Superior Capsular Reconstruction Combined With Lower Trapezius Tendon Transfer Improves the Biomechanics in Posterosuperior Massive Rotator Cuff Tears

Jun-Bum Lee,* MD, Erica Kholinne,† MD, PhD, Hui Ben,‡ MD, Sang-Pil So,* MD, Hood Alsaqri,§ MD, Kyoung-Hwan Koh,* MD, PhD, and In-Ho Jeon,*‖ MD, PhD

Investigation performed at Asan Medical Center, University of Ulsan College of Medicine, Seoul, Republic of Korea

Background: Surgical treatments for chronic posterosuperior massive rotator cuff tear (MRCT) are still controversial. Superior capsular reconstruction (SCR), which provides a static stabilizer to decrease superior humeral head translation, and lower trapezius tendon transfer (LTTT) with centralization of the humeral head, which prevents superior humeral head migration, are potential surgical options. To date, SCR combined with LTTT has not been fully investigated.

Hypothesis: Restoration of static stabilizer and dynamic stabilizer together would effectively improve shoulder kinematics in posterosuperior MRCT.

Study Design: Controlled laboratory study.

Methods: A custom-made shoulder mechanics testing system was used to test 8 fresh-frozen cadaveric shoulders. The testing conditions were as follows: (1) intact; (2) posterosuperior MRCT (supraspinatus and infraspinatus removed); (3) SCR using the fascia lata; (4) LTTT; and (5) SCR combined with LTTT. The total rotational range of motion (ROM), superior translation, anteroposterior translation, and peak subacromial contact pressure were evaluated at 0°, 30°, and 60° of shoulder abduction. Repeated-measures analysis of variance and Tukey post hoc tests were performed.

Results: The total rotational ROM, superior translation, anteroposterior translation, and peak subacromial contact pressure increased in posterosuperior MRCTs (all, $P < .05$). The rotational ROM, superior translation, anteroposterior translation, and peak subacromial contact pressure at 0° and 30° of shoulder abduction decreased in SCR (all, $P < .05$). However, there was no significant improvement in rotational ROM, superior translation, and peak subacromial contact pressure at 60° of shoulder abduction ($P > .05$). LTTT resulted in a significant decrease in the superior translation, anteroposterior translation, and peak subacromial contact pressure at 0°, 30°, and 60° of shoulder abduction ($P < .05$). SCR combined with LTTT restored the total rotational ROM, superior translation, anteroposterior translation, and peak subacromial contact pressure at 0°, 30°, and 60° of shoulder abduction (all, $P < .05$).

Conclusion: In the cadaveric model, SCR combined with LTTT showed improved shoulder kinematics and contact pressures in the posterosuperior MRCT model compared with SCR or LTTT alone.

Clinical Relevance: SCR combined with LTTT may be regarded as an alternative surgical procedure for posterosuperior MRCTs.

Keywords: biomechanical study; cadaveric study; lower trapezius tendon transfer; posterosuperior massive rotator cuff tear; superior capsular reconstruction

The natural history of massive chronic irreparable rotator cuff tears (MRCTs) involves a predictable progression to arthritic changes of the glenohumeral joint.[17] The unpredictable and inconsistent surgical outcome after MRCT treated with rotator cuff repair remains a great challenge for orthopaedic surgeons. Retear rates after arthroscopic rotator cuff repair have been reported to range from 30% to 94%, which are often associated with poor clinical outcomes.[5,7] Other surgical options have been introduced for MRCT, including arthroscopic debridement,[31] partial or complete repair,[6,20] graft augmentation,[19] tendon transfer,[10] superior capsular reconstruction (SCR),[12] and arthroplasty.[22]

SCR is a static stabilizer reconstruction method in which the autologous fascia lata is used as a graft fixed between the humerus and the glenoid.[16] In biomechanical studies, SCR has-shown improved superior stability,

The American Journal of Sports Medicine
2023;51(14):3817–3824
DOI: 10.1177/03635465231207834

improved muscle balance, and decreased humeral head migration.[14,16] Favorable clinical outcomes—including pain relief and shoulder function improvement in short-term follow-up studies—have been reported.[11-13,15,16]

As a dynamic stabilizer reconstruction method, lower trapezius tendon transfer (LTTT) has been developed for posterosuperior MRCTs. Anatomically, the lower trapezius muscle shows a similar excursion to the infraspinatus muscle; thus, LTTT could be expected to restore external rotation and transverse couple force in posterosuperior MRCTs.[3,4,29] Previous LTTT studies showed favorable surgical outcomes in posterosuperior MRCT cases.[3] However, when considering restoration of shoulder kinematics, LTTT might have limitations because of the lack of static stabilizer restoration.

As mentioned above, SCR is reported to restore superior stability by restoring static stabilizers, and LTTT is known to restore dynamic stabilizers in posterosuperior MRCTs. Thus, it is posited that if SCR and LTTT are performed simultaneously, they will produce superior results. However, to our knowledge, no research has been conducted on this topic. Therefore, this study aimed to conduct a biomechanical evaluation of SCR using the fascia lata, LTTT, and SCR combined with LTTT. We hypothesized that SCR combined with LTTT would better restore normal shoulder kinematics in terms of the total shoulder rotational range of motion (ROM), superior head migration, anteroposterior humeral head translation, and peak subacromial contact pressure compared with each method alone in the posterosuperior MRCT model.

METHODS

Specimen Preparation

Our institutional review board approved this study (2022-1519). In this biomechanical study, 8 fresh-frozen human cadaveric shoulder models were tested. All cadaveric shoulders were donated to the university anatomy program. Six male and 2 female specimens were prepared with 4 right and 4 left shoulders—pairs from 2 male and 1 female donors and individual right and left shoulders from 2 male donors; mean age was 61.5 ± 11.7 years. All specimens were thoroughly checked before the experiment, and specimens with rotator cuff tear glenohumeral joint arthritis were excluded. The fresh cadaveric shoulders were stored at −14°C and thawed overnight at room temperature before testing.

An orthopaedic fellowship–trained surgeon (J.L.) performed all specimen preparation consistently. The humeral bone was cut from 10 cm distal to the deltoid tuberosity using a microsaw. All the soft tissues were dissected and removed except for the coracoacromial, coracohumeral ligaments, and the glenohumeral joint capsule. The rotator cuff tendons—supraspinatus, infraspinatus, teres minor, and subscapularis—were cut from 10 cm above each of their insertion points. The deltoid, latissimus dorsi, teres major, and pectoralis major tendons were cut from 10 cm above each insertion point. The muscular portion of those muscles were removed from the respective origins. The rotator interval was opened to release the intra-articular negative pressure. Each muscle's tendinous portion was sutured using the Krakow method with high-strength suture (FiberWire; Arthrex). Tendon sutures were placed based on the orientation of the muscle fiber for anatomic muscle loading.[13,16,24] Tendon sutures were placed in the following locations in this study: anterior and posterior sutures for the supraspinatus; superior and inferior sutures for the subscapularis; superior and inferior sutures for the infraspinatus and teres minor; superior and inferior sutures for the pectoralis major; superior and inferior sutures for the latissimus dorsi and teres major; and anterior, middle, and posterior sutures for the deltoid. To pull the lines, we used a fishing line (monofilament; diameter, 0.320 mm; strength, 9.3 kg) to link each tendon suture. The direction of the pull was set based on muscle orientation. The total amount of the muscle loads was determined according to previous studies.[1,24,27]

To digitize the distance between the humeral head and the acromion, we inserted 2 screws (2.4 mm in diameter) in the acromion (anterior margin of the acromion and posterior margin of the acromion), and we inserted 2 screws (2.4 mm in diameter) in the humerus (superior margin of the bicipital groove and posterior aspect of the greater tuberosity).

The scapula was fixed in the custom-made jig. The scapula was positioned with a 20° anterior tilt and a 30° humeral anterior tilt in the sagittal plane. The position of the humerus was set at a 30° anterior tilt to the coronal plane of the scapular plane, which was defined as a neutral humeral rotation angle. With reference to a previous biomechanical study,[16] the humeral axial rotation was defined as the relative position between the bicipital groove and the anterolateral corner of the acromion. The humerus was held with an aluminum rod, which was inserted in the medullary canal. Interlocking screws were inserted to secure the stable fixation of the rod (Figure 1).

Biomechanical Testing

Five conditions were tested: (1) intact shoulder joint; (2) posterosuperior MRCT (supraspinatus and infraspinatus

[||]Address correspondence to In-Ho Jeon, MD, PhD, Department of Orthopaedic Surgery, Asan Medical Center, University of Ulsan College of Medicine, 88 Olympic-ro 43-gil, Songpa-gu, Seoul 05535, Republic of Korea (email: jeonchoi@gmail.com).

*Department of Orthopaedic Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Republic of Korea.

[†]Department of Orthopedic Surgery, Saint Carolus Hospital, Faculty of Medicine, Universitas Trisakti, Jakarta, Indonesia.

[‡]Asan Institute for Life Sciences, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Republic of Korea.

[§]Department of Orthopaedic Surgery, Rustaq Hospital, Rustaq, Sultanate of Oman.

Submitted January 27, 2023; accepted August 23, 2023.

The authors declared that they have no conflicts of interest in the authorship and publication of this contribution. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

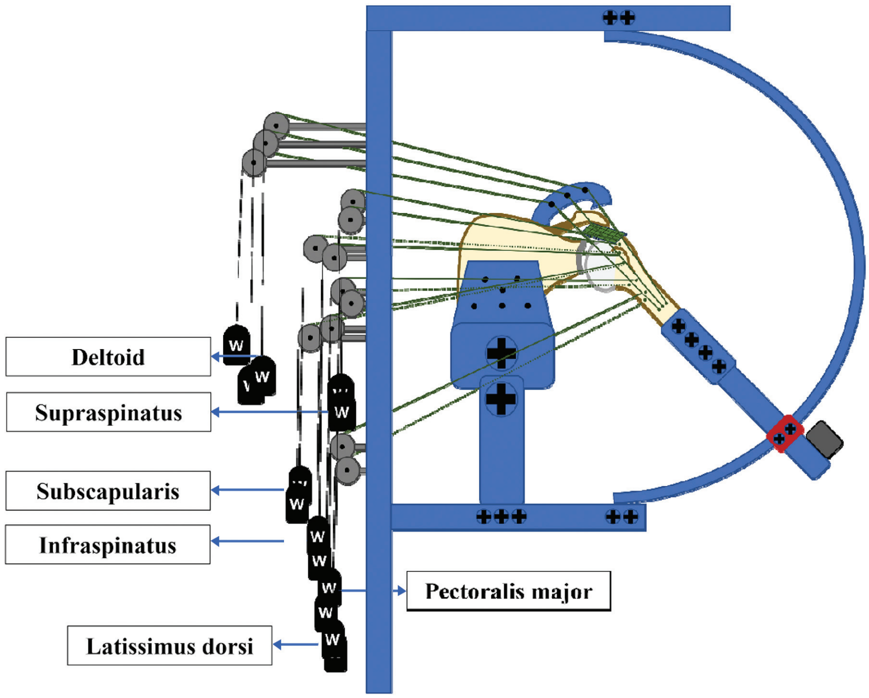

Figure 1. Biomechanical testing machine and muscle loading condition. A schematic of biomechanical testing machine and lines of muscle pull. The scapula was mounted in the custom-made jig. An aluminum rod was inserted in the intramedullary canal of the humerus, and interlocking screws with an external fixator were fixed with the humerus. The foil pressure was fixed under the acromion with high-strength suture. W, weight.

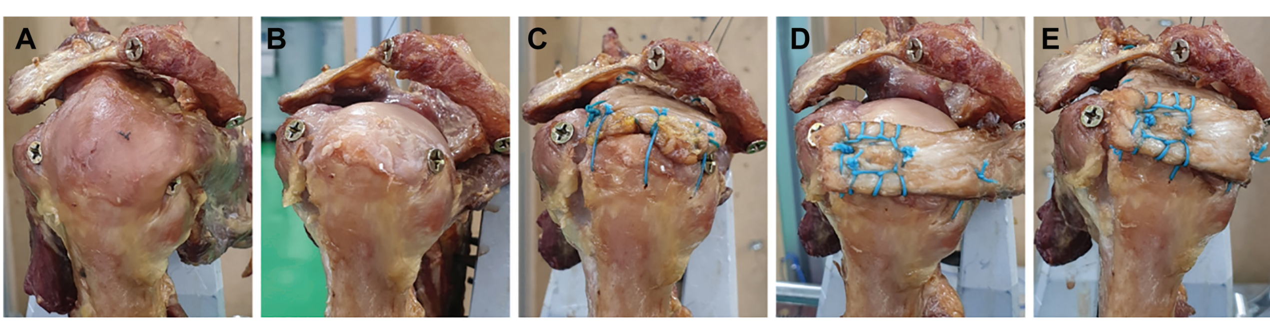

Figure 2. Experimental conditions. (A) Intact. (B) Posterosuperior MRCT. (C) SCR using the fascia lata. (D) LTTT using the Achilles tendon. (E) SCR combined with LTTT. LTTT, lower trapezius tendon transfer; MRCT, massive rotator cuff tear; SCR, superior capsular reconstruction.

were cut from the footprint and removed); (3) SCR using the fascia lata; (4) LTTT using the Achilles tendon; and (5) SCR combined with LTTT. A posterosuperior MRCT was created by removing the posterosuperior joint capsule and rotator cuff tendons, including the supraspinatus and infraspinatus.[24,26] After each testing condition, all specimens were checked for fixation failure (Figure 2).

We set the 2 different loading conditions. Loading condition 1 was defined as a balanced muscle loading. Loading condition 2 was defined as a superior-directed muscle loading. All the applied loads were determined according to the muscle physiological cross-sectional area and electromyographic studies.[1,27] For loading condition 1, the supraspinatus (only intact condition), infraspinatus (only intact condition), and teres minor were loaded with 10 N distributed across the 2 lines of pull; the subscapularis, pectoralis major, and latissimus dorsi were each loaded with 20 N across their 2 lines of pull; and the deltoid was loaded with 40 N distributed across the 3 lines of pull. For loading condition 2, the supraspinatus (only intact condition), infraspinatus (only intact condition), and teres minor were loaded with 10 N distributed across the 2 lines of pull; the subscapularis was loaded with 20 N across 2 lines of pull; and the deltoid was loaded with 80 N distributed across the 3 lines of pull. The superior translation forces for loading condition 2 were generated by increased deltoid loading (40 N $\longrightarrow$

80 N), which decreased the pectoralis major and latissimus dorsi loading (each of 20 N ⟶ 0 N).[16] The supraspinatus and infraspinatus were cut after measuring the intact condition. This was performed to demonstrate the lack of physiological muscle tension that follows a posterosuperior MRCT when the muscle becomes severely atrophied.[24,26] The tendons at the footprint of the supraspinatus (SST) and infraspinatus (IST) tendon were removed.[18] The capsular layer, which is the innermost layer of the rotator cuff, and the capsule's glenoid attachment corresponding to the removed muscles were also removed. The defect size was measured at 0° of abduction using a 3-dimensional digitizing system (MicroScribe 3DX; Revware, Raleigh, NC). The mediolateral defect was measured from the lateral margin of the glenoid to the lateral margin of the greater tuberosity (GT) of the humerus. The anteroposterior defect size was measured for each humerus and glenoid defect. Muscle loading was not applied after tendon resection for MRCTs (10 N for the supraspinatus and 10 N for the infraspinatus). For LTTT loading, the Achilles tendon was loaded with 24 N across 2 pull lines (Appendix Figure A1, available in the online version of this article).

The rotational ROM of the humerus was measured using a 360° goniometer attached to the testing machine. Internal and external rotation were measured applying 2.2 N·m of torque to the humerus under a balanced load. All specimens were preconditioned routinely using 5 cycles of maximum rotational motion with 2.2 N·m of torque before obtaining the final data of total rotational ROM. Total rotational ROM was determined as the sum of the maximum internal and maximum external rotation. Each measurement was performed under load condition 1 at 0°, 30°, and 60° of abduction. However, when considering 30° of scapular motion, the equivalent combined abduction angles would be 30°, 60°, and 90°.[12]

The relative location between the humeral head and the acromion was recorded using a 3-dimensional digitizing system at loading conditions 1 and 2. The superior translation of the humeral head was determined by calculating the distance between the screws of the acromion and the humerus in the vertical direction under each of loading conditions 1 and 2. The humerus was positioned in neutral rotation, and muscle loading was performed at 0°, 30°, and 60° of abduction.

Anteroposterior translation of the humerus was determined by calculating the distance between the screws of the acromion and the humerus in the anteroposterior direction under each of loading conditions 1 and 2. Positive values indicated that the humeral head was posteriorly translated.

Subacromial contact pressures were recorded using a foil pressure sensor (Tekscan model 4000; Tekscan). The calibration of the pressure sensor was performed with 2 points (10 N to 20 N) using a load cell (Instron).[2] The postcalibration mean saturation pressure was 1.42 MPa. The sensitivity was set at 35. The pressure sensor was placed in the subacromial space and fixed by suture to the acromion using high-strength sutures. The pressure sensor was replaced after any detection of sensor disturbances. Contact area, contact force, and peak pressure were measured with the humerus in neutral rotation at 0°, 30°, and 60° of abduction. The contact pressure was determined by contact force/contact area.

Surgical Procedure

Superior Capsular Reconstruction. We harvested the tensor fascia lata from the thigh and prepared it as a -double-folded 2-layer graft.[8] The graft margin was sutured using continuous running suture (Ethibond 2-0; Ethicon Inc). Three soft anchors (1.7-mm suture fix Anchor; Smith & Nephew) were inserted on the superior margin of the glenoid. For humeral fixation, 3 bone tunnels were created to perform transosseous repair in the greater tuberosity. For SCR, the fascia lata was fixed at 30° of glenohumeral joint abduction. The graft size was determined based on the defect size. Considering the defect dimension and the gap between the anchors, we performed a graft fixation at 30° of abduction and found that this resulted in a neutral tension at 30°. For the graft fixation on the glenoid, 3 simple sutures were performed. For the graft fixation on the humerus, 3 modified Mason-Allen sutures were utilized.

SCR Combined With LTTT. After fascia lata fixation, Achilles tendon fixation was performed for SCR combined with LTTT. The Achilles tendon was harvested for LTTT in this study.[4] The distal tendinous part was sutured using a No. 2 high-strength suture (FiberWire Suture; Arthrex) with multiple Krackow stitches. The harvested graft was fixed on the greater tuberosity using the transosseous technique. Three bone tunnels were created in the greater tuberosity on the lateral side of the fascia lata graft margin. The distal part of the Achilles tendon was partially covered on the lateral edge of the SCR graft. However, the total thickness of the overlapping part of the 2 grafts did not affect the full ROM of abduction motion (Appendix Figure A1H). Loading of the Achilles tendon for LTTT was maintained at 24 N. All the Achilles tendons used for the LTTT procedure were harvested from the ipsilateral side of the lower legs. The size of each Achilles tendon was not particularly larger than the usual Achilles tendon used for LTTT. We cut the Achilles tendon just above the calcaneal bone and removed the muscle. The mean total length of the Achilles tendon was 11.20 ± 0.21 cm. The mean thickness of the distal tendinous portion of the Achilles tendon was 6.24 ± 1.56 mm.

To evaluate the effect of LTTT alone, we removed the Achilles tendon and the SCR graft after the test of SCR combined with LTTT. The Achilles tendon for LTTT was fixed using the transosseous suture technique, as mentioned above.

Statistical Analysis

All measurements for data acquisition were performed twice. Repeated-measure analyses of variance and Tukey post hoc tests were performed to analyze the differences of each measurement (total rotational ROM, superior head translation, anteroposterior head translation, and

TABLE 1
Total Rotational Range of Motion[a]

	Total Rotational ROM (IR + ER, deg)				
	Intact	MRCTs	SCR	LTTT	SCR + LTTT
0° of abduction	105.3 ± 5.4	150.8 ± 6.8[b]	73.1 ± 3.8[c]	131.3 ± 5.9[c,d,e]	71.6 ± 3.2[c]
30° of abduction	92.8 ± 16.2	136.1 ± 9.6[b]	90.1 ± 13[c]	124.1 ± 4.6[d,e]	90.7 ± 14.4[c]
60° of abduction	100.1 ± 25.9	126.3 ± 20.1[b]	108.1 ± 15.4	125.5 ± 8.6	102.1 ± 14.8[c]

[a]Data are presented as mean ± SD. ER, external rotation; IR, internal rotation; LTTT, lower trapezius tendon transfer; MRCT, massive rotator cuff tear; ROM, range of motion; SCR, superior capsular reconstruction.
[b]Post hoc significance versus the intact state ($P < .05$).
[c]Post hoc significance versus MRCT ($P < .05$).
[d]Post hoc significance versus SCR ($P < .05$).
[e]Post hoc significance versus SCR + LTTT ($P < .05$).

subacromial peak pressure) among the 5 test conditions. The statistical significance was defined as $P < .05$. SAS statistics software was used for all statistical analyses (version 9.4; Cary, NC, USA).

RESULTS

In the MRCT model, the mean mediolateral defect size was 5.01 ± 0.76 mm, and the mean anteroposterior defect size was 3.98 ± 0.54 mm. The graft size for SCR was determined based on the defect size—5 mm larger than the mediolateral defect and 5 mm larger than the anteroposterior defect—to ensure complete coverage of the defect area. The mean thickness of the SCR graft was 7 ± 0.56 mm.

Total Rotational ROM

Total rotational ROM was significantly increased in the posterosuperior MRCTs compared with the intact state at all abduction angles (all, $P < .001$). SCR significantly reduced the total rotational ROM at 0° and 30° of abduction (0°, $P < .001$; 30°, $P < .001$). The LTTT group had significantly restored total rotational ROM at 0° compared with the MRCT group ($P < .05$). However, no significant effect was found in terms of restoring total rotational ROM at 30° and 60° of abduction (both, $P > .05$). SCR combined with LTTT significantly restored the total rotational ROM at all abduction angles (all, $P < .001$). SCR and SCR combined with LTTT showed significantly lower total rotational ROM than LTTT alone in 0° and 30° of abduction ($P < .001$) (Table 1).

Humeral Head Superior Translation

At all abduction shoulder angles, posterosuperior MRCT showed significantly increased superior humeral head translation compared with cases with the intact condition (all, $P < .001$). SCR significantly reduced superior humeral head translation at 0° and 30° compared with MRCT (both, $P < .001$). LTTT alone significantly reduced the superior humeral head translation at all degrees of abduction (all, $P < .001$). However, at 0° and 30° of abduction, SCR showed significantly lower superior humeral head translation than LTTT alone ($P < .01$ and $P = .02$, respectively). The combined SCR and LTTT significantly reduced the superior humeral head translation compared with MRCT alone (all, $P < .001$) (Table 2) (Appendix Table A1).

Humeral Head Anteroposterior Translation

Posterosuperior MRCT significantly increased posterior humeral head translation compared with the intact condition (all, $P < .001$). SCR significantly reduced posterior translation in 0°, 30°, and 60° of abduction compared with MRCTs (all, $P < .001$). LTTT alone significantly reduced posterior translation at all degrees of abduction (all, $P < .001$). SCR combined with LTTT reduced posterior translation significantly compared with MRCT ($P < .001$ in all abduction angles). SCR combined with LTTT showed significantly lower posterior translation than LTTT alone in 0° and 30° of abduction ($P < .001$). At 60° of abduction, SCR combined with LTTT showed significantly lower posterior translation than SCR alone and LTTT alone (both, $P < .001$) (Table 3) (Appendix Table A2).

Subacromial Peak Contact Pressure

Posterosuperior MRCT significantly increased the subacromial peak contact pressure relative to the intact condition at all abduction angles (all, $P < .001$). SCR alone showed significantly lower subacromial peak contact pressure at 0° and 30° of abduction than MRCT alone (both, $P < .001$). LTTT alone significantly reduced the subacromial peak contact pressure at all abduction angles compared with MRCT (0°, $P < .001$; 30°, $P < .001$; 60°, $P = .012$). SCR combined with LTTT significantly reduced the superior humeral head translation at all degrees of abduction (all, $P < .001$). SCR and SCR combined with LTTT showed significantly lower subacromial peak pressure than LTTT alone in 0° and 30° of abduction (both, $P < .001$). At 60° of abduction, LTTT showed significantly lower subacromial peak pressure than SCR ($P = .002$) (Table 4).

TABLE 2
Superior Head Translation[a]

	Superior Head Translation, mm				
	Intact	MRCTs	SCR	LTTT	SCR + LTTT
0° of abduction	2.9 ± 0.7	11.1 ± 1.5[b]	0.5 ± 0.4[c]	5.6 ± 0.7[c,d,e]	0.6 ± 0.4[c]
30° of abduction	2.2 ± 0.7	5.4 ± 0.9[b]	2.4 ± 0.5[c]	3.0 ± 0.8[c,d,e]	1.2 ± 0.7[c]
60° of abduction	1.7 ± 0.8	3.0 ± 0.4[b]	2.4 ± 0.8	2.1 ± 0.4[c]	1.1 ± 0.4[c,d]

[a]Data are presented as the mean ± SD distance between the humeral head and the acromion. LTTT, lower trapezius tendon transfer; MRCT, massive rotator cuff tear; SCR, superior capsular reconstruction.
[b]Post hoc significance versus the intact state ($P < .05$).
[c]Post hoc significance versus MRCT ($P < .05$).
[d]Post hoc significance versus SCR ($P < .05$).
[e]Post hoc significance versus SCR + LTTT ($P < .05$).

TABLE 3
Anteroposterior Head Translation[a]

	Anteroposterior Head Translation, mm				
	Intact	MRCT	SCR	LTTT	SCR + LTTT
0° of abduction	0.4 ± 1.5	6.7 ± 0.3[b]	0.5 ± 0.5[c]	4.8 ± 0.5[c,d,e]	0.6 ± 0.3[c]
30° of abduction	0.1 ± 3.1	5.9 ± 1.6[b]	1.1 ± 0.8[c]	4.3 ± 0.2[c,d,e]	–0.7 ± 1.3[c]
60° of abduction	1.5 ± 2	4 ± 0.7[b]	2.2 ± 1.3[c,e]	2.4 ± 0.7[c,e]	0.9 ± 0.7[c]

[a]Data are presented as mean ± SD. Negative values represent antterior translation. LTTT, lower trapezius tendon transfer; MRCT, massive rotator cuff tear; SCR, superior capsular reconstruction.
[b]Post hoc significance versus the intact state ($P < .05$).
[c]Post hoc significance versus MRCT ($P < .05$).
[d]Post hoc significance versus SCR ($P < .05$).
[e]Post hoc significance versus SCR + LTTT ($P < .05$).

TABLE 4
Subacromial Peak Pressure[a]

	Subacromial Peak Pressure, kPa				
	Intact	MRCT	SCR	LTTT	SCR + LTTT
0° of abduction	144.6 ± 39.3	582.7 ± 161.5[b]	116.9 ± 21.8[c]	283.9 ± 57.4[c,d,e]	107.6 ± 11.3[c]
30° of abduction	155.3 ± 27.3	656.5 ± 87.0[b]	123.9 ± 37.2[c]	249.7 ± 27.7[c,d,e]	91.7 ± 17.0[c]
60° of abduction	216.8 ± 26.6	508.4 ± 99.4[b]	436.8 ± 53.8	256.3 ± 36.4[c,d]	224.3 ± 36.9[c,d]

[a]Data are presented as mean ± SD. LTTT, lower trapezius tendon transfer; MRCT, massive rotator cuff tear; SCR, superior capsular reconstruction.
[b]Post hoc significance versus the intact state ($P < .05$).
[c]Post hoc significance versus MRCT ($P < .05$).
[d]Post hoc significance versus SCR ($P < .05$).
[e]Post hoc significance versus SCR + LTTT ($P < .05$).

DISCUSSION

In this biomechanical study, we demonstrated that SCR combined with LTTT improves shoulder biomechanics in 0°, 30°, and 60° of abduction. The results of this study are expected to provide biomechanical information for clinical applications of SCR combined with LTTT in the future.

SCR has been reported to restore superior glenohumeral stability in previous biomechanical studies.[16,28] SCR showed favorable clinical outcomes in terms of functional score improvement, pain relief, and acromiohumeral distance increase.[12] However, the reported graft failure rates after SCR varied from 0% to 55%.[9] Some studies have reported that severe fatty infiltration of the infraspinatus was related to graft failure.[12,30] In case of severe fatty infiltration of the infraspinatus, the transverse couple force may be unbalanced so that deltoid muscle force cannot be adequately compensated. Then, the graft is subjected to compression between the humeral head and the acromion, resulting in graft failure. In this biomechanical study, we checked that the SCR effect was diminished in 60° of abduction, which was greater than the graft fixation angle. The laxity could decrease the tension of the graft at higher abduction angles. The lax graft might not prevent the superior migration of the humeral head properly and subacromial peak pressure, and humeral head superior migration would be increased eventually.

LTTT is a surgical management for posterosuperior irreparable rotator cuff tears. In previous anatomic studies, the tendon excursion of the lower trapezius was similar to that of the infraspinatus.[4,10,23] It has been reported that LTTT can be effective in restoring the transverse couple force of the glenohumeral joint and centralizing the humeral head.[21,25] In their clinical studies, Elhassan et al[3,4] reported positive outcomes after LTTT in patients with posterosuperior MRCT, with improvements in forward elevation, external rotation, and postoperative pain. However, theoretically, LTTT alone may be limited in restoring superior stability because the space corresponding to the superior capsule is not restored even with LTTT surgery. Omid et al[23] reported that loading 24 N load applied to the lower trapezius tendon restored superior head migration. However, it was not equivalent to the normal shoulder joint. In our cadaveric study, LTTT alone reduced the superior head migration and subacromial peak pressure compared with posterosuperior MRCT. However, there were significant differences between LTTT and the normal group in superior head translation, anteroposterior head translation, and subacromial peak pressure at 0° and 30° of abduction ($P < .05$). Compared with LTTT, SCR was more effective in restoring the superior head migration and subacromial peak pressure in the shoulder at 0° and 30° of abduction. LTTT did not significantly improve total rotational ROM at 30° and 60° of abduction. There was no static-constrained effect on the glenohumeral joint because LTTT was not the static stabilizer reconstruction. In addition, it is not clear whether the effect of LTTT in vivo is that of a dynamic stabilizer or a dynamic tenodesis. Although LTTT has shown good results in clinical practice, it is difficult to interpret this as the lower trapezius tendon replacing the infraspinatus. The same position, force, and vector of muscle forces as the infraspinatus tendon would be required to meet the requirements of a dynamic stabilizer. Thus, it is anticipated that the function of the lower trapezius tendon in vivo may not be the same as the results of this biomechanical study. Future studies should investigate how LTTT functions in terms of a dynamic stabilizer or dynamic tenodesis effect on the shoulder joint.

There was a complementary effect when SCR and LTTT were performed together. SCR is effective in 0° and 30° of abduction in terms of the total rotational ROM, superior humeral head translation, anteroposterior head translation, and subacromial peak pressure. However, SCR was less effective in the 60° of abduction angle. LTTT was effective in all abduction angles compared with MRCT in terms of superior humeral head translation, anteroposterior head translation, and subacromial peak pressure. However, LTTT was less effective than SCR in the 0° and 30° of abduction. Also, LTTT was ineffective for restoring total rotational ROM in 30° and 60° of abduction. SCR combined with LTTT showed better results in all measurements of all respective abduction angles in this study. Also, SCR combined with LTTT significantly decreased superior migration and subacromial peak pressure compared with LTTT alone in 0° and 30° of abduction or with SCR alone in 60° of abduction. Thus, the combination of SCR and LTTT may have an advantage for additional stability. The results of this study are expected to provide biomechanical information for clinical applications of SCR combined with LTTT in the future.

This study has several limitations. First, the experiment was conducted under static conditions. Therefore, there are limitations to replicating the dynamic and static environments of in vivo settings. Further clinical studies dealing with SCR and LTTT are necessary to confirm the complementary roles of each procedure. Second, our results did not include the effect of the scapulothoracic motion and focused on the glenohumeral joint motions. Therefore, there may be limitations in replicating the coordinated motion between the scapulothoracic and glenohumeral joints in vivo. Third, it was not feasible to entirely simulate the LTTT condition in vivo solely by pulling the Achilles tendon. Although we attempted to align the force vector with that of the actual LTTT, the loading of the Achilles tendon pulling force could not replicate the minimal excursion of the trapezius that would occur in vivo. Fourth, the results represent the biomechanics at time zero after surgery, which do not include the biological healing or rehabilitation effect. Therefore, caution is needed in interpreting our results.

Even if both SCR and LTTT are performed, the effect of supraspinatus muscle dynamic head compression cannot be restored; thus, there are inevitably inherent limitations of SCR and LTTT. However, we believe this study will help in understanding of the shoulder kinetics regarding current surgical techniques and will suggest a new concept of shoulder surgery by combining the 2 surgical methods.

CONCLUSION

In this cadaveric study, SCR combined with LTTT showed better shoulder kinematics in the posterosuperior MRCTs model than SCR or LTTT alone. The combination of SCR and LTTT may be regarded as an alternative surgical procedure for posterosuperior MRCTs.

ORCID iDs

Erica Kholinne https://orcid.org/0000-0002-4326-8205
Kyoung-Hwan Koh https://orcid.org/0000-0002-6181-9621

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