Outcomes After Arthroscopic Rotator Cuff Repair Using Margin Convergence Versus Superior Capsular Reconstruction

Should Candidates for Margin Convergence Be Treated With Superior Capsular Reconstruction?

Michael Ciccotti,*† MD, Marilee P. Horan,* MPH, Philip-C. Nolte,*‡ MD, MA, Bryant P. Elrick,* MD, MS, and Peter J. Millett,†§ MD, MSc

Investigation performed at the Steadman Philippon Research Institute, Vail, Colorado, USA

Background: Both margin convergence rotator cuff repair (MC-RCR) and superior capsular reconstruction (SCR) result in improved clinical outcomes in the treatment of massive rotator cuff tears (RCTs). The question remains whether it is better to perform MC-RCR using native, albeit occasionally deficient, tissues or to perform primary SCR.

Purpose/Hypothesis: To compare the clinical results of MC-RCR versus SCR for the treatment of massive RCTs. It was hypothesized that SCR would yield better outcomes.

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

Methods: Included were patients who underwent arthroscopic MC-RCR or SCR for massive RCTs performed by a single surgeon between 2014 and 2019. MC-RCR was performed if it was technically possible to close the defect; otherwise, SCR was performed. Outcomes were assessed at 6 months and then annually using American Shoulder and Elbow Surgeons; Single Assessment Numerical Evaluation; shortened version of Disabilities of the Arm, Shoulder and Hand; 12-Item Short Form Health Survey Physical Component Summary; and patient satisfaction scores. The minimal clinically important difference (MCID), substantial clinical benefit (SCB), and Patient Acceptable Symptom State (PASS) were compared between groups. Revision surgeries and complications were reported.

Results: Included were 46 patients in the MC-RCR group (mean age, 59 ± 8 years) and 46 patients in the SCR group (mean age, 57 ± 7 years); 29 patients in each group were available at 2-year follow-up. Preoperative outcome scores were not significantly different between groups. Within groups, all outcome scores improved from pre- to postoperatively ($P < .05$), with no significant differences in postoperative scores or patient satisfaction between groups. No significant between-group differences were noted in the percentage of patients who reached the MCID, SCB, and PASS (MCID, 92.3% vs 84.6%; SCB, 80.8% vs 80.8%; and PASS, 66.7% vs 66.7%). SCR had a significantly lower survivorship rate compared with MC-RCR (84.7% vs 100%) ($P = .026$).

Conclusion: Both MC-RCR and SCR provided similar improvement in outcomes; however, SCR resulted in a significantly lower survivorship rate at 2 years postoperatively. If an RCT is technically repairable, we recommend that it be repaired primarily, even if MC techniques are needed to close the defect. SCR remains a good option for massive RCTs that are not technically repairable.

Keywords: margin convergence; rotator cuff repair; rotator cuff tear; superior capsular reconstruction

Rotator cuff tears (RCTs) are extremely common, with estimated prevalence as high as 25% in patients in the seventh decade of life and >50% by the ninth decade of life.[50] Prior studies have demonstrated that these tears progress in size even in asymptomatic patients, with larger tears progressing more quickly and correlating with increasing shoulder pain and dysfunction.[23,31,43] With many tears progressing in both size and symptoms over time, massive RCTs are estimated to comprise up to 40% of all RCTs.[3] Despite the improved visualization, pattern recognition, and mobilization afforded by modern arthroscopic techniques, large to massive RCTs remain technically difficult to manage as a result of retraction, scarring, and atrophy.[5,29,51,52] Longitudinal tear patterns such as U-shaped

The Orthopaedic Journal of Sports Medicine, 9(11), 23259671211050624
DOI: 10.1177/23259671211050624

tears pose a particular technical challenge because of the high strain that develops with attempted anatomic repair, putting the repair at risk of failure.[6,15,19,51] Numerous management strategies have been proposed for massive RCTs, including nonoperative management, debridement and biceps tenodesis/tenotomy, partial repair, medialized repair, tendon transfer, and reverse total shoulder arthroplasty (RTSA).[||]

Although McLaughlin first described side-to-side sutures to assist with repair of U-shaped tears in 1944, Burkhart popularized "margin convergence" (MC) in the 1990s.[4,33] A number of cadaveric biomechanical studies have demonstrated that MC techniques can allow surgeons to overcome the high strain of reducing massive, U-shaped RCTs.[4,20,32] This technique allows some U-shaped massive tears to be repaired in circumstances in which anatomic reduction of the tendons to the tuberosity would otherwise be technically impossible or generate such strain as to invite failure. Rotator cuff repair using MC (MC-RCR) has demonstrated improved postoperative outcomes and benefit while maintaining the patient's native tissue.[2,5,24] More recently, Mihata et al[36,37] introduced superior capsular reconstruction (SCR) using fascia lata autograft, and their technique has been further modified for the use of dermal allograft (DA) for the management of massive RCTs.[1,40] A number of studies have demonstrated good to excellent short- and midterm clinical and radiographic results with SCR.[12,26,40] Candidates for anatomic RCR using MC or SCR have substantial overlap, and to our knowledge, no previous study has directly compared the outcomes of the 2 procedures.

The purpose of this study was to compare the clinical results of MC-RCR and SCR for the treatment of massive RCTs. Given the good to excellent early results achieved with SCR, we hypothesized that SCR would yield better clinical outcomes.

METHODS

All patients with massive RCTs who underwent RCR using MC-RCR or SCR using a DA performed by a single surgeon (P.J.M.) between 2014 and 2019 were included. Massive RCT was defined as a tear involving $\geq$2 tendons of the posterosuperior rotator cuff as documented in the operative report. Preoperative diagnosis of RCT was made via clinical examination and magnetic resonance imaging (MRI) with attention to tendon retraction, muscle atrophy, and fatty infiltration (Goutallier/Fuchs classification).[14,17] Surgery was indicated through joint decision making with the patient to treat persistent pain, loss of strength, and impaired function of the affected arm. Preoperatively, all patients provided informed consent to undergo either RCR or SCR depending on the technical repairability of their tear as assessed intraoperatively. Tear patterns and technical reparability of the RCT were confirmed at the time of diagnostic arthroscopy. Concomitant subscapularis pathology was not an absolute contraindication to either treatment, and subscapularis tendon repair was performed in conjunction with treatment of the posterosuperior cuff pathology when indicated. MC-RCR was performed if the tear was a technically repairable U-shaped tear, and SCR using DA was performed if it was not technically repairable. Patients in whom MC or MC to bone was utilized to assist in the repair of L-shaped and reverse L-shaped tears were excluded.

Surgical Technique

All surgeries were performed by a single surgeon utilizing uniform technique for both procedures being studied. In all cases, after standard posterior and anterosuperior portals were established, diagnostic arthroscopy including evaluation of the RCT was performed, and repairability or irreparability was confirmed. If necessary, the subscapularis tendon was repaired using $\geq$1 knotless suture anchors (4.75-mm SwiveLock; Arthrex). Subscapularis repair was performed in both groups when indicated and did not by itself determine treatment of the posterosuperior RCT. All patients ended up with effective treatment of the long head of the biceps tendon. Patients either underwent biceps tenodesis at the time of SCR or MC-RCR or did not require further treatment of the biceps because (1) it was previously tenodesed or tenotomized at an earlier surgery or (2) it was found to be ruptured at the time of SCR or MC-RCR and was asymptomatic, thus not requiring further treatment. If biceps tenodesis was performed at the time of MC-RCR or SCR, an intra-articular biceps tenotomy and later mini-open subpectoral biceps tenodesis using a 7-mm (female patient) or 8-mm (male patient) interference screw (Arthrex) was performed. The presence or absence of these concomitant procedures was noted for each patient.

[||]References 8, 9, 12, 16, 21, 25, 26, 30, 36, 39, 40, 42, 44, 47, 49.

[§]Address correspondence to Peter J. Millett, MD, MSc, Steadman Philippon Research Institute, The Steadman Clinic, 181 West Meadow Drive, Suite 400, Vail, CO 81657, USA (email: drmillett@thesteadmanclinic.com).

*Steadman Philippon Research Institute, Vail, Colorado, USA.

[†]The Steadman Clinic, Vail, Colorado, USA.

[‡]Clinic for Trauma and Orthopaedic Surgery, BG Trauma Center Ludwigshafen, Ludwigshafen, Germany.

Final revision submitted June 14, 2021; accepted June 29, 2021.

One or more of the authors has declared the following potential conflict of interest or source of funding: This work was partially funded directly by a grant from Arthrex. M.C. has received education support from Liberty Surgical. P.-C.N.'s position at the Steadman Philippon Research Institute was supported by AGA, via Arthrex, for 1 calendar year. P.J.M. has received research support from Arthrex, Ossur, Siemens, and Smith & Nephew; consulting fees from Arthrex; royalties from Arthrex, Medbridge, and Springer; and hospitality payments from Merz Pharmaceuticals, Arthrosurface, Stryker, and Sanofi-Aventis and has stock/stock options in VuMedi. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from Vail Valley Hospital (protocol No. 2019-48).

If the tear was determined to be a technically repairable U-shaped tear, MC-RCR was performed. Soft tissue releases were performed anteriorly, superiorly, and inferiorly to optimize tendon mobility as necessary. A suture-passing device was utilized to pass No. 2 FiberWire sutures (Arthrex) in an MC fashion from medial to lateral to effectively convert the U-shaped tear to a crescent tear. The MC sutures were not tied immediately so as not to obscure the articular margin at the edge of the rotator cuff footprint. After medial-row suture anchors were placed along this articular margin, MC sutures were tied sequentially from medial to lateral. The number of MC sutures utilized in each repair was noted. We then proceeded with our standard technique for double-row anatomic RCR to the footprint.

If the tear was deemed technically irreparable on diagnostic arthroscopy, SCR was performed. A motorized rasp was utilized to prepare the bony surfaces of the greater tuberosity and the superior glenoid. The superior labrum was preserved if it remained in good condition; otherwise, it was debrided. An arthroscopic measuring device was then used to determine the dimensions of the DA in both the anteroposterior (AP) and the mediolateral directions. A 3 mm–thick human acellular DA was sized to incorporate 7- to 8-mm coverage medially on the superior glenoid and 15- to 18-mm coverage laterally over the anatomic rotator cuff footprint on the greater tuberosity.

The first superior glenoid anchor (3.0-mm SutureTak; Arthrex) was inserted at the 12-o'clock position using a Neviaser portal with care to avoid violating the articular surface of the glenoid face. The sutures from this anchor were shuttled through the anterolateral portal and stitched through the middle and medial aspect of the graft while it remained outside the shoulder joint. Two additional sutures were placed on the anterolateral and posterolateral aspects of the graft. The graft was then shuttled into the shoulder through the anterolateral portal assisted by an arthroscopic knot pusher. After appropriately unfolding and orienting the graft, the surgeon tied the first glenoid anchor to secure the graft in place while achieving additional fixation with additional suture anchors (3.0-mm SutureTak) placed at the 10-o'clock and the 2-o'clock positions. The sutures from these anchors were passed through the medial edge of the graft and tied to complete fixation of the graft on the glenoid side.

Next, the lateral fixation to the anatomic footprint on the greater tuberosity was performed via a crossing, knotless, double-row anchor reconstruction using 4 to 6 anchors (4.75-mm Swivelock); 2 to 3 anchors were placed medially, just lateral to the articular surface, and 2 to 3 anchors were placed 1.5 to 1.8 cm laterally to this medial row.

Finally, the tendon of the infraspinatus or the teres minor was secured to the graft posteriorly in the coronal plane utilizing side to side sutures. Anterolaterally, the subscapularis was secured to the anterolateral aspect of the graft, although the DA was not secured to the rotator interval medially. Laterally, the coronal edges of the graft can be secured in MC to bone configurations using the No. 2 Fiberwire tip retention sutures from the medial row anchors on the humeral side.

Postoperative Rehabilitation

Postoperatively, MC-RCR arms were immobilized in a sling with early limited passive range of motion (ROM) only until week 6. At that point, full passive ROM was permitted, and patients began active-assisted ROM for another 2 to 3 weeks. Once active-assisted shoulder movement was performed pain-free, patients were cleared for active movement. At 8 to 10 weeks postoperatively, strengthening of the rotator cuff was initiated. If patients underwent a biceps tenodesis, passive and active elbow flexion were initiated immediately but resisted elbow flexion was avoided for the first 6 weeks. Patients were usually cleared for full activities beginning at 14 to 16 weeks.[46]

Postoperatively, SCR arms were immobilized in an abduction pillow for a minimum of 6 weeks. Then, at 6 weeks, patients were started on full passive and active-assisted ROM as tolerated. At 10 to 12 weeks postoperatively, full active ROM was permitted, and strengthening exercises were begun. Return to full activity and recreational activities without restriction was allowed approximately 3 months postoperatively.[41]

Patient Characteristics and Clinical Assessment

Institutional review board approval was obtained prior to the initiation of this retrospective analysis of prospectively collected data. Descriptive data including age and sex, number of prior surgeries on the operative shoulder, and concomitant procedures performed were collected.

Reoperation and Complications

Any complications or clinical failures were reported. Clinical failure was defined as the need for revision surgery or conversion to RTSA.

Radiographic Assessment

Radiographic evaluation included plain radiographs in 3 planes (AP, scapular Y, and axillary views). Preoperative MRI scans were evaluated for all patients, and postoperative MRI scans were evaluated whenever available. Radiographic evaluation included measurement of the acromiohumeral distance (AHD), acromial index (AI), Hamada score, critical shoulder angle (CSA), and superior capsular distance (SCD) using standard described techniques. The AHD was measured as the shortest distance between a radiodense line on the inferior acromial cortex and a line parallel to it tangent to the humeral head on AP radiograph. The AI was calculated as the ratio of the distance from the plane of the glenoid to the lateral edge of the acromion over the distance from the plane of the glenoid to the lateral cortex of the humeral head on AP radiograph. The Hamada score was determined based on the classification scheme proposed by Hamada et al[18] on AP radiograph. The CSA was measured as the angle formed by a line from the supraglenoid tubercle to the infraglenoid tubercle and a line from the infraglenoid tubercle to the lateral edge of the acromion on AP radiograph. The SCD was measured on AP radiograph according to the description by

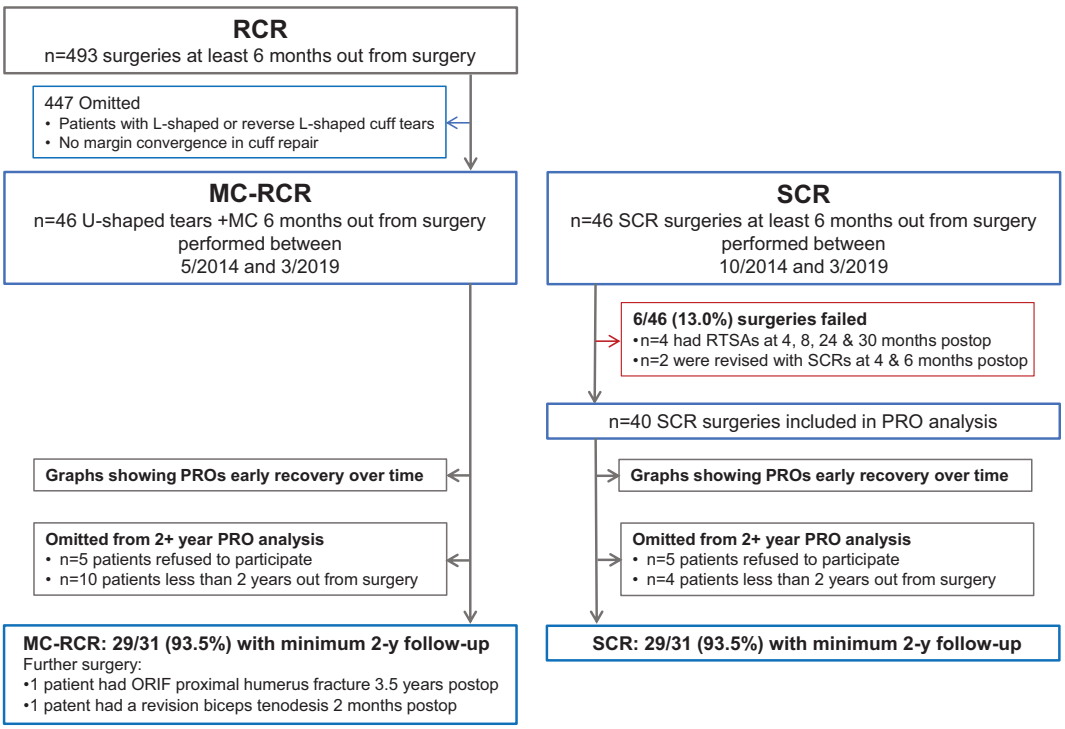

Figure 1. Flow diagram of the study groups. MC-RCR, margin convergence rotator cuff repair; ORIF, open reduction and internal fixation; postop, postoperatively; PRO, patient-reported outcome; RCR, rotator cuff repair; RTSA, reverse total shoulder arthroplasty; SCR, superior capsular reconstruction.

Pennington et al.[39] Preoperative MRI evaluation determined the Goutallier grade on T1-weighted sagittal sequences. The tendon stump length was measured according to the description by Meyer et al.[34]

Subjective Outcome Assessment/Patient-Reported Outcomes

The following patient-reported outcome (PRO) scores were collected preoperatively, 6 months postoperatively, and then annually: American Shoulder and Elbow Surgeons (ASES) score; Single Assessment Numerical Evaluation (SANE) score; shortened version of Disabilities of the Arm, Shoulder and Hand (QuickDASH) score; 12-Item Short Form Health Survey (SF-12) Physical Component Summary; and patient satisfaction (on a 1-10 scale, with 10 being the best). Additional optional questions assessed patients' participation in sports, both preoperatively and postoperatively. The minimal clinically important difference (MCID), substantial clinical benefit (SCB), and Patient Acceptable Symptom State (PASS) for the ASES and SANE score outcome parameter were reported.[10]

Statistical Analysis

Bivariate statistical analysis was used to address the primary aim of group comparisons between the MC-RCR and SCR groups. Group comparisons were made with respect to baseline covariates using the Mann-Whitney U test or Fisher exact test for continuous or dichotomous variables, respectively. The chi-square test was used to assess relationships between 2 categorical variables. The Mann-Whitney U test was also used to compare PROs between groups, and the Wilcoxon signed rank test was used to compare baseline and postoperative scores. Continuous data correlations were determined using Pearson (r) or Spearman (rho) analysis, depending on whether data were normally distributed. Survivorship analysis was performed using Kaplan-Meier survival curves for progression to revision RCR or shoulder arthroplasty on the index shoulder as an endpoint. Level of significance for univariate, paired t tests, Wilcoxon rank sum, and categorical comparisons was set at $P < .05$. All statistical analyses were performed using SPSS Version 11.0 (IBM Corp).

RESULTS

Included in the study were 46 patients in the MC-RCR group and 46 in the SCR group who were a minimum 6 months out from surgery, as shown in the flow diagram (Figure 1).

The mean age of the MC-RCR group was 59 ± 8 years (22 women and 24 men), and the mean age of the SCR group was 57 ± 7 years (14 women and 32 men) (Table 1). Concomitant subscapularis repair was performed in 10 patients in the MC-RCR group and 3 patients in the

TABLE 1
Patient Characteristics and Preoperative Radiographic Variables[a]

	MC-RCR (n = 46)	SCR (n = 46)	*P*
Age, y	59 ± 8	57 ± 7	.201
Sex, % male	52.2	69.6	.134
Prior rotator cuff repairs, n, mean (range)	0 (0-2)	1 (0-4)	**<.001**
Preoperative radiographic variables			
Tendon stump length, mm	17.4	14.9	.089
Tendon stump length <15 mm, %	32.5	50.0	**.017**
Goutallier grade, median (range)	2 (1-3)	3 (2-4)	**<.001**
Hamada grade, median (range)	1 (1-3)	1 (1-3)	.070
CSA, deg	34.6 ± 3.7	35.9 ± 4.3	.158
CSA >35°, %	43.2	52.5	.512
Acromial index	0.68 ± 0.06	0.70 ± 0.08	.201
AHD on MRI scan, mm	5.6 ± 2.2	5.6 ± 1.7	.954
AHD on plain radiograph, mm	9.5 ± 2.9	7.2 ± 2.9	**.001**
AHD <6 mm, %	11.6	65.4	**.006**
SCD, mm	44.8 ± 13.4	56.3 ± 7.6	**<.001**

[a]Data are reported as mean ± SD unless otherwise indicated. Bolded *P* values indicate statistically significant difference between groups ($P < .05$). AHD, acromiohumeral distance; CSA, critical shoulder angle; MC-RCR, margin convergence rotator cuff repair; MRI, magnetic resonance imaging; SCD, superior capsular distance; SCR, superior capsular reconstruction.

SCR group. While the MC-RCR group of patients had 100% survivorship at a minimum of 2 years, the SCR group had a significantly lower survivorship rate of 84.7% ($P = .026$) (Figure 2). In the MC-RCR group, 6 of the 46 patients underwent concomitant biceps tenodesis. In the SCR group, 26 of the 46 patients had undergone concomitant biceps tenodesis. As noted, all patients either underwent biceps tenodesis at time of SCR or MC-RCR or did not require further treatment of the biceps because it was previously tenodesed or tenotomized at an earlier surgery or because it was found to be ruptured at the time of SCR or MC-RCR and was asymptomatic, thus not requiring further treatment.

In the SCR group, 2 patients underwent revision SCR, and 4 progressed to RTSA at a mean of 16 months postoperatively (range, 4-30 months); all patients had a combination of persistent pain and subjective weakness. In the MC-RCR group, 1 patient underwent later revision biceps tenodesis, and 1 patient underwent open reduction and internal fixation of a traumatic proximal humeral fracture.

Imaging Findings

Although postoperative radiographs were obtained routinely for SCR, neither radiographs nor MRI scans were

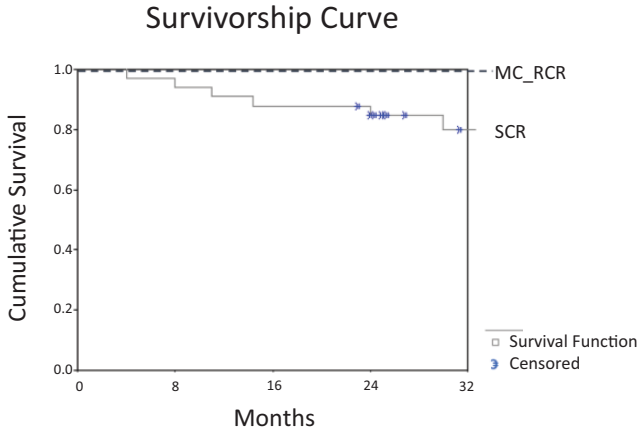

Figure 2. Comparison of survivorship rates between the MC-RCR group (100%) and the SCR (84.7%) group. MC-RCR, margin convergence rotator cuff repair; SCR, superior capsular reconstruction. Small blue dots are censored data points, not known at last contact if these patients had an event of interest or failure of the SCR surgery.

obtained routinely as part of the postoperative protocol for RCRs, limiting the number of films available for pre- to postoperative comparison within the MC-RCR group. In the SCR group, the mean AHD was 7.4 ± 2.9 mm preoperatively and 8.3 ± 3.2 mm postoperatively but was not statistically significant ($P = .060$). Preoperatively, there was a significant difference between the groups in terms of AHD (Table 1). In the SCR group, for which routine postoperative radiographs were obtained, postoperative AHD was significantly positively correlated with satisfaction scores (rho = 0.462; $P = .035$). Male and female patients were noted to have significantly different AI and SCD regardless of group (AI: male, 0.68 ± 0.07 vs female, 0.71 ± 0.06 [$P = .049$]; SCD preoperatively: male, 54.9 ± 7.9 vs female, 43.2 ± 14.5 mm [$P < .001$]; SCD postoperatively: male, 56.4 ± 6.3 vs female, 44.4 ± 5.0 mm [$P < .001$]). Although there was a significant preoperative between-group difference in SCD (MC-RCR: 44.8 ± 13.4 vs SCR: 56.3 ± 7.6 mm; $P < .001$), the greater number of male patients in the SCR group versus the MC-RCR group may have confounded comparisons between the groups for SCD and AI. The median preoperative supraspinatus Goutallier grade was 2 in the MC-RCR group and 3 in the SCR group ($P < .001$) (Table 1). The mean tendon stump length was greater in the MC-RCR group, although this difference was not significantly different; however, there was a significant difference between groups in the proportion of patients with a preoperative tendon stump length <15 mm on MRI scans (MC-RCR: 32.5% vs SCR: 50.0%; $P = .017$).

Patient-Reported Outcomes

For final PRO analysis, all patients who were not 2 years out from surgery or had undergone revision surgery were removed from the analysis. Minimum 2-year follow-up was obtained for 29 of 31 patients (93.5%) in the MC-RCR group

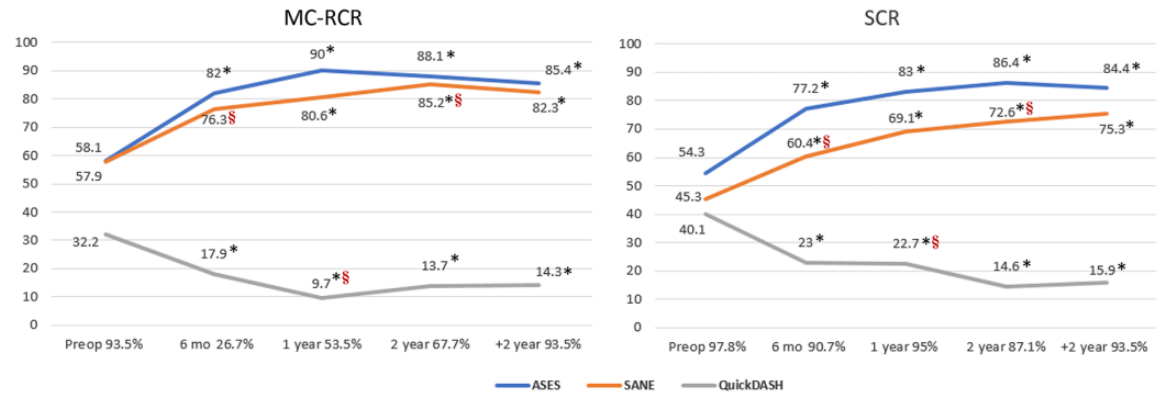

Figure 3. Patient-reported outcome scores by group. In both groups, early and sustained recovery was seen from preoperatively (Preop) to 6 months, 1 year, 2 years, and minimum 2 years postoperatively. ASES, American Shoulder and Elbow Surgeons score; QuickDASH, shortened version of Disabilities of the Arm, Shoulder and Hand score; MC-RCR, margin convergence rotator cuff repair; SANE, Single Assessment Numerical Evaluation score; SCR, superior capsular reconstruction. *Significant improvement from baseline preoperative scores. §Significant difference at various time points between the 2 groups.

and 29 of 31 patients (93.5%) in the SCR group. The mean follow-up times were 3.5 years (range, 2-5.9 years) in the MC-RCR group and 2.8 years (range, 2-4.7 years) in the SCR group. Preoperative PROs were not significantly different between the groups. Within each group, all PROs significantly improved from pre- to postoperatively. Curves demonstrating pre- and postoperative PROs for both groups are presented in Figure 3, with data from minimum 2-year follow-up presented in Table 2.

The MC-RCR group had significantly higher SANE scores at 6 months (76.3 vs 60.4; $P = .024$) and at 2 years (85.2 vs 72.6; $P = .019$) compared with the SCR group (Figure 3). The MC-RCR group showed significantly better QuickDASH scores at 1 year compared with the SCR group (9.7 vs 22.7; $P = .038$). Since the SANE is a functional score, this finding may demonstrate that the SCR group did not recover as quickly early in the recovery process as the MC-RCR group did. The ASES, SF-12 Physical Component Summary, and final median satisfaction scores were not significantly different between groups postoperatively.

A higher percentage of the MC-RCR group reached the ASES MCID compared with the SCR group, but there was no difference in the proportion reaching SCB or PASS (MCID, 92.3% vs 84.6%; SCB, 80.8% vs 80.8%; and PASS, 66.7% vs 66.7%); none of the differences between the groups was statistically significant. Similarly, a higher percentage of patients reached the SANE MCID in the MC-RCR group compared with the SCR group (MCID, 50% vs 57.1%; SCB, 50% vs 53.6%; and PASS, 64% vs 48%), but these differences were not statistically significant.

The distribution of Goutallier grades in each group is presented in Figure 4, and PROs by Goutallier grade are presented in Figure 5.

TABLE 2
Minimum 2-Year Follow-up PRO Comparisons[a]

	MC-RCR (n = 29)	SCR (n = 29)	*P*, Group
ASES			
Preoperative	60.5 ± 20.7	54.3 ± 16.3	.225
Minimum 2-y postoperative	85.4 ± 15	85.4 ± 16.5	.742
P, pre-post	**.001**	**>.001**	
ΔASES, pre-post	33.0 ± 20.8	33.2 ± 20	.795
SANE			
Preoperative	58.3 ± 28	49.7 ± 26.6	.252
Minimum 2-y postoperative	82.3 ± 19.5	77.8 ± 19.3	.161
P, pre-post	**>.001**	**.001**	
ΔSANE, pre-post	28.9 ± 29.3	26.6 ± 35.4	.798
QuickDASH			
Preoperative	31.0 ± 19	39.4 ± 16.8	.094
Minimum 2-y postoperative	14.3 ± 14.6	14.3 ± 15.3	.906
P, pre-post	**>.001**	**>.001**	
SF-12 PCS			
Preoperative	43.7 ± 9.3	39.4 ± 6.7	.061
Minimum 2-y postoperative	49.0 ± 9.2	50.7 ± 7.3	.842
P, pre-post	**.006**	**>.001**	
Satisfaction, median (range)	10 (1-10)	10 (1-10)	.930

[a]Values are presented as mean ± SD unless otherwise indicated. Bolded *P* values indicate statistical significance ($P < .05$). ASES, American Shoulder and Elbow Surgeons score; MC-RCR, margin convergence rotator cuff repair; PCS, Physical Component Summary; pre-, preoperatively; post-, postoperatively; PRO, patient-reported outcome; QuickDASH, shortened version of Disabilities of the Arm, Shoulder and Hand score; SANE, Single Assessment Numerical Evaluation score; SCR, superior capsular reconstruction; SF-12, 12-Item Short Form Health Survey.

DISCUSSION

The most important finding of the current study is that both MC-RCR and SCR resulted in significantly improved PROs from pre- to postoperatively among patients without failure. No significant postoperative differences were seen at 2 years and beyond with very high satisfaction for both

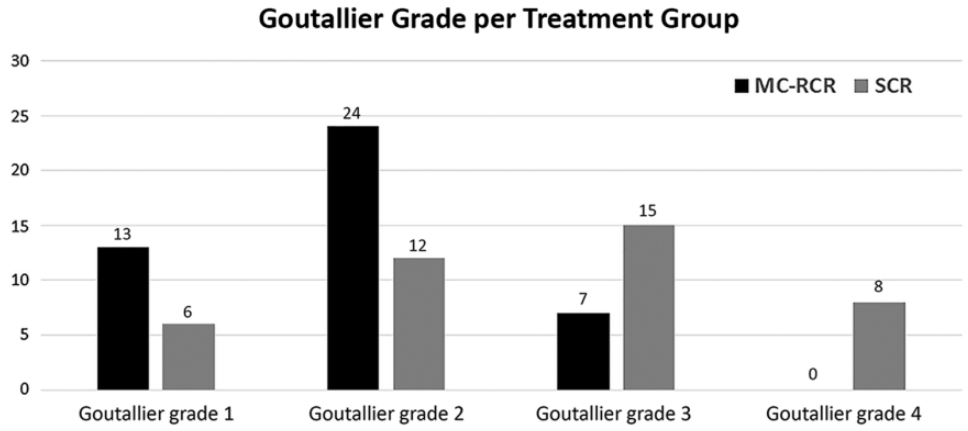

Figure 4. Distribution of Goutallier grades in each group. Missing are data for 2 patients in the MC-RCR group and 5 patients in the SCR group. MC-RCR, margin convergence rotator cuff repair; SCR, superior capsular reconstruction.

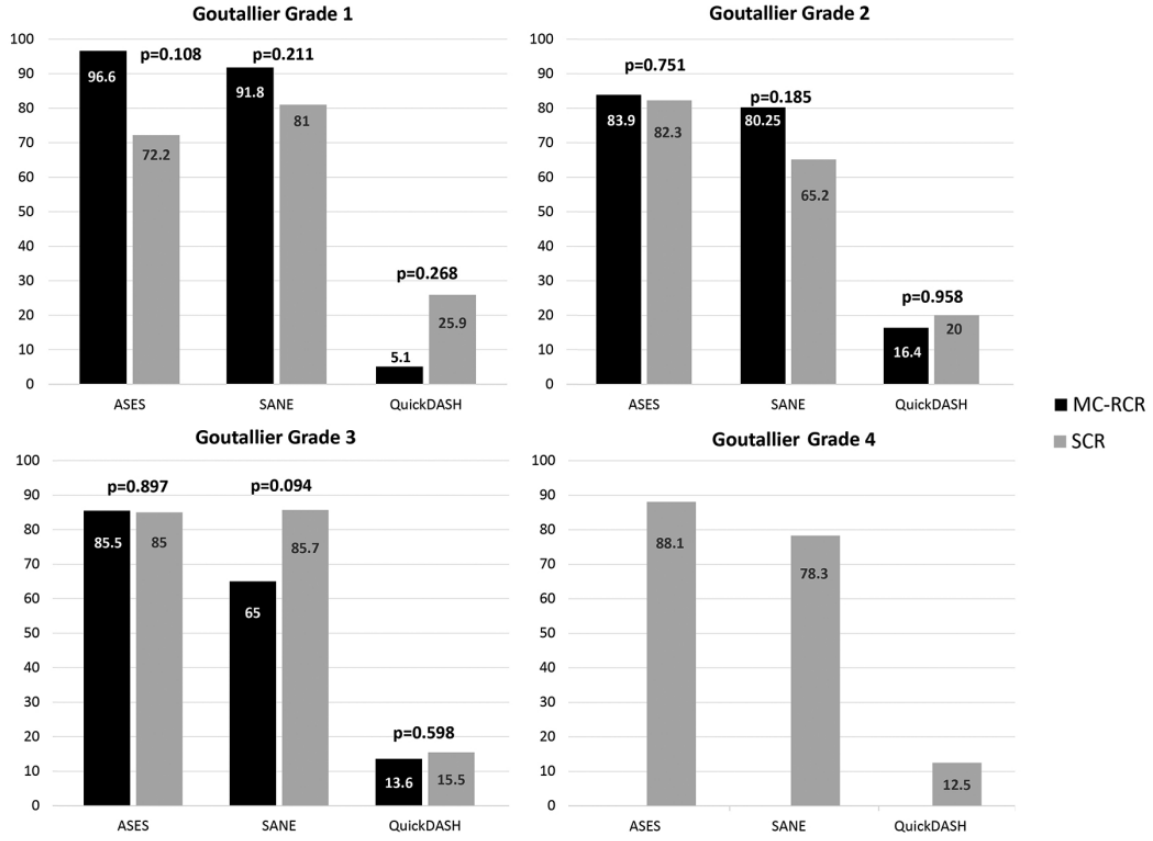

Figure 5. Patient-reported outcome scores according to Goutallier grade. ASES, American Shoulder and Elbow Surgeons score; MC-RCR, margin convergence rotator cuff repair; QuickDASH, shortened version of Disabilities of the Arm, Shoulder and Hand score; SANE, Single Assessment Numerical Evaluation score; SCR, superior capsular reconstruction.

procedures. However, MC-RCR resulted in significantly fewer revision surgeries ($P = .026$). Given prior good to excellent clinical and radiographic results, we had hypothesized that SCR would be the preferred strategy for management of massive RCTs. However, when a patient is a candidate for both procedures with a technically repairable U-shaped RCT, our results suggest that MC-RCR may be the preferred treatment option rather than performing primary SCR. MC-RCR closes the tear defect and preserves native tissue. Although SCR creates a static restraint that suppresses cranial humeral head migration, reduces secondary subacromial impingement, and helps to restore

force couples, it theoretically sacrifices any remaining function that might be harnessed from repair of the rotator cuff muscles involved. MC-RCR is also less potentially costly than SCR by eliminating the expense associated with an allograft. Finally, if MC-RCR does go on to failure, SCR remains a valid option, whereas the converse is not true. If SCR is elected primarily, MC-RCR cannot later be performed as a salvage; the only options remaining include revision SCR, tendon transfer, or conversion to RTSA. For these reasons, we advocate for treating technically repairable massive, U-shaped, RCTs with MC-RCR.

It is important to note that this is an evidence level 3 cohort study, retrospectively comparing prospectively collected data. The final decision between MC-RCR and SCR for all patients was made at the time of surgery based on the technical repairability of the RCT. However, readers will note that there were indeed some statistically significant differences between those patients who underwent MC-RCR versus those who underwent SCR. It is critical to understand that the current study does not attempt to argue that there were no differences between the groups as would be the case in a randomized study. However, despite these differences, there is a valuable conclusion to be drawn. Although many patients with SCR may not be candidates for MC-RCR, many patients treated with MC would be candidates for a primary SCR. Among patients who would theoretically be a candidate for both procedures, preoperatively and intraoperatively the surgeon is faced with a decision about which procedure to perform. We believe the data presented in the current study are of value to the surgeon faced with a tear that is a candidate for either MC or primary SCR to aid in that decision making. The data in this study suggested that if the tear is found to be reparable at the time of surgery, repair should be performed, even if MC techniques are required, rather than electing to perform primary SCR. Furthermore, the differences between the groups may be instructive for surgeons as they evaluate and indicate their own patients with massive RCTs. The group that ultimately was indicated for SCR included a significantly greater proportion of patients who had undergone prior RCR. Radiographically, the SCR group included a greater proportion of patients with tendon stumps measuring <15 mm, the critical value identified by Meyer et al,[33] and had a greater median preoperative Goutallier grade. The distribution of Goutallier grade was such that, for grade 2, there were 1.5 times as many patients treated with MC-RCR as SCR. This relationship was reversed for grade 3, where twice as many patients were treated with SCR as MC-RCR. No patients with Goutallier grade 4 changes were treated with MC-RCR. In addition, patients with SCR had a smaller preoperative AHD and a greater proportion of AHD <6 mm. Finally, patients with SCR had a significantly greater preoperative SCD. While a decision for repairability is ultimately made based upon the diagnostic arthroscopy and the technical skill of the surgeon, the above parameters can be considered by the surgeon preoperatively and intraoperatively.

Massive RCTs remain a commonly seen but challenging entity for orthopaedic surgeons, and an optimized algorithm for treatment has yet to be established given the number and complexity of variables involved.[23,31,43,50] Although some disagreement remains on what qualifies as an irreparable tear, the feasibility of repair ultimately hinges on the diagnostic arthroscopy, during which the torn tendons can be directly visualized, manipulated, and mobilized.[17,18,38,45,48] Traditional attempts at repair aimed to achieve translation of a retracted tendon to the anatomic footprint, resulting in high strain and high failure.[13] This has been demonstrated specifically for massive longitudinal, U-shaped tears, in which tendon to bone repair alone results in high tension and a higher rate of failure.[6,7] Furthermore, attempted anatomic repair often results in less than optimal coverage of greater tuberosity footprint. Yoo et al[51] demonstrated that a high retear rate of 45.5% with this strategy during arthroscopic single-row repair of large to massive RCTs.

MC was described by Burkhart et al[4] in the 1990s in a technical note providing the biomechanical basis for the strain reduction achieved by this technique, theorizing that reduced strain would lead to reduced activation of pain receptors; that is, "no strain, no pain." Biomechanical studies by Mazzocca et al[32] and Hatta et al[20] have demonstrated that MC can reduce strain in adjacent tissue and stiffness within the supraspinatus to reduce stress on the subsequent repair. Multiple clinical outcome studies have demonstrated successful results.[2,5,24] The current study is in agreement with these studies that MC-RCR is a reliable strategy for addressing massive U-shaped RCTs.

Due to expanding experience with the procedure, SCR has become more commonly considered as an index procedure, even for some technically repairable massive RCTs. In 2013, Mihata et al[36] proposed SCR with tensor fascia lata, and the technique has been modified for use of acellular DA to reduce the increased morbidity and surgical time associated with autograft harvest.[35,37,40] A recently published systematic review of the SCR literature identified 8 level 3 or 4 studies reporting on outcomes in 352 unique patients (358 shoulders).[1,11,12,22,27,28,35,39] Although there was heterogeneous reporting of outcome measures, SCR provided significant improvement in PROs and pain visual analog scores with high satisfaction. Furthermore, there was significant reported improvement in ROM and a high rate of reversal of preoperative pseudoparalysis. Nonetheless, a relatively high rate of overall complications has been reported, including 13% retear rate. Although these relatively short-term findings may be promising, additional research is necessary to determine the longevity of the results achieved.

To our knowledge, there are no published, English-language studies that have directly compared the results of MC-RCR for massive, U-shaped tear and SCR. The current study benefits from comprehensive, prospectively gathered PROs in an effort to reduce bias. However, we must also acknowledge limitations. Although SCR failures that went on to be revised to RTSA were included for the purpose of survivorship analysis, the affected patients were excluded in terms of PROs because their postoperative PROs reflected the results of the RTSA and not the index SCR. It is possible that this may have biased the results in favor of SCR. The comparisons were based on subjective

short-term clinical outcomes; thus, conclusions cannot be drawn regarding the performance of MC-RCR and SCR in the mid- or long term. Our results were from a high-volume, referral sports medicine facility and, thus, may not be universally generalizable. In addition, there is the risk that selection bias may have affected the results, as patients were not randomized to treatment. Furthermore, we actively identified ways in which the groups did in fact differ in hopes that this information might further aid surgeons' decision making. The number of patients included, although consistent with many similar studies, was relatively small, due, at least in part, to the relatively novel technique of SCR as a treatment for irreparable, massive RCTs. As noted, routine postoperative radiographs and MRI scans were not obtained routinely for RCRs, limiting the ability to make comparisons of objective postoperative radiographic outcomes. Although the postoperative rehabilitation protocols were similar for the 2 procedures, they were not identical, and such differences may be related theoretically to early term functional differences between the 2 groups. The greatest future research need remains continued reporting of mid- and long-term follow-up on both treatment strategies.

CONCLUSION

Both MC-RCR and SCR provided significant improvements in outcome scores pre- to postoperatively in patients with massive rotator cuff tears, achieving good to excellent results. While both MC-RCR and SCR provided similar improvement in PROs, MC-RCR resulted in fewer reoperations compared with SCR. If an RCT is technically repairable, our recommendation is that it be repaired primarily, even if MC techniques are needed to close the defect. SCR remains a good option for massive RCTs that are not technically repairable.

REFERENCES

1. Altintas B, Scheidt M, Kremser V, et al. Superior capsule reconstruction for irreparable massive rotator cuff tears: does it make sense? A systematic review of early clinical evidence. *Am J Sports Med*. 2020; 48(13):3365-3375. doi:10.1177/0363546520904378
2. Baumgarten KM. Patient-determined outcomes after arthroscopic margin convergence rotator cuff repair. *Arthrosc Sports Med Rehabil*. 2020;2(5):e517-e522. doi:10.1016/j.asmr.2020.05.017
3. Bedi A, Dines J, Warren RF, Dines DM. Massive tears of the rotator cuff. *J Bone Joint Surg Am*. 2010;92(9):1894-1908. doi:10.2106/JBJS.I.01531
4. Burkhart SS, Athanasiou KA, Wirth MA. Margin convergence: a method of reducing strain in massive rotator cuff tears. *Arthroscopy*. 1996;12(3):335-338. doi:10.1016/s0749-8063(96)90070-5
5. Burkhart SS, Danaceau SM, Pearce CEJ. Arthroscopic rotator cuff repair: analysis of results by tear size and by repair technique-margin convergence versus direct tendon-to-bone repair. *Arthroscopy*. 2001;17(9):905-912. doi:10.1053/jars.2001.26821
6. Burkhart SS, Diaz Pagàn JL, Wirth MA, Athanasiou KA. Cyclic loading of anchor-based rotator cuff repairs: confirmation of the tension overload phenomenon and comparison of suture anchor fixation with transosseous fixation. *Arthroscopy*. 1997;13(6):720-724. doi:10.1016/s0749-8063(97)90006-2
7. Burkhart SS, Johnson TC, Wirth MA, Athanasiou KA. Cyclic loading of transosseous rotator cuff repairs: tension overload as a possible cause of failure. *Arthroscopy*. 1997;13(2):172-176. doi:10.1016/s0749-8063(97)90151-1
8. Burkhart SS, Nottage WM, Ogilvie-Harris DJ, Kohn HS, Pachelli A. Partial repair of irreparable rotator cuff tears. *Arthroscopy*. 1994; 10(4):363-370. doi:10.1016/s0749-8063(05)80186-0
9. Chen K-H, Chiang E-R, Wang H-Y, Ma H-L. Arthroscopic partial repair of irreparable rotator cuff tears: factors related to greater degree of clinical improvement at 2 years of follow-up. *Arthroscopy*. 2017; 33(11):1949-1955. doi:10.1016/j.arthro.2017.06.047
10. Cvetanovich GL, Gowd AK, Liu JN, et al. Establishing clinically significant outcome after arthroscopic rotator cuff repair. *J Shoulder Elbow Surg*. 2019;28(5):939-948. doi:10.1016/j.jse.2018.10.013
11. De Campos Azevedo CI, Ângelo ACLPG, Vinga S. Arthroscopic superior capsular reconstruction with a minimally invasive harvested fascia lata autograft produces good clinical results. *Orthop J Sports Med*. 2018;6(11):2325967118808242. doi:10.1177/2325967118808242
12. Denard PJ, Brady PC, Adams CR, Tokish JM, Burkhart SS. Preliminary results of arthroscopic superior capsule reconstruction with dermal allograft. *Arthroscopy*. 2018;34(1):93-99. doi:10.1016/j.arthro.2017.08.265
13. Duralde XA, Bair B. Massive rotator cuff tears: the result of partial rotator cuff repair. *J Shoulder Elbow Surg*. 2005;14(2):121-127. doi:10.1016/j.jse.2004.06.015
14. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. *J Shoulder Elbow Surg*. 1999;8(6):599-605. doi:10.1016/s1058-2746(99)90097-6
15. Galatz LM, Ball CM, Teefey SA, Middleton WD, Yamaguchi K. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. *J Bone Joint Surg Am*. 2004; 86(2):219-224. doi:10.2106/00004623-200402000-00002
16. Gerber C, Vinh TS, Hertel R, Hess CW. Latissimus dorsi transfer for the treatment of massive tears of the rotator cuff: a preliminary report. *Clin Orthop Relat Res*. 1988;232:51-61.
17. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures: pre- and postoperative evaluation by CT scan. *Clin Orthop Relat Res*. 1994;304:78-83.
18. Hamada K, Fukuda H, Mikasa M, Kobayashi Y. Roentgenographic findings in massive rotator cuff tears: a long-term observation. *Clin Orthop Relat Res*. 1990;254:92-96.
19. Hansen ML, Otis JC, Johnson JS, Cordasco FA, Craig EV, Warren RF. Biomechanics of massive rotator cuff tears: implications for treatment. *J Bone Joint Surg Am*. 2008;90(2):316-325. doi:10.2106/JBJS.F.00880
20. Hatta T, Giambini H, Zhao C, et al. Biomechanical effect of margin convergence techniques: quantitative assessment of supraspinatus muscle stiffness. *PloS One*. 2016;11(9):e0162110. doi:10.1371/journal.pone.0162110
21. Henseler JF, Nagels J, van der Zwaal P, Nelissen RGHH. Teres major tendon transfer for patients with massive irreparable posterosuperior rotator cuff tears: short-term clinical results. *Bone Joint J*. 2013;95(4): 523-529. doi:10.1302/0301-620X.95B4.30390
22. Hirahara AM, Andersen WJ, Panero AJ. Superior capsular reconstruction: clinical outcomes after minimum 2-year follow-up. *Am J Orthop (Belle Mead NJ)*. 2017;46(6):266-278.
23. Keener JD, Galatz LM, Teefey SA, et al. A prospective evaluation of survivorship of asymptomatic degenerative rotator cuff tears. *J Bone Joint Surg Am*. 2015;97(2):89-98.
24. Kim KC, Shin HD, Cha SM, Kim JH. Repair integrity and functional outcomes for arthroscopic margin convergence of rotator cuff tears. *J Bone Joint Surg Am*. 2013;95(6):536-541. doi:10.2106/JBJS.L.00397
25. König MA, Braunstein VA. Tendon repair leads to better long-term clinical outcome than debridement in massive rotator cuff tears. *Open Orthop J*. 2017;11:546-553. doi:10.2174/1874325001611010546
26. Lacheta L, Horan MP, Schairer WW, et al. Clinical and imaging outcomes after arthroscopic superior capsule reconstruction with human dermal allograft for irreparable posterosuperior rotator cuff tears: a

minimum two year follow up. *Arthroscopy*. 36(4):1011-1019. doi:10.1016/j.arthro.2019.12.024
27. Lee S-J, Min Y-K. Can inadequate acromiohumeral distance improvement and poor posterior remnant tissue be the predictive factors of re-tear? Preliminary outcomes of arthroscopic superior capsular reconstruction. *Knee Surg Sports Traumatol Arthrosc*. 2018;26(7):2205-2213. doi:10.1007/s00167-018-4912-8
28. Lim S, AlRamadhan H, Kwak J-M, Hong H, Jeon I-H. Graft tears after arthroscopic superior capsule reconstruction (ASCR): pattern of failure and its correlation with clinical outcome. *Arch Orthop Trauma Surg*. 2019;139(2):231-239. doi:10.1007/s00402-018-3025-7
29. Lo IKY, Burkhart SS. Arthroscopic repair of massive, contracted, immobile rotator cuff tears using single and double interval slides: technique and preliminary results. *Arthroscopy*. 2004;20(1):22-33. doi:10.1016/j.arthro.2003.11.013
30. Maillot C, Harly E, Demezon H, Le Huec J-C. Surgical repair of large-to-massive rotator cuff tears seems to be a better option than patch augmentation or débridement and biceps tenotomy: a prospective comparative study. *J Shoulder Elbow Surg*. 2018;27(9):1545-1552. doi:10.1016/j.jse.2018.05.023
31. Mall NA, Kim HM, Keener JD, et al. Symptomatic progression of asymptomatic rotator cuff tears: a prospective study of clinical and sonographic variables. *J Bone Joint Surg Am*. 2010;92(16):2623-2633.
32. Mazzocca AD, Bollier M, Fehsenfeld D, et al. Biomechanical evaluation of margin convergence. *Arthroscopy*. 2011;27(3):330-338. doi:10.1016/j.arthro.2010.09.003
33. McLaughlin HL. Lesions of the musculotendinous cuff of the shoulder. The exposure and treatment of tears with retraction. 1944. *Clin Orthop Relat Res*. 1994;304:3-9.
34. Meyer DC, Wieser K, Farshad M, Gerber C. Retraction of supraspinatus muscle and tendon as predictors of success of rotator cuff repair. *Am J Sports Med*. 2012;40(10):2242-2247. doi:10.1177/0363546512457587
35. Mihata T, Lee TQ, Hasegawa A, et al. Arthroscopic superior capsule reconstruction can eliminate pseudoparalysis in patients with irreparable rotator cuff tears. *Am J Sports Med*. 2018;46(11):2707-2716. doi:10.1177/0363546518786489
36. Mihata T, Lee TQ, Watanabe C, et al. Clinical results of arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. *Arthroscopy*. 2013;29(3):459-470. doi:10.1016/j.arthro.2012.10.022
37. Mihata T, McGarry MH, Pirolo JM, Kinoshita M, Lee TQ. Superior capsule reconstruction to restore superior stability in irreparable rotator cuff tears: a biomechanical cadaveric study. *Am J Sports Med*. 2012;40(10):2248-2255. doi:10.1177/0363546512456195
38. Nové-Josserand L, Edwards TB, O'Connor DP, Walch G. The acromiohumeral and coracohumeral intervals are abnormal in rotator cuff tears with muscular fatty degeneration. *Clin Orthop Relat Res*. 2005;433:90-96. doi:10.1097/01.blo.0000151441.05180.0e
39. Pennington WT, Bartz BA, Pauli JM, Walker CE, Schmidt W. Arthroscopic superior capsular reconstruction with acellular dermal allograft for the treatment of massive irreparable rotator cuff tears: short-term clinical outcomes and the radiographic parameter of superior capsular distance. *Arthroscopy*. 2018;34(6):1764-1773. doi:10.1016/j.arthro.2018.01.009
40. Petri M, Greenspoon JA, Millett PJ. Arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. *Arthrosc Tech*. 2015;4(6):e751-e755. doi:10.1016/j.eats.2015.07.018
41. Pogorzelski J, DelVecchio BM, Hussain ZB, Fritz EM, Godin JA, Millett PJ. Superior capsule reconstruction for massive rotator cuff tears—key considerations for rehabilitation. *Int J Sports Phys Ther*. 2017;12(3):390-401.
42. Pogorzelski J, Horan MP, Godin JA, Hussain ZB, Fritz EM, Millett PJ. Achilles tendon allograft-augmented latissimus dorsi tendon transfer for the treatment of massive irreparable posterosuperior rotator cuff tears. *Arch Orthop Trauma Surg*. 2018;138(9):1207-1212. doi:10.1007/s00402-018-2943-8
43. Safran O, Schroeder J, Bloom R, Weil Y, Milgrom C. Natural history of nonoperatively treated symptomatic rotator cuff tears in patients 60 years old or younger. *Am J Sports Med*. 2011;39(4):710-714. doi:10.1177/0363546510393944
44. Sershon RA, Van Thiel GS, Lin EC, et al. Clinical outcomes of reverse total shoulder arthroplasty in patients aged younger than 60 years. *J Shoulder Elbow Surg*. 2014;23(3):395-400. doi:10.1016/j.jse.2013.07.047
45. Thomazeau H, Rolland Y, Lucas C, Duval JM, Langlais F. Atrophy of the supraspinatus belly: assessment by MRI in 55 patients with rotator cuff pathology. *Acta Orthop Scand*. 1996;67(3):264-268. doi:10.3109/17453679608994685
46. Van der Meijden OA, Westgard P, Chandler Z, Gaskill TR, Kokmeyer D, Millett PJ. Rehabilitation after arthroscopic rotator cuff repair: current concepts review and evidence-based guidelines. *Int J Sports Phys Ther*. 2012;7(2):197-218.
47. Walch G, Nové-Josserand L, Boileau P, Levigne C. Subluxations and dislocations of the tendon of the long head of the biceps. *J Shoulder Elbow Surg*. 1998;7(2):100-108. doi:10.1016/s1058-2746(98)90218-x
48. Werner CML, Conrad SJ, Meyer DC, Keller A, Hodler J, Gerber C. Intermethod agreement and interobserver correlation of radiologic acromiohumeral distance measurements. *J Shoulder Elbow Surg*. 2008;17(2):237-240. doi:10.1016/j.jse.2007.06.002
49. Werner CML, Steinmann PA, Gilbart M, Gerber C. Treatment of painful pseudoparesis due to irreparable rotator cuff dysfunction with the Delta III reverse-ball-and-socket total shoulder prosthesis. *J Bone Joint Surg Am*. 2005;87(7):1476-1486. doi:10.2106/JBJS.D.02342
50. Yamamoto A, Takagishi K, Osawa T, et al. Prevalence and risk factors of a rotator cuff tear in the general population. *J Shoulder Elbow Surg*. 2010;19(1):116-120. doi:10.1016/j.jse.2009.04.006
51. Yoo JC, Ahn JH, Koh KH, Lim KS. Rotator cuff integrity after arthroscopic repair for large tears with less-than-optimal footprint coverage. *Arthroscopy*. 2009;25(10):1093-1100. doi:10.1016/j.arthro.2009.07.010
52. Zumstein MA, Jost B, Hempel J, Hodler J, Gerber C. The clinical and structural long-term results of open repair of massive tears of the rotator cuff. *J Bone Joint Surg Am*. 2008;90(11):2423-2431. doi:10.2106/JBJS.G.00677