Systematic Review

Arthroscopic Superior Capsular Reconstruction for Massive Irreparable Rotator Cuff Tears Results in Significant Improvements in Patient Reported Outcomes and Range of Motion: A Systematic Review

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Purpose: The purposes of this study were to evaluate the clinical outcomes (with the minimum mean follow-up period of 2 years) of arthroscopic superior capsular reconstruction (ASCR) using different grafts for massive irreparable rotator cuff tears (MIRCTs) and to explore whether margin convergence in ASCR affects range of motion (ROM) outcomes. **Methods:** This systematic review was registered in PROSPERO and was then conducted following PRISMA guidelines by searching the databases: MEDLINE, EMBASE, Web of Science, and Cochrane Library database before April 2021. These literature searches investigating the clinical outcomes of ASCR were included. The methodological quality of included studies was assessed using the MINORS criteria. The data, including margin convergence, patient-reported outcome scores, range of motion, and complications, were extracted and analyzed. The minimal clinically important differences (MCID) criteria was used to define clinical significance. **Results:** 15 studies met the inclusion criteria. All studies reported statistically significant improvements in visual analog scale scores (range: 2.07 to 7.1) and American Shoulder and Elbow Surgeons scores (range: 18.1 to 58). Significant improvements of Constant scores were noted in 4 of 5 reporting studies (mean improvement ranged from 14.64 to 50.79). Active forward flexion/elevation (11 studies), active abduction (4 studies), and active external rotation (8 studies) displayed improvements in all reporting studies, with mean changes ranging from 12 to 73.68, 19 to 89.21, and 1 to 24.74, respectively. The mean change of postoperative acromiohumeral distance ranged from −0.86 mm to 3.2 mm in 9 studies. The postoperative complication rate of ASCR ranged from 4.5% to 47.6%. The anterior margin convergence in SCR was associated with a relatively poor improvement in active external rotation. **Conclusions:** ASCR contributes to significant improvements in patient-reported clinical outcomes and ROM at follow-up after a mean of more than two years, emerging as a viable option for patients with MIRCTs. The anterior margin convergence should be prudently chosen, especially in ASCR using fascia lata autograft, on account of the probable restriction on postoperative active external rotation. **Level of Evidence:** Level IV, systematic review of Level III and IV studies.

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Introduction

Massive irreparable rotator cuff tears (MIRCTs) usually lead to advanced muscle atrophy and fatty infiltration of inferior tendons, and it is difficult for surgeons to pull the retracted tendons back to the anatomical footprint of greater tuberosity.[1] As such, MIRCTs inflict great pain and functional disability on patients and present a major clinical challenge for shoulder surgeons.

There are several available clinical management strategies for MIRCTs, ranging from nonoperative physical therapy,[2,3] partial repair (PR),[4-6] graft interposition,[7] latissimus tendon transfer,[8-10] and reverse shoulder arthroplasty (RSA).[11-13] PR, first described in 1994 by Burkhart, has been shown to be a more reliable option for MIRCTs.[5,14] However, in patients with severe muscle atrophy and fatty infiltration in the rotator cuff, PR may not lead to a satisfactory outcome.[15] RSA is recognized as an effective measure for elderly, lower-demand patients but has been associated with a high rate of complications.[16] As such, the optimal treatment for MIRCTs remains ambiguous.

ASCR, reported by Mihata in 2010 in their pilot study,[17] has emerged as an alternative treatment modality for patients with MIRCTs. Reconstruction of the superior capsule can stabilize the glenohumeral joint and muscle balance,[18] improve shoulder function, and relieve pain.[19] It has been validated that ASCR for MIRCTs leads to promising short-term clinical outcomes with low complications.[20-23] The previous systematic reviews[24-26] have evaluated the short-term clinical outcomes of ASCR only using the graft of fascia lata autograft (FLA) and human dermal allograft (HDA). However, there is still no consensus on the midterm or long-term therapeutic effectiveness of ASCR for MIRCTs, and whether ASCR using other kinds of graft leads to the similar clinical outcomes for MIRCTs remains unclear. The purposes of this study were to evaluate the clinical outcomes (with the minimum mean follow-up period of two years) of arthroscopic superior capsular reconstruction (ASCR) using different grafts for massive irreparable rotator cuff tears (MIRCTs) and to explore whether margin convergence in ASCR affects range of motion (ROM) outcomes. The authors hypothesize that ASCR still contributes to significant clinical improvements in patients with MIRCTs at follow-up after more than 2 years, and margin convergence in SCR affects the ROM postoperatively.

Methods

The systematic review was registered, and performed according to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) guidelines.

Search Strategy

A literature search was conducted using the online databases: MEDLINE, EMBASE, Web of Science, and the Cochrane Library database by two authors (both of whom are doctor of orthopaedic surgery, Y.J.W. and W.D.). The terms "superior capsular reconstruction" OR "superior capsule reconstruction" were applied to find all resources in these databases as comprehensively as possible. The inclusion criteria were as follows: 1) Clinical studies published in English language were considered for eligibility. 2) Case series or comparative studies reporting the clinical outcome (with the minimum mean follow-up period of two years) of ASCR by any type of graft were included. The exclusion criteria were as follows: 1) We excluded these studies that reported patients with reparable rotator cuff tears or those with obvious arthritis in the glenohumeral joint or serious infection of glenohumeral joint or fractures. 2) Any literature that studied the outcomes of non-arthroscopic SCR was excluded. 3) Comments, case reports, letters, animal studies, cadaveric biomechanical studies, review articles, technique articles, and studies with no abstract or no full article available were excluded. Any disputes of inclusion of studies were resolved by the senior professors (W.L.S. and S.H.D.).

Data Extraction and Analysis

Data were extracted according to the pre-established standardized forms. The preoperative and the final follow-up clinical measures were extracted, including visual analog scale (VAS), American Shoulder and Elbow Surgeons scale (ASES), Constant scores (CS), range of motion (ROM), acromiohumeral distance (AHD), and rate of complications. The information of margin convergence during SCR was also extracted.

A meta-analysis could not be conducted due to the heterogeneity of studies (derived from clinical heterogeneity and methodological heterogeneity). A narrative synthesis was conducted to handle all studies included. We calculated summary statistics of intervention effect estimates to identify the range and distribution of observed effects following the SWiM guideline[27] (The Synthesis Without Meta-analysis guideline) and chapter 12 of the second edition of the Cochrane Handbook for Systematic Reviews of Interventions. MCID is defined as the smallest difference in an outcome score that a patient perceives as beneficial.[28] In this study, the confidence intervals of changes between preoperation and final follow-up were compared with MCID to determine whether clinically meaningful improvements truly exist. The MCID threshold value of VAS (1.37) and ASES (11) were established by prior studies.[29,30] These data recorded postoperative VAS scores and ASES scores at two or more timepoints during the follow-up period were extracted and presented.

Methodological Assessment

The methodological qualities of studies were appraised by authors independently using the Methodological Index for nonrandomized studies scores (MINORS). The criteria included 12 items, with the highest scores of 24 points and 16 points for comparative study and noncomparative study, respectively.

Results

Search Results

Using the terms established previously, we found 717 records within the databases. Duplications (431 records) were initially eliminated by the software of Endnote X9. After the title and abstract review, 28 records were remaining. Then, we performed the full-text review, and 15 articles were finally included in the systematic review. Details of searches and reasons for exclusion were presented by a flowchart (Fig 1).

Characteristics and Demographics of Eligible Studies

Fifteen studies met the inclusion criteria, with a total of 555 patients being included (the number of patients of each study ranged from 5 to 193). Seven studies presented Level III evidence, while 8 studies presented Level IV evidence. The mean age of patients in 12 of 15 studies ranged from 56 to 69.1 years. All studies had the minimum mean follow-up period of 2 years, ranging from 24 to 43 months (Table 1).

With respect to the 15 articles included, 7 articles were reported for ASCR using autografts, of which 6 used fascia lata autograft (FLA), and 2 used long head of the biceps tendon (LHBT) (as one study[31] showed the results of both FLA and LHBT); 5 used human dermal allograft (HDA); 2 used porcine dermal xenograft (PDX), and 1 used the synthetic graft. 14 studies had reported the thickness of grafts. FLA was used by folding into 2-3 layers with the final thickness of 5-8 mm in 5 studies, and only 1 study[32] performed the ASCR with 1-layer FLA. All HDA and PDX presented in 7 studies were 3 mm thick. In a study of synthetic graft,[33] a comparison of clinical outcomes of ASCR was conducted between 1-layer and 3-layer grafts. In addition, one of these studies reported the clinical outcomes of ASCR using FLA and FLA with artificial mesh augmentation.[34] (The results of ASCR using FLA with artificial mesh augmentation were not extracted and analyzed in this review.) Margin convergences were performed during ASCR in 14 of 15 studies. Posterior margin convergences were reported in all 14 studies, while anterior margin convergences were reported in only 3 studies.

Methodology Evaluation of Included Studies

The methodology of included studies was evaluated by MINORS scores, ranging from 15 to 19 scores in 7 comparative studies, and ranged from 10 to 13 scores in 8 noncomparative studies (Table 2).

Standardized Pain and Functional Scales

The VAS, ASES, and CS scores were reported as outcome measures in 12, 13, and 4 studies, respectively. The ROM recording by active forward flexion/elevation, active abduction, and active external rotation was reported in 11, 4, and 8 studies, respectively. The mean improvements between preoperation and final follow-up were measured if data were available. Across all studies included, Kocaoglu et al.[31] compared the clinical outcomes of FLA with LHBT for ASCR. Therefore, the outcome measurements between the two treatments were extracted and managed separately.

All 11 studies[31-40] (13 items) recorded statistically significant improvements in VAS scores with the mean improvement score ranging from 2.07 to 7.1, $P < .001$ for all. The mean improvements of ASES scores reporting in 13[31-43] (15 items) of 15 studies ranged from 18.1 to 58 ($P < .05$ for all; Table 3). There were clinically significant improvements in both VAS scores and ASES scores by meeting the MCID threshold (Fig 2).[16] The mean improvements in CS scores ranged from 14.64 to 50.79 points in 4 studies[18,32,40,44] ($P < .05$ for all). One study by Mihata et al.[35] reported the Japanese Orthopedic Association score (JOA) with a mean improvement of 39.42 points ($P < .05$). Two of 15 studies recorded the simple shoulder test (SST) score with 4.6 and 7.47 ± 4.73 points improvement, respectively (both $P < .05$). 5 studies[36-39,43] described postoperative VAS scores and ASES score at two or more timepoints during the follow-up period, and the upward tendencies of these two measure outcomes are presented in Fig 3.

Range of Motion

As for the change of ROM at final follow-up, active forward flexion/elevation, active abduction, and active external rotation were characterized as clinical outcome measurements (Table 3). The mean improvements in active forward flexion/active elevation were reported in 11 studies[18,31-38,40,41] (13 items), with a range improvement of 12 to 73.68° (in two studies[32,33] $P > .05$, as for others, $P < .05$). 4 of 4 studies demonstrated significant improvements in active abduction, ranging from 19 to 89.21° ($P < .05$ for three studies,[18,36,41] $P > .05$ for one).[32] Eight studies (9 items) reported the active external rotation with mean improvements ranging from 1 to 24.74° ($P < .05$ for four studies,[18,31,35,37] while $P > .05$ for others).[32,34,40,41]

Radiological Outcome Measure

Mean change of postoperative AHD ranged from −0.86 to 3.2 mm in 9 studies.[31,32,34,36-39,42,44] The main outcome measures, from preoperation to final follow-up, are shown in Table 4.
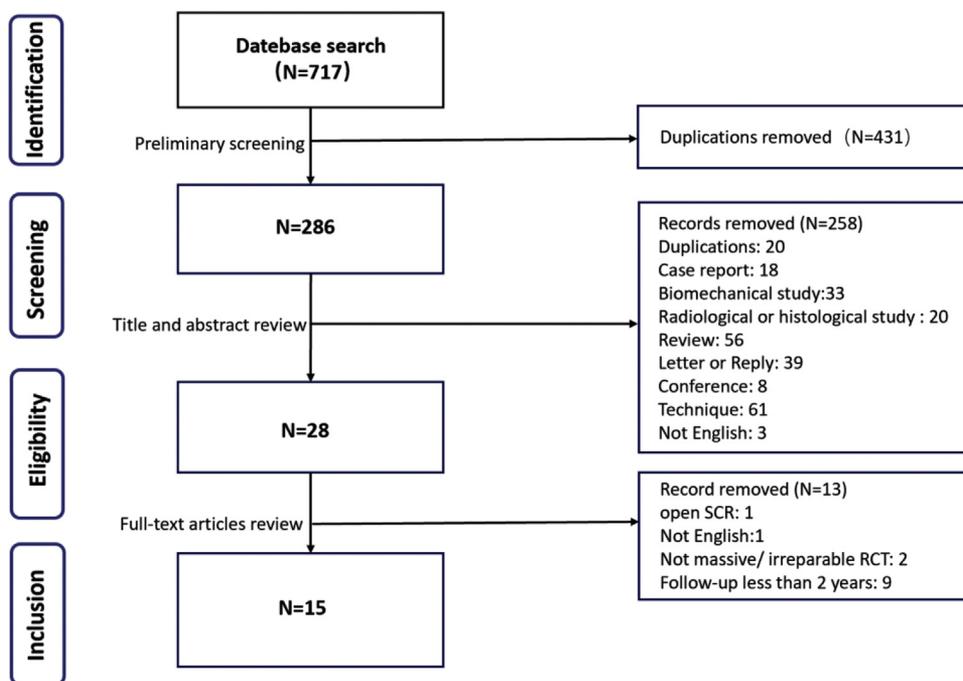
Complications

All studies had reported the postoperative complications of ASCR, with the complication rate ranging from 4.5% to 47.6%. These complications included graft failure, infection, severe shoulder stiffness, suture anchor pullout, donor site problem, progressed arthritis, subscapularis tendon retear, loss of function, and severe synovitis. Structural graft failure such as graft tears were diagnosed by postoperative magnetic resonance imaging (MRI) scans in 14 studies,[18,31,33-44] of which 10 studies,[18,34,36-39,41,42,44] described the locations of graft failures. The reoperation was showed in 11 studies,[18,33,35-39,41-44] and the reoperation rate ranged from 0 to 12.5%. Reported complications and reoperation are detailed in Table 4.

Discussion

It was determined from this systematic review that ASCR for MIRCTS leads to significant improvements in patient-reported clinical outcomes and range of motion at follow-up after more than 2 years.

ASCR for MIRCTs Leads to Significant Improvements in Patient-Reported Pain and Functional Scales

The MCID, defined as the smallest change in a clinical outcome, was used to evaluate whether there were significant improvements of symptoms in patients treated for rotator cuff disease. In the various studies included in this review, the improvements of ASES scores and VAS scores both exceeded the MCID, presenting clinically significant improvements following ASCR for MIRCTs. This result is similar to the improvement of clinical outcomes using RSA for MIRCTs from a previous study,[45] which reported that patients with MIRCTs showed a mean improvement of 4.7 and 42.8 points for VAS and ASES scores after treatment of RSA, respectively. Because of the heterogeneity among the studies, we can hardly draw any meaningful conclusion that ASCR leads to a better clinical outcome compared to other treatments for patients with MIRCT. Additionally, in the current study, it was noticed that the patient-reported ASES and VAS scores improved rapidly during the first year of postoperation. During the second year of postoperation, the outcomes of ASES and VAS remained stable and were maintained at relatively high levels. As a result, our study suggests that patients would have promising improvements of clinical outcomes of pain and functional scales at follow-up after more than 2 years.

ASCR for MIRCTs Leads to Improvements in ROM

In our systematic review, all studies presented statistically significant improvements in forward flexion/elevation and abduction except one study,[32] which was conducted between 2013 and 2015, with only 5 patients being enrolled in performing ASCR for MIRCTs. As such, the poor ROM results of those studies are probably attributable to the small sample size and sampling error. The range of active external rotation statistically improved postoperatively at final follow-up in only 5 of 9 studies, and the poor improvement of active external rotation was showed in the other four studies (3 using FLA and 1 using LHBT). In 2[32,34] of the

Table 1. Characteristics of Included Studies

Author (year)	Source of Graft	Graft thickness (mm)	Mean Age, year (range)	Sample Size, n (male/female)	Follow up, M/Y (range)	Margin convergence (with bursal tissue or rotator cuff tendon)
Kholinne et al. (2020)	FLA	at least 6	NR	34	31.3 ± 8.2, M	both posterior and anterior (bursal tissue)
Mihata et al. (2020)	FLA	6 to 8	68.6	193	3Y7M (2-11, Y)	posterior (infraspinatus or teres minor tendon)
Yoon et al. (2018)	FLA	1 layer	58.4	5 (5/0)	25.6 M	both posterior and anterior (infraspinatus, supraspinatus and subscapularis)
Takayama et al. (2020)	FLA	8 ± 1	69.1 ± 4.8	20 (11/9)	36.5M (24-66, M)	posterior (infraspinatus)
Azevedo et al. (2020)	FLA	5 to 8	65.21 ± 9.21	19 (71/2)	3 Y	posterior (infraspinatus)
Kocaoglu et al. (2020)	FLA	8	62.5 ± 6.5	12	32 M	posterior (infraspinatus)
	LHBT	NR	64.6 ± 8.4	14	28 M	NR
Barth et al. (2020)	LHBT	NR	60 ± 7 (47-81)	24 (16/8)	25 ± 2, M (24-29, M)	posterior (infraspinatus)
Pennington et al. (2018)	HDA	3 (2.75-3.25)	NR	38	2Y	both posterior and anterior (infraspinatus and subscapularis)
Lacheta et al. (2019)	HDA	3	56 (41-65)	22	2.1Y (2-3, Y)	both posterior and anterior (infraspinatus and subscapularis)
Burkhart et al. (2019)	HDA	3	64 ± 1.4 (39-78)	41 (33/8)	34 M (24-50, M)	posterior (rotator cuff) tendon, anterior (bursal tissue)
Pashuck et al. (2020)	HDA	3	58.9 ± 11	14 (12/2)	2.1 Y	posterior (rotator cuff tendon)
Hirahara et al. (2017)	HDA	3	61.33 (47-78)	8 (6/2)	32.38 M (25-39, M)	posterior (rotator cuff tendon); Anterior in 3 cases (rotator cuff tendon)
Greiner et al. (2021)	PDX	3	62.1 (47-77)	20 (16/4)	25.7 M (24-30, M)	posterior (rotator cuff tendon)
Ferrando et al. (2020)	PDX	3	65 ± 9	56 (39/17)	34 ± 8, M	posterior (infraspinatus or teres minor)
Okamura et al. (2020)	TFSG	2.9 †	75.1 (63-88) †	15 †	42M †‡	NR
		8.7 ‡	76.6 (61-90) ‡	20 ‡	42M †‡	

FLA, fascia lata autograft; LHBT, long head of the biceps tendon; HDA, human dermal allograft; LOE, level of evidence; MINORS, methodological index for non-randomized studies scores; M, month; NR, not reported; PDX, porcine dermal xenograft; TFSG, Teflon felt synthetic graft; Y, year.

†ASCR using 1-layer graft.
‡ASCR using 3-layer graft.
†‡the result was calculated from patients using 1-layer graft and 3-layer graft.

Table 2. MINORS Scores of Included Studies

	Kholinne (2020)	Mihata et al. (2020)	Yoon et al. (2018)	Takayama et al. (2020)	Azevedo et al. (2020)	Kocaoglu et al. (2020)	Barth et al. (2020)	Pennington et al. (2018)
A clearly stated aim	2	2	2	2	2	2	2	2
Inclusion of consecutive patients	2	2	2	2	2	2	2	2
Prospective collection of data	2	2	2	2	2	2	2	2
Endpoints appropriate to the aim of the study	2	2	2	2	2	2	2	2
Unbiased assessment of the study endpoint	1	0	0	0	1	2	1	1
Follow-up period appropriate to the aim of the study	2	2	1	2	2	1	2	1
Loss to follow-up less than 5%	1	2	2	2	1	1	2	2
Prospective calculation of the study size	0	0	0	0	0	0	0	0
Additional Criteria in the Case of Comparative Studies								
An adequate control group	2	2	N/A	2	N/A	1	1	N/A
Contemporary groups	1	2	N/A	1	N/A	1	1	N/A
Baseline equivalence of groups	2	1	N/A	2	N/A	2	1	N/A
Adequate statistical analyses	2	2	N/A	2	N/A	2	2	N/A
Total score	19	19	11	19	12	18	18	12

	Lacheta et al. (2019)	Burkhart et al. (2019)	Pashuck et al. (2020)	Hirahara et al. (2017)	Greiner et al. (2021)	Ferrando et al. (2020)	Okamura et al. (2020)
A clearly stated aim	2	2	2	1	2	2	2
Inclusion of consecutive patients	2	1	2	1	1	2	2
Prospective collection of data	2	2	2	2	2	2	2
Endpoints appropriate to the aim of the study	2	2	2	2	1	2	2
Unbiased assessment of the study endpoint	0	0	1	0	0	0	0
Follow-up period appropriate to the aim of the study	2	2	2	2	2	2	2
Loss to follow up less than 5%	2	2	2	2	2	2	2
Prospective calculation of the study size	0	0	0	0	0	0	0
Additional Criteria in the Case of Comparative Studies							
An adequate control group	N/A	N/A	N/A	N/A	1	N/A	1
Contemporary groups	N/A	N/A	N/A	N/A	1	N/A	1
Baseline equivalence of groups	N/A	N/A	N/A	N/A	1	N/A	2
Adequate statistical analyses	N/A	N/A	N/A	N/A	2	N/A	2
Total score	12	11	13	10	15	12	18

MINOR scores: 0 (not reported), 1 (reported but inadequate) and 2 (reported and adequate). There are 12 items with a total score of 24 for comparative studies, and 8 items with a total score of 16 for noncomparative studies.
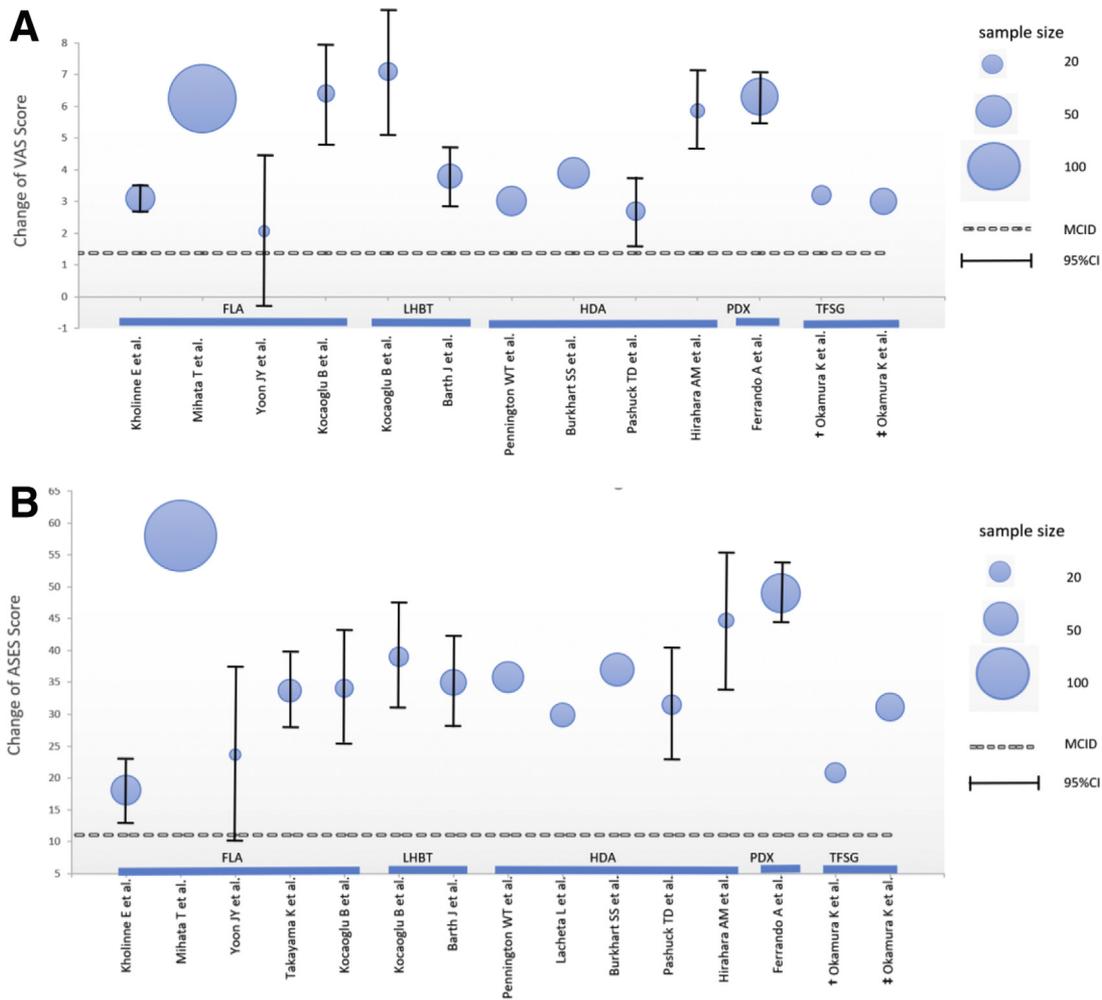
Fig 2. Bubble-forest plots of mean changes and 95% confidence intervals of outcome measures (VAS and ASES score) from preoperative to last follow-up for each study. The sample size is directly proportional to the size of the bubble. †, ASCR using 1-layer graft; ‡; ASCR using 3-layer graft. ASES, American Shoulder and Elbow Surgeons scale; ASCR, arthroscopic superior capsular reconstruction; CI, confidence interval; FLA, fascia lata autograft; HDA, human dermal allograft; LHBT, long head of the biceps tendon; MCID, minimal clinically important difference; PDX, porcine dermal xenograft; PR, partial repair; RSA, reverse shoulder arthroplasty; TFSG, Teflon felt synthetic graft; VAS, visual analog scale.

3 studies that used FLA as the graft, anterior margin convergence with bursal tissue or rotator cuff tendon was performed in the procedure of ASCR, which may restrict the range of external rotation. The poor improvement another FLA study reporting may result from the relatively good preoperative active external rotation (mean preoperative active external rotation: 45°). This result is similar with the previous biomechanical cadaveric studies.[46,47] Mihata et al. indicated that the addition of anterior side-to-side suturing did not change superior translation and cubacromial contact pressure during SCR using FLA, leading to the postoperative shoulder stiffness by closing the rotator interval. While in another HDA graft study,[37] a statistical improvement was presented even though the anterior margin convergence was underwent ([Fig 4]). This may result from the elongation of the dermal graft

that occurs with shoulder ROM.[46] Overall, the decision of performing anterior margin convergence should be made prudently especially in ASCR using FLA. More further comparative studies need to be performed to investigate whether margin convergence should be included when performing a standard ASCR, as well as the role of bursal tissue and rotator cuff tendon in this technique.

ASCR Leads to Significant Improvements in AHD in Patients With MIRCTs

AHD has been applied to evaluate the degree of glenohumeral osteoarthritis and the balance of the rotator cuff force couples, and it is also used as a prognostic radiographic marker following rotator cuff surgery.[48] In a shoulder with MIRCT, the humeral head would be pulled superiorly by the deltoid, leading to the
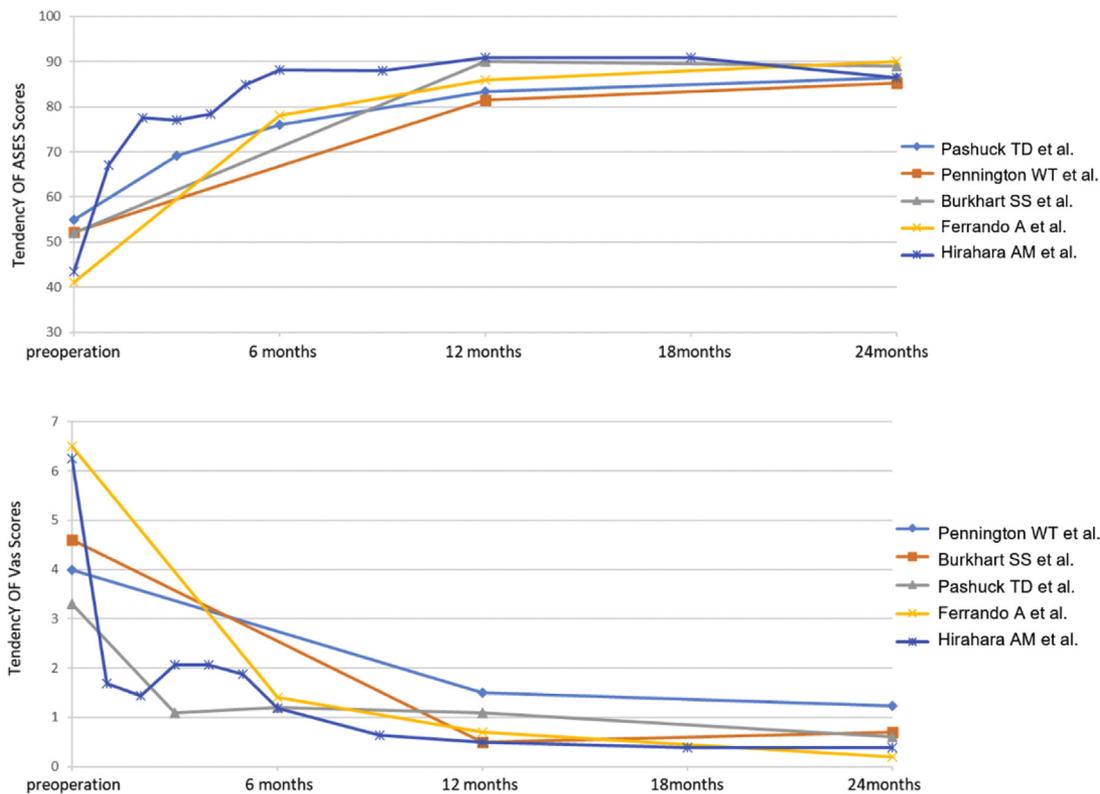
Fig 3. The broken line graphs demonstrate the tendencies of ASES and VAS scores after ASCR.

reduction of AHD, and even bone-to-bone contact between the bare tuberosity with the acromion. By contrast, in a shoulder with MIRCT using ASCR, the reconstructed superior capsule maintains the superior stability of the shoulder joint restricting humeral head in the rotator center, and avoiding the pain generated by acromion impingement. A recent study[49] reported that AHD had increased 2.2 mm postoperatively at 1-year follow up, which was significantly higher than in a current study (mean improvement of AHD: 2.2 versus 1.7 mm, $P < .05$). Lee et al.[50] demonstrated that humeral head superior translation was detected between 6 months and 12 months after ASCR for MIRCTs. As such, the authors speculate that AHD may decrease over time postoperatively. In addition, a previous cadaveric biomechanical study[47] has suggested that repair of the ASCR graft with posterior or anterior rotator cuff tissue could increase the AHD postoperatively by decreasing the glenohumeral superior translation. (Fig 5) Furthermore, posterior or anterior margin convergence may increase the survival rate of graft by accelerating the vascularization,[51] which reinforced the structural strength of the graft as well.

Complications

The previous studies[52,53] had reported the postoperative complication rate of ASCR with 25% and 29%, and the average follow-up was 12 months after surgery for both studies. In this review, the overall complication rate ranged from 4.5% to 47.6%. For reason of heterogeneity among studies, the infeasibility of complication rate pooling made it difficult to compare the results of the current review with that of previous studies. Notably, among the included studies in this review, postoperative MRI was not routinely performed in each study, which reminded us that the actual complication rate of ASCR for MIRCTs might be higher than the value presented by this review.

The "Biologic Tuberoplasty Effect" Improves Postoperative Satisfaction of Patients

Interestingly, several studies[18,35,37,39,42] included in this review demonstrateed that some patients who suffered graft tears postoperatively also presented good clinical outcomes and were satisfied with previous surgery of ASCR so that they did not require additional treatment. Lacheta et al.[42] determined that the absence of healing was not reflected in the clinical outcome scores in specific situations, while the graft was still covering over the tuberosity, which was defined as type 2 graft retear.[53] The possible reasons of this phenomenon may be the persistent spacer effect of the graft between the humeral head and acromion, which was first described as the "Biologic Tuberoplasty Effect" by Mirzayan et al.[54] (Fig 6B). As the pain in shoulders with MIRCTs is partially due to bone-to-bone contact

Table 3. Summary of Clinical Outcome

Author (year)	Source of Graft	VAS Pre / Post	ASES Pre / Post	CS Pre / Post	Forward Flexion or Elevation Pre / Post, deg	Abduction Pre / Post, deg	External Rotation Pre / Post, deg
Kholinne et al. (2020)	FLA	6.0 ± 1.1 / 2.9 ± 0.8	54.4 ± 17.2 / 73.7 ± 13.8	NR	103 ± 20 / 129 ± 27	NR	26 ± 16 / 32 ± 12a
Mihata et al. (2020)	FLA	6.92 / 0.68	35.38 / 93.38	NR	94.92 / 153.49	NR	26.75 / 42.07
Yoon et al. (2018)	FLA	3.34 / 1.27	63.33 / 87	61 / 75.64	154 / 166a	152 / 171a	31 / 36a
Takayama et al. (2020)	FLA	NR	52.4 ± 12.6 / 86.1 ± 13.8	NR	101 ± 45 / 146 ± 35	96 ± 43 / 141 ± 39	45 ± 24 / 47 ± 20a
Azevedo et al. (2020)	FLA	NR	NR	18.84 / 69.63	77.63 / 151.32	54.47 / 143.68	13.95 / 38.68
Kocaoglu et al. (2020)	FLA	8.0 ± 2.5 / 1.6 ± 2.4	48.5 ± 15.5 / 82.6 ± 15.0	NR	136.2 ± 24.4 / 160.0 ± 14.5	NR	38.0 ± 15.0 / 50.3 ± 23.4
	LHBT	8.5±3.5 / 1.4±0.8	46.2 ± 16.2 / 85.2 ± 12.4	NR	135.0 ± 15.5 / 162.5 ± 32.0	NR	35.0 ± 1.0 / 52.8 ± 25.0
Barth et al. (2020)	LHBT	5.2 ± 2 (2-9) / 1.4 ± 1.4 (0-5)	45 ± 19 (13-75) / 80 ± 15 (35-97)	50 ± 13 (25-73) / 77 ± 10 (48-87)	143 ± 33 (70-180) / 165 ± 16 (125-180)	NR	49 ± 16 (0-80) / 50 ± 16 (15-80)a
Pennington et al. (2018)	had	4.26 / 1.24	49.5 / 85.3	NR	123 / 162	106 / 160	NR
Lacheta et al. (2019)	HDA	Medians 4 / 0	54.0 / 83.9	NR	NR	NR	NR
Burkhart et al. (2019)	HDA	4.6 / 0.7	52 / 89	NR	140 [120-159] / 167 [159-176]	NR	37[29-44] / 59[51-67]
Pashuck et al. (2020)	HDA	3.3 ± 2 / 0.6 ± 1	55 ± 17 / 86.5 ± 9	NR	128 ± 36 / 172 ± 4	NR	NR
Hirahara et al. (2017)	HDA	6.25 ± 1.56 / 0.38 ± 1.06	41.75 ± 12.71 / 86.50 ± 12.66	NR	NR	NR	NR
Greiner et al. (2021)	PDX	NR	NR	49.7 / 77.1 ± 10.5	NR	NR	NR
Ferrando et al. (2020)	PDX	6.5 ± 2.1 / 0.2 ± 0.4	41 ± 19 / 90 ± 9	NR	NR	NR	NR
Okamura et al. (2020)	TFSG	3.9 / 0.7† 5.2 / 2.2‡	42.4 / 63.2† 40.3 / 71.4‡	NR	76 / 107† 79 / 142‡	NR	NR

ASES, American Shoulder and Elbow Surgeons scale; CS, Constant scores; deg, degree; FLA, fascia lata autograft; LHBT, long head of the biceps tendon; Post, postoperation; Pre, pre-operation; NR, not reported; HDA, human dermal allograft; PDX, porcine dermal xenograft; NR, not reported; TFSG, Teflon felt synthetic graft; VAS, visual analog scale. Data are shown as means ± SD (range) unless otherwise indicated.

†ASCR using 1-layer graft.
‡ASCR using 3-layer graft.
aThere is no statistically significant change between preoperation and postoperation.

Table 4. Summary of Complications and Radiographic Evaluation

Author (year)	Graft	AHD (mm) Pre / Post	Complications P, N/Total (Details)	TS	Midsubstance	GS	Posterior	Reoperation P, N/Total (Details)
Kholinne et al. (2020)	FLA	4.0 ± 0.7 / 6.3 ± 1.8	41.2%, 14/34 (14 graft failure)	7	3	4		NR
Mihata et al. (2020)	FLA	NR	11.9%, 23/193 (9 graft failure; 6 infection; 3 severe shoulder stiffness; 3 suture anchor pullout; 2 harvest site discomfort)					4.1%, 8/193 (1 RSA)
Yoon et al. (2018)	FLA	5.11 / 4.25	20.0%, 1/5 (0 graft failure; 1 patient progressed arthritis)					NR
Takayama et al. (2020)	FLA	NR	20.0%, 4/20 (2 graft failure; 1 subscapularis tendon retear; 1 swelling at donor site)	1			1	5.0%, 1/20(1 RSA)
Azevedo et al. (2020)	FLA	NR	28.6%, 6/21# (4 graft failure; 1 donor site problem, 1 infection)		4			9.5%, 2/21#
Kocaoglu et al. (2020)	FLA	7.8 ± 2.8 / 9.3 ± 3.0	16.7%, 2/12 (2 graft failure)					
	LHBT	7.0 ± 1.5 / 10.2 ± 2.5	21.4%, 3/14 (3 graft failure)					
Barth et al. (2020)	LHBT	NR	8.3%, 2/24 (2 graft failure)					
Pennington et al. (2018)	HDA	7.3 / 9.9	4.5%, 4/88※ (4 graft failure)	2				1.1%, 1/88※ (1 RSA)
Lacheta et al. (2019)	HDA	7.0 / 8.3	47.6%, 10/21 (9 graft failure; 1 loss of function)	0	5	4		4.8%, 1/21
Burkhart et al. (2019)	HDA	7 ± 0.4 / 8 ± 0.4	7.3%, 3/41 (3 graft tear)	1				7.3%, 3/41(1 RSA)
Pashuck et al. (2020)	HDA	6 ± 2 / 6.7 ± 2	14.3%, 2/14 (2 graft failure)			1		7.1%, 1/14 (1 RSA)
Hirahara et al. (2017)	HDA	4.50±2.25 / 7.70 ± 2.08	25%, 2/8 (2 graft failure)		1	1		12.5%, 1/8
Greiner et al. (2021)	PDX	7.1 ± 2.1 / 7.8 ± 2.7	5.0%, 1/20 (1 graft failure)	1				5.0%, 1/20
Ferrando et al. (2020)	PDX	NR	25.0%, 14/56 (14 graft failure)	14				7.1%, 4/56 (4 RSA)
Okamura et al. (2020)	TFSG	NR	20.0%, 3/15 (2 graft failure;1 severe synovitis) †0%, 0/20‡					6.7%, 1/15†; 0%, 0/20‡

AHD, acromiohumeral distance; N, number; P, percentage (%); Pre, preoperation; Post, postoperation at final follow-up; TS, tuberosity side; GS, glenoid side; NR, not reported; RSA, reverse shoulder arthroplasty. Columns with no data denote not reporting in studies or no data available in details.

#We included a patient with early complication of infection who had not participated in the final clinical or radiological assessments.

※These patients with 1-year follow-up were also included for calculating the rate of postoperative complication of ASCR comprehensively.

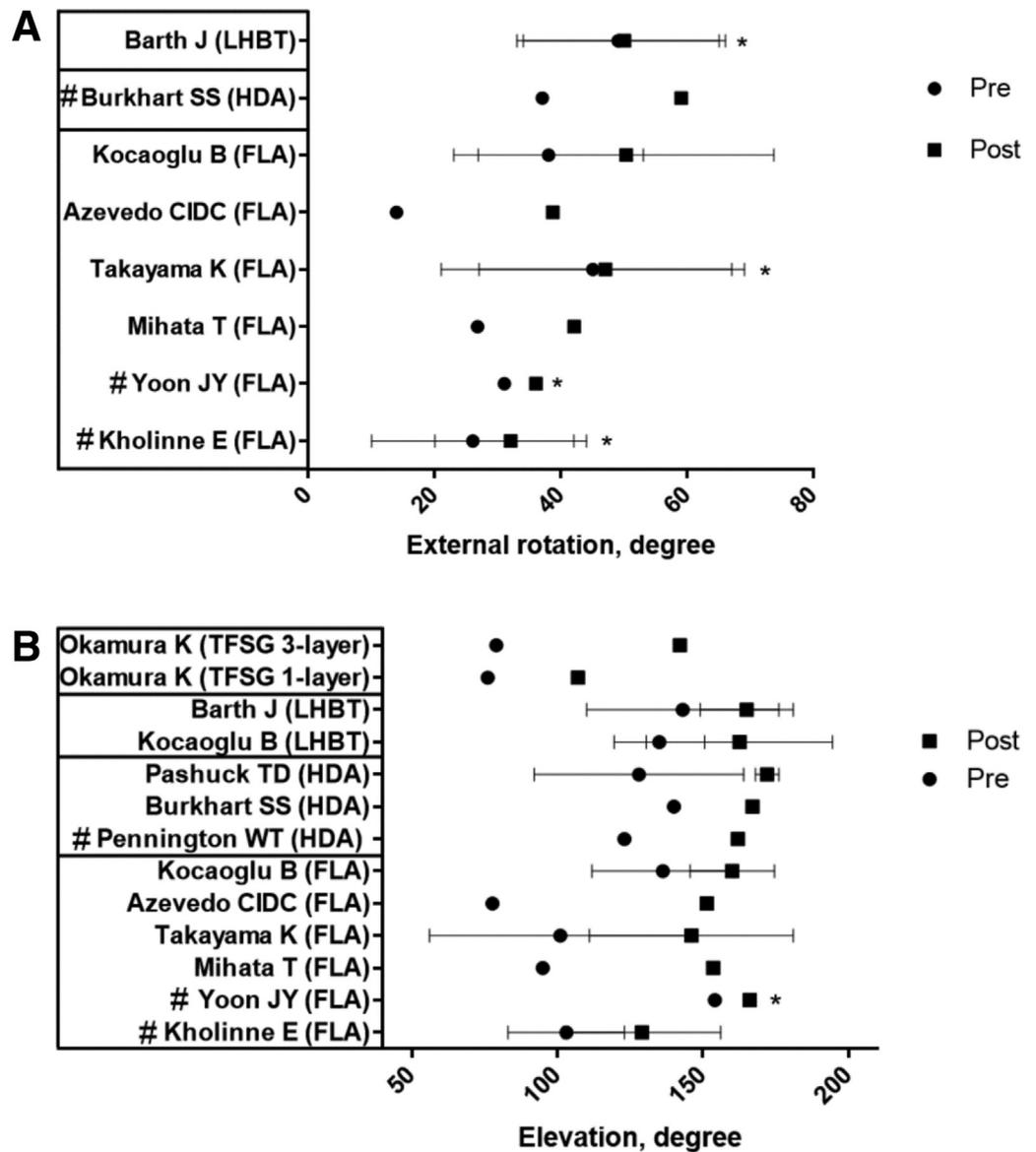†ASCR using 1-layer graft.

‡ASCR using 3-layer graft.

Fig 4. Forest plot describing preoperation and postoperation ROM, which is presented as means ± SD (if available). FLA, fascia lata autograft; HDA, human dermal allograft; LHBT, long head of the biceps tendon; Post, postoperation; Pre, preoperation; ROM, range of motion; TFSG, Teflon felt synthetic graft. *Indicates there are no statistically significant improvements between preoperation and postoperation. #Indicates anterior margin convergence was performed.

between the tuberosity and acromion, coverage of the tuberosity with an intact graft or a graft that is torn in a way that the tuberosity remains covered will act as an interpositional tissue like a spacer, preventing acromion impingement and leading to clinical improvement.[54] In our study, most graft failures occurred at the greater tuberosity of the humerus attachment site, and this result was in accordance with previously reported studies.[36,53,55] In this scenario, a firm fixation of graft-bone at the tuberosity side is of great importance during the ASCR procedure.

Which Type of Graft Is Recommended in ASCR?

Because of the heterogeneity of the included studies, this current review can hardly recommend either for or against one graft type over another for the ASCR

procedure. The most commonly used grafts for ASCR reported previously were FLA and HDA. FLA has advantages such as the stability of graft origin, leading to a good clinical outcome and economic efficiency. However, donor-site complications can be the main reason limiting the wide application of FLA.[36,42] On the contrary, ASCR using HDA avoids donor-site morbidity,[21] reduces the duration of operation, but increases the economic burden to the patients because of the high cost of had.[33] The xenograft and artificial graft for ASCR in our study showed promising patient-reported outcomes, with the rates of complications ranging from 5% to 25%. Among these articles that studied the xenograft and artificial graft, no immune reaction had been reported, which showed the biocompatibility of these graft types. Therefore, our study suggested that
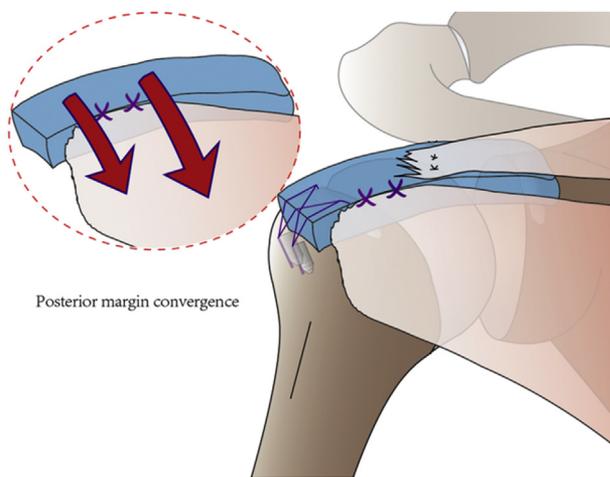
Fig 5. Posterior margin convergence may increase the postoperative acromiohumeral distance (AHD) postoperatively by decreasing the glenohumeral superior translation.

xenografts and artificial grafts are alternative patches for ASCR when commercial human dermal allograft is not available in some countries.

Recently, "The Chinese way", first reported by Boutsiadis et al.[43,56] in 2017, has emerged as an effective method to reconstruct the superior capsule, in which the long head of the biceps was used as a local tissue autograft instead of FLA or HDA. Several advantages of this technique over the traditional ASCR are the lower costs, the lower donor-site morbidity compared to other autografts, and the potential decrease of infection rates due to the shorter operative time.[57,58] However, this technique was not suitable in patients who developed MIRCTs with ruptured or severely degenerated LHBT.[31] Owing to the novelty of

the technique, only 2 articles[31,40] that described the clinical outcomes of ASCR using LHBT for MIRCTs with follow-ups after a minimum of 2 years were included. This may limit the validity of the conclusions. Further studies should be conducted to evaluate the long-term efficacy of ASCR with LHBT for MIRCTs.

How to Choose Graft Thickness in ASCR?

Graft thickness may play an important role in clinical success following ASCR with different graft types. A previous anatomic cadaveric study demonstrated that the thickness of the superior shoulder capsule was 4.4 to 9.1 mm at the attachment of greater tuberosity.[59] In the current review, the common thickness of FLA was 5 to 8 mm by folding two or three times (in 5 of 6 studies), with only one study using one-layer FLA to reconstruct the superior capsule. As for HDA, all 5 included studies used the 3-mm thickness HDA for ASCR. A previous biomechanical study[60] showed that an 8-mm-thick FLA graft had greater stability than a 4-mm-thick FLA graft, and superior humerus translation significantly decreased when an 8-mm-thick graft was used. Similarly, Scheiderer et al.[61] reported that ASCR with a 6-mm-thick acellular dermal allograft better restored normal glenohumeral joint position and forces, as compared with a 3-mm-thick graft for the treatment of irreparable rotator cuff tears. To sum up, a thicker graft may better increase the superior stability, restricting superior translation of humeral head (Fig 6). However, because of the limited number of comparative studies, it is difficult for us to conclude that a thicker graft is recommended for ASCR. In the future, more comparative randomized controlled trials are necessary to determine the appropriate thickness of grafts for ASCR.
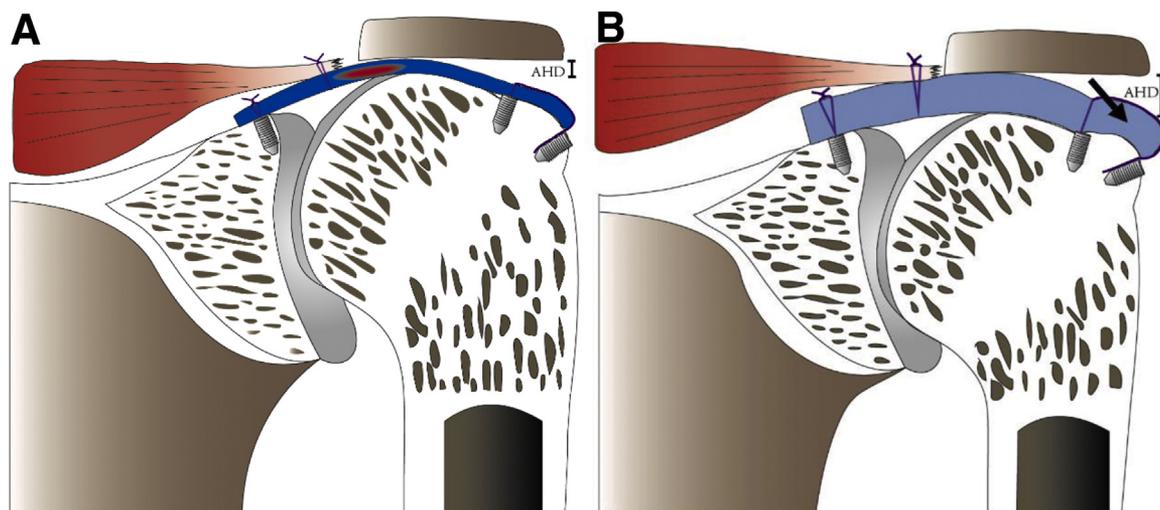

Fig 6. A thicker graft may better to restore the balance of force couple, and decrease superior humerus translation. The "Biologic Tuberoplasty Effect" (black arrow). The great tuberosity is covered by the graft, which acts as a spacer, avoiding the pain generated by acromion impingement.

Limitations

There are some limitations to this systematic review. First, studies included in the current review showed relatively low levels of evidence, including eight studies with Level IV evidence and seven studies with Level III. In addition, most articles included were non-comparative studies. As such, we cannot definitely compare the clinical effects of ASCR with other surgical techniques that are commonly performed. Owing to the discrepancy of surgical procedures and postoperative rehabilitation, heterogeneity among studies make comparisons difficult.

Conclusions

ASCR contributes to significant improvements in patient-reported clinical outcomes and ROM at follow-up after a mean of more than two years, emerging as a viable option for patients with MIRCTs. The anterior margin convergence should be prudently chosen especially in ASCR using FLA, on account of the probable restriction on postoperative active external rotation.

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