The University of Pennsylvania Orthopaedic Journal
13: 53–59, 2000

Treatment of Scapholunate Dissociation With Palmaris Longus Tendon Graft: A Biomechanical Study

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Introduction

Posttraumatic instability of the wrist, resulting in scapholunate dissociation, is a common injury pattern in the wrist [2]. Mayfield et al. [1] described instability progressing sequentially from a scapholunate interosseous ligament (SLIL) tear to complete ligament failure around the lunate, resulting in lunate dislocation. Linscheid et al. [4] also demonstrated that excision of the dorsal radiocarpal and scapholunate interosseous ligament produced rotary subluxation of the scaphoid. Further sectioning of the volar radiocarpal ligament increased the rotary subluxation. If scapholunate dissociation is left untreated, it may result in degenerative arthritis of the wrist. A survey by Watson and Brenner [3] found that degenerative arthritis was associated with scapholunate advance collapse (SLAC) in 55% of the cases. Viegas et al. [5] have shown that destabilizing the lunate by sectioning ligaments to create a scapholunate dissociation increases the joint contact pressure on the scaphoid and decreases the contact surface area of the scaphoid.

There is no single treatment for scapholunate dissociation. Current repair techniques consist of ligament repair, tendon grafting, limited intercarpal arthrodesis, and proximal row carpectomy. Each of the repair techniques has certain advantages. However, none restores the normal motion and stability of the uninjured wrist. For acute scapholunate dissociation without joint arthrosis, most authors advocate direct repair of the SLIL with temporary Kirschner (K) wire fixation [8,9]. Dorsal capsulodesis can augment a direct repair [6] or the capsulodesis can be performed alone [7]. For chronic scapholunate dissociation with arthrosis of the radioscaphoid fossa, the treatment is limited to SLIL reconstruction, a fusion of the capitate, lunate, triquetrum, and hamate with scaphoid excision [10], or proximal row carpectomy [11,15].

The treatment of chronic scapholunate dissociation without degenerative changes of the periscapholunate joints is controversial. Watson et al. [12], Rotman et al. [13], and Pisano et al. [14] have had clinical success with various intercarpal arthrodeses. However, Kleinman and Carroll [17] have noted a high rate of complication with scaphotrapeziotrapezoid (STT) intercarpal fusions. In a cadaveric study of STT fusion, Viegas et al. [18] noted increase contact pressure of the radioscaphoid fossa, which may eventually lead to degenerative arthritis over time. Ligament reconstructions using local tendon weave have been reported by Palmer et al. [8], Linscheid and Dobyns [22], Brunelli and Brunelli [23], and Almquist et al. [19], with good results. However, this treatment has been criticized for being technically difficult [8,19,20] and for having the potential problem of tendon loosening [21].

At our institution, the senior author has been performing a scapholunate ligament reconstruction using the palmaris longus tendon. This is performed through a dorsal and volar approach and the ligament is passed through drill holes in the anteroposterior plane of the scaphoid and the lunate to reconstruct the ligament. This has the advantage of being a simpler operation than the four-bone tendon weave performed by Almquist et al. [19] because only the scaphoid and lunate are included in the reconstruction.

Biomechanical studies by Augsburger et al. [21] have shown that a four-bone tendon weave restores the radiocarpal contact characteristic similar to that of the intact wrist versus that of the STT fusion using pressure-sensitive film. Our study is based on the hypothesis that the scapholunate ligament reconstruction will improve the radiocarpal joint forces to that of the intact wrist.

Materials and Methods

Four pairs of fresh upper extremities harvested from donor cadavers and transected at the midhumerus level were used. Radiographs of the wrist were taken to rule out anatomic variations and/or degenerative changes. The following radiographs were taken: posteroanterior, lateral, and Moneim [35] views. These views were used to measure the scapholunate dissociation.

The cadavers were then prepared for testing. Volar and dorsal skin was incised in the distal one third of the forearm. The flexor carpi radialis, flexor carpi ulnaris, extensor carpi radialis longus, and brevis and extensor carpi ulnaris tendons were identified and transected at the musculotendinous

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junction. However, the other forearm muscles were left intact to help stabilize the interosseous membrane. The flexor carpi radialis and the flexor carpi ulnaris tendons were sutured together. This provided a sling to load the radiocarpal joint. In a similar fashion, the extensor carpi radialis longus, extensor carpi radialis brevis, and the extensor carpi ulnaris were sutured together.

The cadaver was placed in a custom jig to allow the wrist to be placed in flexion, extension, or neutral position while stabilizing the forearm as the force was applied to the radiocarpal joint (Fig. 1). At this point, using the previous dorsal incision, a transverse capsulotomy of the dorsal wrist capsule was made. Custom templates of each of the radiocarpal joints were made. Then, pressure-sensitive film was cut to match the template. The ultralow pressure-sensitive film (Fuji, New York), prepared with water- resistant plastic wrap, was placed in the radiocarpal joint to measure the baseline contact pressure of the radiocarpal joint. The tendons were loaded for 10 seconds with 10 kg of load applied to the flexor tendons and 10 kg of load applied to the extensor tendons [24]. The wrists were tested in neutral rotation with the wrist in 30 degrees of extension, 30 degrees of flexion, and neutral flexion. Five impressions were obtained with each position and the best-quality impressions were used for analysis.

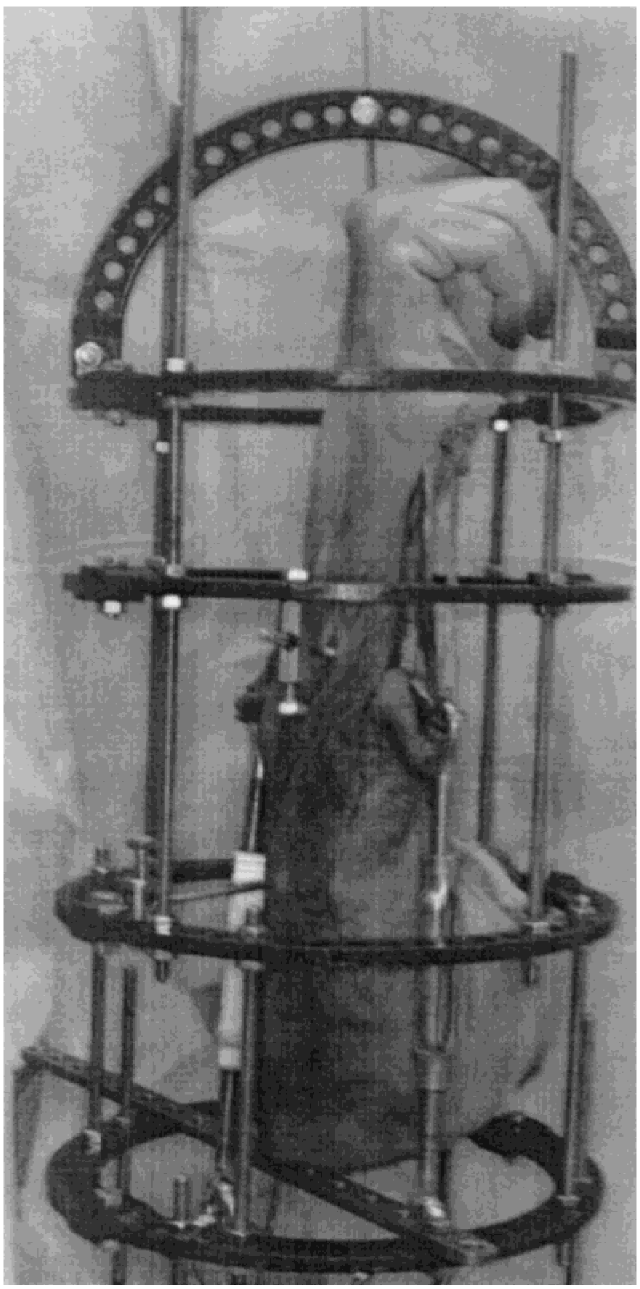

Fig. 1. Custom jig to stabilize cadaveric forearm.

Through the volar and dorsal incisions, the SLIL and the radioscaphoid portion of the radiocapitate ligament were cut to create a scaphoid-lunate (SL) diastasis. The wrist was cycled and radiographs repeated to measure the scapholunate dissociation. Using pressure-sensitive film, the radiocarpal joint forces were measured for the injured wrist with scapholunate dissociation.

Reconstruction of the SLIL was performed by using a free palmaris longus tendon graft. Drill holes were made in the scaphoid and the lunate from dorsal to volar. Each end of the palmaris longus graft was passed from volar to dorsal through both drill holes. The scapholunate dissociation was manually reduced and the tendon graft was tightened and sutured dorsally (Fig. 2). Radiographs were obtained to measure the scapholunate dissociation. Then, in a similar fashion, the joint forces were recorded using pressure-sensitive film.

The pressure-sensitive film was scanned and analyzed using NIH Image software (NIH, Bethesda, MD). The program was used to measure the contact area, peak pressures, and the mathematical center of the pressure (centroid) for the radiocarpal impressions. The values among the intact wrists, injured wrists, and the reconstructed wrists were compared.

Results

Statistical analysis of the test data included one-way analysis of variance (ANOVA) for the three groups (normal, injured, and reconstructed) with Fisher's least significant difference method as post hoc pairwise comparisons. Significance was defined as $p < 0.05$.

Radiographs

The scapholunate separation measured 1.63 mm SD 0.74 in normal specimens, 5.63 mm SD 0.74 in injured specimens, and 1.88 mm SD 0.64 in the reconstructed specimens (Fig. 3). The increased widening from normal to injury is significant ($p = 0.00001$) as is the improvement from injury to reconstructed ($p = 0.00001$). However, the difference between normal and reconstructed is not significant ($p = 0.35$).

Pressure-sensitive film

Scapholunate dissociation

The scapholunate dissociation, as measured by the impression on the pressure-sensitive film in extension, flexion,

Fig. 2. Reconstruction of the scapholunate interosseous ligament with palmaris longus graft.

and neutral, significantly worsened with injury and significantly improved with reconstruction (Table 1, Fig. 4). There is still a significant difference between normal and reconstructed scapholunate ligaments in flexion and neutral but not in extension.

Centroid distance between scaphoid and lunate

The centroid distance, the mathematical center of pressure, between the scaphoid and the lunate increased slightly but not significantly with disruption of the SLIL and the radiocapitate ligament (Table 2, Fig. 5). The reconstructed wrist had a decrease in the centroid distance compared to that of the injured and the normal wrists. However, the decrease in centroid distance was significant only for injury versus reconstruction in neutral and normal versus reconstruction in extension.

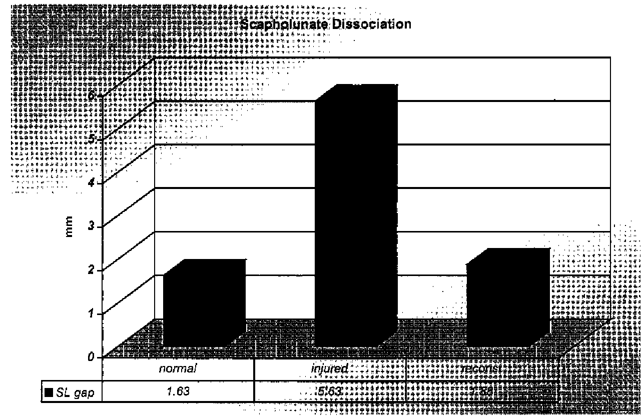

Fig. 3.

Scaphoid-to-lunate contact ratio

The scaphoid-to-lunate contact ratio increased in extension and flexion from normal to injury and decreased in neutral (Table 3, Fig. 6). The reconstruction decreased the scaphoid-to-lunate contact ratio in extension and flexion and increased the ratio in neutral. However, none of the changes was significant except for the change from normal to injury in extension.

Discussion

Traumatic SLIL rupture usually occurs in the active young population. These injuries are often dismissed by the patient or the initial treating physician. There is evidence to suggest that the natural history of scapholunate ligament disruption progresses to degenerative arthritis of the wrist [3]. These scapholunate ligament injuries have been recognized as part of a wrist instability pattern. Linscheid et al. [4] described the terms dorsal intercalated segmental instability and volar intercalated segmental instability patterns. Mayfield et al. [1] then suggested that scapholunate dissociation is part of a progressive perilunar instability pattern. As this injury draws more attention, surgeons are becoming more aggressive in treating these injuries to decrease the progression to degenerative arthritis.

The treatment of acute scapholunate dissociation has focused on trying to heal the native ligament. Closed reduction and pinning [25] and open reduction, internal fixation, and repair of the SLIL [6] have been advocated with good success. The treatment for chronic scapholunate dissociation with degenerative changes has been aimed at eliminating the arthritic radiocarpal joint. If the lunate fossa is free of degenerative changes, these treatment options include scaphoid excision, four-corner fusion [10], and proximal row carpectomy [11,15]. If the lunate fossa is degenerative, then the options include wrist fusion [27] and radius-scaphoid-lunate fusion [26]. However, treatment options for chronic dissociation without degenerative changes are divided between various limited intercarpal fusions and soft tissue augmentations, reconstructions, and repairs.

Various limited intercarpal fusions including STT, scaphoid-capitate-lunate (SCL), SL, and scaphoid-capitate (SC) have been used. These limited intercarpal fusions have been

Table 1. Scapholunate dissociation measurement on pressure-sensitive film in mm

	Extension	Flexion	Neutral
Normal	1.70 SD 1.47	1.58 SD 0.94	1.51 SD 1.06
Injury	6.32 SD 3.53	6.21 SD 2.89	4.99 SD 1.43
Reconstruction	2.43 SD 0.83	3.13 SD 1.44	2.39 SD 0.98
p value			
Normal versus injury	0.003	0.003	0.001
Injury versus reconstruction	0.01	0.01	0.001
Normal versus reconstruction	0.33	0.001	0.03

criticized biomechanically for altered wrist kinematics and changes in the radiocarpal joint reactive forces [18]. Clinical studies of the popular STT fusion have shown good results when performed correctly [17,28,29]. However, there is a high rate of complications [17], development of arthrosis [31], and altered wrist kinematics and range of motion [29]. SL arthrodesis has been unpredictable [30]. The SCL [13] and SC [14] fusions have similar clinical results as the STT fusion with similar changes in wrist kinematics.

Soft tissue repair of the scapholunate ligament offers excellent clinical results when the interosseous ligament is present for repair [6]. However, in subacute cases, the ligament is not present for repair. Blatt [7] and Winterman et al. [32] have described a dorsal radioscaphoid capsulodesis to limit the volar flexion of the distal scaphoid with improvement reported in clinical results. This procedure does not restore the scapholunate relationship and decreases the amount of volar flexion of the wrist [33]. Tendon grafts used to augment repairs have continued to evolve over the past 25 years. Palmer et al. [8] described a method to reconstruct the radioscapholunate ligament complex and the SLIL using a tendon graft. They reported on a series of 30 patients, all with improvement in pain, but cited difficulties in passing tendons and breakage of the dorsal drill holes in the lunate and scaphoid in trying to recreate the dorsal SLIL. The popularity of this method waned as limited intercarpal fusion became popular. In the past eight years, various tendon reconstructions have been devised. These include the Almquist [19], Linscheid [22], and Brunelli [23] ligament reconstructions. Theses repairs address all the ligaments involved in scapholunate diastasis. The scaphoid flexion and

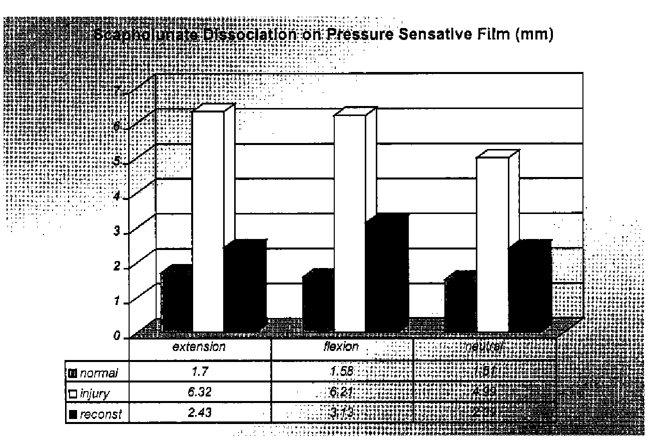

Fig. 4.

the scapholunate diastasis are reduced and maintained with a tendon graft. These authors claim that the ligament reconstruction is superior due to restoration of both the scaphoid flexion and the SL diastasis because Blatt's capsulodesis and limited intercarpal fusions address only the scaphoid flexion [19]. These claims have also been substantiated biomechanically. A comparison of the STT fusion and the Almquist tendon graft revealed that the STT fusion had increased joint pressures within the radioscaphoid joint compared to the tendon graft, which had joint pressures similar to those of a normal joint [21]. Interestingly, this study also demonstrated a much greater increase in radioscaphoid joint pressure with the STT fusion than with the wrist scapholunate dissociation on pressure-sensitive film. The criticism of tendon grafts for reconstruction is due to the compressive forces of the capitate that disrupt the reconstruction before healing and the tendency of tendinous repairs to stretch over time.

Our reconstruction of the SLIL differs from the tendon weaves of Almquist et al. [19], Linscheid and Dobyns [22], and Brunelli and Brunelli [23] whereby only the SLIL is reconstructed. This is similar to Palmer et al.'s reconstruction [8], except that both the volar and dorsal portions of the SLIL are reconstructed, not only the dorsal portion. This method of repair is technically easier to perform. The bony tunnel is drilled through the lunate and the proximal portion of the scaphoid in a dorsal to volar fashion. This avoids the difficulties of Palmer et al.'s method [8], which created an oblique tunnel from the dorsal surface to the SL joint. It also avoids the extensive dissection and drill holes needed to perform the various tendon weaves [19,22,23]. This reconstruction does not directly address the volar flexion of the scaphoid. However, when the SL joint is congruently reduced to 2 mm or less, the scaphoid flexion is reduced indirectly. Therefore, one of the prerequisites for this reconstruction is a reducible rotatory scaphoid flexion and reducible SL diastasis. Clinically, the repair is pinned in the reduced position for 12 weeks, which should allow the volar extrinsic ligaments to tighten. This is analogous to repairing only the ACL in a combination ACL and MCL injury.

In this study, we determined that using the palmaris longus to reconstruct the SLIL can significantly decrease the SL diastasis. We also demonstrated a trend in restoring the joint contact area and the mathematical center of the peak pressures toward normal, although this was not statistically significant.

Table 2. Centroid distance between scaphoid and lunate in mm

	Extension	Flexion	Neutral
Normal	18.77 SD 2.19	18.33 SD 3.20	19.39 SD 2.55
Injury	18.82 SD 2.18	18.73 SD 3.04	20.19 SD 2.37
Reconstruction	16.38 SD 1.89	17.36 SD 2.74	18.07 SD 1.52
p value			
Normal versus injury	0.97	0.67	0.54
Injury versus reconstruction	0.12	0.21	0.03
Normal versus reconstruction	0.02	0.12	0.18

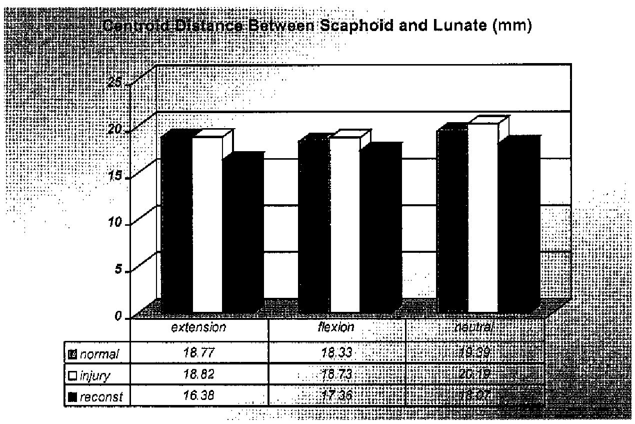

Fig. 5.

In creating the SL instability pattern, the SLIL and the volar radiocapitate ligaments were sectioned. This demonstrated a mean SL diastasis increase from a normal value of 1.63 mm to 5.63 mm on radiographs. The start of the contact points of the scaphoid and the lunate on the pressure-sensitive film also demonstrated an increase in the SL diastasis in all positions of the wrist tested (Fig. 4). Sectioning only the SLIL did not create an SL diastasis. Sectioning of the volar radiocapitate ligament was necessary to obtain a static SL diastasis. However, this did not create a scaphoid rotatory subluxation. In contrast, Blevens et al. [34] demonstrated that sectioning only the SLIL created a static SL diastasis and that sectioning both the SLIL and the palmar intracapsular radiocarpal ligaments (PIRL) or SLIL and scaphotrapezial ligament complex (STLC) created a rotatory flexion deformity of the scaphoid. Stage I of Mayfield et al.'s perilunate instability pattern [1] also revealed SL diastasis and rotatory flexion of the scaphoid. The sectioning of ligaments in Blevens et al.'s study [34] included the scaphotrapezial ligament, the scaphocapitate interosseous ligament, and the STT palmar capsule with SLIL or radiocapitate ligament, radiotriquetral ligament, and the radioscaphoid ligament with SLIL. Our sectioning of only the radioscaphoid portion of the radiocapitate ligament did not destabilize the scaphoid enough to allow rotatory deformity. This is because the STLC is left intact or the other ligament components of the PIRL are left intact to stabilize the scaphoid. In Mayfield et al.'s study [1], stage I includes rupture of the SLIL, radioscaphoid ligament, and the radiocapitate ligament. Therefore, sectioning of the radioscaphoid ligament is needed around the waist of the scaphoid to cause a rotatory flexion deformity.

The SL diastasis was effectively reduced with the free palmaris longus reconstruction. Radiographs on Moneim view [35] noted a significant decrease in the SL gap from 5.63 to 1.88 mm. No significant difference was noted between the normal and reconstructed wrists. Measurement of the SL diastasis by contact pressures on the pressure-sensitive film revealed a significant increase in SL distance from the normal to the injury model and from the injury model to the reconstructed wrists in all three positions tested. However, in flexion and neutral, there was a significant difference between the normal and the reconstructed SL ligament. This may be due to the ligament reconstruction. In a normal SLIL, the dorsal portion is stronger than the volar and there is controlled movement between the scaphoid and the lunate. However, in this repair, the volar and the dorsal portion of the reconstructed SLIL have the same strength, which presumably alters the normal motion between the scaphoid and the lunate.

The method of testing with Fuji pressure-sensitive film is not exact and requires multiple trials to obtain imprints

Table 3. Scaphoid-to-lunate contact ratio

	Extension	Flexion	Neutral
Normal	1.31 SD 0.45	1.28 SD 0.85	1.81 SD 0.74
Injury	2.48 SD 1.43	1.52 SD 0.79	1.22 SD 0.69
Reconstruction	2.22 SD 1.71	0.94 SD 0.64	1.72 SD 0.78
p value			
Normal versus injury	0.04	0.63	0.18
Injury versus reconstruction	0.58	0.23	0.25
Normal versus recostruction	0.12	0.09	0.68

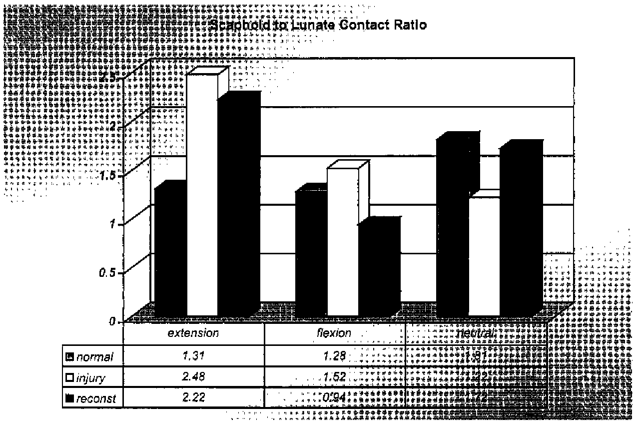

Fig. 6.

without errant background signals. The ultralow pressure-sensitive film has two layers along with the thickness added by the water-proofing layer consisting of Saran Wrap and is held together with adhesive glue. This thickness interposed within the radiocarpal joint occasionally alters the contact points within the joint. Two types of imprints were obtained (figure of point fit and peripheral fit). On one imprint, the thickness of the pressure-sensitive film did not appear to change the contact points. These impressions revealed discrete areas for the lunate and the scaphoid. However, in other specimens, the thickness of the pressure-sensitive film increased the total area of contact. This made a larger imprint on the film with decreased peak pressures. Fortunately, this response to the pressure-sensitive film was consistent whereby the larger contact area was exhibited by the same specimen throughout all testing phases. To eliminate this factor, the ratio of the contact area of the scaphoid to the contact area of the lunate imprint was used.

The contact area ratio between the scaphoid to the lunate decreased in neutral from normal to injured, 1.81 to 1.22, although not significantly ($p = 0.18$). This demonstrates that in SL diastasis, there is decreased contact of the scaphoid on the radius. This is similar to Blevens et al.'s study [34], which showed that sectioning of the SLIL decreased the scaphoid contact area by 37%. Short et al.'s study [36] on the SLIL also revealed a trend toward decreased scaphoid contact area and increased lunate contact area following SLIL sectioniong. Burgess [37] also demonstrated a progressive decrease in the SL contact area as the rotatory subluxation of the scaphoid increased. Finally, Viegas et al. [5] also demonstrated a nonsignificant decrease in the SL contact area ratio from normal to stage I instability. In extension, our study showed a trend to increased scaphoid-to-lunate contact area ratio from 1.31 to 2.48, although not significantly ($p = 0.58$). This is also noted in Blevens et al.'s study [34], where 20 degrees of extension after sequential ligament sectioning resulted in a slight increase in scaphoid contact pressure compared with the normal specimen.

Our study revealed that the centroid distance did not increase significantly when the SL diastasis was created. This corresponds to Viegas et al.'s finding [5] that the overall averaged intercentroid distances did not change significantly. However, our SL reconstruction decreased the intercentroid distance in all three positions to less than the normal value. This was significant in neutral and extension. We believe that this is once again the inability of any tendon reconstruction to allow normal movement between the scaphoid and the lunate. This is because the reconstruction cannot recreate the difference between the strong dorsal portion versus the weaker volar portion of the native SLIL.

Another concern of using a free tendon graft for the SLIL ligament is the ability to heal and to resist stretching over time. We believe that this graft will heal to the surrounding capsule, especially on the dorsal surface. Current clinical experience with hamstring tendon graft for ACL reconstruction appears to show that tendons can heal to surrounding tissue. Also, with ACL reconstruction using patellar tendons, the graft does not stretch clinically with time. Finally, this is a static biomechanical study that does not duplicate the complex carpal kinematics.

Besides being technically easier to perform than limited intercarpal fusions or the tendon weaves, our SLIL reconstruction allows further options for salvage procedures such as proximal row carpectomy, scaphoid excision four-corner fusion, or total wrist arthrodesis if the reconstruction fails. Given our data, we conclude that the SLIL reconstruction effectively decreases the SL diastasis and improves the scaphoid and lunate contact with the radius, but does not restore it to normal. The SLIL ligament probably has an isometric point. Until a ligament reconstruction can reproduce this, there will be abnormal motion between the scaphoid and the lunate, preventing it from restoring normal kinetics and function. Therefore, our current protocol is to perform this ligament reconstruction using the free palmaris longus graft in chronic SL diastasis in patients with correctable rotatory subluxation of the scaphoid without arthrosis where primary repair of the native SLIL ligament is not possible.

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