Scapholunate Ligament Injury and the Effect of Scaphoid Lengthening

Matthew J. Furey, MD, MSc^{1,2} Neil J. White, MD¹ Gurpreet S. Dhaliwal, MD¹

¹Section of Orthopaedic Surgery, Cumming School of Medicine, University of Calgary, Calgary, Alberta, Canada

²Western Upper Limb Facility, Sturgeon Hospital, Edmonton, Alberta, Canada; Division of Orthopaedic Surgery, Department of Surgery, University of Alberta, Edmonton, Alberta, Canada

Address for correspondence Matthew J. Furey, MD, MSc, Division of Orthopaedic Surgery, University of Alberta, Sturgeon Hospital, 201 Boudreau Road, St Albert, Edmonton, Alberta T8N6C4, Canada (e-mail: furey@ualberta.ca).

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Abstract

Objective We hypothesized that lengthening the scaphoid in a model of scapholunate ligament injury (SLI) will result in correction of radiographic markers of dorsal intercalated segment instability (DISI) deformity.

Materials and Methods An SLI with DISI deformity was created by sectioning the SL ligament, the palmar radiocarpal ligaments, and scapho-trapezio-trapezoid ligaments of a cadaveric upper extremity ($n = 5$). The wrist was radiographed in both anteroposterior and lateral planes to confirm creation of SLI and DISI. The scaphoid was then osteotomized at its waist. A series of grafts (1–8 mm) were then placed at the osteotomy site. Radiographs were completed at each length. The main outcome measures were scapholunate interval (SL, mm), scapholunate angle (SLA, degrees), and radiolunate angle (RLA, degrees). These values, measured following the insertion of varying graft lengths, were compared with baseline measurements taken “post-injury” status.

Results The ability to create an SLI with DISI was confirmed in the postinjury group with a statistically significant change in RLA, SLA, and SL compared with preinjury. With osteotomy and progressive insertion of spacers, the values improved into the accepted normal ranges for RLA (6 mm) and SLA (4 mm) with scaphoid lengthening.

Conclusions In this cadaveric model of SL injury, radiographic markers of DISI were returned to within normal ranges with scaphoid osteotomy and lengthening.

Clinical Relevance The results of this study add insight into wrist kinematics in our injury model and may represent a potential future direction for surgical treatment of SLI.

Keywords

- scapholunate
- scaphoid
- DISI

Scapholunate ligament injury (SLI) is one of the most common ligamentous injuries seen in the wrist. Not only can this condition result in wrist pain, decreased grip strength, and decreased motion, the natural history of SL ligament disruption may involve a progressive arthrosis of the radiocarpal and intercarpal articulations.^{1,2} Watson and Ballet initially described this pattern as scapholunate advanced collapse (SLAC).³

Current surgical treatments for SLI prior to degenerative changes, generally attempt to recreate an association between the scaphoid and lunate and include reduction, direct ligament repair and pinning in acute cases. Chronic ligament injuries

have been treated with a variety of corrective procedures including dorsal capsulodesis,⁴ soft tissue reconstruction such as the modified Brunelli⁵ or the newer reduction-association of the scapholunate joint procedure.⁶ The goal of treatment is not only to relieve symptoms associated with the ligament injury but also to halt the progression of SLAC changes, although no long-term studies have definitively proven this.

Recent research regarding proximal pole scaphoid fractures has provided an alternative approach to correcting scapholunate and radiocarpal kinematic dysfunction. As a result of the high rate of nonunion of fractures involving the proximal pole

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of the scaphoid, vascularized bone grafts have garnered significant interest.⁷ One such technique, the medial femoral condyle graft, has been used as a structural vascularized graft with encouraging results.^{8,9} This technique involves the excision of the proximal scaphoid fragment, which contains the origin of the scapholunate ligament, and insertion of a vascularized articular medial femoral condyle graft sculpted to fit the resulting defect. This graft has recently been investigated in a cadaveric study and was shown to result in scapholunate stability and correction of dorsal intercalated segment instability (DISI) deformity in the absence of a scapholunate ligament.¹⁰ The hypothesized mechanism of action was through increased contact of the scaphoid on the lunate, so-called “overstuffing” of the scaphoid facet.

We theorized that the corrective procedure of “overstuffing” the scaphoid facet could be directly translated to a better understanding and treatment of scapholunate injury and dissociation. Our hypothesis was as follows: in a cadaveric model of SLI with DISI confirmed by radiographic markers (scapholunate interval [SL], scapholunate angle [SLA], and radiolunate angle [RLA]), osteotomy and lengthening of the scaphoid will return those markers into the clinically accepted normal ranges.

Materials and Methods

We utilized a cadaveric model of scapholunate dissociation and DISI similar to that which has been previously described in detail by Capito and Higgins.¹⁰ A cadaveric arm ($n = 5$), disarticulated at the elbow, but maintaining the proximal radioulnar joint, underwent longitudinal volar and dorsal incisions to allow side-to-side suturing of the extensor (extensor carpi ulnaris and extensor carpi radialis longus and brevis) and flexor (flexor digitorum superficialis and profundus) tendons. The sutures were then tunneled proximally. This allowed suspension of 2.3 kg weights to the flexors and 2.8 kg to each of the extensors. Loading of tendons was as described by Capito and Higgins¹⁰ to simulate a loaded closed fist position once the arm was mounted vertically. The arm was mounted to a plywood stand utilizing an external fixator (Hoffmann II Compact, Stryker, Kalamazoo, MI). Additionally, a premeasured stainless-steel ball bearing (12mm) was placed in a subcutaneous pocket ulnarly at the wrist to allow standardized fluoroscopic measurement (—Fig. 1A).

At this point, lateral and anteroposterior (AP) images were performed utilizing a C-Arm imaging system (OEC, GE Healthcare, Little Chalfont, United Kingdom). This was to confirm the normal SL interval and lunate positioning. All specimens appeared to be radiographically normal.

This condition was recorded as our control, including radiographic measures of the SL, SLA, and RLA. These variables were measured in similar fashion to as described by Capito and Higgins.¹⁰ All angles were measured on screen with a standard goniometer, while scapholunate distance and the stainless steel ball were measured with a ruler, allowing correction of image magnification using the known diameter of the ball and measured diameter of the ball as a conversion factor.

Fig. 1 Methods. (A) Illustration demonstrating the forearm mounted vertically to a plywood table utilizing an external fixator with two pins in the proximal radius and two pins in the distal radius. Flexor and extensor tendons have been sutured together to allow weighted loading of the tendons, simulating a clenched fist. (B) Illustration demonstrating scaphoid osteotomy and insertion of polyethylene spacer.

SL dissociation and DISI were created by first performing a Russe-style volar approach to the scaphoid. The SL ligament was transected, along with the radioscaphocapitate, long and short radiolunate ligaments (RL), and palmar scaphotrapezial (ST) ligament. This pattern of destabilization was chosen after reviewing previous cadaveric models of scapholunate dissociation and biomechanical evaluation.^{11,12} This condition was recorded as our injury model after remounting the arm and performing AP and lateral fluoroscopy.

A horizontal scaphoid osteotomy was then completed at the level of the distal third scaphoid, just distal to the articulation with the radius. Spacers were inserted into the osteotomy site starting from 1 mm and progressing to 8 mm in length with AP and lateral fluoroscopy and radiographic measurements taken at each interval. Spacers were held in place with a longitudinal Kirschner wire, placed through the volar incision from distal to proximal starting on the radial margin of the scaphoid articular surface distally to avoid impingement on bone or soft tissue (—Fig. 1B). Spacers were made of 8 mm circular polyethylene dowel that was cut and measured in 1 mm increments from 1 to 8 mm utilizing a digital caliper, and predrilled centrally for insertion of the Kirschner wire.

Statistical Analysis

SL, SLA, and RLA measurements taken at control were then statistically compared with injury utilizing two tailed Student's

Fig. 2 Scapholunate ligament injury model results. Value represented with standard deviation. (A) Radiolunate angle. (B) Scapholunate angle. (C) Scapholunate interval.

t-tests, with significance set at $p < 0.05$. Similarly, each interval lengthening was compared with injury and control values. In the experimental group with multiple comparisons (1–8 mm of lengthening), the Holm–Bonferroni method was used to control for type 1 error.¹³

Results

The ability to create an SLI with DISI was confirmed in the injury group with a statistically significant change in RLA, SLA, and SL ($p < 0.05$, $n = 5$) compared with control. Absolute values changed from 2.1 ± 0.65 to 4.1 ± 0.42 (SL), from 50 ± 7.1 to 74.4 ± 8.5 (SLA), and from 2.6 ± 2.5 to 18.4 ± 5.94 (RLA). These injury values fall within accepted clinical values for both scapholunate diastasis and DISI (►Fig. 2A–C).

With osteotomy and progressive insertion of spacers, the values of SL, SLA, and RLA demonstrated a progressive correction, statistically correcting the SLA by 4 mm and

Fig. 3 Scaphoid lengthening. Value represented with standard deviation. (A) Radiolunate angle. (B) Scapholunate angle. (C) Scapholunate interval.

RLA by 6 mm lengthening compared with postinjury ($n = 4$, $p < 0.05$) (►Fig. 3A–C). The SL, while trending toward correction, did not meet statistical significance after Holm–Bonferroni correction.

One specimen fractured during the osteotomy procedure and, though included in control and injury values was not included in the lengthening measurements.

Discussion

The dilemma of treatment of SLIs continues to be unsolved. Current treatments, as discussed above, are seldom entirely satisfactory.^{1,14,15} This is likely due to several factors including the multiple recognized stages of SL injury.¹ The diagnosis of scapholunate dissociation entails a broad spectrum of disease spanning from acute SLI to chronic scapholunate injury with irreducible carpal malalignment and secondary degenerative changes.

Fig. 4 Ring theory. The ring theory of wrist kinematics states the carpal bones are linked in an oval ring, with the links in the ring being the scaphoid, lunate, triquetrum, and distal row. Image (A) demonstrates a normal wrist with an intact ring, under normal tension. Image (B) demonstrates static scapholunate dissociation, with a broken ring and thus relaxed ring tension. A similar situation is created with a scaphoid nonunion, resulting in abnormal ring tension. Image (C) demonstrates repair of the broken ring utilizing a reduction-association of the scapholunate technique, with restored tension of the ring. Image (D) demonstrates the hypothetical restoration of ring tension by placement of a lengthening graft into the scaphoid, fixed with a headless compression screw.

Additionally, the underlying biomechanics of the wrist are still not definitively clear. Multiple theories exist regarding wrist kinematics including the two carpal row theory,¹⁶ three column theory,¹⁷ and ring theory.¹⁸ It is a topic that is still not fully understood.¹⁹

Scapholunate instability is not due to injury to just the scapholunate ligament. Secondary stabilizers must also be compromised along with the scapholunate ligament to allow scapholunate diastasis, flexion, and pronation of the scaphoid, along with extension of the lunate.^{11,12} Reconstruction of the scapholunate ligament alone, controlling one aspect of this complex deformity, will, therefore, be unlikely to be successful in restoring normal biomechanics.

We propose that the effect of lengthening the scaphoid demonstrated in our study likely relates at least in part to the ring theory of wrist kinematics. The ring is likely under tension at baseline loading, somewhat akin to a circular roman arch. In SLI or scaphoid fracture, the tension is broken by a shortened scaphoid, resulting in significantly altered biomechanics. We theorize that a scaphoid osteotomy and graft to increase the length of the scaphoid prevent the scaphoid from having room (laxity at the scapho-trapezio-trapezoid [STT] joint and no restraint at the scapholunate articulation) to flex and pronate. Additionally, it likely increases contact pressure between the scaphoid and lunate and causes retensioning of the ring through the secondary carpal stabilizers, which results in a normalized SL interval and SLA and RLA (► Fig. 4).

One concern that arises from this study as well as the study by Capito and Higgins¹⁰ is the potential increase in contact pressures on the scaphoids articular surfaces. Although not quantified, it was observed that lengthening of 6 mm or more resulted in progressive palmar subluxation of the scaphoid from its STT articulation, with uncovering of the distal scaphoid pole. This likely reflects increased contact pressures between the scaphoid and its neighboring articulations with progressive lengthening. Increased contact pressure between the scaphoid and lunate, scaphoid and trapezium, and scaphoid and radius are of unclear consequence but potentially could be deleterious. This is a potential problem of presently unknown importance.

A specific weakness of this study is the small sample size. This number was chosen for our experimental study

as a sample of convenience and, based on a review of previously published cadaveric studies of SLI having sample sizes of 4 to 5.^{10,20–22} We felt this sample size appropriate for an initial proof of concept study. The number of specimens is, however, too small to make any definitive conclusions. Further studies are required not only to confirm reproducibility but also to investigate potential contact pressure changes at the STT joint, scapholunate articulation, and radiocarpal articulation with lengthening of the scaphoid.

In conclusion, this proof of concept study demonstrates the correction of a cadaveric model of SLI and DISI by progressive scaphoid lengthening. Adopting observations taken from proximal pole scaphoid fracture research, we feel that this study supplies some credence to the ring theory of carpal biomechanics.

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Conflict of Interest

None declared.

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