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In Focus

Scapholunate Ligament Injuries

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Injuries to the scapholunate interosseous ligament (SLIL) complex can result in a predictable cascade of incongruous motion in the carpus that leads to radiocarpal degeneration. Both acute traumatic impact and repetitive motion can render the SLIL insufficient. A thorough understanding of SLIL anatomy is required for appropriate diagnosis and treatment. Here, we review scapholunate ligament anatomy, prevention strategies, methods of diagnosis, nonoperative and operative treatments, and outcomes. A myriad of treatment options exist for each stage of the SLIL injury, and management should be an open discussion between the patient and physician.

Epidemiology

Injuries to the carpal ligaments often occur with an extended ulnarly deviated wrist.[1,2] Traumatic injuries can range from isolated scapholunate interosseous ligament (SLIL) partial tear with occult and/or dynamic instability to complete SLIL tear with injury to secondary ligamentous stabilizers and traumatic SLIL tears with carpal or distal radius fractures or dislocations. Without treatment, SLIL injuries can progress to scapholunate advanced collapse (SLAC), which is historically the most common pattern of wrist arthritis.[3] Degenerative injuries can occur in those who repetitively load across the wrist, such as in divers, gymnasts, football players, and athletes in other sports.[4–7]

Specific Anatomy

Normal wrist motion requires a delicate balance in carpal bones, intrinsic, and extrinsic carpal ligaments.[8–11] The extrinsic ligaments connect the radius and ulna to the carpal bones, whereas the intrinsic ligaments connect the carpal bones to each other (Figs. 1–4). The proximal row is the intercalated segment, over which stabilizers pass, and the SLIL is the most critical ligament of this group. The SLIL is an intrinsic C-shaped ligament composed of transverse fibers with three major parts (Fig. 5).[9] The thick dorsal component is the strongest stabilizer of the scapholunate (SL) joint.[9,10] The center of the C-shape is the proximal component made of fibrocartilaginous membrane. The thin volar ligament acts as a rotational stabilizer of the wrist and is the second strongest segment of SLIL.[11] The recent literature describes the scapholunate complex, rather than the SLIL singularly, as a structure consisting of intrinsic ligaments (SLIL), extrinsic ligaments (scaphotrapezio-trapezoid, long radiolunate, radioscaphocapitate, and dorsal intercarpal [DIC]), active muscle stabilizers (flexor carpi radialis, extensor carpi radialis longus, and flexor carpi ulnaris) and proprioceptive nerve loops acting in tandem to stabilize the scapholunate interval.[12]

Biomechanics

In the uninjured wrist, the scaphoid and lunate flex in unison through the intact SLIL with flexion or radial deviation. The long axis of the scaphoid is oblique to the long axis of the radius and the distal pole is volar to the trapezium. As a result, radial deviation at the radiocarpal joint results in flexion of the scaphoid relative to the radius, whereas ulnar deviation results in extension of the scaphoid. The scaphoid has a smaller radius of curvature at its base compared to the lunate, which allows the scaphoid to flex almost twice as much in the sagittal plane at the radiocarpal joint than the lunate.[13] The lunate base decreases in width from a palmar to dorsal direction, resulting in a tendency for the lunate to assume an

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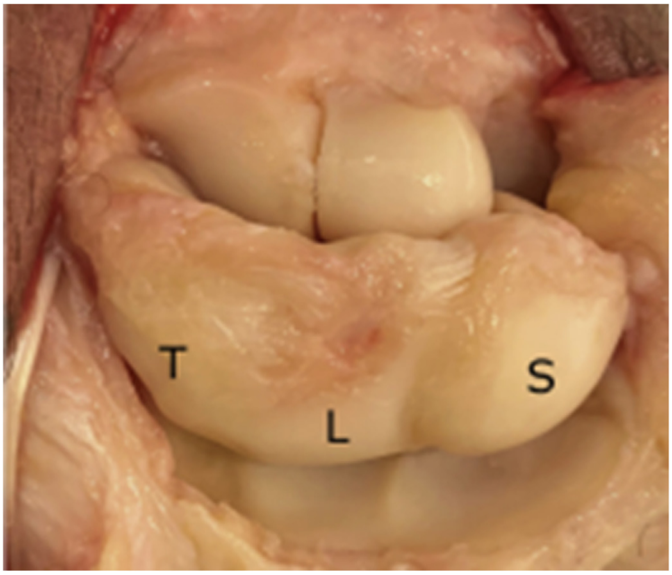

Figure 1. Proximal row of the carpus demonstrating the scapholunate interosseous ligament between the scaphoid (S) and lunate (L) and the lunotriquetral interosseous ligament between the lunate (L) and triquetrum (T).

extended position. The intact SLIL causes the lunate to follow suit and flex and extend passively with the scaphoid, but to a lesser degree. The configuration of the scaphoid, lunate, and the radioscaphoid articulation allows for unique motions such as the "dart-thrower's motion."[13]

Altered carpal mechanics lead to abnormal loading forces across the radiocarpal and intercarpal joints.[14] In the "balanced lunate" theory proposed by Garcia-Elias,[15] the triquetrum and the scaphoid place opposing moments on the lunate. If the lunotriquetral interosseous ligament and critical supporting ligaments are torn, the scaphoid applies a flexion moment on the lunate via the intact SLIL, causing volar intercalated segment instability. If the SLIL and critical supporting ligaments are injured, the scaphoid no longer applies a flexion moment on the lunate through the scapholunate interosseous ligament. The triquetrum then pulls the lunate into extension through the lunotriquetral interosseous ligament (Fig. 6).[15] This causes dorsal intercalated instability (DISI) in which the SL interval widens, the capitate migrates proximally, the scaphoid flexes and shifts dorsally and radially, and the lunate is forced into extension through the lunotriquetral interosseous ligament.[16] Patients with SLIL injury and SL instability are often considered at risk for SL dislocation. There are two distinct planes of instability in SLIL injury: coronal and sagittal. These are described as SL widening and rotational abnormality among the carpal bones, respectively.[17] Gross instability of the SL joint occurs when a combination of ligamentous injuries exist.[18]

Etiology of SL Injuries

Risk factors

Anatomic factors that have been associated with increased risk for SL injuries include low lunate fossa inclination (angle between the sclerotic line of the lunate fossa of the radius and a line perpendicular to the long axis of the distal ulna) and low radial inclination.[19] In addition, patients with increased wrist laxity are more vulnerable to intercarpal ligamentous injuries during repetitive motion activities than patients without laxity.[20,21] Garcia-Elias et al[22] found that patients with increased wrist laxity demonstrated preferential movement of the scaphoid in the sagittal plane during wrist radioulnar deviation, whereas the scaphoid exhibited greater movement in the coronal plane during radioulnar deviation in patients with less wrist laxity. They postulated that this increased out-of-plane scaphoid translation is a likely factor in explaining the increased risk of periscaphoid ligamentous injury in patients with wrist laxity.

Some experts have postulated the concurrence of distal radius fractures with SLIL injury, but there is no statistically significant correlation between the two.[23] However, individuals with an increased ulnar variance at the time of distal radius fracture are more likely to have a scapholunate injury.[24]

Injury mechanism

Pathology in the SLIL is most often a result of repetitive or traumatic injury. SLIL injuries occur from axial loading and extension of the wrist, such as in a fall onto an outstretched hand. In most cases, the ligament avulses off of the scaphoid, the next most common pattern of injury is a midsubstance tear in the SLIL, and the least common pattern of injury is an avulsion off the lunate.[25] Degenerative injuries occur from attenuation of the SLIL over repetitive loading across the wrist.[4,5]

Other causes of atraumatic SLIL attenuation include calcium pyrophosphate dihydrate (CPPD) crystal deposition disease, rheumatoid arthritis, neuropathic diseases, and amyloid deposition diseases.[26,27]

Diagnosis

History and physical exam

A comprehensive history and physical exam should be performed for any acute wrist pain. Wrist pain that seems out of proportion or is not responsive to a brief course of immobilization should raise suspicion for a carpal ligament injury. Patients with SLIL injury often complain of dorsal and radial-sided wrist pain that worsens with loading across the extended wrist, such as when performing a push-up, and with extremes of wrist range of motion. Patients may or may not present with swelling around the periscaphoid region and decreased range of motion, grip strength, and the feeling of sudden shifts or clunks with radioulnar deviation of the wrist.[28] Specific clinical findings that may suggest a SLIL carpal ligament injury include tenderness over the radial and/or dorsal carpus or dorsal prominence of the scaphoid proximal pole.

After an acute injury, special tests for carpal instability can be performed (Table 1). The scapholunate ballottement test detects abnormal motion between the lunate and scaphoid by stabilizing the lunate and displacing the scaphoid in a dorsal-palmar direction. The Watson shift test is classically performed to examine subluxation of the scaphoid as the wrist moves from ulnar to radial deviation in the presence of an incompetent SLIL with resultant clunk.[29] To perform the Watson test, the patient sits with their elbow supported against a table or armrest, with the ulnar aspect of the arm facing the examiner. The examiner grasps circumferentially around the wrist with one hand and uses their thumb to apply volar pressure over the patient's scaphoid. The examiner then uses their free hand to control the patient's metacarpals and directs the hand in ulnar deviation and extension; this position closely aligns the long axis of the scaphoid with the radius. Then, the examiner directs the metacarpals radially with slight flexion, which dorsally subluxates the scaphoid from its fossa on the distal radius. Release of volar pressure over the scaphoid at this point will produce pain or a painful clunk as the scaphoid reduces back over the dorsal rim

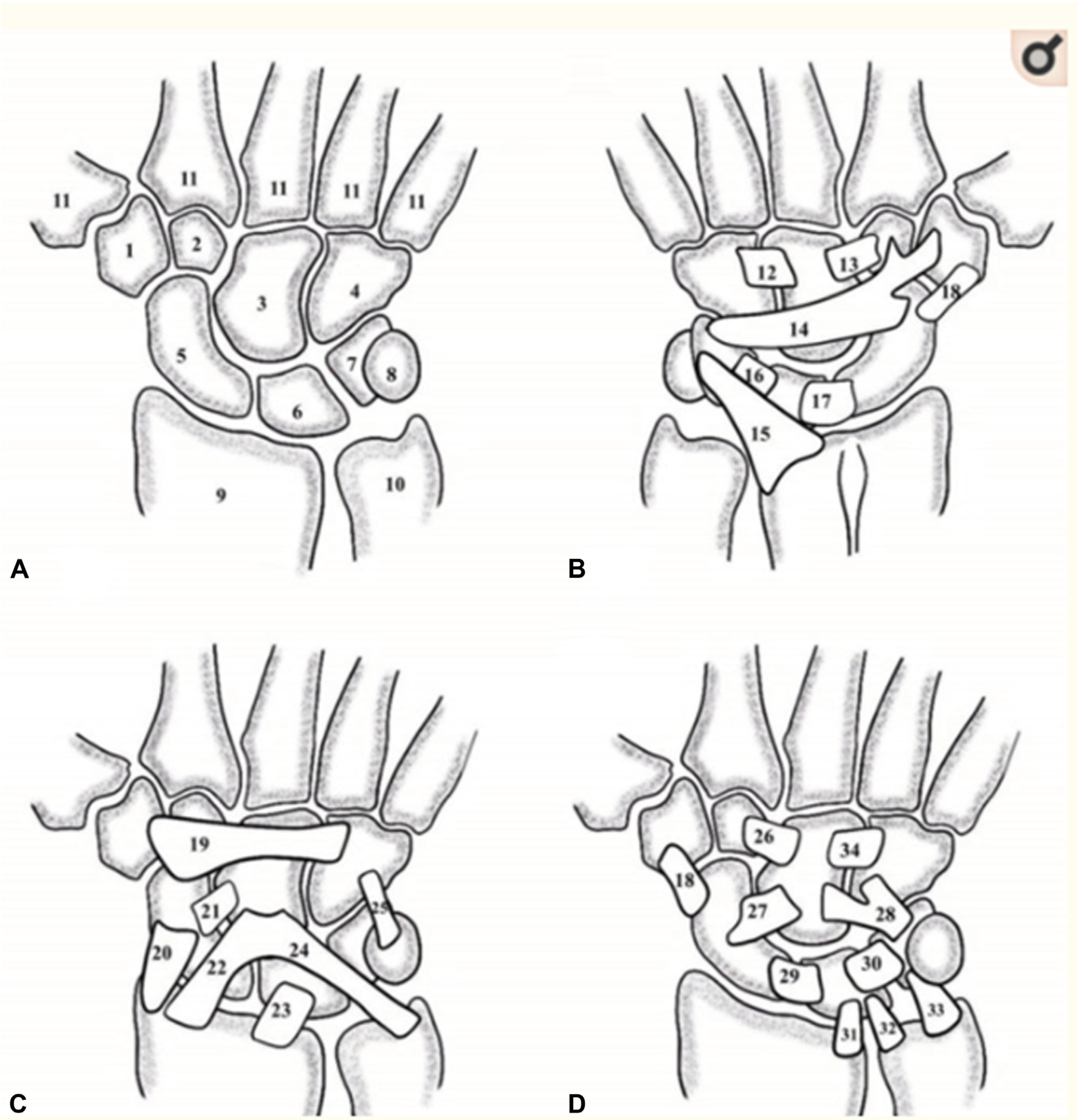

Figure 2. **A** The bones of the wrist: trapezium (1), trapezoid (2), capitate (3), hamate (4), scaphoid (5), lunate (6), triquetrum (7), pisiform (8), radius (9), ulna (10), and the bases of the metacarpals (11). **B** The dorsal wrist ligaments: dorsalcapitohamate (12), dorsal capitotrapezoid (13), dorsal intercarpal ligament (14), radiotriquetral (15), dorsal lunotriquetral (16), dorsal scapholunate (17), and dorsolateral scaphotrapeziotrapezoid (18). **C** The palmar superficial wrist ligaments: transverse carpal ligament (19), radioscaphoid (20), scaphocapitate (21), radioscaphocapitate (22), long radiolunate (23), ulnocapitate (24), and pisohamate (25). **D** The palmar deep wrist ligaments: palmar capitotrapezoid (26), scaphocapitate (27), triquetral-hamate-capitate (28), palmar scapholunate (29), palmar lunotriquetral (30), short radiolunate (31), ulnolunate (32), ulnotriquetral (33), and palmar capitohamate (34). Adapted with permission from Konopka et al.[13]

of the radius. Additionally, the finger extension test loads the carpal joints and can be sensitive for carpal pathology. In this test, the patient's wrist is passively flexed, and the examiner resists index and long finger extension, eliciting pain in a positive test.[30] The SLIL may also be tested with the scaphoid lift test. With the elbow on the table and the forearm fully pronated, the lunate is stabilized in one hand, and the scaphoid tubercle is pushed upward in an attempt to translate the scaphoid in relation to the lunate, with pain indicating the test is positive.[30]

Imaging

SLIL injuries should be evaluated with standard posteroanterior (PA), lateral, and oblique radiographs and comparative

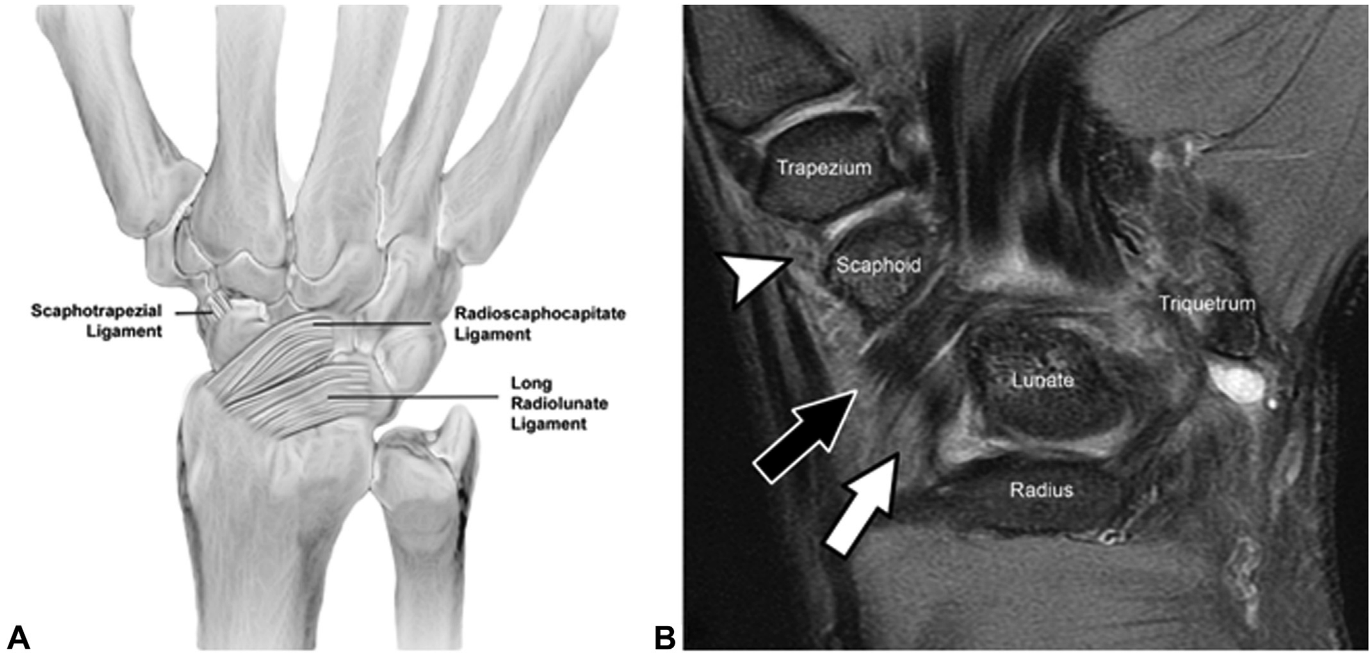

Figure. 3. Volar secondary stabilizers. **A** Diagram of the volar aspect of the wrist shows the three volar secondary stabilizers of the scapholunate joint. **B** Coronal PDW fat-suppressed MR image of the volar aspect of the wrist shows the STT ligament (arrowhead), radioscaphocapitate ligament (black arrow), and long radiolunate ligament (white arrow). (Adapted with permission from Palisch et al[101]).

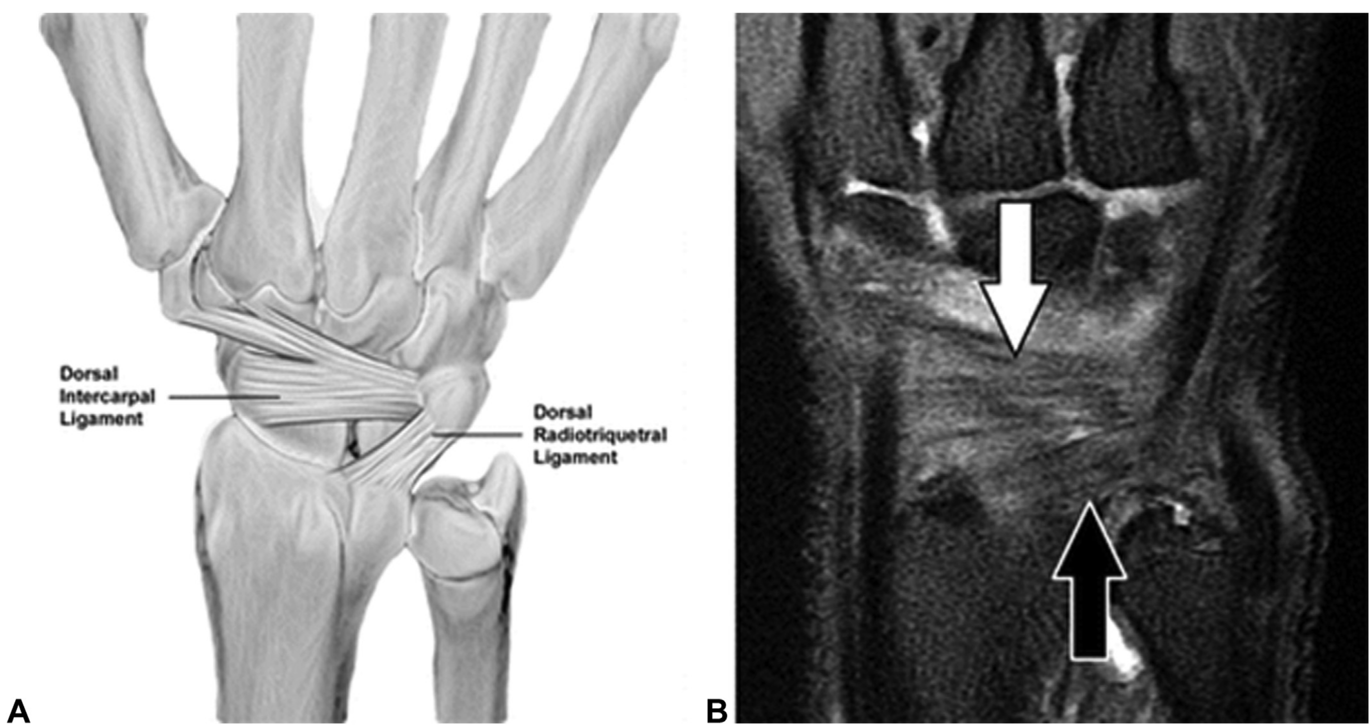

Figure 4. Normal dorsal secondary stabilizers. **A** Diagram of the dorsal aspect of the wrist shows the two dorsal secondary stabilizers of the scapholunate joint. **B** Coronal PDW fat-suppressed MR image of the dorsal aspect of the wrist shows the DRT ligament (black arrow) and DIC ligament (white arrow). (Adapted with permission from Palisch et al[101]).

contralateral views (Fig. 7). The stages of SLIL injury based on imaging are outlined in Table 2. Notable findings include incongruity of carpal arcs (Gilula's lines), intercarpal distance, and angle abnormalities, whereas SL diastasis ("Terry Thomas sign"), a positive ring sign, and dorsal scaphoid rotation indicate more serious injury (Fig. 8).[31]

On PA films, the width of the SL gap should be less than that of the lunotriquetral gap, with an SL gap of 2.5 mm being sensitive, specific and likely to identify an SLIL injury on an unstressed view.[32] However, baseline comparison with the uninjured side is essential given anatomic variants of larger SLIL gaps. Foreshortening and abnormal vertical positioning of the

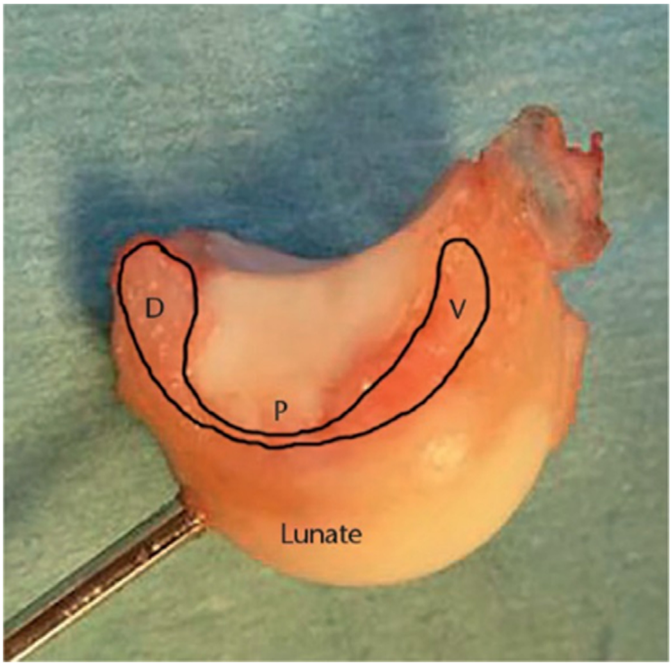

Figure 5. The scapholunate ligament is C-shaped and has dorsal (D) proximal (P), and volar (V) components. (Adapted with permission from Anderrson et al[102]).

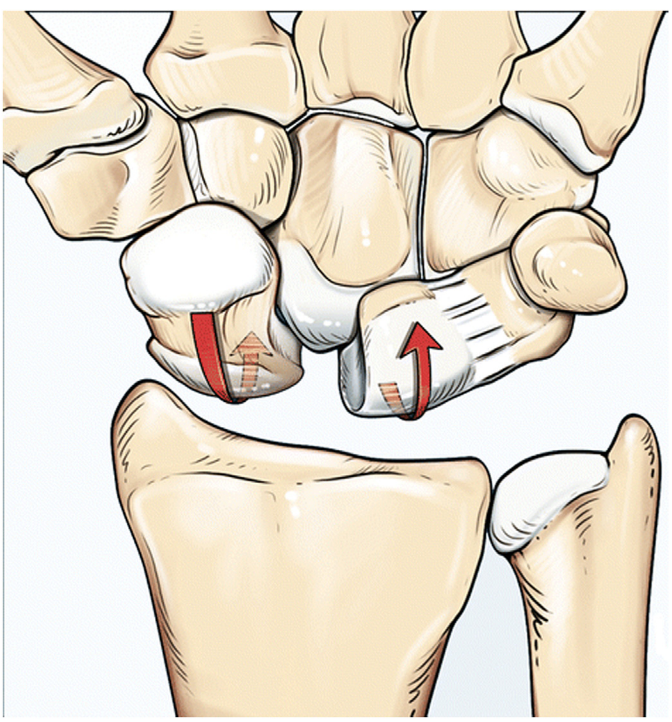

Figure 6. Biomechanics of SLIL injury. With failure of the scapholunate interosseous ligament or partial tear of the dorsal intercarpal ligament, dorsal radiocarpal ligament, or a critical volar ligament, such as the scaphotrapeziotrapezoid ligament or the long radiolunate ligament, there is loss of the normal alignment and consequent movement between the scaphoid and lunate. With axial load, the scaphoid preferentially flexes volarly, while the lunate, being pulled by the triquetrum with an intact lunotriquetral ligament, dorsiflexes (arrows) (Used with permission from Flores et al, 2021[103]).

Table 1
SLIL Examination Maneuvers

Exam Name	Description	Positive Test
Scapholunate ballottement	Stabilize the lunate and displace the scaphoid in a dorsal-palmar direction	Motion between scaphoid and lunate
Watson shift	Examiner applies volar pressure over the patient's scaphoid and passive motion of the patient's metacarpals from ulnar deviation extension to radial deviation with slight flexion	Dorsally subluxation of the scaphoid from its fossa on the distal radius during this maneuver occurs with SLIL incompetency and release of volar pressure over the scaphoid will produce pain or a painful clunk as the scaphoid reduces back over the dorsal rim of the radius
Finger extension	Patient's wrist is passively flexed, and the examiner resists index and long finger extension	Pain with maneuver
Scaphoid lift	With the patient's forearm fully pronated, the examiner stabilizes lunate in one hand and pushes scaphoid tubercle upward in an attempt to extend the scaphoid in relation to the lunate	Pain with maneuver

scaphoid is represented by ring shaped density over the scaphoid on a PA view when visualizing the distal half of the scaphoid end on. Decreased carpal height based on a fixed ratio between the length of the third metacarpal and length of a line drawn from the base of the third metacarpal to the distal part of the radius of less than 0.54 is also indicative of injury.[33] SL dissociation is represented on a lateral film by dorsal translation of the scaphoid. Additionally, a scapholunate angle (angle between the long axis of the scaphoid and lunate with a normal value between 30º and 60º) greater than 70º is consistent with a DISI deformity.

A widened interval between scaphoid and lunate identified only on a clenched PA pencil grip view suggests SLIL dynamic instability (Fig. 9). Additional carpal stress views (axial loading, ulnar deviation, and distraction) may also indicate malalignment. Improvements in magnetic resonance imaging (MRI) sensitivity, specificity, and negative predictive value of SLIL injury through dedicated true plane reformats of 3D T2 Dual Echo Steady State has increased its utility as a supplement to the clinical findings.[34] MRI provides further benefit by analyzing concomitant pathologic radiographic findings including other carpal ligament tears, triangular fibrocartilage complex injuries, capsular impingement, and tendonitis. CT and fluoroscopy can also provide useful information to supplement the clinical exam.

Radiographic films, best suited for static injuries, are primarily used to diagnose suspected SLIL injuries.[35] However, early SLIL injuries tend to be dynamic, requiring imaging such as cineradiography, four-dimensional computed tomography (CT), and cine MRI. For SLIL tears, direct arthroscopy enhances the diagnostic accuracy of both CT and MRI from 56% to 100%. Newer radiographic technology, namely, cone-beam CT (CBCT), has also been shown to detect wrist ligament and cartilage defects, and its reduced effective radiation dose may increase its popularity.[36]

At our institution, we rely mainly on MRI to assess intercarpal ligament injuries, with a 3T magnet preferred due to its superior resolution compared to a 1.5T magnet as the sensitivity and specificity of 3T MR for SLIL tears are 70% to 90% and 94% to 100%, respectively (Figs. 10–12).[35,37]

Proton density scans with fat suppression achieve the best signal-to-noise ratio in an MRI of the carpus.[37] The patient is positioned in the isocenter of the scanner magnet in the "superman" position. Coronal and sagittal views are obtained, with 2 mm

Figure 7. Scapholunate interval in a 20-year-old male collegiate football player. One should use caution when using upper limits in scapholunate interval measurement, and it is important to compare sides. **A** Static posteroanterior radiograph of the asymptomatic left wrist shows a scapholunate interval of 4.5 mm. **B** Static posteroanterior radiograph of the symptomatic right wrist shows a scapholunate interval of 6 mm. (Adapted with permission from Palisch et al[101]).

axial view slices collected between the proximal radius and ulna and the distal capitate. Coronal and axial images best visualize dorsal and volar fibers. On coronal plane slices showing an intact dorsal band, dark linear fibers are attached to the scaphoid and lunate. If direct visualization of SLIL rupture is not present, dorsal

Table 2
Stages of SLIL Injury by Imaging

Stage*	Imaging findings (Figs. 13–17)
1	Occult injury or partial tear with normal X-rays
2	Dynamic tear with an incompetent SLIL, normal static X-rays, abnormal stress views
3	SLIL disruption
4	Dorsal intercalated segment instability (DISI)
5	Scapholunate advanced collapse (SLAC)

* Injuries can progress beyond Stage 5 and include lunate dislocations, perilunate instability, and scaphoid dislocations.

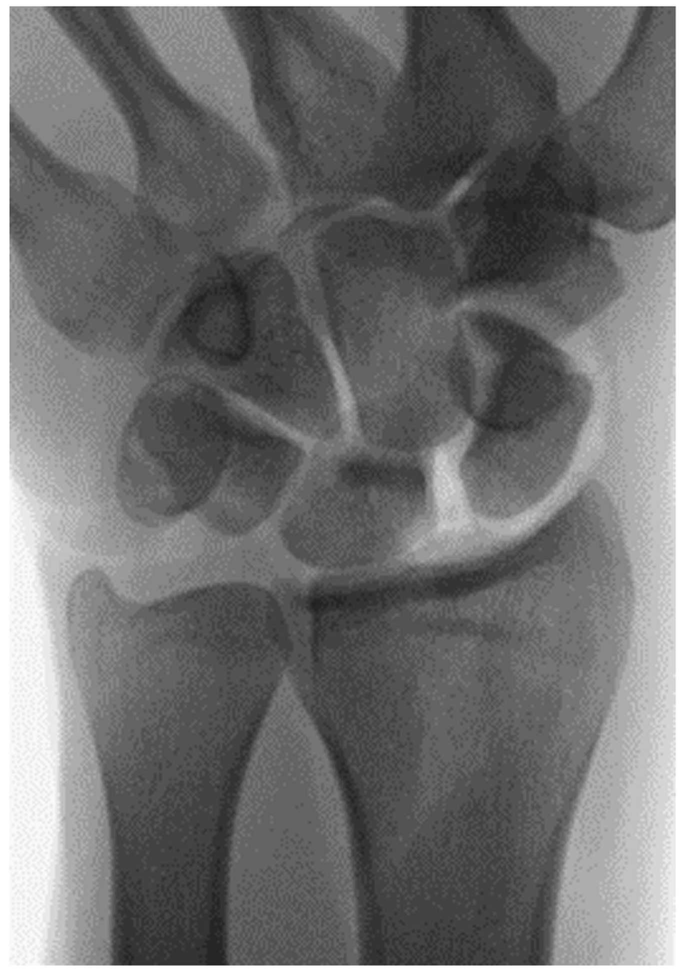

Figure 8. Posteroanterior view of the left wrist demonstrating SL widening ("Terry Thomas sign") and a signet ring sign, suggesting SL injury with rotatory subluxation.

scaphoid translation and cartilage loss in the sagittal view are secondary signs of SLIL injury (Fig. 10).[37]

Diagnostic arthroscopy

The gold standard for carpal ligament injury diagnosis is wrist arthroscopy, which can demonstrate instability of the scapholunate interval with step off in the radiocarpal and midcarpal joints (Geissler III and IV, Table 3). Typically, the 3–4, 6R, and midcarpal portals are used. The radiocarpal joint is insufflated with saline through the 3–4 interval. Interosseous ligament injuries can reveal palpable distension of the midcarpal joint during injection.[38]

The SLIL is best viewed through the 3–4 portal and should appear concave as viewed from the radiocarpal space (Fig. 17). The

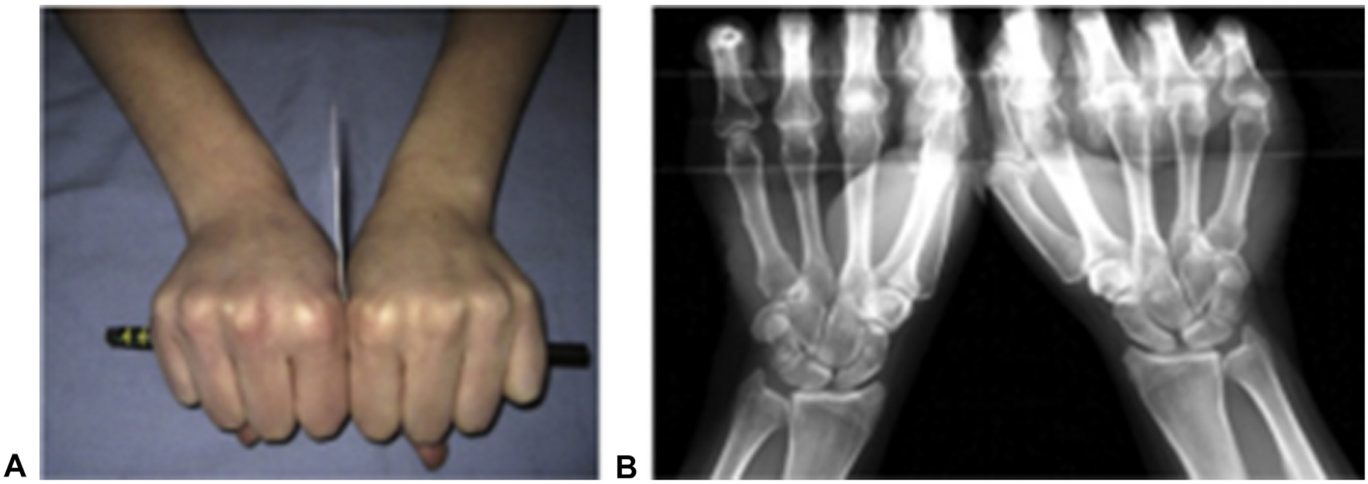

Figure 9. Pencil grip view demonstrating the following: **A** proper patient position and **B** the radiographic image demonstrating scapholunate interval widening on the right. (From Lee SK, Desai H, Silver B, Dhaliwal G, Paksima N. Comparison of radiographic stress views for scapholunate dynamic instability in a cadaver model. J Hand Surg 2011;36A:1149–1157; with permission).

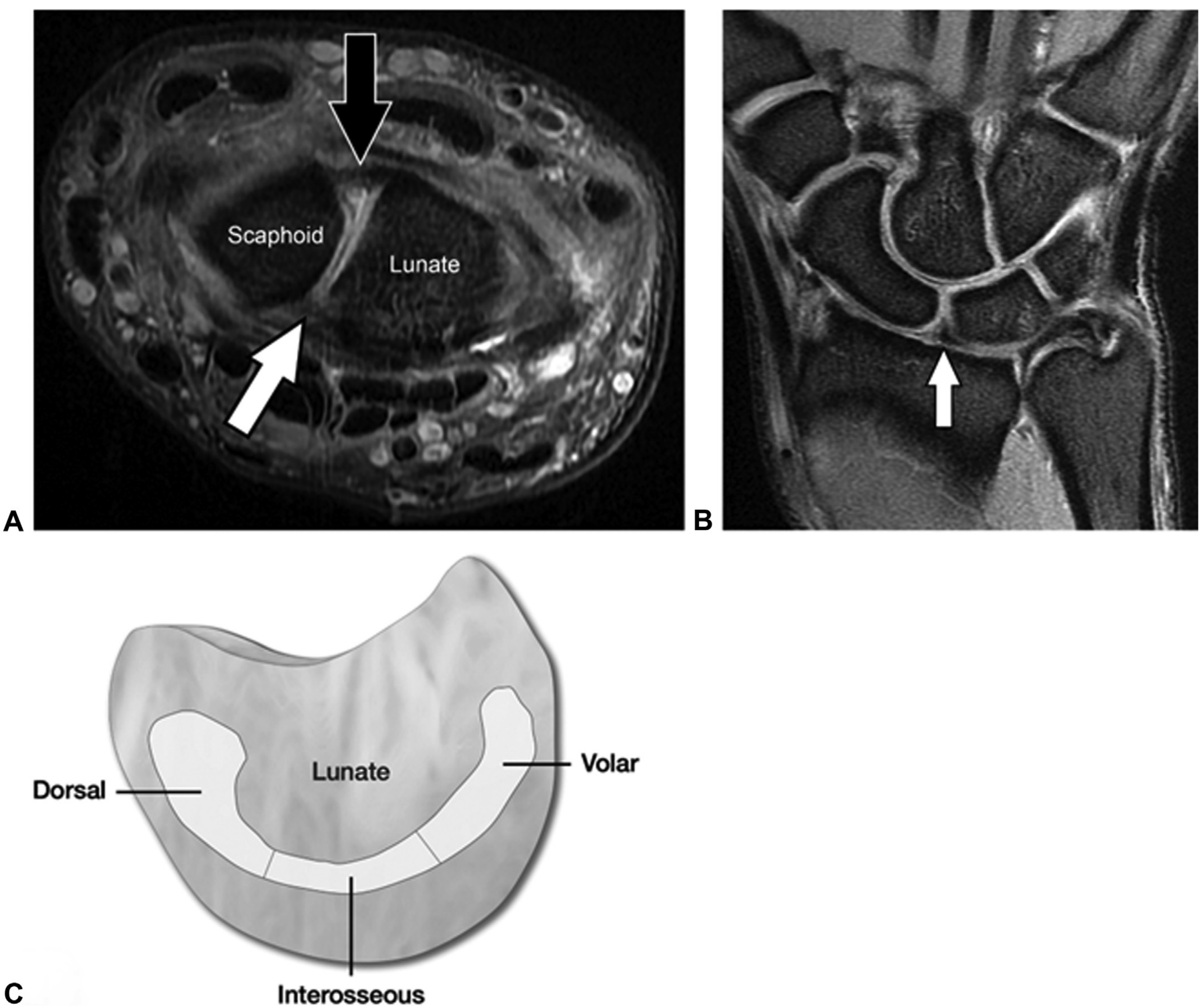

Figure 10. Normal SLIL. **A** Axial proton-density–weighted (PDW) fat-suppressed MR image shows the dorsal band (black arrow) and volar band (white arrow) of the SLL. **B** Coronal PDW fat-suppressed MR image shows the triangular interosseous band (arrow). **C** Diagram shows the dorsal, volar, and interosseous bands of the SLL. (Adapted with permission from Palisch et al[101]).

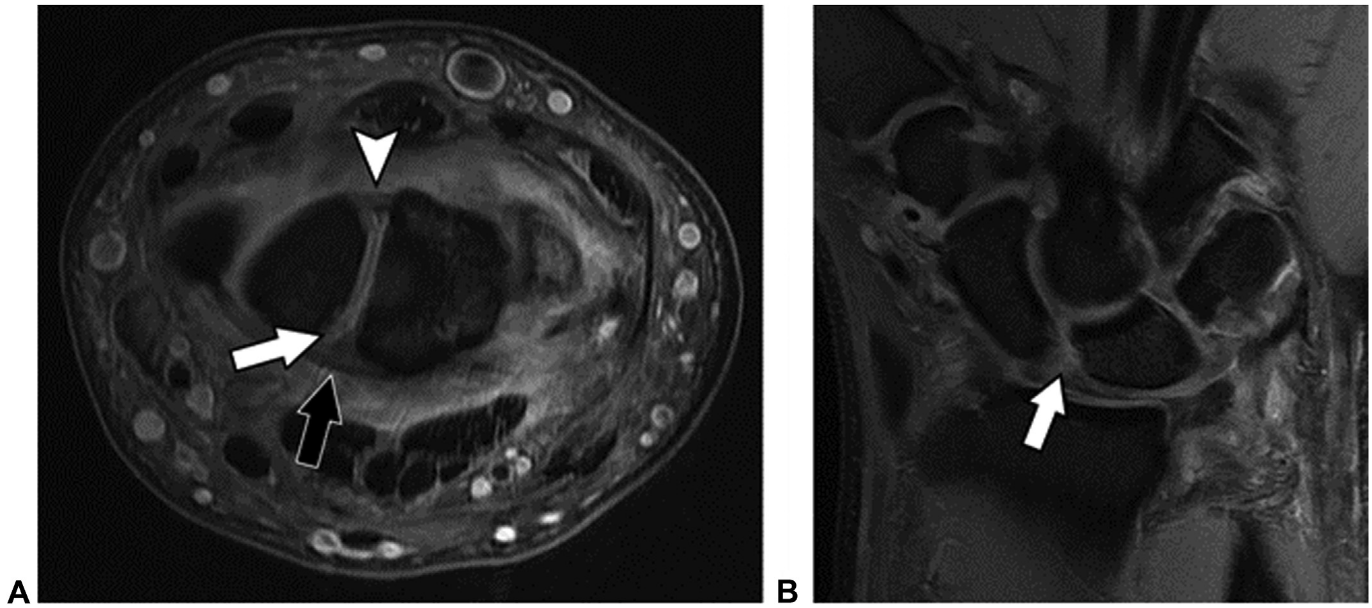

Figure 11. Stage 1 SLIL injury in a 22-year-old professional American football player. The scapholunate interval and angle were within normal limits on static posteroanterior, dynamic clenched fist, and pallateral radiographs. **A** Axial PDW fat-suppressed MR image shows an intact SLIL dorsal band (arrowhead) and torn SLIL volar band (white arrow), which were confirmed at surgery. A normal long radiolunate ligament (black arrow) courses directly over the torn SLIL volar band and can be mistaken for an intact SLIL volar band. **B** Coronal PDW fat-suppressed MR image shows partial tearing (arrow) extending to the SLIL interosseus band. (Adapted with permission from Palisch et al[101]).

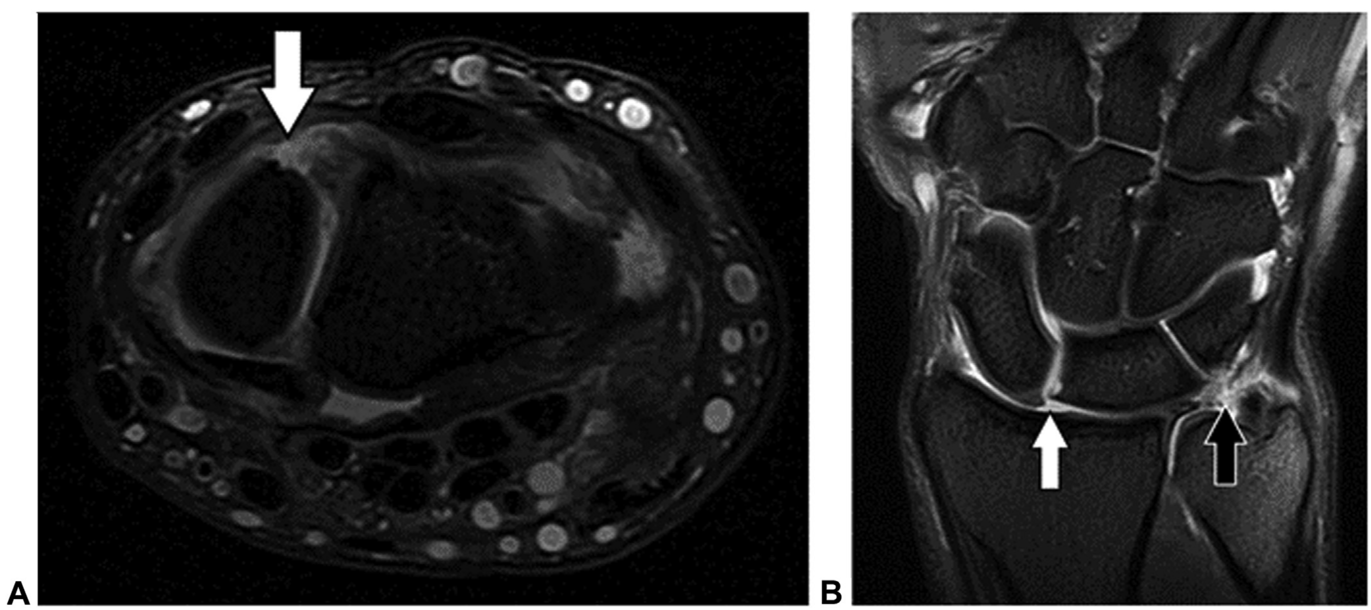

Figure 12. Stage 2 SLIL injury in a 26-year-old professional basketball player with a recent fall on an outstretched hand. The scapholunate interval and angle were within normal limits on static posteroanterior, dynamic clenched fist, and lateral radiographs. **A** Axial PDW fat-suppressed MR image shows a torn SLIL dorsal band (arrow) from the scaphoid. **B** Coronal PDW fat-suppressed MR image shows a torn SLIL interosseus band (white arrow) and an incidental tear of the central triangular fibrocartilage (black arrow). Reparability of the SLIL dorsal band can be suggested with imaging if the tear appears noncomplex and nonelongated but is ultimately determined at surgery. (Adapted with permission from Palisch et al[101]).

SL interval should be tight and congruent without step-offs in the midcarpal space compared to the lunotriquetral (LT) interval, where a 1-mm step-off and slight motion between the bones is normal. Attenuated SLIL hangs down and blocks arthroscopic visualization in the radiocarpal space from the 3–4 portal as the normal concave appearance between carpal bones becomes convex. An unobstructed view in the midcarpal space is best to observe any abnormal motion, separation, or the degree of rotation of the bones.[39] The camera can then be positioned from the 6R portal to identify any dorsal capsular injury. Anatomically, communicating fibers of the DIC ligament insert on SLIL with dorsal capsular bowing. If injured, this arch or septum is absent, and no resistance will be felt as the probe moves dorsally towards the midcarpal joint (Fig. 18).

The midcarpal-radial (MCR) and midcarpal-ulnar (MCU) portals are created 1 cm distal to the 3–4 and 4–5 portals, with

Table 3
Overview of Classifications of SLIL Pathology*

Classification Type	Description		
Temporal		Acute Subacute Chronic	
Structural	Imaging	Radiographs	Static radiographs—complete static dissociation Dynamic radiographs/ fluoroscopy— complete dynamic dissociation
		MRI (Figs. 12–17)	Incomplete and partial Dorsal band Membranous Volar band Complete—dynamic or static
	Arthroscopic	Geissler classification	See Table 5 for detail
	Operative	Incomplete	
		Complete	Dynamic Static Reducible Irreducible

* Adapted with permission from Ross et al.

instability noted and graded per Geissler Classification (Table 4).[28] A volar radial portal can be added for better visualization of volar SL and DRC ligaments. The arthroscope typically starts in the MCR portal, except in smaller wrists. Individuals with a normal interval have tight apposition of the scaphoid and lunate, without step-off or the ability to navigate the probe between them (Fig. 18C). As the level of injury increases, coronal plane instability is first observed with gapping between the carpal bones, followed by sagittal plane instability in the presence of associated extrinsic ligament injury and subsequent articular step-off in the mid carpal joint as the lunate flexes or extends relative to the scaphoid and triquetrum.

The Geissler classification is the most commonly used classification system for SLIL injuries (Table 4).[40] In Geissler grade I injuries, which are considered minor wrist sprains that resolve with immobilization, the SLIL appears convex instead of concave when visualized through the radiocarpal space but remains tight and congruent in the midcarpal space (Fig. 17). In Geissler grade II injuries, the SLIL is still convex in appearance through the radiocarpal portal but loses congruence in the midcarpal space. The scaphoid flexes palmarly, and its dorsal lip is rotated distal to the lunate when viewed from the MCU portal. In Geissler grade III injuries (Fig. 18B), the SLIL lesion has progressed to a tear, typically volar to dorsal progression, with a gap seen between the scaphoid and the lunate in the radiocarpal and midcarpal portals. A 1-mm probe may be passed through the gap and twisted from the midcarpal portal. However, occasionally, the gap is not visualized until a probe pushes the scaphoid away from the lunate as part of the dorsal portion of the SLIL is still attached. In Geissler grade IV injuries, the SLIL is completely torn, and the arthroscope can be freely driven in the SL interval from the radiocarpal to midcarpal spaces ("drive-through sign").

Clinical instability

In addition to arthroscopic and radiographic classification, SL instability has four clinical stages: predynamic instability, dynamic instability, reducible static instability, and nonreducible instability (Table 5).[37] Predynamic instability can be observed on physical examination but not radiographically (Geissler grade I or II). Dynamic instability involves complete tear of the SLIL but intact secondary stabilizers and can be observed radiographically when the wrist is loaded in ulnar deviation or the fist is clenched. Reducible static instability occurs in chronic or irreparable ligament tear when secondary stabilizers cannot reduce the SL dissociation, resulting in DISI deformity. However, the carpal subluxation remains reducible. In nonreducible instability, there is complete rupture of the SLIL and possible articular surface degeneration.[41]

Occult instability can occur with partial SLIL tear or with DIC ligament injuries without associated SLIL tear and typically improve with brief immobilization and therapy.[42,43] In symptomatic patients or athletes dependent on wrist motion, we prioritize early surgical treatment with arthroscopy, debridement, and thermal shrinkage. During arthroscopy, there is abundant synovitis with loss of the normal arch of the dorsal capsuloscapholunate septum (DCSS) is observed through the radiocarpal joint; probing the radiocarpal to midcarpal joint meets with minimal to no resistance (Fig. 19).

Conservative Treatment

Brief immobilization with short arm casts resolve most wrist sprains and intercarpal ligament injuries without radiographic abnormalities. For athletes, lower thresholds for further imaging and surgery can expedite return to play. For individuals with clinically suspected carpal ligament injuries but normal radiographs, immobilization and reevaluation at 4 weeks after injury may allow for pain, synovitis, and swelling to subside sufficiently in repeat provocative testing maneuvers. If splinting, activity modification, and anti-inflammatory medications are ineffective, arthroscopic and fluoroscopic confirmation of injury may be necessary.

Individuals with radiographic evidence of acute carpal ligament injury (static or dynamic) are indicated for early surgery given the narrow window for repair and preference for early intervention to ensure optimal outcomes.[44]

Surgical Options

Early diagnosis and intervention prevents the onset of fixed carpal malalignment.[45] Surgical treatments for a wide spectrum of SLIL injury include acute/subacute SLIL repair, SL and SLIL reconstruction, and salvage procedures, such as intercarpal fusions or wrist arthrodesis.[13] Many techniques exist for SL repair, and the best treatments are still debated in the literature.

Stratification of coronal and sagittal planes of deformity can address approaches to surgical management. To address coronal plane deformity, Garcia-Elias and colleagues[46] proposed five questions to help stratify stages of scapholunate injury and create algorithms for treatment (Table 6).[25] Sagittal plane instability results in rotary subluxation of the scaphoid that stems from additional injury or attenuation of the secondary ligamentous stabilizers and is best addressed with the addition of a dorsal capsulodesis. For this, we additionally consider the Wolfe principles of reconstruction emphasizing surgical techniques to stabilize the SL joint in both the coronal and sagittal planes (Table 7).[25]

Incomplete SLIL injury

Surgical treatment with arthroscopy, debridement, and thermal shrinkage may be indicated for patients with high demands on the wrist with stage one acute or chronic SLIL injuries with partial

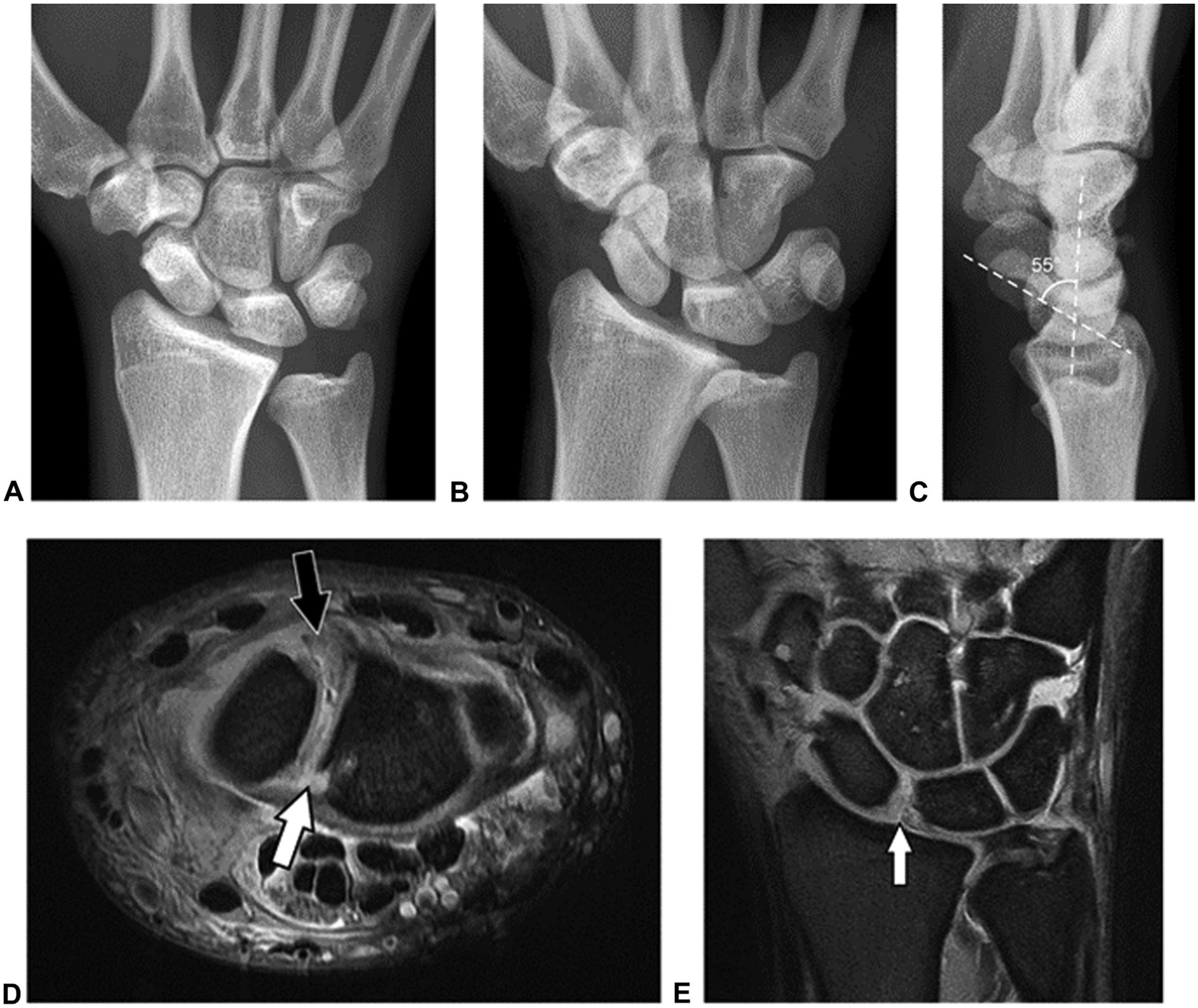

Figure 13. Stage 3 SLIL injury with normal static alignment in a 25-year-old professional American football player who experienced a fall 3 months earlier. **A** Static posteroanterior radiograph shows a scapholunate interval of 2.7 mm. **B** Dynamic clenched fist radiograph shows an increase in the scapholunate interval to 4 mm. **C** Lateral radiograph shows a normal scapholunate angle of 55°. **D** Axial PDW fat-suppressed MR image shows a torn SLIL dorsal band (black arrow) from the scaphoid attachment and a torn SLIL volar band (white arrow), which were confirmed at surgery. **E** Coronal PDW fat-suppressed MR image shows a torn SLIL interosseous band (arrow). Reparability of the SLIL dorsal band can be suggested with imaging if the tear appears noncomplex and nonelongated but is ultimately determined at surgery. (Adapted with permission from Palisch et al[101]).

ruptures and predynamic instability. Thermal shrinkage breaks heat sensitive protein bonds, inducing secondary fibroplasia and destruction of sensory receptors. The technique is performed after arthroscopic confirmation of a stable partial SL tear (Geissler grades I–II) and debridement of any unstable tissue flaps and synovium. A radiofrequency probe can be used to perform thermal shrinkage of the distal volar SL ligament through the midcarpal joint, taking care to maintain adequate irrigation to decrease the risk of thermal injury to surrounding cartilage (Fig. 20).

Immobilization or Kirschner wire (K-wire) fixation can also be used. In Geissler grade I and II ligament injuries, spica cast immobilization is recommended. In Geissler grade III injuries, two 1.4-mm (0.045 in) K-wires are used to transfix the scapholunate joint and protect the ligament for 6 weeks, after which the short arm thumb spica cast and K-wires are removed. Reduction and fixation is performed under fluoroscopy or arthroscopic visualization from the ulnar midcarpal portal. Multiple case series suggest patients experience symptomatic relief from this procedure.[47–49] Outcomes from arthroscopic debridement and electrothermal shrinkage in stage 1 SLL injuries reveal high rates of pain relief and strength comparable to the contralateral limb.[47,50]

DIC ligament injuries can also result in occult instability without associated SL ligament tear (Fig. 21). For patients who complain of pain, a debridement followed by immobilization may suffice. For patients who complain of instability, a capsuloplasty can be performed in which the DCSS is repaired using a single suture anchor placed on the dorsal aspect of the lunate. Alternatively, a 3-0 PDS suture at the 3–4 portal can be advanced through the dorsal SL into the midcarpal joint and tied down over the dorsal capsule with the wrist in extension. After surgery, the patient is placed in a short arm cast for 4 weeks, followed by therapy and return to full activity at 12 weeks.

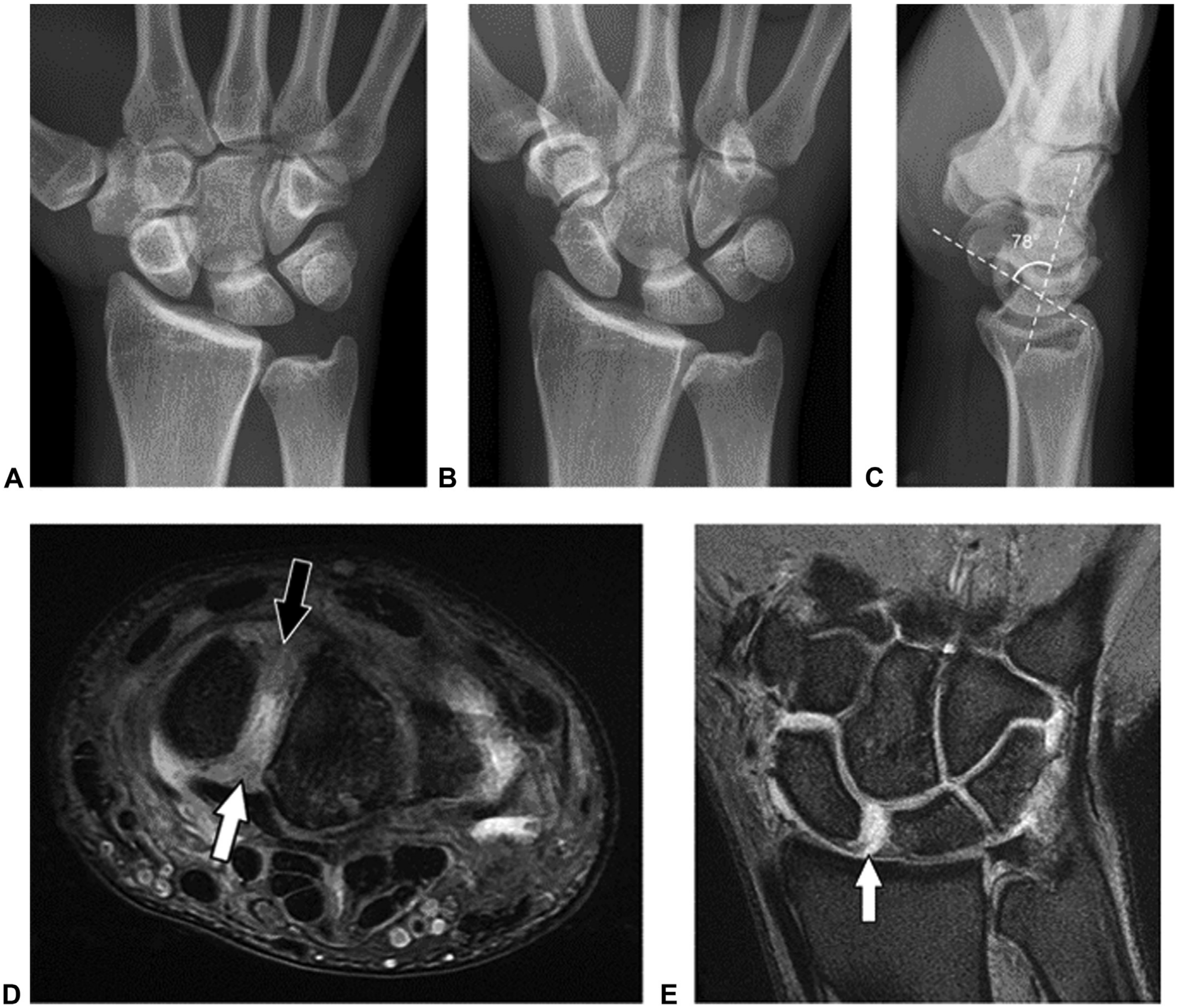

Figure 14. Stage 3 reducible malalignment in a 23-year-old professional American football player with a remote injury. **A** Static posteroanterior radiograph shows a scapholunate interval of 4.5 mm. **B** Dynamic clenched fist radiograph shows an increase in scapholunate interval to 5 mm. **C** Lateral radiograph shows that the scapholunate angle is increased to 78° with dorsal tilting of the lunate, compatible with DISI. **D** Axial PDW fat-suppressed MR image shows a torn SLL dorsal band (black arrow) and torn SLL volar band (white arrow) with scar tissue. **E** Coronal PDW fat-suppressed MR image shows a tear (arrow) of the SLIL interosseous band and scapholunate interval widening. Stage 3 reducible malalignment and stage 4 irreducible malalignment injuries have similar imaging appearances and are differentiated on the basis of reducibility during fluoroscopic traction or surgery. If the malalignment is reducible during fluoroscopic traction or surgery, the patient can undergo SLIL reconstruction. If the malalignment is not reducible, the patient can undergo a salvage procedure. (Adapted with permission from Palisch et al[101]).

Complete SLIL tear amenable to repair

Complete reducible SL instabilities may be amenable to repair. It is important that surgical repair or reconstruction stabilizes the carpus in both coronal and sagittal planes to ensure optimal outcome.[25] Chronicity, host biology, tear morphology, and concomitant injuries dictate ligament viability with repair, but typically 1–2 months from injury, the SLIL is still strong enough to hold a repair.[13,51,52] Static SL interval diastasis occurs with dorsal scaphotrapezial and DIC ligament injuries. Scaphoid flexion and rotatory subluxation occurs with scapho-trapezial-trapezoid injuries. Scaphoid (most common) or lunate avulsions tend to have a greater capacity to heal than midsubstance ruptures.[25] Superiority of arthroscopic versus open repair has not been reported; however, general practice is to use arthroscopy for Geissler grade I–III lesions and open approaches for Geissler grade IV lesions. Arthroscopic reduction and fixation may be adequate in Geissler grade III injuries that do not require full reconstruction, allowing for swifter recovery and minimal soft tissue disruption and potentially decreased stiffness. All-inside arthroscopic techniques have been described by Del Piñal et al[53] for suturing of the palmar scapholunate with dorsal capsuloligamentous plication with promising results.[54]

Our preference for complete SLIL injuries sustained within 8 weeks is to perform an open reduction and dorsal ligament repair with internal fixation with or without capsulodesis using a dorsal ligament sparing approach. In a typical reduction, K-wires are placed into the scaphoid and lunate and used to “joystick” scaphoid proximal and ulnar while the lunate is translated distal and radial. Definitive fixation is accomplished with suture anchors or

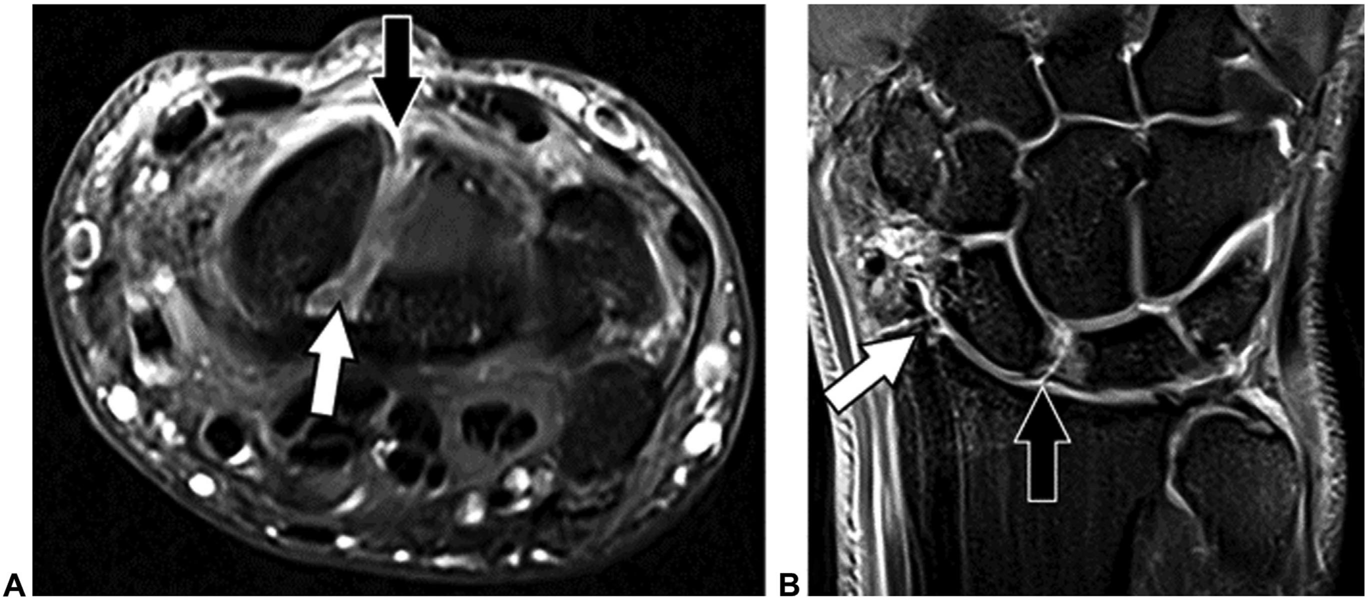

Figure 15. Stage 5 SLIL injury in a 30-year-old professional American football player. **A** Axial PDW fat-suppressed MR image shows a torn SLIL dorsal band (black arrow) and torn SLIL volar band (white arrow). **B** Coronal PDW fat-suppressed MR image shows cartilage loss, most prominent at the articulation of the radial styloid and scaphoid, with osteophyte formation (white arrow) and a torn SLIL interosseous band (black arrow). (Adapted with permission from Palisch et al[101]).

Figure 16. Scapholunate (SL) advanced collapse after an SL injury, with subsequent arthritic changes at the radiocarpal and mid-carpal joints (SL advanced collapse - SLAC III). Also note the volarly flexed scaphoid appearing triangular distally with the so-called "ring sign." (Adapted with permission from Andersson et al).

transosseous sutures and protected with percutaneous K-wires for 8–10 weeks after surgery.

Chronic SLIL tear requiring surgical reconstruction

Indications for SL reconstruction include chronic reducible injuries, injuries with insufficient tissue, and injuries with minimal or no cartilage damage on arthroscopy. A variety of techniques, including tendon reconstructions, tenodesis, bone-tendon-bone reconstruction, and scapholunate screw, all aim to correct the rotatory deformity of the scaphoid and maintain carpal alignment. The many approaches have variable results in part attributed to the multitude of factors that need to be addressed with a SLIL reconstruction, including the chronicity of the injury, location of SLIL injury (dorsal, volar, or complete), the integrity of the secondary stabilizers, lunate alignment, and reducibility of the carpus.[55–65] Reconstruction can often be achieved with local tendon grafts or creation of a fibrous nonunion at the SL joint.[13] However, if the SL joint has lost its primary and secondary stabilizers, additional tissue may be necessary to support the reconstruction.[13]

Brunelli and Brunelli scaphotrapezoid tenodesis

This SLIL reconstruction technique aims to reinforce both primary and secondary stabilizers.[13] In this technique, the flexor carpi radialis (FCR) tendon proximally is divided proximally, maintaining the insertion at the base of the second metacarpal. The tendon is tunneled from the scaphoid tuberosity palmarly to the neck of the scaphoid dorsally and inserted into the dorsal radius at the origin of the dorsal radiocarpal ligament.[13]

Reduction–association of the scapholunate

Rosenwasser et al[61] developed the reduction and association of the scaphoid and lunate (RASL) procedure to close the scapholunate gap with a Herbert screw, which creates a mobile synchondrosis between the scaphoid and lunate.[13,51] Once SL stability is achieved, the screw is removed. This approach does not address secondary stabilizers but can be combined with tendon reconstructions for additional stability.[13] The advantage of a screw

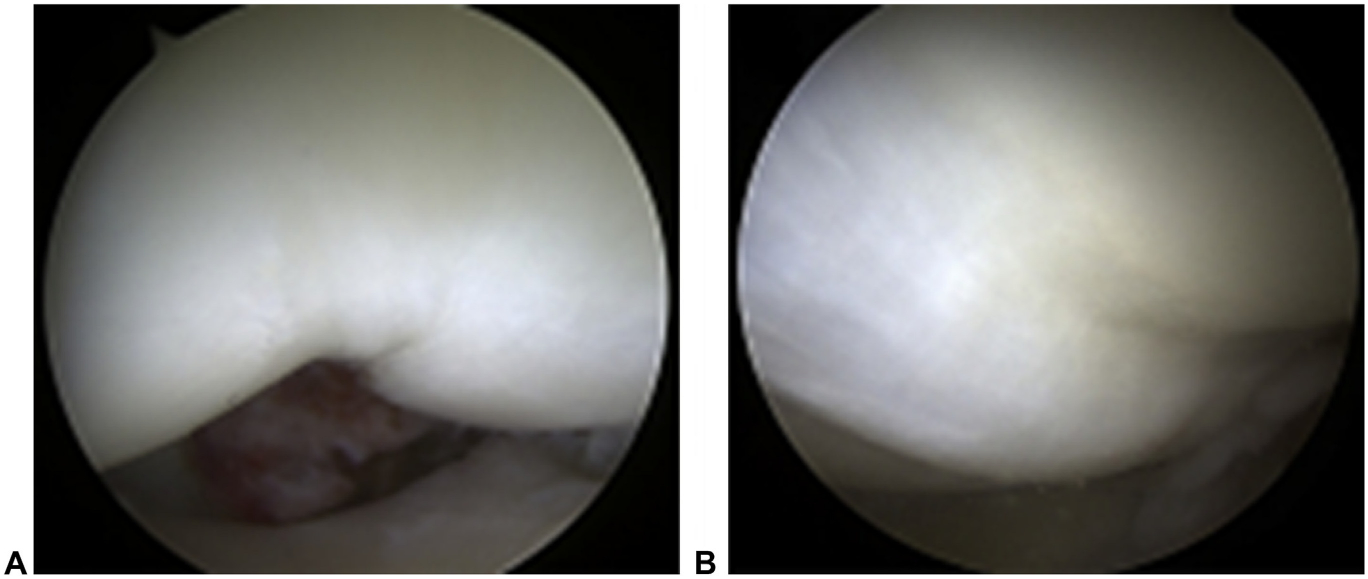

Figure 17. SLIL viewed through the 3–4 portal with **A** normal appearance and **B** abnormal appearance with loss of concavity and laxity observed.

over k-wires is that a screw may allow for early motion, which may be important in athletes. We transition patients after a RASL procedure to a removable brace at 1–2 weeks and initiate therapy at that time. The screw is retained for 6–9 weeks or a minimum of 3 months, with planned removal at that time.[52]

Three-ligament tenodesis

Three-ligament tenodesis (TLT) is the Garcia-Elias modification to the Brunelli technique.[38] TLT uses the FCR tendon to reconstruct the scaphotrapezium/trapezoid (STT) complex and the dorsal SLIL segment.[51] In this procedure, a dorsal ligament sparing capsulotomy is performed. A guide wire for a cannulated 3.2 mm drill is advanced from the dorsal SLIL origin to the palmar distal scaphoid tuberosity under fluoroscopy (Fig. 21). A palmar incision is made over the scaphoid tuberosity. Then, an 8 cm distally based strip of FCR is then passed through the scaphoid tunnel, secured to the lunate with a suture anchor, and tensioned around the radiotriquetral ligament and secured to itself (Fig. 22). The scapholunate and scaphocapitate joints are then transfixed with two 1.4-mm (0.045 in) K-wires to protect the reconstruction, and the wrist is immobilized in a short arm thumb spica for 6 weeks. Return to play is allowed 6–9 months after surgery.

The Ross modification of the TLT brings the FCR tendon through transosseous tunnels in the scaphoid, lunate, and triquetrum and finally fixes the tendon into the triquetrum with an interference screw.[13] The remainder of the tendon is then secured to the DIC ligament.

For stage 4 SLIL injuries with additional injury to the radiolunate ligaments and an ulnarly displaced lunate, the “antipronation spiral tenodesis” modification can be performed.[13] The FCR tendon is tunneled through the scaphoid, translated dorsally across the lunate, pulled from the dorsum of the triquetrum to the palmar aspect of the triquetrum through an interosseous tunnel, and inserted onto the radial styloid.[13]

Anatomic front and back

The anatomic front and back (ANAFAB) approach includes two additional stabilizers. This procedure reconstructs the STT complex, the dorsal SLIL segment, and the long radiolunate ligament.[51]

Arthroscopic SL ligamentoplasties

Corella et al[66] modified the TLT to an arthroscopic approach. In this procedure, the FCR tendon is pulled dorsally through a transosseous tunnel in the scaphoid and then palmarly through a transosseous tunnel in the lunate. At each tunnel, the tendon is fixed in place with interference screws. The remaining FCR tendon is sutured to the volar surface of the scaphoid.[13]

Scapholunate 360 procedure

The SL 360 technique reconstructs both the dorsal and volar SLIL, supports loads across multiple planes, prevents ulnar translation of the lunate, and uses a distal tether to prevent scaphoid flexion.[67] Use of synthetic tape instead of K-wires offers immediate stability for early mobilization. The tape is weaved through cannulations within the interference screws, which decreases the size of bone tunnels and risk of postoperative fracture.[67]

Dorsal capsulodesis

Dorsal capsulodesis is an important component of SL ligament repair in patients with sagittal instability. Various capsulodesis techniques have been described, including all arthroscopic techniques, a proximal radius-based flap, a radial-based DIC capsulodesis, and an ulnar-based DIC ligamentoplasty (69,70) fixed to the scaphoid or lunate.[42,68–71] A dorsal capsuloplasty using a modified Viegas approach has also been described to treat partial SLIL tears in young athletes.[72]

The Blatt technique uses a portion of the radioscaphoid capsule to extend the scaphoid.[68] Using a dorsal approach to the carpus with a radially based ligament sparing capsulotomy (Fig. 23), two 1.6-mm (0.062 in) K-wires are inserted into the lunate and scaphoid as joysticks to assist with reduction at the planned insertion site of a suture anchor.[73] The carpus is stabilized with two 1.4-mm (0.045 in) K-wires through the scapholunate and scaphocapitate joints, and then a dorsal ligament repair is performed using suture anchors (Fig. 24).[74] The suture from the anchor is left intact, and half of the DIC ligament that was maintained on the distal scaphoid is brought over and attached to the dorsal scaphoid and lunate reinforcing the SL repair and completing the capsulodesis (Fig. 25). The capsulotomy is then closed to the dorsal radiotriquetral ligament. The pins are cut beneath the skin, and the wrist is

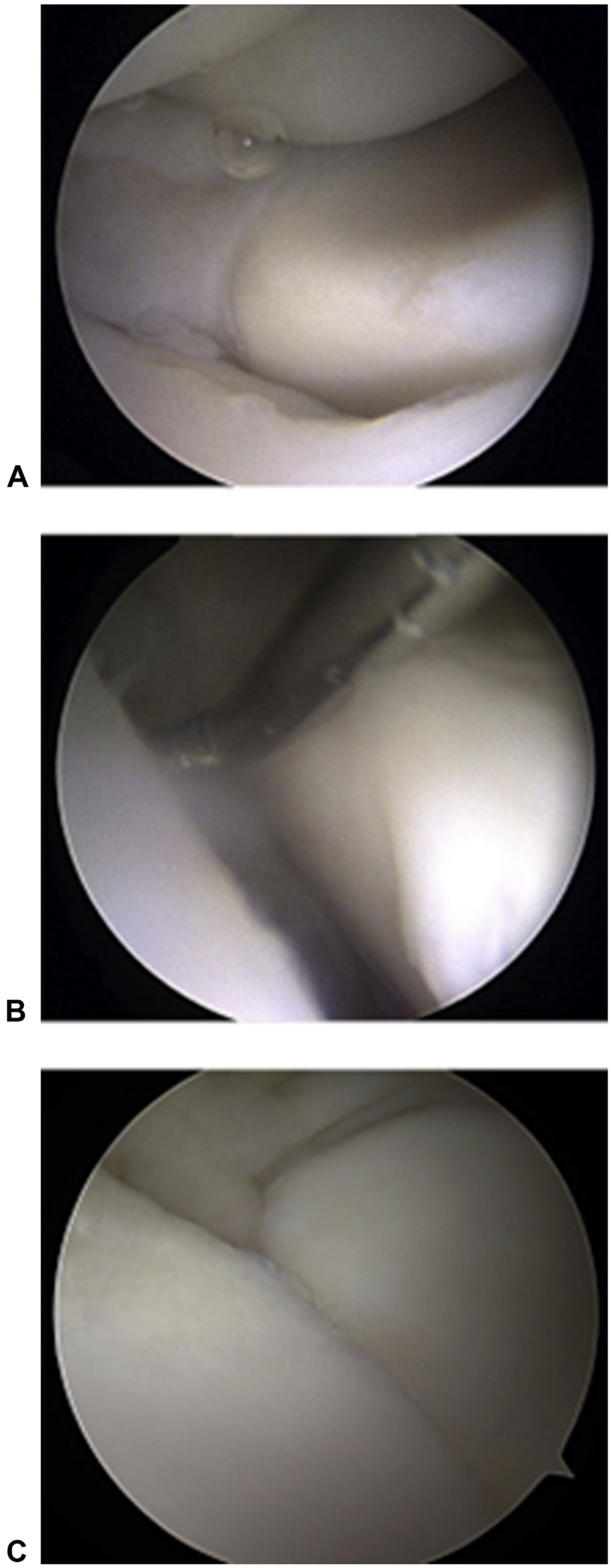

Figure 18. Scapholunate interval viewed through the midcarpal radial portal demonstrating **A** abnormal widening suggestive of SL injury determined to be **B** Geissler grade III on probing. **C** Normal SL interval for comparison with tight apposition of the scaphoid and lunate. (Adapted with permission from Gire et al, 2019[104]).

Table 4
Modified Geissler Classification[31]

Grade	Arthroscopic findings in Modified Geissler classification of SLIL injury
I	SLIL attenuation/hemorrhage, no intercarpal incongruency
II	SLIL attenuation, intercarpal incongruency, 1 mm probe can be passed but not rotated through carpal gap
III	SLIL attenuation, intercarpal incongruency, 1 mm probe can be passed and rotated through carpal gap from midcarpal space to radiocarpal space, cannot pass 2.7 mm arthroscope
IV	Drive-through sign* with 2.7 mm scope

* Drive-through sign is when the arthroscope can drive through from the midcarpal joint to the radiocarpal joint.

Table 5
Overview of Clinical Stages of SLIL Instability

Stage of Instability	Description
Predynamic	Only clinical instability present
Dynamic	Complete SLIL tear with intact secondary stabilizers, visualized with ulnar deviation or clenching of the fist during radiograph
Reducible Static	Chronic or irreparable ligament tear with loss of secondary stabilization, DISI deformity, but reducible carpal subluxation
Nonreducible	Complete SLIL rupture, possible articular surface degeneration

immobilized in a short arm cast for 6–8 weeks. The pins are then removed, and the athlete is transitioned to a removable splint for 4 additional weeks.

Scapholunate ligamentoplasties

In the DIC ligamentoplasty, the scaphoid origin of the dorsal intercarpal ligament is reinserted more radially on the scaphoid neck to correct pronation of the scaphoid.[70,71]

Scapholunate axis method

This is our preferred technique, which utilizes a palmaris longus or a half strip flexor carpi radialis graft.[75] The scapholunate articulation must remain easily reducible with 1.6-mm (0.062 in) K-wires and have carpal bones of sufficient size to support a tendon graft and tenodesis screw. A standard dorsal approach and a separate radial approach over the anatomic snuffbox is utilized (Fig. 26). A dorsal and radial capsulotomy is performed. The scapholunate interval is manually reduced with a volar directed force on the capitate or using K-wires as joy sticks. A transverse incision is made just ulnar to the radiotriquetral ligament, and the tip of a C-shaped drill guide is placed on the proximal ulnar aspect of the lunate midpoint in the anteroposterior plane. The cannulated sleeve is placed midlateral on the scaphoid. A guidewire is passed through the central axis of the scaphoid and lunate, and a second wire is passed just distal through the guide (Fig. 27). Acceptable reduction and wire placement is fluoroscopically confirmed, and then a step drill is utilized to prepare the bone tunnels (Fig. 28). A palmaris or partial FCR free tendon graft is harvested, passed, and secured to the lunate with a bullet anchor (Fig. 29). The graft is then tensioned, and an interference screw is placed (Fig. 30). Then, the remaining graft is sutured to any the remnant dorsal SLIL and then secured to the DRC insertion on the triquetrum (Fig. 31).

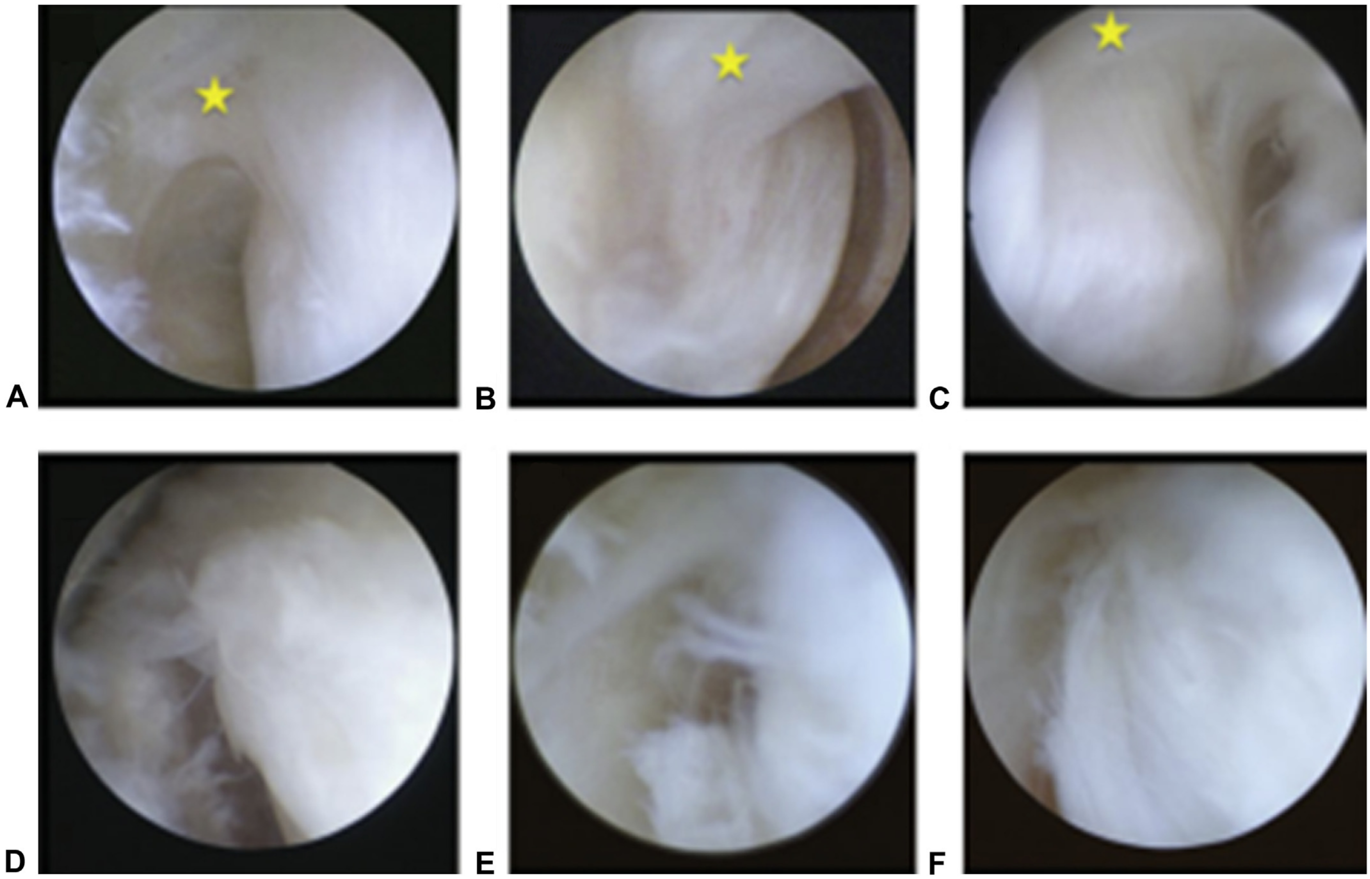

Figure 19. Arthroscopic view of the **A**–**C** normal dorsal capsuloscapholunate septum (stars) in 3 patients and **D**–**F** a torn dorsal capsuloscapholunate septum in 3 patients viewed from the 6R portal. (From Binder AC, Kerfant N, Wahegaonkar AL, et al. Dorsal Wrist Capsular Tears in Association with Scapholunate Instability: Results of an Arthroscopic Dorsal Capsuloplasty. J Wrist Surg 2013;2:160-167; with permission.)

Table 6
Garcia-Elias Principles of Reconstruction and Repair Help Guide Treatment in SLIL Injuries[33]

Garcia-Elias principles of reconstruction
1. Is the dorsal SLIL intact?
2. Is there sufficient dorsal SLIL for repair?
3. Is the scaphoid posture normal?
4. Is any carpal malalignment reducible?
5. Is the cartilage of the radiocarpal and midcarpal surfaces normal?

Intercarpal arthrodesis

When there is fixed, irreducible carpal malalignment, it is very difficult to restore the normal biomechanics of the wrist. Various intercarpal arthrodesis procedures allow for preservation of some range of motion while eliminating pain.[13] Scaphoid-trapezium-trapezoid (STT) arthrodesis corrects the position of the scaphoid in the radial scaphoid fossa, though the fusion limits radial deviation and flexion for the wrist, resulting in decreased wrist range of motion, strength, and occasionally pain. Performing a radial styloidectomy helps decrease radial impingement. The scaphoid-capitate (SC) arthrodesis is a similar procedure to STT arthrodesis with a notable return to work rate and moderate rate of radiocarpal osteoarthritis at 10 years.[13] To correct the entire malalignment pattern, scaphoid-lunate-capitate arthrodesis has been described but resulted in a significant loss of wrist motion. To restore the dart thrower's plane of motion, the radioscapholunate fusion and distal scaphoidectomy were designed at the expense of wrist range of motion; however, the fusion technique prevents SLAC arthritis progression. Garcia-Elias et al[76] described excision of the distal third of the scaphoid to allow for more motion and decrease adjacent joint arthritis at the STT joint.

Table 7
Wolfe Principles of Reconstruction are Used to Guide Repair Strategy[25]

Wolfe principles of reconstruction
1. **Coronal plane instability** is addressed with SL ligament repair.
2. **Sagittal plane instability** is addressed with the addition of dorsal capsulodesis.

SLAC wrist salvage procedures

For static scapholunate dissociation with arthritic changes at the wrist, SLAC wrist salvage procedures can be considered. A wide variety of procedures depending on the stage of arthritis as defined by Watson and Ballet are available.[3] The goals of surgery are to eliminate pain and create space for maintaining some degree of wrist motion.

Partial or total wrist denervation procedures with posterior interosseous nerve neurectomy or anterior interosseous nerve neurectomy can also be performed for symptomatic pain control. These procedures allow for quick rehabilitation for athletes and can be done alone or in addition to the salvage procedures.

The stage 1 SLAC wrist is comprised of arthritic changes between the radial styloid and the distal pole of the scaphoid, and a radial styloidectomy can relieve pain that may occur with radial

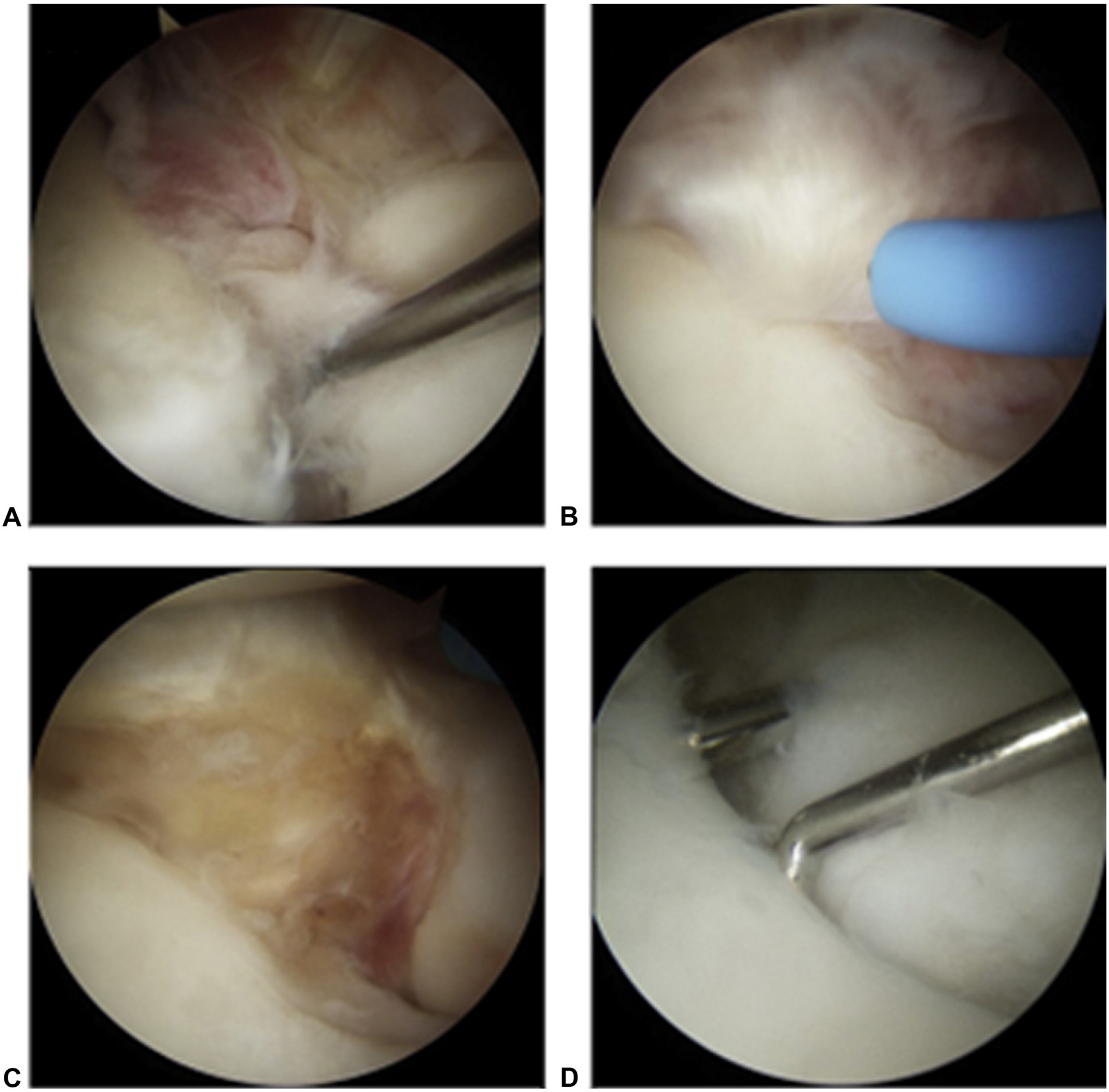

Figure 20. Arthroscopic view of the scapholunate interval through the midcarpal radial portal demonstrating **A** Geissler grade III SL injury, **B** volar SLIL and capsule before thermal shrinkage, **C** golden yellow/tan color change, and **D** improvement in interval stability after shrinkage and K-wire fixation. (Adapted with permission from Burn et al, 2019[50]).

deviation of the wrist. An open or arthroscopic approach through the 1,2 portal can be used to perform a radial styloidectomy; however, it is important to protect the radiocarpal ligaments and avoid creating additional instability.[13]

The stage 2 SLAC wrist is comprised of arthritic changes throughout the radioscaphoid joint with a preserved radiolunate joint. Proximal row carpectomy (PRC) or scaphoidectomy with midcarpal fusion can be performed to remove pressure from the arthritic articulation between the distal radius and scaphoid fossa. PRC is performed by excising the proximal row carpal bones: the scaphoid, lunate, and triquetrum. A new joint is created between the capitate and the lunate fossa of the distal radius. “Four-corner arthrodesis”, otherwise known as scaphoidectomy with midcarpal fusion, is the excision of the scaphoid and fusion of the capitate, hamate, lunate, and triquetrum. Four-corner arthrodesis can be used in stage 2 and 3 SLAC wrists. The arthrodesis can be performed with screws, staples, or procedure-specific plates. Stage 3 is comprised of arthritic changes between the lunate and capitate in addition to the changes seen in stages 1 and 2. PRC is contraindicated in stage 3 SLAC wrists since an arthritic capitate would become the focal point of wrist loading but may be

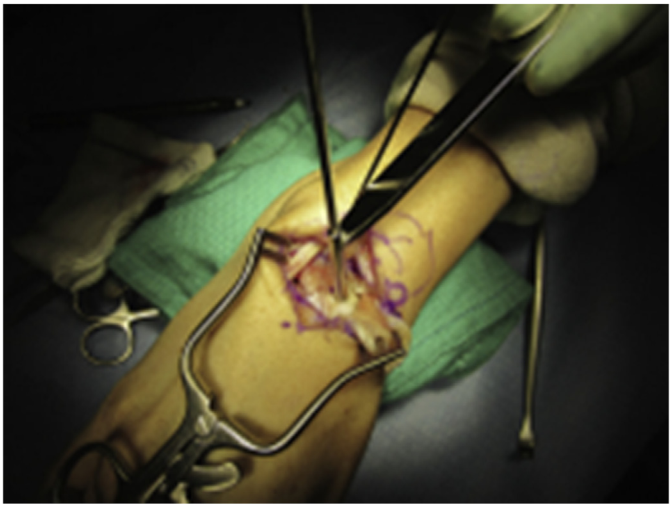

Figure 21. A cannulated 3.2-mm drill is used to create a bone tunnel from the dorsal SL insertion to the scaphoid tuberosity along the central axis in preparation for ligament reconstruction. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

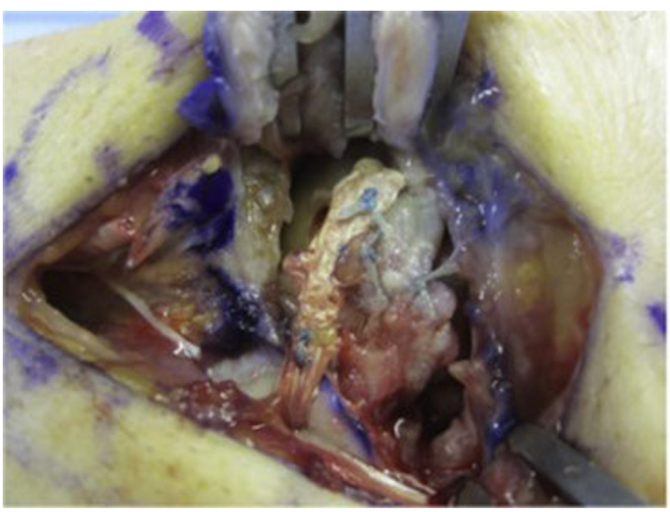

Figure 22. The tendon graft is tensioned and attached to the lunate with a suture anchor and then passed through the radiotriquetral ligament and secured to itself. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

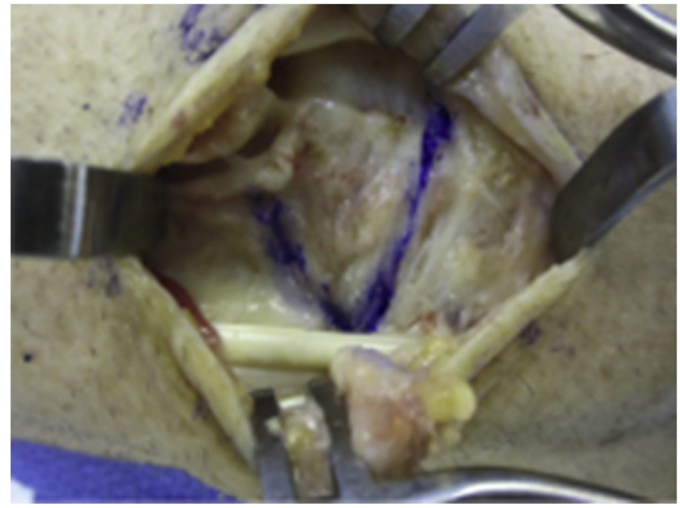

Figure 23. Dorsal ligament-sparing capsulotomy with the dorsal intercarpal and dorsal radiocarpal ligaments outlined. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

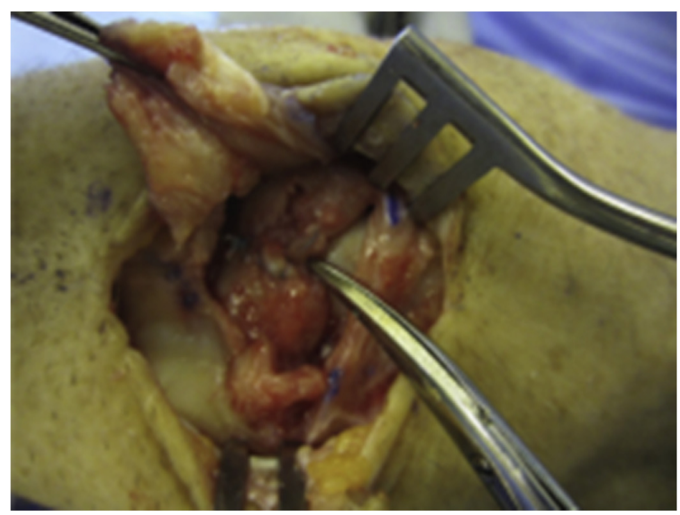

Figure 24. Repair of the scapholunate ligament back to the lunate using suture anchors. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

augmented with a dorsal capsular or allograft interposition. Various modifications in fusion hardware also exist.

The stage 4 SLAC wrist is comprised of radiolunate arthritis in addition to the changes in stages 1, 2, and 3, and a total wrist arthrodesis is typically performed. Total wrist arthroplasty may be considered; however, careful patient selection and counseling is key to manage postoperative weight bearing and range of motion expectations.

Postoperative Rehabilitation

Strengthening the FCR, abductor pollicis longus, and extensor carpi radialis longus after cast removal may improve scaphoid stability and gradual return to activities is allowed if symptoms have resolved.[77–79] After arthroscopic repair, therapy with motion in the dart thrower's plane is started immediately after discontinuation of immobilization and activity is advanced to full active range of motion as tolerated thereafter. Full return to activity is allowed at 12 weeks. Dart thrower's motion (DTM) exercises are also begun after dorsal capsulodesis.

The best exercise for physical rehabilitation after SLIL repair, and varying subsequent immobilization, is the DTM.[80] DTM minimizes stress to the newly intact SLIL as motion arises from the midcarpal joint. According to a meta-analysis of DTM in rehabilitation of the SLIL by Bergner et al,[80] the current literature suggests limiting the end range of the DTM and orthogonal plane motion. Use of custom orthotics can limit this motion. Patients work closely with rehabilitation experts to incorporate DTM along with a range of hand and wrist exercises to strengthen the entire carpal ligament complex.

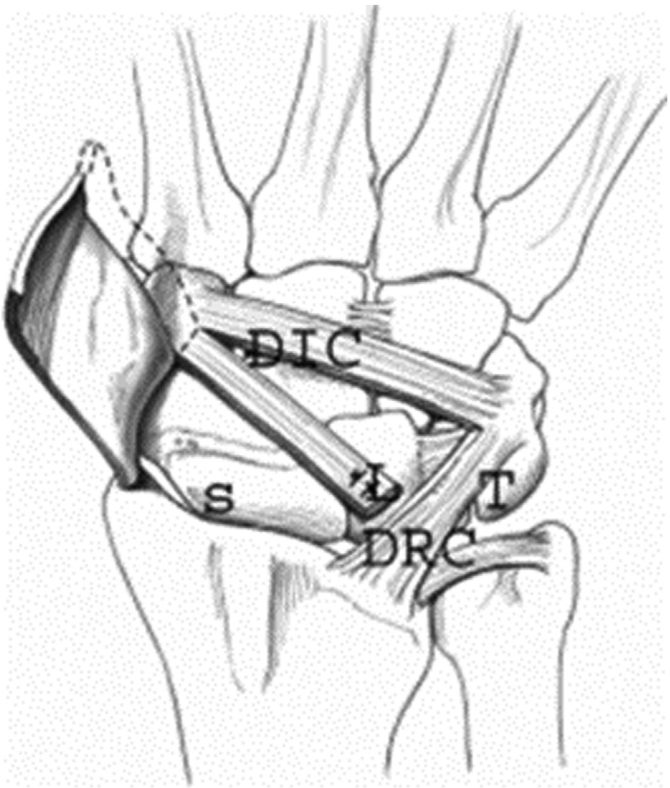

Figure 25. The modified dorsal intercarpal (DIC) capsulodesis with a strip of the DIC maintained on the scaphoid (S) and transferred from the triquetrum (T) to the dorsal lunate (L). DRC, dorsoradiocarpal. (From Manuel J & Moran SL. The diagnosis of treatment of scapholunate instability. Hand Clinic 2010;26:129-144; used with permission of Mayo Foundation for Medical Education and Research, all rights reserved)[105].

Outcomes

Outcomes of arthroscopy

Outcomes after arthroscopic treatment of occult SL instability are limited to case series and expert opinion. Ruch and Poehling[48] reported their outcomes with debridement alone of membranous SLIL tears with satisfactory improvement and no progression to instability in all seven of their patients with at least 2 years of follow-up. Weiss et al[49] reported on debridement of partial tears, with satisfactory improvement in 11 of 13 patients at a mean follow-up of 27 months. Debridement is thought to address any mechanical symptoms related to unstable tissue flaps and pain from synovitis.

Early results for arthroscopic debridement and thermal shrinkage for partial tears have also been favorable for resolution of symptoms, radiographic stability, and functional outcome scores.[47,81] Thermal shrinkage is thought to improve symptoms of instability by tightening the ligaments through heating and denaturing of collagen, which is followed by tissue repair with vascular invasion and fibroblastic activity.[47,82–84] Additionally, pain symptoms may be alleviated through ligament denervation.[50,85]

Patients may benefit from arthroscopic reduction and K-wire fixation without thermal shrinkage. In a series of 40 patients with less than 3 months of symptoms and 3 mm or less side to side difference in scapholunate interval, 83% had maintenance of reduction and symptom relief. Stability was observed to be maintained for 2–7 years on follow-up.[45] Arthroscopic dorsal capsuloplasty as performed by Binder et al[42] had significant

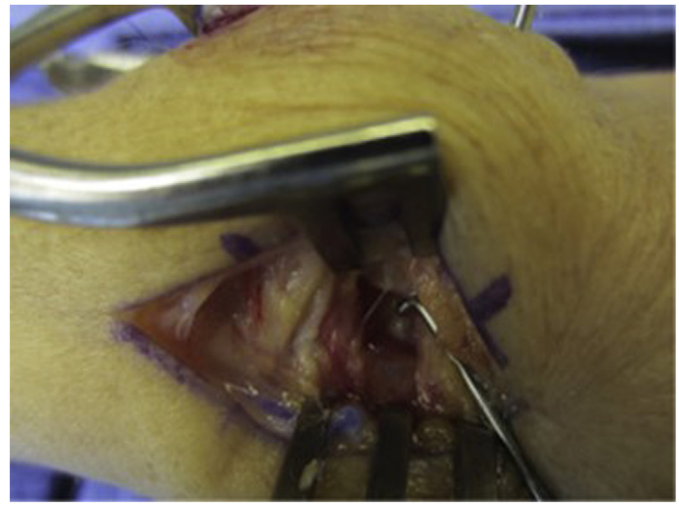

Figure 26. The radial approach through the anatomic snuffbox for the scapholunate axis method exposes the starting point midlateral on the right of the scaphoid as indicated by the probe. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

improvement in wrist range of motion, grip strength, functional scores, and pain scores in 10 patients with a mean follow-up of 16 months.

Outcomes of complete SLIL tear repair

Early operative treatment of the scapholunate ligament (<6 weeks) improves the chances of a successful outcome.[44] Melone and colleagues[86] treated 25 professional basketball players with acute ligament repair and capsulodesis, resulting in considerable improvement in symptoms and all returning to full participation and no need for further surgery at an average of 5 years of follow-up. Three in this cohort had evidence of carpal malalignment and arthritis present 7 or more years after surgery, which matches the findings of Pomerance et al[87] in that that strenuous activity was a risk factor for deterioration over time. Direct comparison of the Blatt proximal radius-based flap to the distal ulnar DIC-based flap in individuals with chronic tears did not show a difference in outcome, with both having a comparable loss of wrist flexion.[69,88] Radiographic evidence of degenerative arthritis may also not correlate with clinical functional outcomes after repair.[89]

Outcomes of reconstruction

Most ligament reconstruction techniques achieve pain relief and satisfactory functional outcomes; however, incomplete return of grip strength, motion, and long term alignment remains common (Fig. 32).[46,69,90] Williams and colleagues[91] described their experience with a modified Brunelli SLIL reconstruction in 14 athletes with 79% returning to play after 4 months; however, notably, only 64% of their cohort were able to return to their preinjury level of competition. Garcia et al[46] studied TLT outcomes in 38 patients with an average follow-up of 46 months and found that pain was relieved in 28; grip strength, flexion, and extension range of motion were 65%, 74% and 77%, respectively, compared with the contralateral side. Seven wrists showed arthritic changes. In addition, a study performed by De Smet et al[92] on patients after TLT for SLIL injury found that preexisting

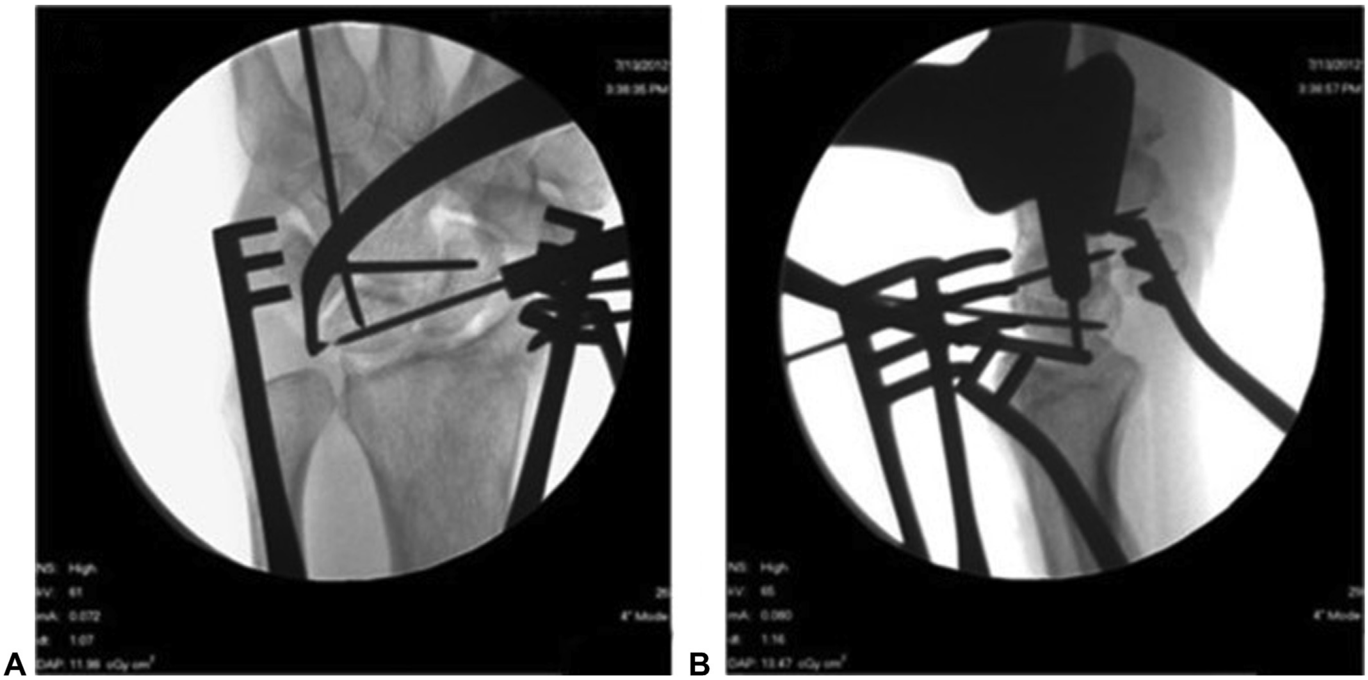

Figure 27. The guidewire is placed along the central axis of the scaphoid and lunate as visualized on the posteroanterior **A** and lateral **B** radiographs, respectively, ending at the proximoulnar corner of the lunate **A**. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

Figure 28. A cannulated step drill (2.9 leading, 3.8 trailing) is used to create the graft tunnel over the central guidewire. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

arthritic changes and poor scapholunate reductions resulted in poor outcomes.[13]

Patients who develop SL fibrous unions from scapholunate arthrodesis show significant clinical improvement.[13] Rosenwasser's RASL technique reported no cases of hardware failure or cut-out in the first 5 years of documented procedures.[13] Although other studies have a majority of patients with recurrence of deformity or progression of arthritis, recent follow-up reports good long-term results of the RASL technique, with an average Disabilities of the Arm Shoulder and Hand score of 17, SL angle of 55°, and SL diastasis of 2.1 mm.[13] Arthroscopic ligamentoplasty outcomes were studied by Ho et al,[93] who followed patients for an average of 48.3 months after reconstruction of the SLIL and found improvements in pain score, wrist motion, and grip strength.

Figure 29. The tendon graft is threaded through the bullet anchor and placed in the proximoulnar corner of the lunate. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

Figure 30. The tendon graft is tensioned and secured with a 4-mm interference screw into the scaphoid. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

Figure 31. The remaining graft is passed dorsal to the scaphoid and then secured to the lunate and the dorsal radiocarpal ligament. (From Paci GM, Yao J. Surgical Techniques for the Treatment of Carpal Ligament Injury in the Athlete. Clin Sports Med 2015;34:11-35; with permission).

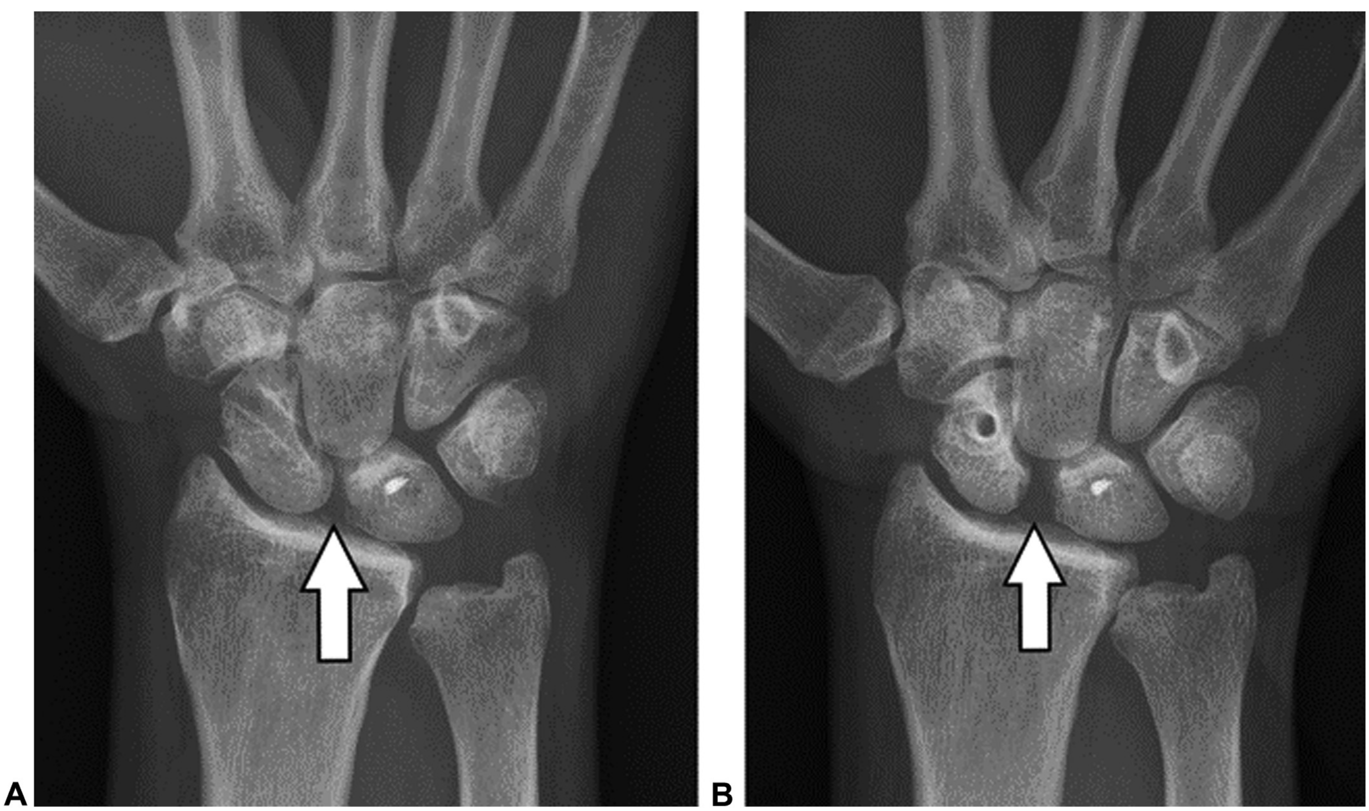

Figure 32. MBR in a 42-year-old salesman with stage 3 chronic SLL injury. Preoperative posteroanterior radiography showed a widened scapholunate interval of 6 mm and DISI deformity. **A** Posteroanterior radiograph 10 weeks after surgery shows a scapholunate interval of 2.5 mm (arrow). **B** Posteroanterior radiograph 7 months after surgery shows a scapholunate interval of 4 mm (arrow). Postoperative widening of the scapholunate interval can occur over time after reconstruction and does not definitely indicate graft failure. The patient was asymptomatic over the scapholunate ligament with no instability at clinical examination. (Adapted with permission from Palisch et al[101]).

Many studies similarly show improvement in symptoms, often at the expense of decreased range of motion, without significant improvement in carpal alignment or prevention of arthritis.[13] These include reviews of the Blatt capsulodesis, the dorsal intercarpal ligamentoplasty, and the Mayo Clinic scapholunate ligamentoplasty.

Intercarpal arthrodesis also has mixed outcomes. Although SC arthrodesis has a 90% return to work rate, there is a 30% rate of radiocarpal osteoarthritis at 10 years.[13] STT arthrodesis was found to have a 86% union rate, higher than that of SL arthrodesis. The radioscapholunate fusion and distal scaphoidectomy exchanged wrist range of motion for possible prevention of SLAC arthritis

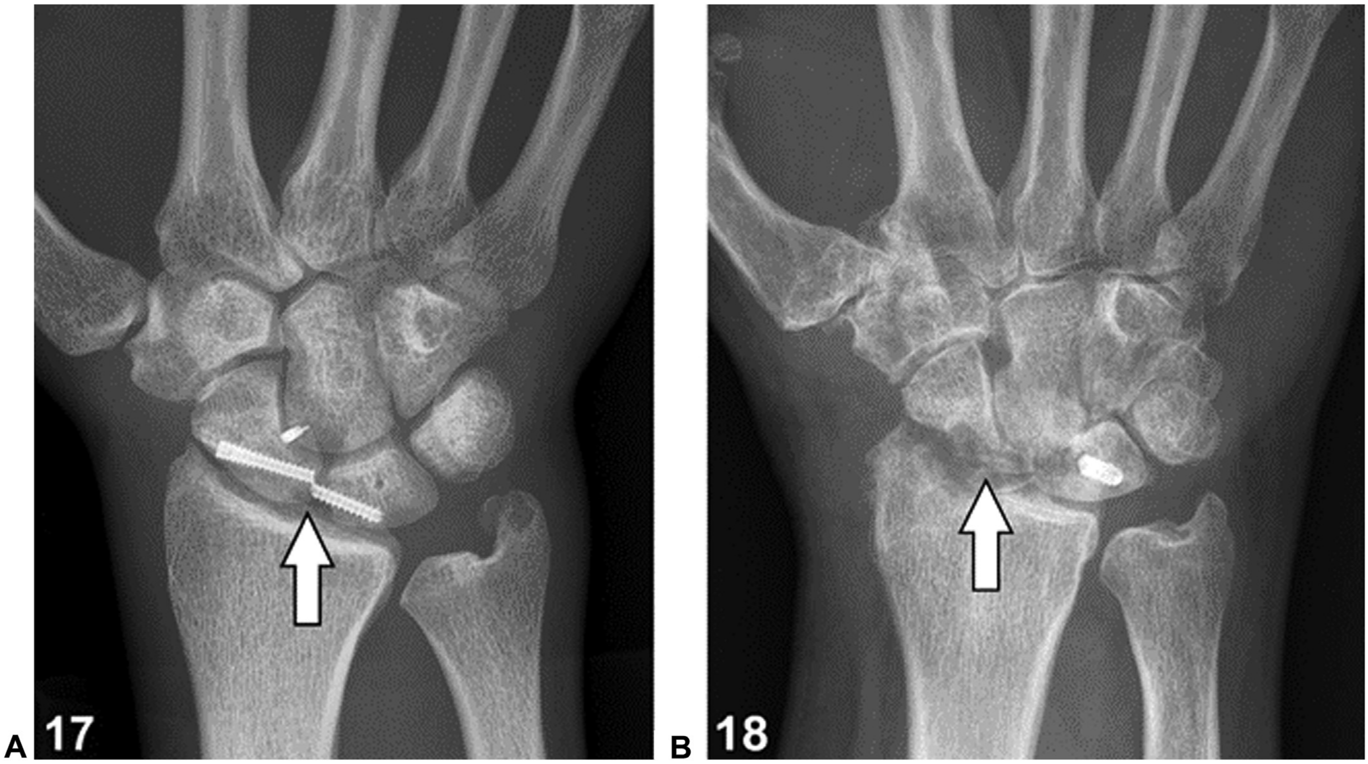

Figure 33. **A** Complication of the RASL procedure. Posteroanterior radiograph after the RASL procedure shows a fractured compression screw (arrow) across the scapholunate interval. **B** Complication of the SLAM procedure. Posteroanterior radiograph after the SLAM procedure shows lucency and collapse in the proximal scaphoid (arrow) from osteonecrosis. Similar changes from osteonecrosis are in the radial aspect of the lunate. (Adapted with permission from Palisch et al[101]).

progression. Garcia-Elias et al[76] followed 16 patients who underwent radioscapholunate fusion for 37 months and found pain relief for daily activities in 81%, but only 32º of wrist flexion, 35º of wrist extension, 14º of radial deviation, and 19º of ulnar deviation.

Biomechanical outcomes of RASL, ANAFAB, and TLT have been compared in cadaveric models.[51] RASL statistically improved scapholunate gap, whereas ANAFAB significantly improved dorsal scaphoid translation. Though TLT and RASL improved radiographic measurements of SL stability, both had a persistent increase in the lunate extension following reconstruction. Each of the three repairs had different effects on carpal posture and alignment.[51]

Outcomes of salvage procedures

Satisfactory long-term results for SLAC wrist salvage procedures have been reported. In longitudinal studies, the average flexion-extension arc was 68°, grip strength was 72% of the contralateral side, and all patients returned to work with 35% patients who underwent a salvage procedure requiring further surgery.[94,95]

Complications

Complications of arthroscopy

Heat-related complications, including collagen necrosis and chondrolysis, are concerns with thermal shrinkage.[71] Although these complications have not been reported with wrist arthroscopy, issues with thermal capsulorrhaphy of the glenohumeral joint, including recurrent instability, deficient anterior capsule, and chondrolysis, have decreased its frequency of use.[96,97] Strict attention to maintaining adequate outflow and using the probe in a pulsed manner for no longer than a few seconds at a time help ensure adequate heat dissipation and may reduce the risk of heat-related complications.[98,99]

Complications of repair and reconstruction

Complications after SL repair and capsulodesis include pin-site infections, wrist stiffness, persistent instability, and the development of post-traumatic arthritis. Carpal fracture and osteonecrosis of the scaphoid or the lunate are the most significant complications that can occur secondary to bone tunnel creation.[90,92,100] Meticulous guidewire placement ensuring central bone tunnel placement can reduce the risk of fracture; however, osteonecrosis is speculated to be secondary to loss of intraosseous blood supply and may be harder to prevent. Osteonecrosis of the lunate after the SLAM procedure and of the scaphoid after TLT have also been described in case reports.[92,100,101] In the RASL procedure, 50% of patients progress to arthritis, and compression screw fractures have been reported (Fig. 33).[101] Incomplete return of function and ongoing pain can be problematic after reconstruction. Long-term recurrent instability and loss of carpal alignment leading to arthrosis has also been commonly observed.[46,69,90]

Conclusion and Summary

Scapholunate ligament injuries are a common cause of dorsal wrist pain and decreased function. Untreated, or inadequately treated, ligamentous injuries can lead to progressive, degenerative change.[3] As health care providers, our goals remain to prevent wrist injuries, make a timely and accurate diagnosis of SL injuries, and provide treatment that safely and expeditiously returns patients to as close to a normal level of function as possible. There are many methods to classify and treat these injuries based on their severity. Current techniques are directed toward restoring stability and function to the injured scapholunate ligament. Choosing a technique depends on the stage and characteristics of the SLIL injury, SL joint stability, and the physical demands of the patient. An appreciation of the nuances of patient wishes, risk tolerance, and athletic or occupational needs allows a physician to develop an individualized treatment strategy.

Conflicts of Interest

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

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