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Arthroscopic superior capsule reconstruction augmentation using a semitendinosus autograft in massive reparable rotator cuff tears

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A R T I C L E I N F O

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Level of evidence: Level III; Retrospective Cohort Comparison; Treatment Study

Background: Arthroscopic superior capsule reconstruction (SCR) augmentation is a viable treatment option for massive reparable cuff tears. This study aimed to retrospectively compare clinical and imaging outcomes of patients with reparable massive rotator cuff tears after arthroscopic rotator cuff repair (ARCR) with those after SCR augmentation using a semitendinosus autograft.

Methods: We retrospectively compared 50 patients with massive reparable rotator cuff tears who underwent ARCR and SCR augmentation (n = 25 each). Patients were clinically followed up for at least 2 years, and the American Shoulder and Elbow index, other patient-reported outcomes, active range of motion, and radiography and magnetic resonance imaging findings were assessed.

Results: At the final follow-up, both patient groups showed significant improvements in forward elevation in range of motion and visual analog scale scores. Improvements in the American Shoulder and Elbow scores in the SCR augmentation group were significantly superior to those in the ARCR group (48.3 and 28.9, $P < .01$). There was a significant difference in the retear rate between the SCR augmentation group and ARCR group (20% and 56%, respectively; $P = .009$).

Conclusion: Our study demonstrated that patient-reported outcomes and retear rates in patients who underwent SCR augmentation with rotator cuff repair for massive rotator cuff tears significantly improved compared with those in patients who underwent ARCR without augmentation. Augmentation with semitendinosus autografting during rotator cuff repair represents a solution for patients with massive reparable rotator cuff tears.

Although arthroscopic repair of massive rotator cuff tears is feasible, achieving satisfactory cuff integrity is difficult due to muscle atrophy, fatty degeneration, tendon retraction, and tissue degeneration.[11,20,28,29,34,46] Several surgical techniques, which include an anterior and posterior interval slide or margin convergence, help to cover the rotator cuff defect, minimize tension at the repair site, and maximize tendon mobility.[5,6,37] Lo and Burkhart[37] reported that the interval slide technique provides a method for the mobilization of massive, severely contracted, immobile rotator cuff tears, allowing for the repair of previously irreparable tears. Despite the development of these techniques, systematic reviews show that the retear rate after arthroscopic rotator cuff repair (ARCR) for massive cuff tears remains high (range 20%-94%).[23,26,27,53]

Several authors have reported that superior capsule reconstruction (SCR) augmentation may improve cuff integrity and stability in patients who undergo complete or partial cuff repair.[2,10,15,40,52,61] The long head of the biceps tendon (LHBT) has previously been used to create an autograft for SCR augmentation.[2,10,36,38] The LHBT is located inside the shoulder joint and has been successfully used to augment support during rotator cuff repair against biomechanical forces.[48] However, LHBT autograft augmentation may not sufficiently restore a stable fulcrum required for normal kinematics.[49] Moreover, the LHBT is often damaged.[32,60]

Recent studies demonstrated the biomechanical and technical feasibility of using the semitendinosus tendon in SCR for irreparable rotator cuff tears.[3,9,13,17,47] The semitendinosus tendon has potential advantages, including simple manipulation and management for secure and anatomical repair because of its cord-like morphology. A graft long enough to be folded can be designed

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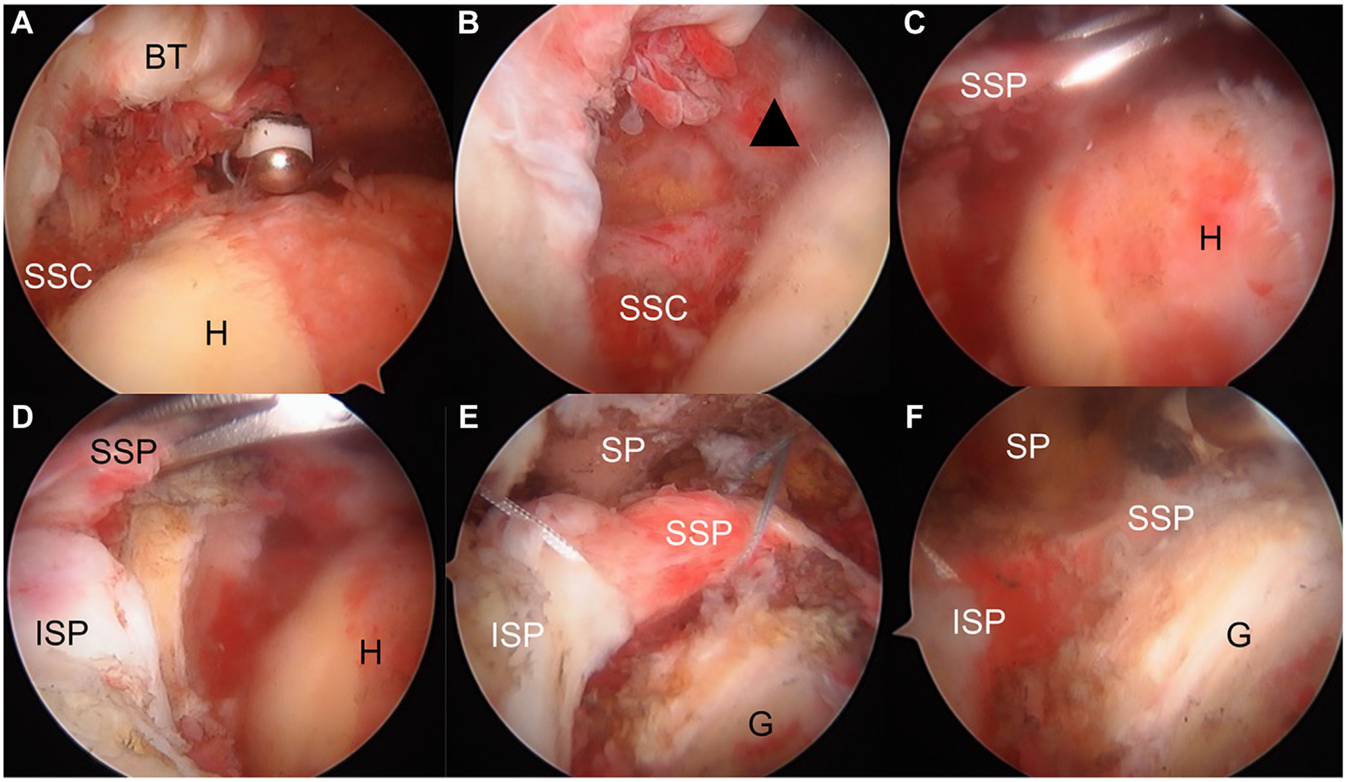

Figure 1 Arthroscopic findings of the right posterolateral subacromial viewing portal. (**A**) Torn edge of the long head of the biceps tendon. (**B**) After identifying the comma sign (▲) and placing a traction stich, anterior interval slide and subscapularis tendon repair are performed. (**C-F**) The quality, stiffness, and retraction of the SSP, ISP, and SSC tendon are evaluated. Double traction sutures are prepared, and posterior interval sliding is performed along the lateral margin of the rotator cuff tendon directing the incision toward the base of the scapular spine. *BT*, biceps tendon; *SSC*, subscapularis tendon; *SSP*, supraspinatus tendon; *ISP*, infraspinatus tendon; *G*, glenoid; *H*, humerus.

based on the size and location of rotator cuff tears. However, the clinical efficacy of SCR augmentation for reparable cuff tears using the semitendinosus tendon is uncertain. We hypothesized that SCR augmentation for reparable massive cuff tears would prevent postoperative retears after ARCR. Therefore, this study aimed to retrospectively compare the clinical and imaging outcomes of patients with reparable massive rotator cuff tears after ARCR with those after semitendinosus autograft SCR augmentation.

Materials and methods

Patients and methods

This study was approved by the Institutional Review Board (3424), and all patients provided informed consent before their participation and the publication of the study. Data of consecutive patients treated for symptomatic large or massive rotator cuff tears at our hospital were retrospectively reviewed.

The primary inclusion criterion was a massive rotator cuff tear, classified using preoperative magnetic resonance imaging (MRI) as an advanced retraction of stage 3, according to Patte,[50] and an advanced tear of grades B, C, D, and E, according to Collin et al.[12] The secondary inclusion criterion was a reparable or partially reparable rotator cuff using several techniques, including anterior and posterior sliding, as described by Burkhart et al.[7,37] Patients with pseudoparalysis of the shoulder joint were included. Rotator cuff tears were diagnosed based on clinical features, plain radiography, ultrasonography, and MRI. To be included in this series, patients were followed up for a minimum of 24 months from the time of surgery. However, only patients who underwent revision surgery, including reverse shoulder arthroplasty, within 24 months of surgery were included. Patients with small-sized or medium-sized rotator cuff tears, irreparable subscapularis tears, or severe osteoarthritis (Hamada IV or V) were excluded. All patients underwent arthroscopic treatment with ARCR or SCR augmentation.

All ARCR surgeries were performed by 4 surgeons (T.F., R.K., H.K., and Y.Y.), and all SCR augmentation surgeries were performed by one surgeon (T.F.).

Surgical technique

Surgeries were performed in the lateral decubitus or beach chair position. Standard posterior, anterosuperior, and lateral portals were used for the evaluation and preparation for repair and reconstruction.

For ARCR, a standard arthroscopic suture bridge with a double pulley technique was used to maximize the chance of healing. First, the quality, stiffness, and retraction of the supraspinatus, infraspinatus, and subscapularis tendons were evaluated. The subscapularis was evaluated and repaired if torn. The biceps tendon was treated with tenodesis or tenotomy during ARCR. The tear pattern was arthroscopically assessed using a tendon grasper, and rotator cuff mobility was improved, if necessary, using the anterior and posterior sliding techniques, according to the Burkhart method.[7,37] A 70° scope was used for visualizing the coracoid base and scapular spine, which were also identified for graft insertion. Briefly, when performing the anterior interval slide, release was performed along the leading edge of the supraspinatus tendon toward the coracoid base, separating the tendon from the rotator interval and subscapularis. When performing the posterior interval slide, release was performed along the lateral margin of the rotator cuff tendon, directing the incision toward the base of the scapular

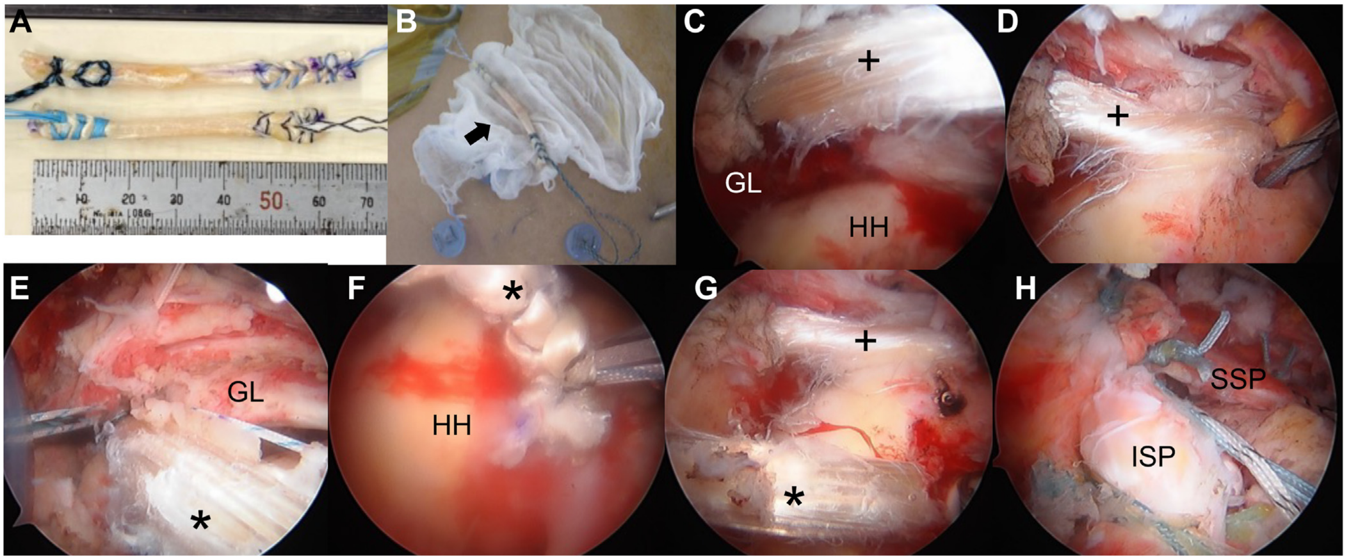

Figure 2 Arthroscopic findings of the right posterolateral subacromial viewing portal. (**A**) Graft preparation using the semitendinosus tendon. The tendon stump is tied in a whip-stitched fashion with a pull-out suture string. (**B**) Then, the graft (⇑) is shuttled from the lateral anchor portal to the anterosuperior portal using a flexible cannula. (**C**) The anterior graft (+) is fixed at the anterosuperior glenoid using a glenoid anchor. (**D**) Then, the graft tendon (+) is inserted into the socket at the greater tuberosity and immobilized using the tenodesis technique with bioabsorbable interference screw fixation in 30°-45° of abduction and 30° of external rotation. (**E**) The posterior graft (*) is fixed at the posterosuperior glenoid using a glenoid anchor. (**F**) The posterior graft (*) is fixed at the greater tuberosity in the same manner. (**G**) The grafts are placed anteriorly (+) and posteriorly (*) for reinforcement of the rotator cuff. (**H**) Finally, a partial repair of the remaining rotator cuff over the top of the graft is performed. *SSP*, supraspinatus tendon; *ISP*, infraspinatus tendon; *GL*, glenoid; *HH*, humeral head.

spine (Fig. 1). Torn rotator cuffs were repaired using the double pulley and cinch-loop techniques.[1]

The decision to perform SCR augmentation was made intraoperatively based on the quality and retraction of the rotator cuff after mobilization. When the quality of the torn tendon was poor or the posterior sliding technique was necessary, SCR augmentation was performed. For SCR augmentation, 1 humeral and 1 glenoid anchor portal with several 8-mm flexible cannulas (PassPort; Arthrex, Naples, FL, USA) were used for each graft. For graft preparation, a 4-cm incision was made in the medial portion on the opposite side of the proximal tibia. The semitendinosus tendon was harvested using a tendon stripper, and the tendon stump was tied using a whip-stitch, 1.3-mm FiberLoop SutureTape (Arthrex, Naples, FL, USA), or 1.5-mm BroadBand Loop (Biomet Sports Medicine; Warsaw, IN, USA) (Fig. 2).

The distances between the glenoid and greater tuberosity were measured with the arm in 20° of forward flexion and 30°-45° of abduction. The length of the graft was determined by measuring the distance between the glenoid and greater tuberosity and adding both 20-mm end margins. The average length of the graft was 70.5 mm. The diameters at both ends of the graft were measured using a sizing system. The anterosuperior and posterosuperior edges of the glenoid and the medial edge of the greater tuberosity were dissected for clear visualization of the anchor insertion and graft-to-bone attachment. To insert the graft smoothly, 1 or 2 bone sockets of the greater tuberosity were created using a 2.4-mm passing pin and a 5-mm or 6-mm cannulated reamer to a depth of 30 mm before graft insertion, depending on the diameter of the graft. Subsequently, a glenoid anchor (JuggerKnot Soft Anchor 2.9 mm; Biomet Sports Medicine, Warsaw, IN, USA) was placed at the anterosuperior glenoid.

The graft was then shuttled from the lateral anchor portal to the anterosuperior portal. First, the graft was fixed to the anterosuperior glenoid using a glenoid anchor. Second, the graft tendon was inserted into the socket at the greater tuberosity and immobilized using the tenodesis technique with bioabsorbable interference screw fixation (5.5 or 6.25 × 20 mm; BioComposit SwiveLock; Arthrex, Naples, FL, USA) in 30°-45° of abduction and 30° of external rotation (ER) (Fig. 2). When the LHBT and superior labrum were intact, the LHBT was used as the anterior graft and tied using the lasso loop technique[33] (Fig. 3). Next, a posterior glenoid anchor was placed at the base of the scapular spine using another posterior portal. The posterior graft was then placed in the same fashion, and the interference screw was immobilized in 30°-45° of abduction and 0° of ER. Grafts were placed anteriorly and posteriorly to reinforce the rotator cuff (Fig. 2). Finally, the remaining rotator cuff was partially or completely repaired at the top of the graft. Notably, the anterior and posterior graft tendons were not tied to the rotator cuff.

Postoperatively, for all patients who underwent ARCR or SCR augmentation, the shoulders were immobilized in an abduction brace for 4-6 weeks. At 2-4 weeks, the patients commenced passive range of motion (ROM) exercises, and after they were permitted to remove the brace, they initiated active ROM exercises. The patients were permitted to participate in full activities, including sports, 6-8 months postoperatively.

Clinical and imaging assessment

Patient-reported outcomes (PROs) were recorded using 5 scoring systems: the visual analog scale (VAS); the shoulder scores of the American Shoulder and Elbow (ASES) index; the Japanese Orthopaedic Association (JOA) score; the Constant score; and the Disabilities of the Arm, Shoulder, and Hand (DASH) score. Active shoulder ROM in forward elevation (FE), ER at the side, and internal rotation (IR) was measured before surgery; 3, 6, 12, and 24 months after surgery; and at the final follow-up. IR was measured as the highest vertebral body that the patient could reach with the thumb of the affected arm. A handheld digital dynamometer (Mobie, Sakai Medical Co., Ltd., Tokyo, Japan) was attached to a table and used to measure strength as the average of the maximum force in Newtons of 3 trials for FE, ER, and IR.

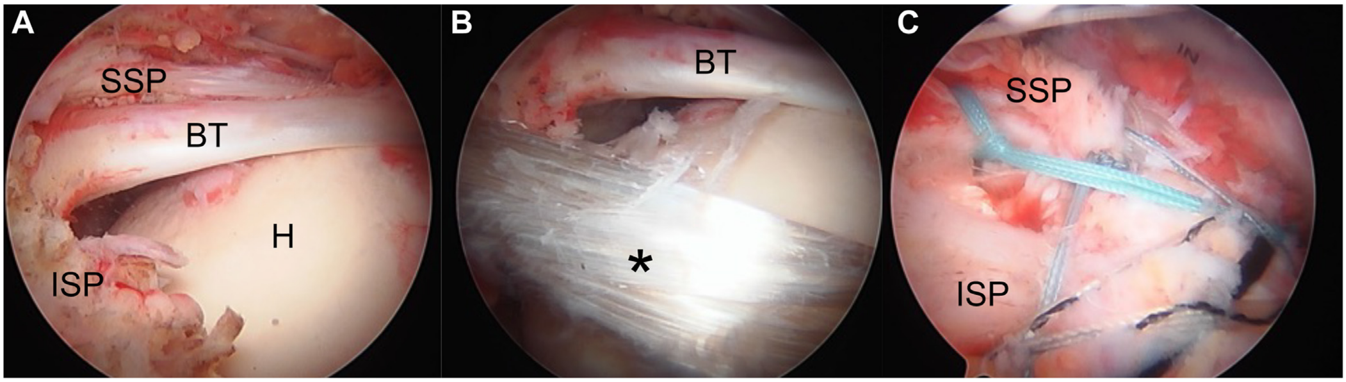

Figure 3 Arthroscopic findings of the right posterolateral subacromial viewing portal. (**A**) Identification of the intact long head of the biceps tendon (BT) and massive cuff tear. (**B**) The BT and semitendinosus tendon (*) are used for reinforcement of the rotator cuff. (**C**) Repair of the remaining rotator cuff over the top of the graft is performed. *SSP*, supraspinatus tendon; *ISP*, infraspinatus tendon; *G*, glenoid; *BT*, biceps tendon; *H*, humerus

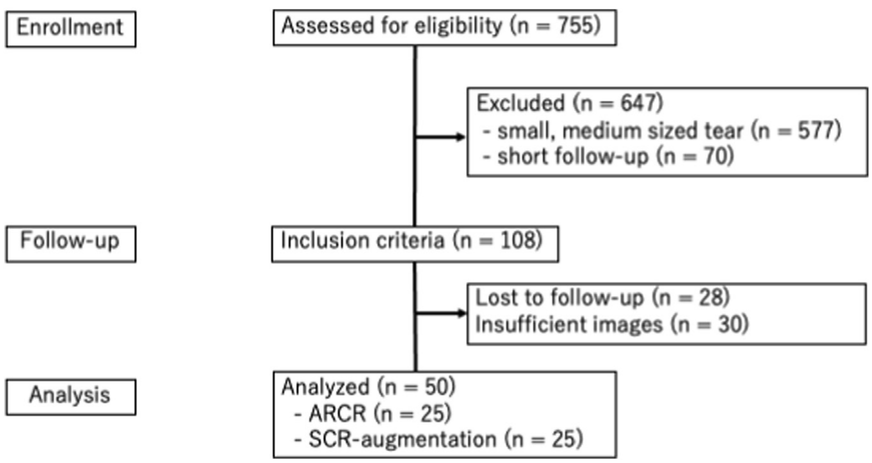

Figure 4 Patient flowchart. The tear size of the rotator cuff is identified using the Collin[12] and Patte[50] classification systems. *ARCR*, arthroscopic rotator cuff repair; *SCR*, superior capsule reconstruction.

A standard anteroposterior radiograph with neutral rotation in the upright position was used to assess the acromiohumeral interval (AHI), index of superior migration of the humeral head,[45] and Hamada classification of the glenohumeral joint.[24] MRI evaluation of rotator cuff integrity was performed before surgery and at the final follow-up. The integrity of the repaired rotator cuff tendon was assessed according to Sugaya's classification.[56] In the present study, continuity of the repaired cuff (Sugaya type I, II, and III) was defined as a healed rotator cuff and discontinuity of the repaired cuff (Sugaya type IV and V) was defined as an unhealed rotator cuff. Muscle atrophy and fatty infiltration were evaluated according to classifications by Goutallier et al[21] and Fuchs et al.[18] Two shoulder surgeons (F.T. and T.T.) blindly reviewed the preoperative and postoperative MRI scans.

Statistical analyses

Clinically significant improvements in the VAS, ASES, and Constant scores were defined based on a minimal clinically important difference (MCID). According to previous reports,[4,14,30] the MCID for the VAS, ASES, and Constant scores were defined as 1.5, 21, and 5.5 points, respectively. For comparison of the 2 groups, the unpaired Student's *t*-test, Mann-Whitney U, Wilcoxon, and chi-square tests were used. *P* values <.05 were considered statistically significant. All statistical data were analyzed using R, version 2.8.1 (R Foundation for Statistical Computing, Vienna, Austria [CRAN freeware]).

Results

Between July 2017 and September 2020, 755 patients underwent ARCR at our institution and 108 were diagnosed with reparable large or massive rotator cuff tears. Twenty-eight patients were lost to follow-up owing to other illnesses or missing contact, and 30 had insufficient images for evaluation, leaving 50 patients (31 females and 19 males; mean age, 67.8 years; range, 49-79 years) whose data could be analyzed (Fig. 4). The 50 patients were divided into 2 groups: 25 with massive tears with ARCR (ARCR group) and 25 with massive tears with SCR augmentation (SCR augmentation group). In the SCR augmentation group, 8 biceps and semitendinosus tendon grafts and 17 double semitendinosus tendon grafts were used for augmentation. In our study, a rotator cuff defect measuring <10 mm was considered a partial repair. The ARCR group achieved 80% complete repair, whereas the SCR augmentation group achieved 88% complete repair. The demographic data of the 50 patients are summarized in Tables I and II. No significant differences were noted in age, sex, rotator cuff tear size, or tear patterns between the 2 groups (Table I). However, the preoperative active FE, ASES, JOA, Constant, and DASH scores in the

Table I
Characteristic of patients.

	ARCR n = 25	SCR augment n = 25	*P* value
Age, y	66.5 ± 8.7	69.2 ± 6.4	.216
Sex (male/female)	12/13	7/18	.145
Body mass index	25.2 ± 6.3	22.9 ± 2.6	.215
Dominant, %	80%	76%	.733
Follow-up, mo	28.3 ± 7.8	30.9 ± 13.8	.572
Acromiohumeral interval, mm	5.9 ± 1.9	6.2 ± 1.9	.440
Superior migration index (0/I/II/III/IV), n	11/10/3/1/0	6/13/5/0/1	.359
Hamada classification (I/II/III), n	7/15/3	8/12/5	.638
Collin classification (A/B/C/D/E), n	0/1/14/10/0	0/2/13/10/0	.831
Patte classification (1/2/3), n	0/0/25	0/0/25	NA
Subscapularis tear, %	100%	88%	.074
Complete repair, %	80%	88%	.458
Biceps and semitendinosus, n	N/A	8	
Double semitendinosus, n	N/A	17	

ARCR, arthroscopic rotator cuff repair; *SCR*, superior capsule reconstruction.
Values are presented as mean ± standard division or n. **P* < .05.
Superior migration index according to Oizumi et al[45]; Hamada classification according to Hamada et al[24]; Collin classification according to Collin et al[12]; Patte classification according to Patte et al.[50]

SCR augmentation group were significantly poorer than those in the ARCR group (*P* = .012, .002, .012, .014, and .001, respectively) (Tables II and III).

Clinical outcomes

The clinical outcomes are summarized in Tables II and III. Both groups showed significant improvements in FE in ROM; FE, ER, and IR in strength; VAS score; and PROs during the final follow-up (Tables II and III). For the ARCR group, the ASES, JOA, Constant, and DASH scores significantly improved from 54.9, 71.7, 49.8, and 29.0, respectively, to 85.9, 86.6, 64.1, and 13.5, respectively, at the final follow-up (*P* < .0001, .001, .001, and .001, respectively). In the SCR augmentation group, the ASES, JOA, Constant, and DASH scores significantly improved from 39.9, 62.5, 40.3, and 47.6, respectively, to 88.9, 88.5, 68.2, and 14.8, respectively, at the final follow-up (all *P* < .0001) (Table III). The rates of achieving the MCID for the VAS, ASES, and Constant scores were 72%, 56%, and 68%, respectively, in the ARCR group and 88%, 92%, and 88%, respectively, in the SCR augmentation group.

In the comparison of postoperative factors between the ARCR and SCR augmentation groups, the FE and IR in ROM and improvement in the PROs in the SCR augmentation group were significantly superior to those in the ARCR group (Tables II-IV). On the contrary, there were no significant differences in the strength and VAS scores between the ARCR and SCR augmentation groups.

Imaging outcomes

The intraobserver reliability was 0.81 and interobserver reproducibility was 0.72. On radiographs in the ARCR and SCR augmentation groups, the preoperative and postoperative mean AHI and superior migration of the humeral head were not significantly different (*P* = .695, .34, .65, and .466, respectively; Table IV). Although fatty degeneration of the infraspinatus tendon did not differ between the ARCR and SCR augmentation groups, fatty degeneration of the supraspinatus tendon was significantly lower in the SCR augmentation group than in the ARCR group. This result is consistent with that of the postoperative cuff integrity (Table IV).

Table II
Comparison of preoperative and postoperative patient-reported outcomes.

	ARCR n = 25	SCR augment n = 25	*P* value
Range of motion			
Forward elevation, degree			
Preoperative	133 ± 43	105 ± 42	.012*
Postoperative	148 ± 28	149 ± 19	.678
P value	.052	<.0001*	
Improvement	15 ± 42	45 ± 46	.031*
External rotation, degree			
Preoperative	29 ± 22	32 ± 16	.55
Postoperative	35 ± 19	28 ± 16	.169
P value	.052	.246	
Improvement	7 ± 17	−4 ± 17	.027*
Internal rotation, degree			
Preoperative	Th12	L1	.341
Postoperative	Th11	Th11	.929
P value	.196	.032*	
Improvement	1 vertebra	2 vertebrae	.346
Strength			
Forward elevation, N			
Preoperative	17 ± 13	15 ± 10	.421
Postoperative	46 ± 22	43 ± 19	.523
P value	<.0001*	<.0001*	
Improvement	29 ± 21	28 ± 18	.89
External rotation, N			
Preoperative	25 ± 16	23 ± 15	.821
Postoperative	60 ± 37	54 ± 24	.48
P value	<.0001*	<.0001*	
Improvement	34 ± 32	30 ± 21	.595
Internal rotation, N			
Preoperative	62 ± 32	50 ± 22	.215
Postoperative	96 ± 36	82 ± 29	.163
P value	<.001*	<.0001*	
Improvement	33 ± 34	33 ± 25	.912

ARCR, arthroscopic rotator cuff repair; *SCR*, superior capsule reconstruction.
Values are presented as mean ± standard division or n. **P* < .05.

At the final follow-up, the MRI study demonstrated 0% and 36% of type I cuff integrity, 28% and 28% of type II cuff integrity, 16% and 16% of type III cuff integrity, 20% and 16% of type IV cuff integrity, and 36% and 4% of type V cuff integrity in the ARCR and SCR augmentation groups, respectively (Table IV).

We observed 31 healed rotator cuffs, including 11 shoulders in the ARCR group and 20 in the SCR augmentation group. We also observed 19 unhealed rotator cuffs, including 14 shoulders in the ARCR group and 5 in the SCR augmentation group (Table IV).

In terms of graft healing, 23 of 25 (92%) shoulders had intact grafts and tendons, and the others had 5 retears of the rotator cuff, which included 2 graft failures with retear of the rotator cuff.

Comparison between the healed and unhealed cuffs

When we compared the healed and unhealed cuffs, the preoperative ER and ASES score, postoperative FE, ER in ROM, PROs, and AHI were significantly superior in the healed cuffs than in the unhealed cuffs (Table V). There were no significant differences in ROM, strength, or VAS scores between the healed and unhealed cuffs.

Complications

There were no infections or neurovascular injuries to the shoulder or knee joints. Complications were observed in 3 patients who underwent revision reverse shoulder arthroplasty in the ARCR group (12%); there were no complications (0%) among patients in the SCR augmentation group who underwent revision surgery.

Table III
Comparison of preoperative and postoperative patient-reported outcomes.

	ARCR n = 25	SCR augment n = 25	*P* value
VAS			
Preoperative	5.3 ± 2.2	5.3 ± 2.4	.952
Postoperative	1.2 ± 2.1	0.72 ± 1.2	.801
P value	<.0001*	<.0001*	
MCID	72%	88%	.157
ASES score			
Preoperative	54.9 ± 17.9	39.9 ± 14.5	.002*
Postoperative	85.9 ± 16.2	88.9 ± 10.6	.671
P value	<.0001*	<.0001*	
Improvement	28.9 ± 18.7	48.3 ± 18.7	.001*
MCID	56%	92%	.004*
JOA score			
Preoperative	71.7 ± 11.5	62.5 ± 13.4	.012*
Postoperative	86.6 ± 11.0	88.5 ± 6.2	.954
P value	<.001*	<.0001*	
Improvement	13.8 ± 13.8	24.8 ± 13.6	.008*
Constant score			
Preoperative	49.8 ± 12.1	40.3 ± 14.1	.014*
Postoperative	64.1 ± 12.0	68.2 ± 11.1	.238
P value	<.001*	<.0001*	
Improvement	14.0 ± 15.8	27.6 ± 16.9	.007*
MCID	68%	88%	.088
DASH score			
Preoperative	29.0 ± 17.4	47.6 ± 18.6	.001*
Postoperative	13.5 ± 12.0	14.8 ± 14.1	.89
P value	<.001*	<.0001*	
Improvement	−15.0 ± 15.3	−32.9 ± 20.7	.002*

ARCR, arthroscopic rotator cuff repair; *SCR*, superior capsule reconstruction; *VAS*, visual analog scale; *ASES*, American Shoulder and Elbow Surgeons; *JOA*, Japanese Orthopaedic Association; *MCID*, minimal clinically important differences; *DASH*, Disabilities of the Arm, Shoulder, and Hand.
Values are presented as mean ± standard division. *$P < .05$.

Table IV
Comparison of preoperative and postoperative imaging.

	ARCR n = 25	SCR augment n = 25	*P* value
Acromiohumeral interval, mm			
Reoperative	5.9 ± 1.9	6.2 ± 1.9	.44
Postoperative	5.8 ± 2.7	6.5 ± 2.2	.332
P value	.695	.65	
Superior migration index (0/I/II/III/IV), n			
Preoperative	11/10/3/1/0	6/13/5/0/1	.36
Postoperative	4/10/4/0/0	7/10/4/3/1	.437
P value	.34	.466	
Fatty degeneration, Goutallier			
Supraspinatus (0/I/II/III/IV)			
Preoperative	0/1/14/6/4	0/3/12/7/3	.223
Postoperative	0/1/11/8/5	0/9/9/4/3	.038*
P value	.432	.033*	
Infraspinatus (0/I/II/III/IV)			
Preoperative	0/8/5/6/6	0/7/6/11/1	.287
Postoperative	0/6/6/7/6	0/4/6/13/2	.158
P value	.063	.388	
Subscapularis (0/I/II/III/IV)			
Preoperative	7/9/3/2/4	8/10/1/3/3	.833
Postoperative	2/13/5/1/4	5/9/4/4/3	.397
P value	.273	.0752	
Cuff integrity, Sugaya (I/II/III/IV/V)	0/7/4/5/9	9/7/4/4/1	.004*
Retear rate (IV and V)	14/25 (56%)	5/25 (20%)	.009*
Graft tear	NA	2/25 (8%)	

ARCR, arthroscopic rotator cuff repair; *SCR*, superior capsule reconstruction.
Values are presented as mean ± standard division or n. *$P < .05$.
Superior migration index according to Oizumi et al[45]; Fatty degeneration according to Goutallier et al[21]; Cuff integrity according to Sugaya et al.[56]

Discussion

Our study demonstrated that the ROM, PROs, fatty degeneration of the supraspinatus, and retear rate in patients who underwent SCR augmentation with a semitendinosus autograft for massive rotator cuff tears were significantly superior than those in patients who underwent ARCR without augmentation for massive rotator cuff tears. There was a significant difference between the achieved MCID of 56% in the ARCR group and 92% in the SCR augmentation group, based on the clinical thresholds for the ASES score. In both the groups, although the stability of the humeral head was maintained in the healed cuff, the humeral head in the unhealed cuff migrated superiorly. These results indicated that SCR augmentation as reinforcement with rotator cuff repairs could prevent retear of the repaired cuff; improve ROM, fatty degeneration of the supraspinatus tendon, and PROs; and maintain superior migration of the humeral head. However, SCR augmentation did not improve the strength or fatty degeneration of the infraspinatus tendon when fatty degeneration advanced preoperatively.

The rotator cuff muscles provide dynamic stabilization to the glenohumeral joint and prevent superior migration of the humeral head upon contraction of the deltoid muscle.[25,58,62] However, clinical outcomes and postoperative cuff integrity after ARCR in patients with massive cuff tears continue to have limitations in terms of durability and indications.[23,26,27,53]

Structural augmentation may provide sufficient primary stabilization and acceptable clinical outcomes in patients undergoing repair of massive rotator cuff tears. However, the role of structural augmentation differs depending on whether the rotator cuff is irreparable. For patients with irreparable rotator cuff tears, structural augmentation, such as SCR using the fascia lata, LHBT, and acellular human dermal matrix, provides promising clinical and biomechanical outcomes.[3,8,16,31,39,41,43,51]

Recent clinical studies have shown that structural augmentation for reparable or partially reparable cuff tears in ARCR improves postoperative cuff integrity.[2,10,15,40,52,61] Mihata et al[40] reported that almost all patients who underwent SCR using a fascia lata autograft for reinforcement of ARCR achieved healing of the torn tendon with favorable thickness and quality. Llinas et al[36] reported that the use of the LHBT for partial SCR to augment massive rotator cuff tears resulted in modestly improved pain and functional outcomes and markedly lower retear rates (14.3% vs. 46%) compared with repair alone. Chiang et al[10] reported that ARCR combined with modified SCR using the LHBT as reinforcement leads to a lower retear rate (16.7% vs. 40.9%) and earlier functional recovery than conventional ARCR for large to massive reparable cuff tears. Lederman et al[35] reported that repair of large rotator cuff tears structurally reinforced with a xenograft resulted in improved functional outcomes and strength. Barth et al[2] reported that SCR with the LHBT prevented infraspinatus retears in massive rotator cuff tears (8.3% vs. 39.3%). Degan et al[15] demonstrated that augmentation of ARCR with SCR might lower the rate of nonhealing because 42% of the supraspinatus and 54% of the infraspinatus tendons healed. The results of our study also demonstrated that the 20% retear rate of SCR augmentation was significantly lower than the 56% retear rate of ARCR without augmentation ($P = .0038$). Our results regarding the retear rates of both ARCR without augmentation and SCR augmentation are consistent with those of previous studies.

However, the correlation between the structural integrity at the bone-to-tendon insertion and fatty degeneration remains

Table V
Comparison of healed and unhealed cuff.

	Healed (n = 31)	Unhealed (n = 19)	*P* value
Range of motion			
Forward elevation, degree			
Preoperative	114 ± 50	128 ± 33	.703
Postoperative	156 ± 15	136 ± 29	.032*
P value	<.0001*	.257	
External rotation, degree			
Preoperative	35 ± 18	23 ± 19	.027*
Postoperative	36 ± 15	25 ± 21	.019*
P value	.843	.338	
Internal rotation, degree	L1	L1	.66
Preoperative	Th10	Th12	.083*
Postoperative	.007*	.852	
P value			
Strength			
Forward elevation, N			
Preoperative	13 ± 10	20 ± 13	.052
Postoperative	45 ± 21	43 ± 19	.676
P value	<.0001*	<.0001*	
External rotation, N			
Preoperative	24 ± 15	24 ± 17	.949
Postoperative	61 ± 33	50 ± 26	.284
P value	<.0001*	<.0001*	
Internal rotation, N			
Preoperative	51 ± 21	63 ± 37	.224
Postoperative	87 ± 34	93 ± 32	.347
P value	<.0001*	.001*	
VAS			
Preoperative	5.4 ± 2.2	5.1 ± 2.5	.641
Postoperative	0.6 ± 1.2	1.4 ± 2.3	.234
P value	<.0001*	.00018*	
ASES score			
Preoperative	43.2 ± 17.5	53.8 ± 16.7	.041*
Postoperative	91.7 ± 10.4	80.5 ± 15.4	.003*
P value	<.0001*	<.0001*	
JOA score			
Preoperative	65.5 ± 15.0	69.6 ± 9.3	.295
Postoperative	89.8 ± 8.5	84.0 ± 8.3	.005*
P value	<.0001*	<.001*	
Constant score			
Preoperative	44.7 ± 16.1	45.6 ± 9.5	.818
Postoperative	69.9 ± 10.4	60.3 ± 11.3	.004*
P value	<.0001*	<.001*	
DASH score			
Preoperative	42.2 ± 20.1	31.7 ± 19.0	.119
Postoperative	10.8 ± 12.5	19.6 ± 12.1	.004*
P value	<.0001*	.00316*	
Acromiohumeral interval, mm			
Preoperative	6.2 ± 2.1	5.9 ± 1.8	.557
Postoperative	7.2 ± 2.0	3.9 ± 1.6	< .00001*
P value	.032*	.003*	

VAS, visual analog scale; *ASES*, American Shoulder and Elbow Surgeons; *JOA*, Japanese Orthopaedic Association; *DASH*, Disabilities of the Arm, Shoulder, and Hand.
Values are presented as mean ± standard division. $^*P < .05$.

controversial. It is widely accepted that the progression of fatty degeneration is closely associated with retear after ARCR.[19,44,59,63] The healed bone-to-tendon insertion may improve fatty degeneration after ARCR.[22,57,63] Goutallier et al[22] reported that in rotator cuff tears with baseline fatty degeneration index values no more than 2, tension-free tendon-to-bone sutures with an intact cuff at 1 year virtually consistently produced an intact cuff without notable shoulder osteoarthritis after 9 years. However, several studies have shown that fatty acid degeneration is irreversible despite successful repair.[19,20]

The present study showed that SCR augmentation as a reinforcement for ARCR could prevent retear and improve fatty degeneration of the supraspinatus tendon. However, cuff repair with augmentation did not improve the strength of the FE, ER, or IR or fatty degeneration of the infraspinatus tendon. It is difficult to clarify the differences between the supraspinatus and infraspinatus owing to the small sample size and low reliability of fatty degeneration in MRI evaluation. We believe that secure augmentation, as a reinforcement for ARCR, may facilitate the improvement of fatty degeneration. Our augmentation technique may be more favorable for the supraspinatus than for the infraspinatus tendon. For the supraspinatus, the double bundle as an anterior and posterior cable may prevent retears and improve fatty degeneration. In the subscapularis or infraspinatus, only one bundle can function as a posterior cable. Less improvement in fatty degeneration of the subscapularis or infraspinatus tendon leads to insufficient strength in the FE, ER, and IR. Favorable operative indications for SCR augmentation in patients with massive cuff tears who have undergone complete or partial cuff repair are less fatty degeneration of the rotator cuff, especially subscapularis and infraspinatus tears with fatty degeneration values no more than 2. Further studies are required to develop more effective strategies for infraspinatus tendon recovery.

Graft options for augmentation include fascia lata,[40] LHBT,[36] semitendinosus tendon,[9] and acellular dermal allografts.[15] The selection of the LHBT as an autograft source is convincing owing to its anatomy being similar to that of the anterior cable and the common pathology of rotator cuff tears, which are usually treated with tenotomy or tenodesis. However, this is not always intact in massive rotator cuff tears. Several studies showed the pathology of the LHBT in massive cuff tears.[32,60] Walch et al[60] reported that 71% of LHBT dislocations were found in subscapularis, supraspinatus, and infraspinatus tendon tears. Lafosse et al[32] reported that the size of the rotator cuff tear was strongly associated with a lesion of the LHBT. Seventy-eight percent of the 3 tendon injuries had a grade II LHBT lesion. Moreover, a recent study indicated that LHBT autograft augmentation may not sufficiently restore a stable fulcrum required for normal kinematics in patients with massive cuff tears.[49]

Recent studies have demonstrated that the semitendinosus tendon has several advantages as a graft option for ARCR reinforcement.[9,17,47] First, the semitendinosus tendon is a standard graft source due to the harvesting technique, sufficient length and strength, and minimal donor-site morbidity. Biomechanically, the hamstring has been described as a static stabilizer that allows sufficient centering of the humeral head.[3,17,47] Berthold et al[3] showed that in a dynamic biomechanical shoulder model, both the semitendinosus tendon and semitendinosus-LHBT repair techniques decreased the cumulative deltoid force and superior humeral head migration. Park et al[47] reported that anterior cable reconstruction using a cord-like semitendinosus tendon allograft can biomechanically improve superior migration and subacromial contact pressure (primarily in the lower combined abduction and rotation positions), without limiting the ROM for large rotator cuff tendon defects or tears. A study by Denard et al[17] suggested that a V-shaped semitendinosus allograft is biomechanically strong enough to restore the disrupted cable attachments and correct superior migration of the humeral head. Second, because the semitendinosus tendon is sufficiently long and has a cord-like shape, the tunnel repair technique with an interference screw may be adequate to secure fixation[54] and leads to better healing[55] than the suture anchor technique. Third, semitendinosus tenodesis with the tunnel repair technique using an interference screw can manage the graft tensioning, depending on various tear patterns and retraction of the rotator cuff tear. Finally, with the tunnel repair technique, the semitendinosus tendon can be placed at the appropriate point, leaving enough space for native rotator cuff-to-bone healing.

In contrast, the semitendinosus tendon autograft has inherent donor-site morbidity. Hyperethesia is common after tendon harvesting but diminishes gradually over time. However, it can seldom be seen and results in permanent decreased sensation or hyperethesia. In addition, permanent residual terminal flexion weakness may be a residual complication, although only the semitendinous tendon is harvested and the gracilis tendon is intact.

Mihata et al[39,42] recommended a much thicker graft in the SCR for irreparable cuffs. In a 2016 biomechanical study of cadaveric shoulders, Mihata et al[42] reported that 8-mm grafts decreased both the peak subacromial pressure and superior humeral translation, while 4-mm thick grafts only improved the peak subacromial pressure. In grafts for reinforcement, a thicker graft may prevent the healing of the insertion between the native cuff tendon and the bone. Despite these advantages, bone quality should be carefully considered, particularly in elderly patients with osteoporosis. Although graft tensioning is a critical part of this procedure, further mechanical testing is required to determine the optimal tension.

This preliminary study had certain limitations, including a small sample size; short follow-up period; heterogenous background, including preoperative ROM and PROs; heterogenous surgical techniques, including with or without the biceps tendon; lack of blinding during the evaluation of clinical and radiographic data; and a retrospective design. We did not compare the clinical and imaging outcomes of SCR augmentation with cuff repair and SCR without cuff repair. In addition, we did not compare the differences in clinical outcomes between SCR augmentation with and without the biceps tendon. No appropriate indication for SCR augmentation and graft options were determined in this study. There was a certain learning curve, which plays an important role in complex procedures. Thus, the development of surgical techniques necessitates a larger sample size and an extended study period. These factors, such as patient selection and surgical technique, are surgeon-dependent, thereby introducing a notable potential for bias.

Several other options for joint-preserving procedures, including tendon transfers and subacromial balloons, have not been investigated. The optimal treatment strategy should be determined after adequately considering several surgical options for each patient with a massive cuff tear.

Conclusion

Our study demonstrated that PROs and retear rates in patients undergoing SCR augmentation with rotator cuff repair for massive rotator cuff tears significantly improved compared to those in patients undergoing ARCR without augmentation. Augmentation with autografting of the semitendinosus during rotator cuff repair is a viable solution for patients with massive reparable rotator cuff tears.

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