Original Research

Biomechanical Effects of Superior Capsule Reconstruction for Reinforcement of Rotator Cuff Repair in a Degenerated Reparable Supraspinatus Tendon Tear Model

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Background: Postoperative retear of the repaired rotator cuff tendon may decrease postoperative shoulder muscle strength, worsen patient outcome, and decrease patient satisfaction. Although superior capsule reconstruction for reinforcement of rotator cuff repair (SCR-R) is reported to prevent postoperative retear, the biomechanical benefit of SCR-R is yet to be explored.

Hypothesis: SCR-R would restore superior glenohumeral stability and decrease subacromial contact pressure in a simulated degenerated supraspinatus tendon tear.

Study Design: Controlled laboratory study.

Methods: Eight fresh-frozen cadaveric shoulders were tested using a custom shoulder-testing system. Subacromial peak contact pressure, glenohumeral superior translation, and glenohumeral range of motion (ROM) were compared for 6 conditions: (1) intact shoulder, (2) traumatic reparable supraspinatus tendon tear model, (3) rotator cuff repair of condition 2, (4) degenerated reparable supraspinatus tendon tear model, (5) rotator cuff repair of condition 4, and (6) SCR-R of condition 4.

Results: Creation of the degenerated reparable supraspinatus tear significantly increased superior glenohumeral translation at 0° ($P < .0001$) and 30° ($P = .003$) of glenohumeral abduction. Rotator cuff repair of degenerated reparable supraspinatus tendon tear did not significantly improve superior glenohumeral translation in any abduction position. Compared with that after creation of degenerated reparable supraspinatus tear (condition 4), SCR-R significantly decreased superior glenohumeral translation at 0° ($P = .0001$), 30° ($P = .0002$), and 60° ($P = .004$) of glenohumeral abduction, and significantly decreased subacromial peak contact pressure at 0° ($P = .03$) and 60° ($P = .04$) of glenohumeral abduction. Neither rotator cuff repair alone (condition 5) nor SCR-R significantly decreased glenohumeral ROM compared with creating the degenerated reparable supraspinatus tear (condition 4) in any abduction position.

Conclusion: SCR-R completely restored superior glenohumeral translation and subacromial peak contact pressure when the torn tendon had no superior shoulder capsule, as seen in degenerated supraspinatus tendon tear, whereas rotator cuff repair alone did not provide a significant improvement.

Clinical Relevance: SCR-R is recommended for degenerated reparable supraspinatus tendon tear to improve glenohumeral superior stability after surgery.

Keywords: capsule; reconstruction; rotator cuff; shoulder; stability

Arthroscopic rotator cuff repair for the treatment of symptomatic rotator cuff tear provides satisfactory clinical results.[8,11,34,40] However, postoperative retear of the repaired tendon significantly decreases postoperative

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muscle strength in the shoulder, worsens patient outcome, and decreases patient satisfaction.[8,11,16,34,40] Most risk factors for rotator cuff retear are related to tendon and muscle degeneration due to age, overuse before initial tear, and disuse after initial tear.[4-6,10,14,17-22,36,39] For the repair of severely degenerated rotator cuff tendons, high tension must be applied to fix the torn tendons to the greater tuberosity due to shortening of the tendon tissue and severe retraction even with footprint medialization[9,17,41] or other options, such as partial repair or patch graft surgery, are applied. Such degenerated tendon tissues mainly at the articular side are weaker and thinner than native tendons,[37] thus reducing tensile strength.[7,38] Therefore, when the degenerated tendons are repaired, the increased tension in the weakened tendon tissue may lead to a relatively high rate of retear in rotator cuffs.

Another risk factor for rotator cuff retear is postoperative subacromial impingement due to lack of superior stability after surgery.[13,15] When the torn tendon is severely degenerated, the articular side of the supraspinatus tendon, including the superior shoulder capsule, is severely retracted or absent altogether. The superior shoulder capsule works as a superior stabilizer in the glenohumeral joint.[12] Therefore, superior stability may not be completely restored after rotator cuff repair of a degenerated supraspinatus tendon tear, an injury that usually manifests with a defective or dysfunctional superior shoulder capsule.[1,33,35] leading to abrasion and tearing of the repaired tendon on the undersurface of the acromion due to postoperative subacromial impingement.

Superior capsule reconstruction (SCR) has been developed to restore superior shoulder stability and function for the treatment of irreparable rotator cuff tears.[23,27,29-33] In 2013 at our institute, we started to add SCR using fascia lata autograft to rotator cuff repair to restore superior stability and to augment thin and weakened tendon tissue in the degenerated supraspinatus tendon tear; we call this "SCR for reinforcement of rotator cuff repair" (SCR-R). A clinical study showed that SCR-R for degenerated rotator cuff tears (Goutallier grade: mean, 2.8; range, 2-4) completely prevented retear at 1 year after arthroscopic rotator cuff repair and improved the quality of the thinned tendon on magnetic resonance imaging.[28] However, the biomechanical benefit of SCR-R for degenerated supraspinatus tendon tear has not yet been explored.

Here, we investigated the biomechanical effects of a defective superior shoulder capsule and the effects of SCR-R on superior glenohumeral stability and subacromial impingement in shoulders with supraspinatus tendon tear and repair. We hypothesized that SCR-R would restore superior glenohumeral stability and decrease subacromial contact pressure in a simulated degenerated supraspinatus tendon tear.

METHODS

Specimen Preparation

Eight fresh-frozen cadaveric shoulders (mean age, 68.5 years; range, 50-75 years) were tested in a custom shoulder-testing system (Figure 1); 2 left shoulders and 6 right shoulders were tested. There were 5 male and 3 female donors. Human cadaveric shoulders were acquired from a body donation program (Science Care). All specimens were thawed overnight before dissection and testing and had no evidence of rotator cuff tear or other gross disease. All skin, soft tissues, and muscles were removed from the specimens except for the coracoacromial ligament, shoulder capsule, and tendinous insertions of the rotator cuff, deltoid, pectoralis major, and latissimus dorsi. The humeral shaft was transected 2 cm distal to the deltoid tuberosity. No. 2 FiberWire (Arthrex) sutures were placed in Krackow fashion through subdivisions of each preserved muscle-tendon insertion to allow muscle loading during testing (supraspinatus, subscapularis, infraspinatus, teres minor, deltoid, pectoralis major, latissimus dorsi). An intramedullary rod was rigidly fixed to the humerus and secured to the testing system, which permitted precise positioning control of all 6 degrees of freedom at the glenohumeral joint. Six screws, 3 in the scapula and 3 in the proximal humerus posterior to the bicipital groove, were placed to track the position of the humerus relative to the fixed scapula.

Muscles were loaded using a braided low-stretch Dacron fishing line (Izorline) to the No. 2 FiberWire sutures in each tendon. The lines were fed through customized muscle plates that were positioned to allow anatomic lines of pull and then routed over adjustable pulleys. The desired forces for each particular loading condition were applied using weights. Two different loading conditions were used during this study: balanced and unbalanced muscle loading conditions. The muscle forces were determined on the basis of physiologic cross-sectional area ratios and electromyographic studies.[2,42] Specifically, the following muscle forces for balanced load were used: deltoid, 40 N; pectoralis major, 20 N; latissimus dorsi, 20 N; supraspinatus, 10 N; subscapularis, 10 N; infraspinatus, 5 N; and teres minor, 5 N. The unbalanced loading condition

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Ethical approval was not sought for the present study.

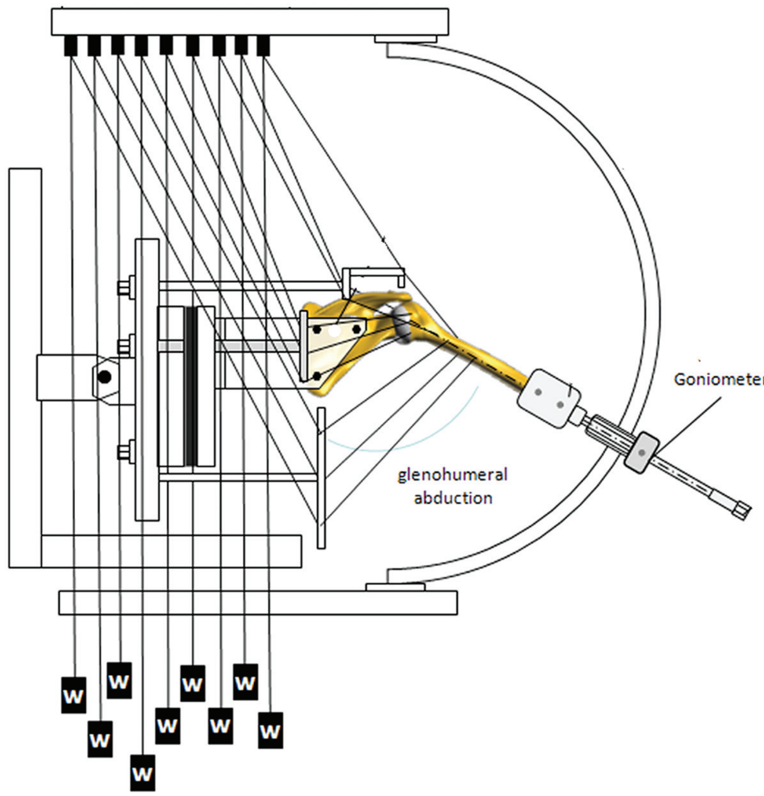

Figure 1. Custom shoulder-testing system. W, weight.

simulated a superior load being applied to the humeral head and was achieved by removing the weights from the latissimus dorsi and pectoralis major and applying an additional 40 N to the deltoid for a total load of 80 N.

Measurements

Glenohumeral superior translation and subacromial peak contact pressure were measured at 0°, 30°, and 60° of glenohumeral abduction, which respectively corresponded to 0°, 45°, and 90° of shoulder abduction, in the scapular plane. The rotation angle was fixed at 30° of external rotation with all muscle loads applied, as described in a previous study.[25] For the measurement of superior translation, the reference planes and coordinate system (x, anteroposterior; y, superoinferior; z, mediolateral) were defined before testing. To establish a reproducible starting point, the initial position was determined by centering the humeral head under the balanced load. The amount and direction of translation relative to the initial position were quantified by using a 3-dimensional digitizer (MicroScribe 3DLX; Immersion Corp); the accuracy of this device was 0.30 mm, according to the manufacturer. Before testing, 2 small screws were placed at the anterolateral acromion, and a third was placed at the proximal portion of the bicipital groove. The location of the humeral head relative to the acromion was recorded under the balanced and unbalanced loading conditions. To evaluate superior shoulder stability, superior translation of the humerus was calculated by comparing the distance between 2 small screws on the acromion and humerus in the superoinferior direction under the unbalanced loading condition with that under the balanced loading condition. Peak contact pressure between the coracoacromial arch (coracoacromial ligament and acromion) and humerus was recorded at an applied superior translation force by using a pressure-measuring system (saturation pressure, 10.3 MPa; Model 4000; Tekscan).[25]

Humeral rotational range of motion (ROM) was measured at 0°, 30°, and 60° of glenohumeral abduction in the scapular plane by using a 360° digital goniometer (Novotechnik US, Inc) in the balanced loading condition; 90° external rotation was defined as the point at which the anterior edge of the acromion aligned with the long head of the biceps tendon in the bicipital groove at 60° of glenohumeral abduction.[3,12,25,26] The specimens were preconditioned with 5 cycles of 2.2 N·m of torque in external and internal rotation. Maximal rotation was measured by applying a 2.2-N·m torque. These torque values were determined from preliminary studies to measure humeral rotation without capsular stretching or tearing.[3,12,26,33] Total rotational ROM was calculated by summing the external and internal rotational ROMs.

Test Conditions

In total, 6 conditions were tested during the experiment (Figure 2). Condition 1 was the intact rotator cuff as

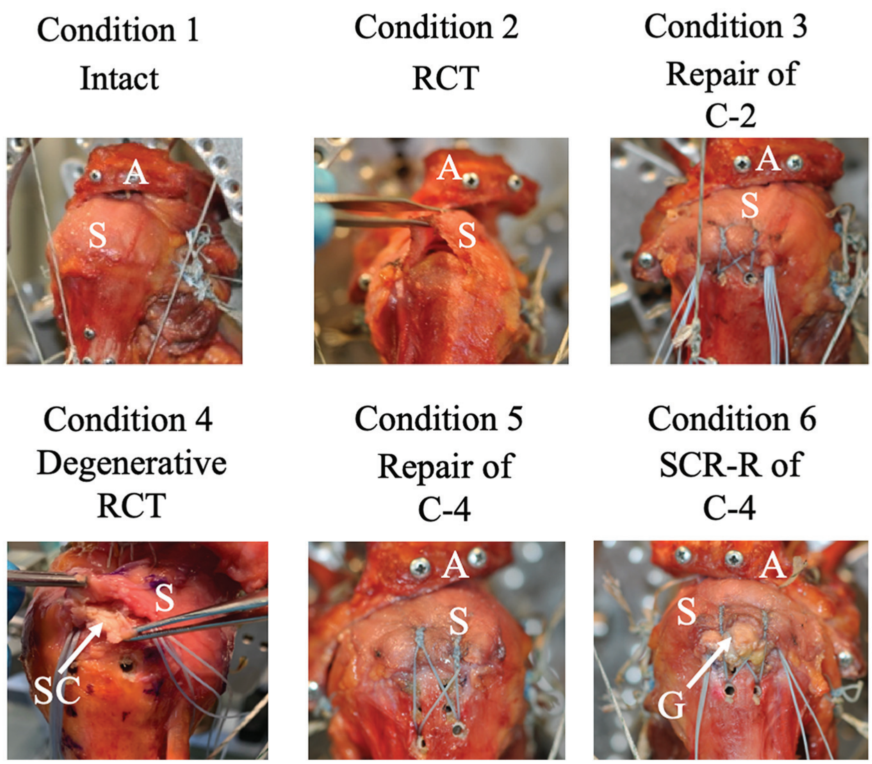

Figure 2. Testing conditions: Condition 1, intact shoulder. Condition 2 (C-2), traumatic reparable supraspinatus tendon tear model. Condition 3, rotator cuff repair of C-2. Condition 4 (C-4), degenerated reparable supraspinatus tendon tear model. The superior shoulder capsule underlying the supraspinatus muscle and tendon was excised completely. After this process, the supraspinatus tendon had a thinned-out, degenerative appearance. Condition 5, rotator cuff repair of C-4. Condition 6, SCR-R of C-4. *A*, acromion; *G*, graft; RCT, rotator cuff tear; *S*, supraspinatus; *SC*, superior capsule; SCR-R, superior capsule reconstruction for reinforcement of rotator cuff repair.

a control. After all measurements were made in the intact condition, a traumatic reparable supraspinatus tear model was created by cutting the entire supraspinatus tendon and superior capsule completely at the greater tuberosity insertion (medium-size tear) and used as condition 2. Thereafter, rotator cuff repair was performed using the double-row suture-bridge technique (condition 3). Two Bio-Composite SwiveLock anchors (4.75 × 19.1 mm) (Arthrex), triple-loaded with No. 2 FiberWire, were inserted at the medial margin of the footprint. The anterior anchor was inserted at the medial aspect of the supraspinatus footprint, just lateral to the articular surface, 5 mm posterior to the anterior edge of the supraspinatus tear. In a similar manner, a second posterior anchor was inserted 5 mm anterior to the posterior edge of the supraspinatus tear. The No. 2 FiberWire was passed through the supraspinatus tendon. Four passes were made, all 1 cm medial to the lateral edge of the tendon. The first limb (anterior anchor) was passed 5 mm anterior to the position of the anterior anchor, and the second limb (anterior anchor) was passed 5 mm posterior to the anterior anchor. The third limb (posterior anchor) was passed 5 mm anterior to the position of the posterior anchor, and the fourth limb was passed 5 mm posterior to the position of the posterior anchor. Each of the passes were therefore 1 cm apart and 1 cm medial to the lateral edge of the supraspinatus tendon. The shoulder was positioned at 20° of glenohumeral abduction in the scapular plane at a rotation angle where the bicipital groove was aligned with the anterolateral edge of the acromion (neutral rotation). The 2 limbs of the anterior anchor were tied together using 1 square sliding knot followed by 3 half-hitch knots, alternating post and throws. The 2 limbs of the posterior anchor were tied similarly. One limb from each anchor was then passed into the eyelet of another 4.75 × 19.1–mm SwiveLock anchor and this anchor was inserted at 10 mm inferior to the lateral edge of the greater tuberosity footprint and lateral to the anterior medial anchor. This was repeated, and a posterior lateral row anchor (4.75 × 19.1–mm SwiveLock) was inserted.

After condition 3 was tested, a degenerative reparable cuff tear model, which simulates thin tendon due to aging, was then created (condition 4). All of the sutures used in the primary repair (condition 3) were removed while being careful not to cut the rotator cuff tendons. The supraspinatus muscle tissue was peeled off from the bony supraspinatus fossa on the scapula, after which the superior shoulder capsule could be seen under the supraspinatus muscle tissue. The supraspinatus muscle tissue was kept from peeling off from the superior shoulder capsule laterally up to

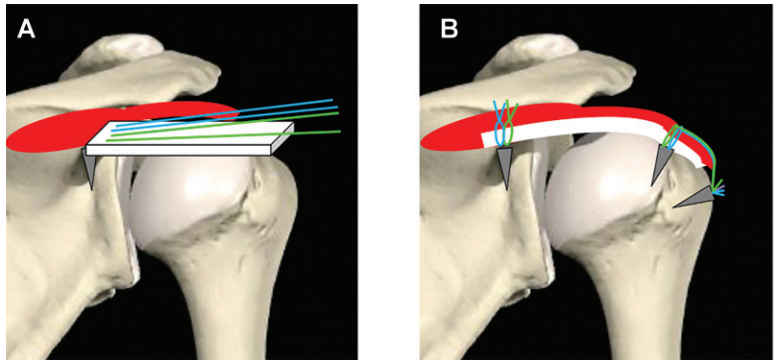

Figure 3. Superior capsule reconstruction for reinforcement of rotator cuff repair. (A) First, the graft was inserted under the torn supraspinatus tendon. (B) The torn tendons were repaired on the fascia lata graft by using the double-row suture-bridge technique.

the torn edge of the supraspinatus tendon in the traumatic reparable supraspinatus tear model. After the entire superior shoulder capsule was exposed, the segment of the superior shoulder capsule underlying the supraspinatus muscle and tendon was excised completely. After this process, the supraspinatus tendon had a thinned-out, degenerative appearance.

After condition 4 was tested, the degenerative supraspinatus tendon tear was repaired (condition 5) with the double-row suture-bridge technique as described above for the primary repair (condition 3). We used another pair of sutures of the triple-loaded medial row footprint anchors used in the primary repair. Two lateral row anchors (4.75 × 19.1–mm SwiveLock) were inserted at 5 mm inferior to the lateral row anchors in condition 3.

Finally, SCR-R (rotator cuff repair + SCR) was performed on the degenerative supraspinatus tear model using the double-row suture-bridge technique to afford condition 6 (Figure 3). Again, all of the sutures were removed from the repair of condition 5 while care was taken not to cut the rotator cuff tendons. One BioComposite Corkscrew FT anchor (4.5 × 14 mm) (Arthrex) double-loaded with No. 2 FiberWire was inserted 1 cm medial to the osseous edge of the glenoid at the midpoint of the anteroposterior defect. The shoulder was locked at 20° of glenohumeral abduction and neutral rotation before measurements.

A single layer of fascia lata graft (graft thickness, 2-3 mm) was used for SCR-R in a manner similar to that used in the clinic. The size of the superior capsular defect was measured in the anteroposterior direction (from the anterior to the posterior edge of the torn tendon laterally and from anterior to the posterior edge of the capsular defect medially) and the mediolateral direction (from the superior edge of the glenoid to the lateral edge of the greater tuberosity). Based on the defect size, the graft size was determined as described previously.[28] The graft length in the anteroposterior direction was exactly the same as the length of the defect in the anteroposterior direction. The graft length in the mediolateral direction was 15 mm longer than the length from the superior edge of the glenoid to the lateral edge of the greater tuberosity.

Leading and lagging sutures were applied to the medial and lateral aspects of the graft to allow for passage underneath the torn supraspinatus tendon in the degenerative tear model. The 4 limbs of the double-loaded glenoid side (medial) anchor were passed 1 cm lateral to the medial edge of the graft in mattress fashion. The triple-loaded medial anchors used in the primary repairs (conditions 3 and 5) were reutilized. One suture pair from the posterior footprint anchor was passed in mattress fashion 15 mm medial to the lateral edge of the graft. The other suture pair from the anterior footprint anchor were passed in mattress fashion with equal distances between the limbs to the anterior portion of the lateral side of the graft. Then the graft was passed underneath the torn supraspinatus tendon (into the glenohumeral joint) through the tendon tear. When the medial edge of the graft reached the superior glenoid, all sutures from the glenoid suture anchor were tied to fix the graft onto the glenoid. Finally, the supraspinatus tendon was fixed over the fascia lata graft in tandem. The same suture limbs from the suture anchors at the medial footprint of the greater tuberosity (already passed into the graft as described above) were passed 1 cm medial to the lateral edge of the supraspinatus tendon in mattress fashion at the same marked positions described for condition 3, and tied using a nonsliding RC knot.[24] The sutures were not cut after the knots were tied so that the suture limbs could be used to repair the torn tendons over the graft. Suture bridges were completed using all suture limbs and two 4.75-mm SwiveLock suture anchors using the same sequence as described for condition 3. No side-to-side suturing between the graft and the infraspinatus tendon was performed.

Data Analysis

All measurements were performed twice, and the mean value was used for the data analyses. Statistical analyses were performed using the Statistica software (Version 6.0; StatSoft). Repeated-measures analysis of variance

TABLE 1
Superior Glenohumeral Translation (in mm)[a]

	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6
Glenohumeral Abduction	Intact	RCT	RCR	Degenerative RCT	RCR of Degenerative RCT	SCR-R of Degenerative RCT
0°	2.0 ± 0.4	2.2 ± 0.4	2.9 ± 0.4	4.0 ± 0.5[b,c]	3.6 ± 0.6[b,c]	1.4 ± 0.5[d,e]
30°	2.0 ± 0.5	2.1 ± 0.5	2.4 ± 0.7	3.4 ± 0.5[b,c]	2.8 ± 0.4	1.6 ± 0.4[d,e]
60°	1.4 ± 0.3	1.8 ± 0.3	2.2 ± 0.3	2.3 ± 0.3	1.2 ± 0.3	0.9 ± 0.4[d]

[a]Values are given as means ± SE. RCR, rotator cuff repair; RCT, rotator cuff tear; SCR-R, superior capsule reconstruction for reinforcement of rotator cuff repair.
[b]Value increased significantly ($P < .05$) from that for the intact condition.
[c]Value increased significantly ($P < .05$) from that for the RCT condition.
[d]Value decreased significantly ($P < .05$) from that for the degenerative RCT condition.
[e]Value decreased significantly ($P < .05$) from that for the RCR of degenerative RCT condition.

TABLE 2
Subacromial Peak Contact Pressure (in KPa)[a]

	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6
Glenohumeral Abduction	Intact	RCT	RCR	Degenerative RCT	RCR of Degenerative RCT	SCR-R of Degenerative RCT
0°	435 ± 65	464 ± 41	417 ± 44	418 ± 53	355 ± 53	278 ± 31[b,c,d]
30°	438 ± 64	400 ± 65	431 ± 55	331 ± 56	295 ± 31	291 ± 42[b]
60°	1002 ± 168	885 ± 167	664 ± 106	870 ± 174	808 ± 125	489 ± 92[b,c,d]

[a]Values are given as means ± SE. RCR, rotator cuff repair; RCT, rotator cuff tear; SCR-R, superior capsule reconstruction for reinforcement of rotator cuff repair.
[b]Value decreased significantly ($P < .05$) from that for the intact condition.
[c]Value decreased significantly ($P < .05$) from that for the RCT condition.
[d]Value decreased significantly ($P < .05$) from that for the degenerative RCT condition.

was performed for each independent variable, including glenohumeral superior translation, subacromial peak contact pressure, and glenohumeral ROM. Post hoc analyses using the Tukey test were performed to identify differences between conditions when a significant main effect was found. Data are presented as mean ± SE, and the significance level was set at $P < .05$.

To determine the appropriate sample size, a power analysis was performed by using the G*Power3 statistical analysis software package. Power ($1 - \beta$) was calculated by defining the sample size as 8, the level of significance (α) as .05, and the effect size as 2.27 at 0° abduction, 1.16 at 30° abduction, 1.70 at 60° abduction in superior glenohumeral translation and 0.95 at 0° abduction, 0.96 at 30° abduction, 0.99 at 60° abduction in subacromial peak contact pressure. The power analysis indicated that a total sample size of 8 specimens provided 80% power ($1 - \beta = 0.8$; $\alpha = .05$) to detect significant differences in superior glenohumeral translation and subacromial peak contact pressure between 6 conditions, assuming a power of 1.00.

RESULTS

Compared with intact shoulders, creation of the traumatic reparable supraspinatus tear (condition 2, medium-size tear without thinning of the torn tendon) and rotator cuff repair (condition 3) did not change superior glenohumeral translation in any abduction position (Table 1). Creation of the degenerated reparable supraspinatus tear significantly increased superior glenohumeral translation at 0° ($P < .0001$) and 30° ($P = .003$) of glenohumeral abduction. Rotator cuff repair alone for the degenerated reparable supraspinatus tear (condition 5) did not improve superior glenohumeral translation significantly in any abduction position. Compared with that after creation of the degenerated reparable supraspinatus tear (condition 4), SCR-R (condition 6) significantly decreased superior glenohumeral translation at 0° ($P = .0001$), 30° ($P = .0002$), and 60° ($P = .004$) of glenohumeral abduction.

Creation of the traumatic reparable supraspinatus tear (condition 2) and rotator cuff repair (condition 3) did not change subacromial peak contact pressure compared with intact shoulders in any abduction position (Table 2). Also, rotator cuff repair alone for the degenerated reparable supraspinatus tear (condition 5) did not change subacromial peak contact pressure significantly in any abduction position. Compared with that after creation of the degenerated reparable supraspinatus tear (condition 4, 418 KPa at 0° and 870 KPa at 60°), SCR-R (condition 6, 278 KPa at 0° and 489 KPa at 60°) significantly decreased subacromial

TABLE 3
Total Rotational Range of Motion (in degrees)[a]

	Condition 1	Condition 2	Condition 3	Condition 4	Condition 5	Condition 6
Glenohumeral Abduction	Intact	RCT	RCR	Degenerative RCT	RCR of Degenerative RCT	SCR-R of Degenerative RCT
0°	113 ± 8	118 ± 7	116 ± 7	[b]120 ± 7	[b]120 ± 8	117 ± 7
30°	134 ± 6	138 ± 5	137 ± 5	[b]141 ± 6	[b]140 ± 6	137 ± 5
60°	132 ± 8	134 ± 8	132 ± 8	[b]138 ± 8	[b]137 ± 8	133 ± 7

[a]Values are given as means ± SE. RCR, rotator cuff repair; RCT, rotator cuff tear; SCR-R, superior capsule reconstruction for reinforcement of rotator cuff repair.
[b]Value increased significantly ($P < .05$) from that for the intact condition.

peak contact pressure at 0° (P = .03) and 60° (P = .04) of glenohumeral abduction.

Creation of the traumatic reparable supraspinatus tear (condition 2) and rotator cuff repair (condition 3) did not change external rotation or internal rotation, or total rotational ROM (Table 3), compared with intact shoulders in any abduction position. Creation of the degenerated reparable supraspinatus tear (condition 4) significantly increased internal rotation and total rotational ROM at 0° (by 2° [P = .01] and 7° [P = .004]), 30° (by 3° [P = .01] and 7° [P = .001]), and 60° (by 5° [P = .003] and 6° [P = .02]) of glenohumeral abduction, and significantly increased external rotation at 0° (by 5° [P = .01]) and 30° (by 4° [P = .03]) of glenohumeral abduction. Both rotator cuff repair alone (condition 5) and SCR-R (condition 6) did not significantly decrease external rotation, internal rotation, or total rotational ROM compared with those after creation of the degenerated reparable supraspinatus tear (condition 4) in any abduction position.

DISCUSSION

Recently, SCR-R has been developed to reduce the rate of retear after rotator cuff repair for reparable but degenerated supraspinatus and/or infraspinatus tendon tear. A clinical study of SCR-R showed no postoperative retear of the repaired tendon and graft at 1 year after surgery, whereas rotator cuff repair alone showed a 4% rate of retear of the repaired tendon.[28] In the present biomechanical study, we found that SCR-R normalized superior glenohumeral translation and subacromial peak contact pressure in degenerated supraspinatus tendon tear, although rotator cuff repair alone did not afford statistically significant improvements. Thus, SCR can improve superior stability and decrease subacromial impingement, consequently protecting the repaired rotator cuff tendons from retearing.

For the degenerated supraspinatus tendon tear, rotator cuff repair alone did not significantly improve superior glenohumeral translation and subacromial peak contact pressure. Furthermore, superior glenohumeral translation after rotator cuff repair alone in the degenerated supraspinatus tendon tear was significantly larger than that in the intact condition. Therefore, some patients with degenerated rotator cuff tear most likely have superior migration, which may cause retear of the repaired tendon,[13,15] even after rotator cuff repair. In such situations, we recommend the addition of SCR to the rotator cuff repair

Previous biomechanical studies have shown that SCR for irreparable rotator cuff tear decreased passive total rotational ROM in the shoulder by around 5° at 60° of glenohumeral abduction.[33] However, in the present biomechanical study, shoulder rotational ROM did not change after SCR-R. One difference between SCR for irreparable rotator cuff tear and for reinforcement of rotator cuff repair is graft thickness. The graft thickness is 6 to 8 mm for SCR for irreparable rotator cuff tear[30] but only 2 to 3 mm for SCR-R. Therefore, graft thickness may affect shoulder rotational ROM after SCR.

The present study also showed that after completely cutting the supraspinatus tendon at the footprint of the greater tuberosity (condition 2), superior glenohumeral translation and subacromial contact pressure did not change compared with the intact condition. This suggests that isolated rotator cuff repair is recommended rather than SCR-R for traumatic tear of the supraspinatus tendon when the tendon has sufficient thickness without degeneration due to age, overuse before initial tear, and disuse after initial tear. However, after removing the superior shoulder capsule (articular side of the supraspinatus tendon) (condition 4), superior glenohumeral translation was significantly increased compared with the intact condition. Furthermore, repair of the degenerated supraspinatus tendon without the superior shoulder capsule did not restore superior glenohumeral translation. Therefore, surgeons should check the thickness of the torn supraspinatus tendon by magnetic resonance imaging before surgery to assess the severity of the degeneration of the torn tendon. When the tendon thickness is <50%, we recommend SCR-R to restore superior shoulder stability.

Strengths and Limitations

The strengths of this study include its direct measurement of superior glenohumeral translation, glenohumeral ROM, and subacromial contact pressure in cadaveric shoulders.

Also, several conditions were tested on each specimen. These parameters and repetitive measurements cannot be applied in living patients. In addition, the same rotator cuff tear conditions could be created in each cadaveric shoulder. However, this study also has a few weaknesses. First, muscle loading was static rather than dynamic because it was a cadaveric study. Second, biologic healing potential could not be assessed, even after rotator cuff repair or SCR, again because it was a cadaveric study. Third, an increased ROM after creation of rotator cuff tear is not seen in the clinical situation because pain and concomitant shoulder stiffness decrease ROM in patients with rotator cuff tears. However, the present study did evaluate glenohumeral ROM to allow assessment of the possibility of shoulder stiffness after adding SCR. Fourth, there was no significant difference in subacromial peak contact pressure between conditions 1 and 4, although superior glenohumeral translation in condition 4 was significantly higher than that in condition 1. One of the possible reasons is cadaveric setting. Some significant difference might not be detected because only limited conditions, including shoulder position and muscle loading, can be applied in biomechanical studies. Fifth, our degenerative rotator cuff tear model may not accurately represent the clinical situation. Sixth, the change in superior glenohumeral translation may not represent a clinically significant difference although there was a statistically significant difference in the biomechanical study.

CONCLUSION

Addition of SCR to rotator cuff repair completely restored superior glenohumeral translation and subacromial peak contact pressure when the torn tendon had no superior shoulder capsule, as seen in degenerated supraspinatus tendon tear. In contrast, rotator cuff repair alone did not provide any significant improvement. Therefore, we recommend SCR-R in degenerated reparable supraspinatus tendon tear.

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