Superior Capsular Reconstruction Versus Lower Trapezius Transfer for Posterosuperior Irreparable Rotator Cuff Tears With High-Grade Fatty Infiltration in the Infraspinatus

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Background: Superior capsular reconstruction (SCR) and lower trapezius transfer (LTT) have recently been utilized to treat irreparable rotator cuff tears (IRCTs). There is still no clear guideline on which treatment method is a better fit for posterosuperior IRCTs with high-grade 4 fatty infiltration in the infraspinatus.

Purpose: To compare the clinical and radiological outcomes between arthroscopic-assisted SCR (aSCR) and arthroscopic-assisted LTT (aLTT) in patients with posterosuperior IRCTs with high-grade (Goutallier grade 4) fatty infiltration in the infraspinatus muscle.

Study Design: Cohort study; Level of evidence, 3.

Methods: This retrospective study included patients who underwent aSCR or aLTT for posterosuperior IRCTs with high-grade 4 fatty infiltration in the infraspinatus and had a minimum follow-up of 2 years between 2017 and 2019. A total of 58 patients were divided into 2 groups according to the surgical procedure: aSCR group (n = 22) and aLTT group (n = 36). Clinical outcomes comprised the visual analog scale score for pain, active shoulder range of motion (ROM), the American Shoulder and Elbow Surgeons (ASES) score, and patient satisfaction. Radiological outcomes comprised the acromiohumeral distance (AHD). The progression of arthritis was evaluated via the Hamada grade. Graft integrity was assessed on postoperative magnetic resonance imaging scans.

Results: Significant improvements in clinical outcomes were observed in both groups. However, active shoulder ROM (forward elevation: 165.7° ± 22.3° vs 145.5° ± 32.3°, respectively [$P = .015$]; external rotation: 51.7° ± 10.9° vs 41.1° ± 7.0°, respectively [$P < .001$]), the postoperative ASES score (84.8 ± 7.6 vs 76.8 ± 20.3, respectively; $P = .045$), and patient satisfaction (8.9 ± 1.2 vs 6.4 ± 2.1, respectively; $P = .041$) were significantly higher with aLTT than with aSCR. There was no significant difference between the groups in AHD at 2 years postoperatively. However, the rate of progression of arthritis was significantly higher with aSCR (22.7%) than with aLTT (2.8%) ($P = .027$). Moreover, the graft retear rate was significantly higher with aSCR (63.6%) than with aLTT (8.3%) at 2 years postoperatively ($P < .001$).

Conclusion: Although aSCR and aLTT both provided improvements in overall clinical outcomes for posterosuperior IRCTs with high-grade 4 fatty infiltration in the infraspinatus, aLTT was superior in terms of functional improvement, patient satisfaction, progression of arthritis, and graft integrity. Therefore, we prefer aLTT for posterosuperior IRCTs under the condition of high-grade 4 fatty infiltration in the infraspinatus.

Keywords: posterosuperior irreparable rotator cuff tear; high-grade fatty infiltration; superior capsular reconstruction; lower trapezius transfer

Joint-preserving surgery for posterosuperior irreparable rotator cuff tears (IRCTs) without arthritis of the glenohumeral joint is favorable for relatively young active patients and older patients with high-demand activities.[2]

Various surgical options for IRCTs have been introduced; among them, superior capsular reconstruction (SCR) and lower trapezius transfer (LTT) have recently been utilized, as satisfactory results have been well documented.[8,15] SCR aids in maintaining the proper function of the remaining rotator cuff by providing superior static stability in the glenohumeral joint.[19] However, many studies have reported a high graft retear rate after SCR for posterosuperior IRCTs with poor muscle quality.[15,26] On the other hand, LTT aims to maintain dynamic equilibrium to improve

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shoulder function under the condition of IRCTs.[5] Several clinical and biomechanical studies have shown that LTT provides efficient shoulder range of motion (ROM), results in functional improvement, and better restores glenohumeral kinematics and joint reaction forces.[6-8]

Either SCR or LTT could be selected for patients with posterosuperior IRCTs. However, there are no detailed guidelines based on the muscle quality of the remaining rotator cuff muscles, especially in cases with high-grade fatty infiltration. The purpose of this study was to evaluate and compare short-term clinical and radiological outcomes between arthroscopic-assisted SCR (aSCR) and arthroscopic-assisted LTT (aLTT) in patients with posterosuperior IRCTs with high-grade 4 fatty infiltration in the infraspinatus. We hypothesized that patients with posterosuperior IRCTs with high-grade 4 fatty infiltration in the infraspinatus would have better clinical and radiological outcomes with aLTT.

METHODS

This study was approved by our institutional review board (ethics committee). Informed consent was waived because of the retrospective nature of the study.

Patient Selection

We performed a retrospective clinical comparative study of patients who underwent aSCR or aLTT for posterosuperior IRCTs between February 2017 and February 2019. The indications for aSCR and aLTT were as follows: (1) incapacitating pain and/or lost shoulder functionality that hindered daily activities, (2) failure of nonoperative treatment, (3) posterosuperior IRCTs with poor muscle quality of the supraspinatus and infraspinatus (Goutallier classification[13] grade 3 or 4), (4) an intact or reparable subscapularis tendon, (5) Hamada grade[15] $\leq$2 arthritic changes, and (6) no neurological disorder that affects clinical outcomes. Rotator cuff tears were considered irreparable if patients had advanced fatty infiltration of the muscles (Goutallier classification[10] grade 3 or 4) and retraction of the tendons to the level of the glenoid. The rotator cuff tendons were also assessed intraoperatively and deemed irreparable if the retracted rotator cuff tendons could not be pulled to the footprint area, despite mobilization techniques and soft tissue release. We excluded patients with grade 3 fatty infiltration of the supraspinatus or infraspinatus muscles, a torn teres minor tendon, <2 years of follow-up, SCR using a dermal allograft, and nonavailability for magnetic resonance imaging (MRI) and a clinical assessment preoperatively and at 2 years postoperatively. Finally, patients who underwent aSCR using a fascia lata autograft (n = 22) and aLTT using an Achilles tendon allograft (n = 36) with preoperative grade 4 fatty infiltration of the supraspinatus and infraspinatus were included (Figures 1 and 2). Because this study was a retrospective study, the patients were not randomized into groups according to whether they underwent aSCR or aLTT. The decision to perform aSCR or aLTT was based on the patient's overall condition, such as willingness to undergo rehabilitation and return to his or her previous work, desired activity level, medical comorbidity, and so on. We explained the mechanism, surgical procedure, skin incision, and use of an autograft or allograft for aSCR or aLTT to patients before the operative procedure. In most cases, aSCR or aLTT was performed according to the patient's decision. Although there was no significant

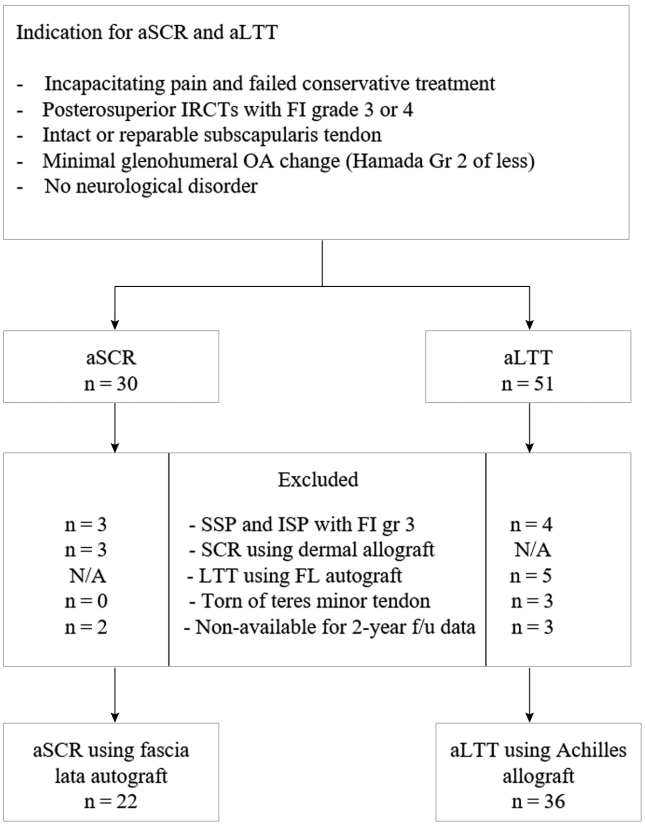

Figure 1. Flowchart showing patient selection for this study. aLTT, arthroscopic lower trapezius transfer; aSCR, arthroscopic superior capsular reconstruction; FI, fatty infiltration; FL, fascia lata; f/u, follow-up; Gr, grade; IRCT, irreparable rotator cuff tear; ISP, infraspinatus; LTT, lower trapezius transfer; N/A, not available; OA, osteoarthritis; SCR, superior capsular reconstruction; SSP, supraspinatus.

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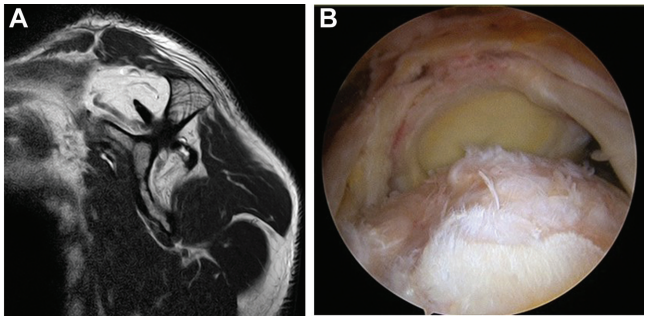

Figure 2. Posterosuperior irreparable rotator cuff tear with high-grade 4 fatty infiltration in the supraspinatus and infraspinatus muscles. (A) Magnetic resonance imaging scan. (B) Arthroscopic image.

difference in the preoperative characteristics between the 2 groups, this limitation may have led to a performance or selection bias.

Surgical Techniques

All surgical procedures were performed by the same senior surgeon (C.H.B). The patients underwent surgery in the lateral decubitus position, under general anesthesia, with an interscalene block. All patients underwent diagnostic arthroscopic surgery to assess the mobilization and reparability of the remaining supraspinatus and infraspinatus tendons and to debride any residual scar tissue or nonfeasible rotator cuff tissue. For patients with a reparable subscapularis tendon tear, repair using the double-row suture bridge technique was performed. In addition, acromioplasty was routinely performed to prevent postoperative attrition of the graft because of a subacromial spur.

Arthroscopic SCR. After confirming that the supraspinatus and infraspinatus tendons were irreparable, we harvested a fascia lata graft. To determine the size of the fascia lata graft, we measured the distance from the medial glenoid to the footprint of the lateral greater tuberosity and the anterior-to-posterior area of the rotator cuff defect with the shoulder in 45° of abduction. According to the measured defect size, the harvested fascia lata was folded 3 or 4 times to obtain a minimal graft thickness of 6 mm and prepared using the Krackow method (Figure 3). After graft preparation, the superior glenoid and footprint were decorticated to the attachment site, and tenotomy was performed on the long head of the biceps tendon. Next, two 4.5-mm anchors (Corkscrew FT; Arthrex) were inserted into the superior portion of the glenoid rim and the greater tuberosity of the lateral humerus. The graft was shuttled through the lateral portal to the subacromial space using suture anchors, and the graft's medial margin was positioned between the remnant supraspinatus and the glenoid. Medial glenoid fixation was performed using a mattress-tying technique, while the lateral end of the graft was fixed on the footprint of the lateral greater tuberosity using a double-row suture bridge technique with a dual-threaded anchor (4.75-mm SwiveLock; Arthrex).

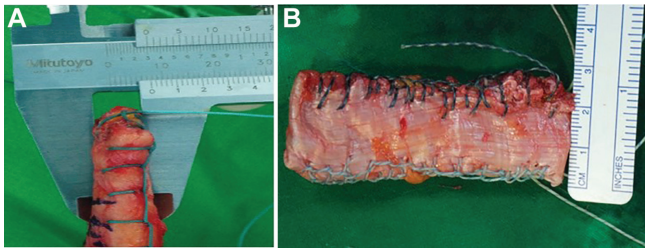

Figure 3. A fascia lata autograft for arthroscopic superior capsular reconstruction. (A) The harvested fascia lata was folded 3 or 4 times to obtain a minimal graft thickness of 6 mm and (B) was prepared using the Krackow method.

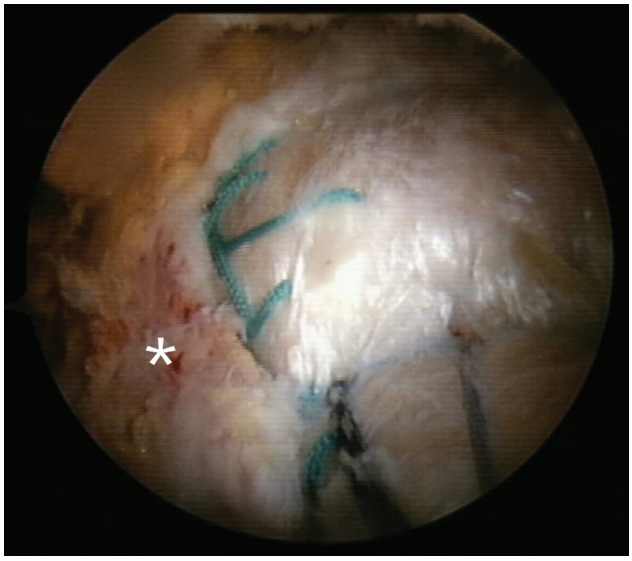

Figure 4. Arthroscopic image of superior capsular reconstruction in a patient with a posterosuperior irreparable rotator cuff tear with Goutallier grade 4 fatty infiltration in the infraspinatus muscle (asterisk). Side-to-side suturing was performed between the graft and the posterior remnant rotator cuff.

Finally, side-to-side suturing was performed between the graft and the posterior remnant rotator cuff (Figure 4).

Arthroscopic LTT. After confirming that the supraspinatus and infraspinatus tendons were irreparable, we harvested the lower trapezius tendon. First, a 5-cm horizontal skin incision was made laterally from the medial edge along the scapular spine. The triangular-shaped portion of the lower trapezius tendon was identified at the medial border of the inferior scapular spine and was detached from the scapular spine. To prevent excessive tearing, we used No. 2 nonabsorbable suture material (Ethibond No.2; Ethicon Inc., Somerville, NJ, USA) to prepare the end of the lower trapezius via the Krackow method (Figure 5). After lower trapezius tendon preparation, we performed arthroscopic debridement of the supraspinatus footprint to the bleeding subchondral bone. We created the interval for

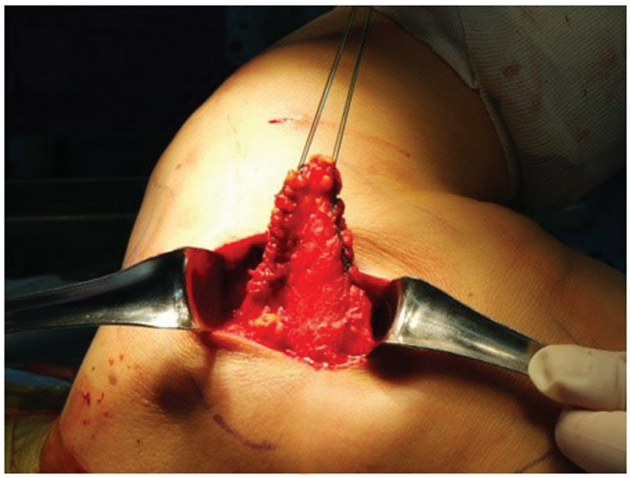

Figure 5. Preparation of the lower trapezius tendon. No. 2 nonabsorbable suture material was used to prepare the end of the lower trapezius via the Krackow method.

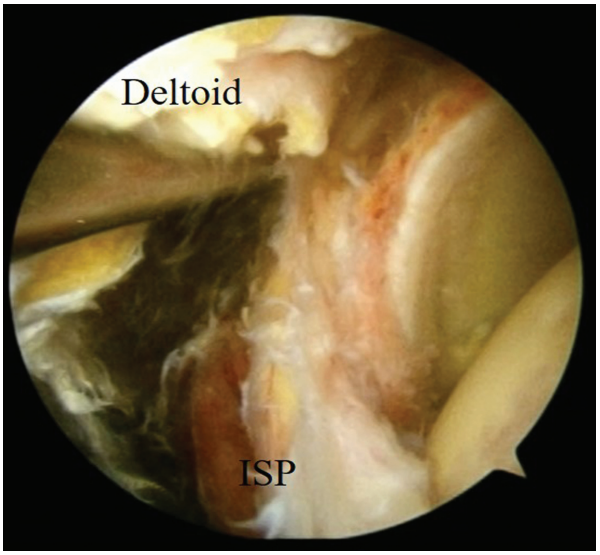

Figure 6. The interval for Achilles tendon allograft passage between the infraspinatus (ISP) muscle and deltoid muscle.

Achilles tendon allograft passage between the infraspinatus muscle and deltoid muscle (Figure 6). The infraspinatus fascia was incised via a medial incision to make adequate room for the transferred lower trapezius tendon.

An Achilles tendon allograft was prepared using Krackow sutures in the portion of the tendon-bone junction after the removal of part of the calcaneus (Figure 7). A 3-row suture anchor was inserted into the footprint of the supraspinatus. Then, 2 threads of the 3-row suture anchor were passed through the posterior remnant rotator cuff using SutureLasso (Arthrex) for side-to-side suturing with the Achilles tendon allograft. The remaining threads were drawn out of the joint through a lateral portal, passed through the Achilles tendon allograft, and

Figure 7. An Achilles tendon allograft prepared using Krackow sutures in a portion of the tendon-bone junction.

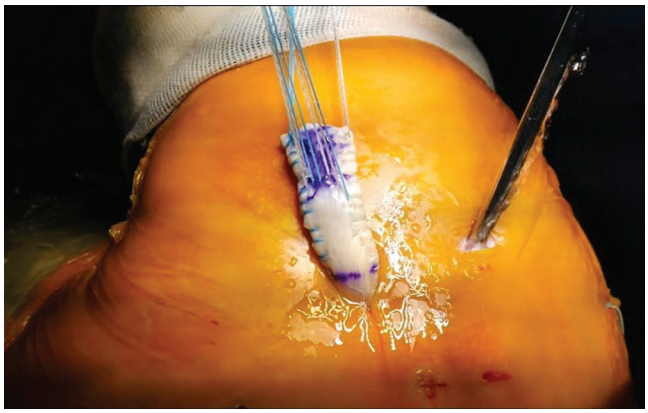

Figure 8. Achilles tendon allograft passage. Essentially, 2 threads of a 3-row suture anchor passed through the posterior remnant rotator cuff of the left shoulder. The remaining threads were drawn out of the joint through a lateral portal and passed through the Achilles tendon allograft.

attached to the footprint of the supraspinatus (Figure 8). A large grasping clamp was inserted through a skin incision in the back, aimed at the lateral portal, for Achilles tendon transfer. Next, the nonprepared site of the Achilles tendon was grabbed and pulled out through the skin incision in the back. After placing the Achilles tendon on the supraspinatus footprint, we fixed the allograft on the supraspinatus footprint using the double-row suture bridge technique. Then, side-to-side suturing was performed using a thread passed through the posterior remnant rotator cuff and a thread passed through the Achilles tendon allograft. After fixation of the allograft on the footprint, we attached the Achilles tendon allograft to the inferior margin of the lower trapezius using the Pulvertaft technique to make the line of pull of aLTT similar to the physiological line of pull of the native infraspinatus. Anastomosis was performed with the shoulder in maximal external rotation, with 60° of abduction for physiological tensioning (Figure 9).

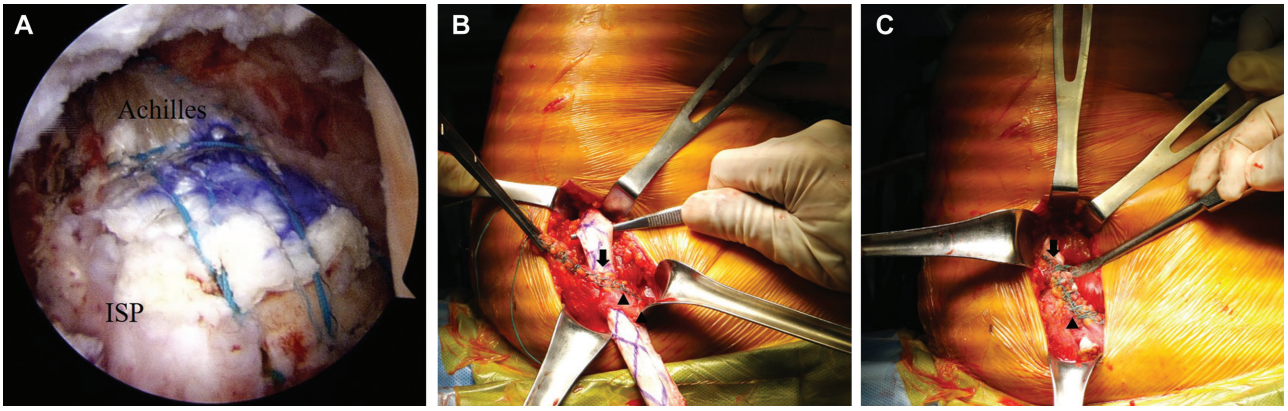

Figure 9. Arthroscopic image and intraoperative photograph of lower trapezius transfer in a patient with a posterosuperior irreparable rotator cuff tear in the right shoulder with Goutallier grade 4 fatty infiltration in the infraspinatus (ISP) muscle. (A) For a static spacing effect of the bridging Achilles tendon, we attempted to create a humeral head depressor by fixing the Achilles tendon allograft to the more ventral supraspinatus footprint using the double-row suture bridge technique. (B) The Achilles tendon graft (arrow) was attached to the inferior margin of the prepared lower trapezius (arrowhead) via (C) the Pulvertaft technique to mimic the line of pull of the native ISP.

Postoperative Rehabilitation

Postoperatively, all patients used a brace with the shoulder maintained at 0° of external rotation. The brace was applied continuously to inhibit accidental internal rotation for 8 weeks; during this time, patients were allowed to intermittently move the elbow, wrist, and fingers. After 8 weeks of immobilization, patients started active assisted ROM exercises in every direction for 4 weeks. The patients then progressed to full ROM and gentle strengthening exercises, and all patients returned to unrestricted activities after 6 months.

Clinical Outcomes

Age, sex, body mass index, smoking status, and medical comorbidity data were collected. Preoperative and postoperative clinical outcomes were evaluated using the visual analog scale (VAS) score for pain, active shoulder ROM, the American Shoulder and Elbow Surgeons (ASES) score, and patient satisfaction. The 10-point VAS was used to measure the perceived level of pain. ROM was assessed at each follow-up visit, and all clinical scores were recorded by a research coordinator in the outpatient department. Active shoulder ROM was measured using a standard goniometer. Forward elevation, measured during scapular-plane forward elevation and external rotation, was determined via movements of the arm. The ASES score is a standardized and validated measure for assessing shoulder pain, level of daily activities, and function. Patient satisfaction was evaluated on a 10-point scale as follows: unsatisfied (1-4), satisfied (5-7), and very satisfied (8-10).

Radiological Outcomes

True anteroposterior (Grashey), lateral scapular, and axillary lateral radiographic views were used for all shoulders preoperatively and postoperatively. To evaluate radiological outcomes, we measured the acromiohumeral distance (AHD) as the shortest distance between the inferior border of the acromion undersurface and the apex of the humeral head preoperatively and at 2-year follow-up. The progression of arthritis in the glenohumeral joint was evaluated via the Hamada grade. A Hamada grade of 3, 4, or 5 at 2-year follow-up was considered as a marked progression of arthritis. The fatty infiltration grades of rotator cuff muscles (subscapularis, supraspinatus, infraspinatus, and teres minor) were determined from sagittal oblique images (ie, Y-view) using the Goutallier grading system[10] as follows: 0, no fat; 1, fatty streaks within the muscle; 2, less fat than muscle; 3, as much fat as muscle; and 4, more fat than muscle. Patients underwent MRI preoperatively and at 6 weeks, 1 year, and 2 years postoperatively for the evaluation of graft integrity and tendon-to-bone and tendon-to-tendon healing. The transferred tendon was evaluated and classified into 5 categories according to the classification of Sugaya et al[25]; types IV and V were regarded as tears. An independent musculoskeletal radiologist who was blinded to the clinical results read all MRI scans.

Statistical Analysis

Clinical and radiological outcomes were compared between the 2 groups using the nonparametric Mann-Whitney *U* test for continuous data and the Fisher exact test for categorical data. Analyses were performed using SPSS for Windows (Release 11.0; SPSS Inc, Chicago, Illinois), and the level of significance was set at 95%.

RESULTS

Of a total 81 patients (aSCR: n = 30; aLTT: n = 51), 23 patients (aSCR: n = 8; aLTT: n = 15) were excluded. We

TABLE 1
Patient Characteristics[a]

	aSCR Group (n = 22)	aLTT Group (n = 36)	*P* Value
Age, y	64.8 ± 5.8	63.1 ± 5.5	.284
Sex, male:female	12:10	22:14	.447
Body mass index	24.6 ± 2.9	24.4 ± 2.5	.818
Smoker	2	6	.331
Diabetes mellitus	3	5	.425
Previous surgery	4	8	.471
Symptom duration, mo	12.3 ± 4.8	11.0 ± 11.3	.635
Fatty infiltration (Goutallier grade)			
Subscapularis	1.3 ± 0.5	1.4 ± 0.5	.548
Supraspinatus	4.0 ± 0.0	4.0 ± 0.0	—
Infraspinatus	4.0 ± 0.0	4.0 ± 0.0	—
Teres minor	1.5 ± 0.6	1.5 ± 0.5	.486
Follow-up, mo	39.3 ± 5.2	37.6 ± 9.8	.742

[a]Data are shown as mean ± SD or No. unless otherwise indicated. aLTT, arthroscopic lower trapezius transfer; aSCR, arthroscopic superior capsular reconstruction. Dashes indicate no value.

excluded patients with grade 3 fatty infiltration of the supraspinatus or infraspinatus (n = 7), aSCR using a dermal allograft (n = 3), aLTT using a fascia lata autograft (n = 5), a torn teres minor tendon (n = 3), and <2 years of follow-up or nonavailability for MRI and a clinical assessment preoperatively and at 2 years postoperatively (n = 5). Finally, 58 patients were retrospectively enrolled in this study, with 22 patients in the aSCR group and 36 patients in the aLTT group. The mean follow-up period was 39.3 ± 5.2 months (range, 26-49 months) in the aSCR group and 37.6 ± 9.8 months (range, 27-54 months) in the aLTT group ($P = .742$). There were no significant differences in patient characteristics, underlying disease (diabetes mellitus), smoking status, and fatty infiltration grade between the groups preoperatively (Table 1).

Clinical Outcomes

Significant improvements in clinical outcomes were observed in both groups (Table 2). However, postoperative ASES scores were significantly higher in the aLTT group. Although there was no significant difference in active forward elevation, there was a significant difference in active external rotation between the 2 groups. Patient satisfaction was significantly higher in the aLTT group. Regarding the return to usual preinjury function (an ASES score parameter), 14 patients in the aSCR group and 32 patients in the aLTT group returned to their usual activities. Accordingly, the rate of return to usual activities was significantly higher in the aLTT group (88.9%) than in the aSCR group (63.6%) ($P = .042$).

Radiological Outcomes

There was no significant difference between the 2 groups in AHD at 2 years postoperatively. However, the progression of glenohumeral joint arthritis was observed in 5 patients in the aSCR group and in only 1 patient in the aLTT group. Accordingly, the rate of progression of arthritis was significantly higher in the aSCR group (22.7%) than in the aLTT group (2.8%) ($P = .027$) (Figure 10).

In the aSCR group, a graft retear was observed at the footprint of the greater tuberosity in 3 patients and at the midsubstance in 11 patients (Figure 11). In the aLTT group, a transferred tendon retear was observed between the Achilles tendon allograft and the footprint in 3 patients (Figure 12). The graft retear rate was significantly higher in the aSCR group (63.6%) than in the aLTT group (8.3%) at 2 years postoperatively ($P < .001$) (Table 3).

TABLE 2
Clinical Outcomes[a]

	aSCR Group	aLTT Group	*P* Value
VAS pain score			
Preoperative	4.0 ± 1.6	4.5 ± 1.8	.226
Postoperative	1.8 ± 2.4	1.3 ± 1.0	.340
P value	.002	<.001	
Active forward elevation, deg			
Preoperative	126.4 ± 54.5	134.2 ± 53.6	.597
Postoperative	145.5 ± 32.3	165.7 ± 22.3	.015
P value	.203	.003	
Active external rotation, deg			
Preoperative	28.6 ± 11.2	27.5 ± 14.3	.768
Postoperative	41.1 ± 7.0	51.7 ± 10.9	<.001
P value	<.001	.003	
ASES score			
Preoperative	52.1 ± 14.4	47.2 ± 17.3	.264
Postoperative	76.8 ± 20.3	84.8 ± 7.6	.045
P value	<.001	<.001	
Patient satisfaction	6.4 ± 2.1	8.9 ± 1.2	.041

[a]Data are shown as mean ± SD. aLTT, arthroscopic lower trapezius transfer; aSCR, arthroscopic superior capsular reconstruction; ASES, American Shoulder and Elbow Surgeons; VAS, visual analog scale.

DISCUSSION

To our knowledge, this study is the first clinical comparative study of aSCR and aLTT for posterosuperior IRCTs with high-grade 4 fatty infiltration in the infraspinatus. The main finding of this study was that the clinical outcomes of aLTT were superior in terms of functional improvement, patient satisfaction, and return to activities. Moreover, the rate of progression of arthritis and the graft retear rate were significantly higher with aSCR. Therefore, the cause of this difference in outcomes, even when treatment was performed according to known appropriate indications, requires analysis.

SCR is a reliable surgical option for patients with severe pain and/or intolerable dysfunction who have massive IRCTs with minimal to no glenohumeral joint arthritic changes (Hamada grade 1 or 2) and an intact or reparable subscapularis tendon.[15] The mechanism of SCR is to

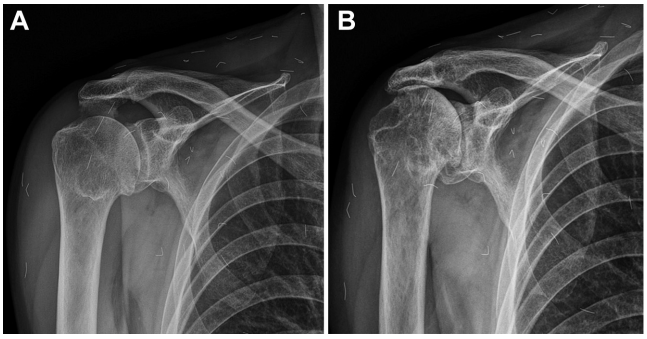

Figure 10. The progression of arthritis after arthroscopic superior capsular reconstruction. (A) Preoperative radiography showed Hamada grade 2 arthritis without significant arthritis in the glenohumeral joint. (B) A significant progression of arthritis was observed at 2 years postoperatively.

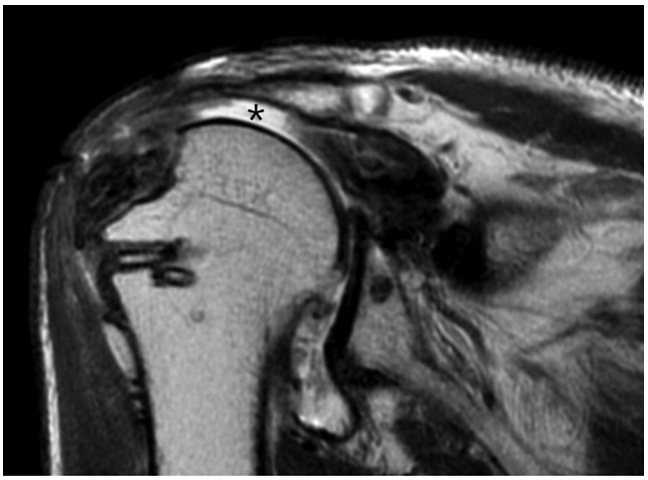

Figure 11. A graft retear after arthroscopic superior capsular reconstruction. Magnetic resonance imaging scan showing acromial wear and a graft retear at the midsubstance (asterisk), with the graft remaining at the footprint and glenoid attachment site. Remnants of the retorn graft could have contributed to maintaining the acromiohumeral distance, as a spacer effect.

restore normal glenohumeral kinematics and force coupling of the rotator cuff muscle by suturing between the graft and the residual anterior supraspinatus and between the graft and the infraspinatus.[19] However, Mihata et al[15] reported that the rate of retears of the repaired infraspinatus tendon after SCR was high in cases with high-grade fatty infiltration of the infraspinatus; such patients with retears of the repaired infraspinatus tendon showed poor clinical outcomes and underwent revision procedures. Moreover, Woodmass et al[26] reported that 65% of patients had persistent pain and nonimproving functional impairment after SCR, which was related to high-grade fatty infiltration of the infraspinatus. Lee and Min[13] demonstrated an increasing SCR failure rate for posterosuperior

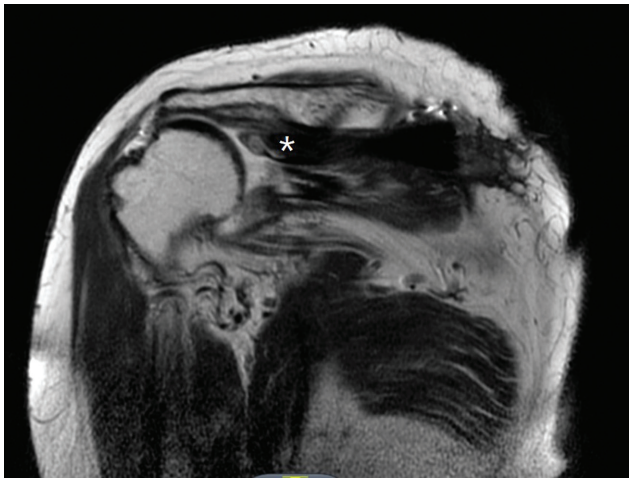

Figure 12. A transferred tendon retear after arthroscopic lower trapezius transfer. Magnetic resonance imaging scan showing a transferred tendon retear between the Achilles tendon allograft (asterisk) and the footprint.

TABLE 3
Radiological Outcomes[a]

	aSCR Group	aLTT Group	*P* Value
AHD, mm			
Preoperative	6.9 ± 2.8	7.1 ± 2.5	.911
Postoperative	7.2 ± 2.6	7.5 ± 1.2	.324
P value	.355	.047	
Arthritis			.027
No change	17	35	
Progression	5	1	
Graft or transferred tendon integrity			<.001
Intact	8	33	
Retear	14	3	

[a]Data are shown as mean ± SD or No. AHD, acromiohumeral distance; aLTT, arthroscopic lower trapezius transfer; aSCR, arthroscopic superior capsular reconstruction.

IRCTs with poorer infraspinatus muscle quality. As a result, when the remnant infraspinatus muscle condition is poor, restoring normal glenohumeral kinematics and force coupling can fail because of retears of the repaired infraspinatus tendon, with poor clinical outcomes.

In this study, we performed side-to-side suturing between the graft and remnant posterior tissue in the aSCR group for restoring normal glenohumeral kinematics and force coupling of the rotator cuff muscle. Unfortunately, more than half of the patients in the aSCR group experienced a graft retear; moreover, the repaired infraspinatus did not show good tendon-to-bone healing. In the current study, the quality of the remnant infraspinatus muscle was poor in all patients, and the tendon also had a thin and fragile shape. Side-to-side repair for normal glenohumeral kinematics and force coupling might be very fragile and fail in such patients. Moreover, Itami et al[12] reported that large rotator cuff tears involving a complete

supraspinatus tendon tear and an anterior half of the infraspinatus tendon tear caused significant posterior and superior translation of the humeral head in a cadaveric study; the authors recommended that posterior translation be considered when treating large posterosuperior rotator cuff tears. From this point of view, we speculated that the graft retear rate would be high under the condition of high-grade fatty infiltration of the remaining infraspinatus. As a result, restoring normal glenohumeral kinematics and force coupling failed with aSCR for posterosuperior IRCTs with high-grade 4 fatty infiltration in the infraspinatus.

The other mechanism of SCR is static depression of the humeral head during shoulder motion to maintain the AHD and prevent the progression of arthritis.[18] In this study, a graft retear was observed at the footprint of the greater tuberosity in 3 patients of the aSCR group and at the midsubstance in 11 patients of the aSCR group. Although we used a minimum graft thickness of 6 mm and performed acromioplasty to decrease the subacromial contact area, in accordance with Mihata et al,[16,17] a graft retear was more common at the midsubstance. We speculated that graft wear beneath the acromial area was increased because of posterior and superior instability under the condition of high-grade 4 fatty infiltration of the infraspinatus, which may lead to graft retears. However, the AHD in these patients was well maintained at 2-year follow-up compared with the preoperative AHD, and the clinical outcomes were also significantly improved. We speculated that with graft retears at the midsubstance, the graft remaining at the footprint and glenoid attachment site contributed to maintaining the AHD, as a spacer effect (Figure 11). These results are consistent with previous reports that graft integrity had no correlation with clinically better outcomes.[13,14]

The rate of progression of arthritis was significantly higher in the aSCR group. For the mechanism of rotator cuff arthropathy, failure of anteroposterior and compressive-distractive force coupling may lead to superior migration of the humeral head, resulting in degenerative wear on the acromion and coracoid process. Moreover, uncoupling leads to shoulder instability and reduced motion, resulting in chondral loss.[4] In this study, graft retears in the aSCR group occurred under the condition of poor-quality remnant infraspinatus muscle, which led to failure of anteroposterior and compressive-distractive force coupling. Failure of force coupling may have caused the progression of arthritis in the aSCR group. As a result, the choice of SCR should be approached carefully under the condition of high-grade 4 fatty infiltration of the remaining infraspinatus.

Recently, LTT has emerged as an alternative tendon transfer method to restore shoulder external rotation and abduction while stabilizing the humeral head. Elhassan et al[7] reported good clinical outcomes after aLTT using an Achilles tendon allograft in patients with massive posterosuperior IRCTs. However, before the current study, comparative clinical studies of SCR and LTT for posterosuperior IRCTs were lacking. In the current study, we found that although both aSCR and aLTT provided improvements in overall clinical outcomes, aLTT was superior in terms of the ASES score, patient satisfaction, active forward elevation, and active external rotation. Moreover, despite a deficit in the superior capsule after aLTT, the subacromial space (AHD) was significantly increased at 2 years postoperatively. Also, the rate of graft retears and the rate of arthritic changes were lower than those in the aSCR group.

We consider these results to be caused by differences between the 2 methods in the mechanism for maintaining shoulder stability and the biomechanical advantage of aLTT. In terms of the principle of tendon transfer, the line of pull of LTT is similar to the physiological line of pull of the native infraspinatus.[22] To maximize this principle, we attached the Achilles tendon to the inferior margin of the prepared lower trapezius, which differed from the original surgical technique. The lower trapezius contracts simultaneously during shoulder external rotation and abduction (in-phase contraction).[24] Moreover, the lower trapezius has adequate excursion and tension to replace the function of the infraspinatus.[11] These features may allow better restoration of shoulder biomechanics and kinematics. In a cadaveric biomechanical study, LTT restored glenohumeral kinematics and joint reaction forces in both anteroposterior and compressive-distractive planes.[21] In a 3-dimensional computed biomechanical study, LTT generated abduction moment arms throughout a normal ROM and mimicked the intact supraspinatus.[23] Moreover, a 3-dimensional kinematic tracking study suggested that with LTT, it may be possible to normalize scapulothoracic motion.[9] As a result, aLTT can dynamically restore native glenohumeral kinematics, including anteroposterior and superoinferior force coupling. We considered these biomechanical advantages to contribute to the improved clinical outcomes.

The static spacing effect of the bridging Achilles tendon can be another advantage of aLTT for posterosuperior IRCTs with high-grade 4 fatty infiltration in the infraspinatus. Recently, Moroder et al[20] reported that transposition of the trapezius through the subacromial space and reattachment of it to the former footprint of the supraspinatus provide a static spacing effect, as well as a dynamic joint centering effect in irreparable supraspinatus tendon tears. In this study, we considered the bridging Achilles tendon of the transposed lower trapezius throughout the subacromial space to act as a static spacer. To enable this static spacing effect of the bridging Achilles tendon, we attempted to create a humeral head depressor by fixing the Achilles tendon allograft to the more ventral supraspinatus footprint rather than the infraspinatus footprint. We suggest that this static spacing effect with aLTT can depress the humeral head during shoulder motion to maintain the AHD.

The rate of progression of arthritis was significantly lower in the aLTT group. In this study, although the condition of the remnant infraspinatus muscle was poor, glenohumeral kinematics, including anteroposterior and superoinferior force coupling, was achieved in the aLTT group. Moreover, the static spacing effect of the bridging Achilles tendon with aLTT can effectively depress the

humeral head and maintain the AHD. As a result, the restoration of force coupling and static spacing with aLTT can prevent the progression of arthritis. Therefore, we consider aLTT a good treatment option for posterosuperior IRCTs under the condition of high-grade 4 fatty infiltration in the infraspinatus in relatively young and active patients.

Some complications, including nerve injuries, hematoma formation, adhesive capsulitis, and loss of normal function of the transferred tendon, can occur after LTT.[3] However, Camp et al[1] reported performing >100 LTT procedures with few complications and a low risk of reoperations. Moreover, we did not encounter irreversible complications such as nerve damage and did not encounter an impairment of scapular motion due to detachment from the original insertion of the lower trapezius. However, transferred tendon retears occurred at the site where the Achilles tendon allograft attached to the footprint in 3 patients of the aLTT group. It is thought that decreased healing between the Achilles tendon allograft and the footprint was the cause of the transferred tendon retears, and efforts to improve graft healing are necessary.

This study had several inherent limitations. First, this study was a retrospective study. The patients were not randomized into groups according to whether they underwent aSCR or aLTT. In most cases, aSCR or aLTT was performed according to the patient's decision. There was no significant difference in preoperative characteristics between the 2 groups. However, this limitation may have led to a performance or selection bias. Second, the relatively small sample size limited the study's validity for clinical practice. Third, the outcomes were evaluated in the short term; thus, it remains unclear whether aLTT would show better results than aSCR in the long term. Nevertheless, to our knowledge, the current study is the first demonstrating comparative results after aLTT and aSCR. Finally, the amount of active movement force was not quantitatively evaluated in the postoperative functional evaluation. However, it was possible to evaluate differences between the 2 groups using only the distinction in the angle of active ROM.

In conclusion, although aSCR and aLTT both provided improvements in overall clinical outcomes for posterosuperior IRCTs with high-grade 4 fatty infiltration in the infraspinatus, aLTT was superior in terms of functional improvement, patient satisfaction, progression of arthritis, and graft or transferred tendon integrity. Therefore, we prefer aLTT for posterosuperior IRCTs under the condition of high-grade 4 fatty infiltration in the infraspinatus.

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