There is general consensus that either limited wrist arthrodesis with scaphoid excision or proximal row carpectomy with fascial interposition is the procedure of choice for stage-III scapholunate advanced collapse\textsuperscript{79-82}.

**Adaptive Instability**

Dorsiflexion malunion after fracture of the distal part of the radius is the most common cause of adaptive carpal instability\textsuperscript{83,84}. The osseous deformity leads to malalignment of the bones of the proximal carpal row, loss of wrist flexion, and radiocarpal or midcarpal instability. Biomechanical studies have shown that there is a shift of load from the radius to the ulna (from 20 to 67 percent of the total load) when dorsal angulation is increased beyond 15 degrees of dorsal tilt (a 26-degree loss of normal palmar tilt)\textsuperscript{85,86}. Fernandez observed that symptoms occurred most frequently when dorsal angulation of the distal part of the radius was greater than 20 degrees\textsuperscript{87}, and other authors have recommended that 15 to 30 degrees of dorsal angulation be considered an indication for distal radial osteotomy.

Adaptive instability of the carpus may occur at either the radiocarpal or the midcarpal joint\textsuperscript{88,89}. With radiocarpal instability, dorsal radiocarpal subluxation occurs as the lunate contact area translates dorsally.

**Fig. 23**

Schematic drawings of a corrective osteotomy, showing interposition of bone graft from the iliac crest to restore the length and tilt of the distal part of the radius. The upper-left drawing shows the graft in place with temporary Kirschner-wire fixation, the lower-left drawing is a lateral view of T-plate fixation with the interposition graft, and the right drawing is a posteroanterior view of the graft and T-plate in place.

**Fig. 24**

Postoperative lateral radiograph showing the scapholunate angle corrected to 45 degrees and the lunocapitate angle corrected to less than 5 degrees after corrective osteotomy for the treatment of malunion of the distal part of the radius.
along the inclined plane of the distal part of the radius (Figs. 20-A and 20-B). For the hand to become realigned with the forearm, flexion takes place at the radioulnar joint. With midcarpal instability, the angular relationship between the articular surface of the radius and the longitudinal axis of the lunate remains unchanged. For the hand to become realigned with the forearm, palmar flexion occurs at the lunocapitate level (Figs. 21 and 22). Instability occurs gradually, after the fracture has united, as the midcarpal joint is stressed during loading of the wrist. With both types of instability, a zigzag collapse deformity of the carpus results. While the condition is initially dynamic, both radiocarpal and midcarpal instability may become static over time. Adaptive carpal instability results in a change of the moment arm of the flexor and extensor tendons, an alteration in carpal kinematics, and a loss of power transmission across the wrist. With radial shortening and progressively increasing positive ulnar variance, the proximal row of carpal bones abuts the distal end of the ulna, either limiting rotation of the radius or causing palmar or dorsal displacement of the carpus.

Patients with adaptive carpal instability most frequently present with wrist pain, which is often delayed in onset for several weeks to months after fracture-healing, and loss of wrist motion and grip strength. Additional sequelae may include median neuropathy at the wrist and tendon rupture.

The preferred treatment for radial dorsiflexion malunion in young patients (those less than fifty years of age) who have greater than five millimeters of shortening consists of operative restoration of both radial length and palmar tilt. Recent modifications in preoperative planning and operative technique have improved the outcome of dorsal opening-wedge osteotomy, which is the procedure of choice (Figs. 23 and 24). Postoperatively, the adaptive instability pattern corrects spontaneously in most cases and forearm rotation is restored. For wrists in which the adaptive instability pattern has become static, either ligament reconstruction or intercarpal arthrodesis is recommended.

References


CARPAL INSTABILITY 593


