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

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Purpose: This outcome analysis presents 88 consecutive shoulders presenting with irreparable rotator cuff tears that we treated with arthroscopic superior capsular reconstruction (SCR) using an acellular dermal allograft. We also present the concept of superior capsular distance to quantitatively measure the decreased distance present upon restoration of superior capsular integrity. **Methods:** A retrospective review was conducted of patients treated with arthroscopic SCR with a minimum 12-month follow-up. Outcome analysis was performed via an internet-based outcome-tracking system to evaluate visual analog scale (VAS) and American Shoulder and Elbow Surgeons (ASES) scores. Radiographic analysis of anteroposterior radiographs analyzed acromiohumeral interval and superior capsular distance. Digital dynamometric strength and functional range of motion assessments were also obtained. The main inclusion criteria for patients in this analysis was all patients who underwent superior capsular reconstruction during the time period of this report. **Results:** Eighty-six patients with an average age of 59.4 years presented with massive rotator cuff tears (Cofield >5 cm). Outcome data revealed improvement in VAS (4.0-1.5), and ASES (52-82) scores at 1 year ($P = .005$). Radiographic analysis showed increase in acromiohumeral interval (mean 7.1 mm preoperatively to mean 9.7 mm at 1 year) ($P = .049$) and superior capsular distance (mean 52.9 mm preoperatively to mean 46.2 mm at 1 year) ($P = .011$). Strength improved significantly (forward flexion/abduction/external rotation of 4.8/4.1/7.7 lb preoperatively to 9.8/9.2/12.3 lb at 1 year) as well as range of motion (forward flexion/abduction of 120°/103° preoperatively to 160°/159° at 1 year) ($P = .044$/$P = .007$/$P = .02$). At follow-up, 90% of patients were satisfied. **Conclusions:** This analysis reveals that arthroscopic SCR with acellular dermal allograft has been successful in decreasing pain and improving function in this patient subset. Radiographic analysis has also shown a consistent and lasting decrease in superior capsular distance and increase in acromiohumeral interval, indicating maintenance of superior capsular stability. **Level of Evidence:** Level IV, retrospective case series.

Treatment options for young, active patients with massive, retracted rotator cuff tears have historically been considered unpredictable. Repairs of massive tears are fraught with high failure rates because of tendon inelasticity and the poor tissue quality typically present in these retracted tears.[1] When repair is possible, the tension that is typically created likely also contributes to these increased failure rates.[1] Treatment options in these patients traditionally include debridement and biceps tenotomy, partial repair, interval slide

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with repair, rotator cuff partial repair with augmentation or bridge grafting if full repair to the humerus is not achievable, muscle transfer procedure, or reverse total shoulder arthroplasty.[2-14] In the active and physiologically young patient, reverse total shoulder arthroplasty is not the preferred option because of concerns of early loosening, complication rates, and permanent destruction of the glenohumeral joint.[4]

In 2013, Mihata et al. described the arthroscopic superior capsular reconstruction (SCR) as a successful procedure treating massive, irreparable rotator cuff tears. He introduced this procedure as having the goal of restoring glenohumeral mechanics through the reestablishment of superior stability.[2] In a subsequent report of clinical outcomes, Mihata et al. reported results using a fascia lata autograft to arthroscopically reconstruct the superior capsule in 24 shoulders of 23 patients with large, irreparable rotator cuff tears. Reported outcomes in his study were excellent with significant improvements in pain, function, and range of motion in forward flexion and abduction.[3] They also reported a significant improvement in acromiohumeral distance and an 83% graft integrity on follow-up.[3] As this procedure has evolved, a technique of arthroscopic SCR with acellular dermal allograft has been developed to obviate the need for fascia lata autograft use and the graft site morbidity associated with fascia lata harvest.[4,5] This procedure has gained rapid momentum as anecdotal, and now clinical, reports of outcomes among surgeons have been favorable.

We have introduced superior capsular distance as a radiographic measure that can be used to show restoration and maintenance of superior stability provided by the SCR. Defined as the arc length from the medial aspect of the greater tuberosity to the superior aspect of the glenoid, this measurement aims to provide another means of quantifying the superior translation of the humeral head. We feel that this measure, in addition to the acromiohumeral distance, validates the function of this procedure in restoring superior capsular integrity in these patients, leading to their improved function. The purpose of this study was to present our outcome analysis of 88 consecutive shoulders presenting with irreparable rotator cuff tears that we treated with arthroscopic SCR using an acellular dermal allograft. We also present the concept of superior capsular distance to quantitatively measure the decreased distance present on restoration of superior capsular integrity. We hypothesized that the SCR using an acellular dermal allograft is a clinically successful procedure to reduce pain and improve function in the young, active patient with massive, irreparable rotator cuff tears and provide results on par with Mihata's original experiment using fascia lata autograft.

Methods

Between February 5, 2015, and June 30, 2016, a consecutive group of patients presented with massive rotator cuff tears and symptoms of rotator cuff arthropathy without significant degenerative joint disease revealed by severe weakness, pain, and significantly decreased range of motion. These patients were assessed by the lead author, orthopaedic surgeon (W.T.P.). The average age was 59.4 years, with 61% male and 39% female. By our practice standards, these patients were too young (age <70 years), too physically active (labor employment or significant sport participation), or both to consider reverse total shoulder arthroplasty. A few more elderly patients, including a 79-year-old, were also included in this study as they were either too active or refused reverse total shoulder arthroplasty. All patients were dissatisfied with previous courses of nonsurgical treatment, including physical therapy for a minimum of 3 months and cortisone injections. Clinically, none of the surgical failures had infection. All reported an unacceptable loss of function and level of pain; therefore, they were requesting surgical intervention. No patients who underwent this procedure were excluded from this analysis, and concomitant procedures included biceps release, subacromial smoothing, capsular release, distal clavicle excision, and debridement of the glenohumeral joint and labrum. The main inclusion criteria of patients that are in this outcome analysis were patients who had irreparable rotator cuff repairs that failed all previous treatment methods. These patients all had unacceptable pain levels and loss of function and were deemed too young or too active to undergo reverse total shoulder arthroplasty. These patients were all treated with arthroscopic SCR using an acellular dermal allograft and have a minimum of 1-year follow-up.

Radiographic analysis was performed with preoperative standard radiographs that included true standing anteroposterior, axillary, and outlet views. Advanced imaging studies in the form of magnetic resonance imaging (MRI) scans were obtained in all patients preoperatively. These studies were analyzed to preoperatively grade their rotator cuff tears in respect to size, retraction, and atrophy using classification systems introduced by Cofield et al.[15] and Goutalier et al.,[16] respectively. Postoperative advanced imaging with MRI was only performed on those patients who expressed dissatisfaction with their level of pain, or who had insufficient functional improvement in terms of strength and range of motion.

Preoperative assessment of standard radiographs was performed by a research assistant under the direct supervision of lead author to obtain acromiohumeral distance and superior capsular distance by methods

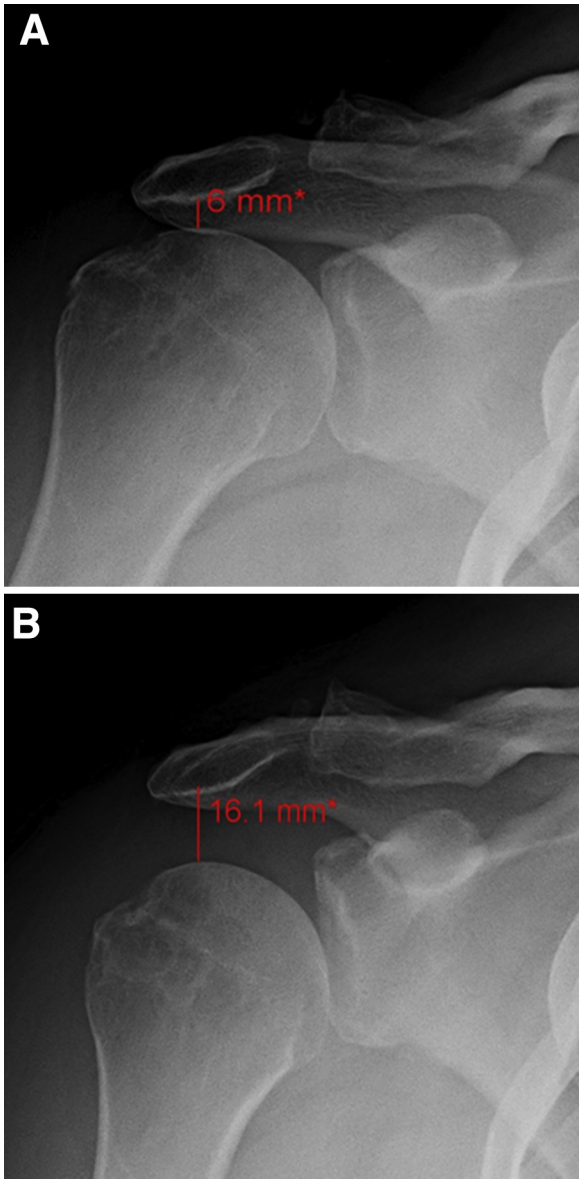

Fig 1. On the standing AP radiograph, acromiohumeral interval (AHI) measurement is quantified by the distance between the inferior aspect of the acromion to the subchondral lamina of the humeral head. (A) Preoperative AHI. (B) Postoperative AHI. (AP, anteroposterior.)

described in Figures 1 and 2. We present and define superior capsular distance as the curvilinear distance ($2\pi r \times \measuredangle^{\circ}/360^{\circ}$) traversing the superior aspect of the humeral head from the superior aspect of the glenoid to the medical aspect of the greater tuberosity (Fig 2). These radiographic measurements were obtained using the digital radiographic calibration software inherent to our digital radiographic system (Medstrat, Downers Grove, IL). Validation was performed by selection of random radiographs and independently interpreted by physician assistants specializing in shoulder surgery. No significant intra- or interobserver variation was noted. Evaluation with standard radiographs was performed preoperatively, as well as 1 week, 6 months, and 1 year postoperatively, with repeat measurements being performed to evaluate postoperative change and maintenance of these changes.

Surgical reconstruction was performed by a single surgeon as an outpatient arthroscopic procedure using acellular dermal allograft in all patients in this analysis with the technique described in the surgical technique section to follow.

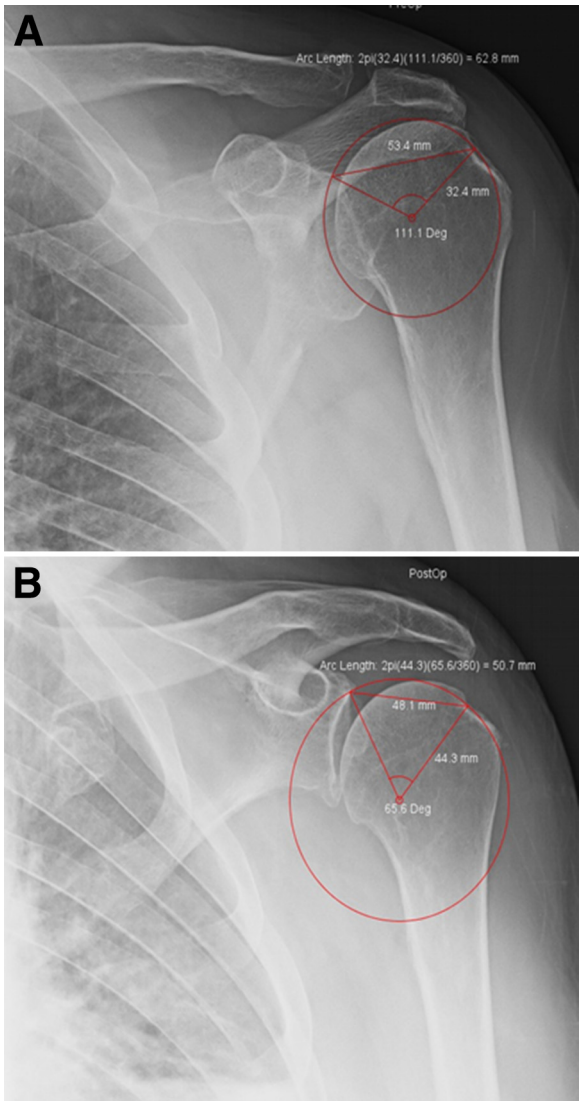

Fig 2. Method for measuring superior capsular distance (SCD) on standing AP radiographs. We defined this as the arc length (mm) between the superior aspect of the glenoid and the medial aspect of the greater tuberosity of the humerus [$2\pi r \times \measuredangle^{\circ}/360^{\circ}$]. This alternate measurement on standard AP radiographs can be used to measure the re-establishment and maintenance of superior capsular integrity. The 53.4 and 48.1 mm in the pre- and postoperative figures, respectively, represent the direct distance from the superior aspect of the glenoid to the medial aspect of the greater tuberosity. (A) Preoperative SCD. (B) Postoperative SCD. (AP, anteroposterior.)

Outcome analysis was performed via the Internet-based Surgical Outcomes System (Arthrex, Naples, FL) to collect and evaluate visual analog scale (VAS) scores and American Shoulder and Elbow Surgeons (ASES) scores. Our primary outcome measure is the ASES score to assess overall function. VAS scores assessing pain in this patient population is obviously also very relevant as pain relief is a major goal in this patient population. Patient data were obtained preoperatively by this Internet-based questionnaire that allowed assessment of these measures at the time that it was decided to schedule the surgery. These scores were obtained preoperatively as well as at intervals of 2 weeks, 3 months, 6 months, 1 year, and 2 years postoperatively.

Functional measures of the patient's active forward flexion and abduction were obtained by a certified physical therapist using a goniometer. These measures were obtained with the patient standing, the arm actively raised against gravity resistance, and the scapula stabilized to isolate true glenohumeral motion. Similarly, strength testing with a single maximum effort in forward flexion, abduction (supraspinatus), and external rotation (infraspinatus) was also measured and recorded during functional evaluation using a digital dynamometer. Forward flexion strength was measured with the thumb internally rotated and the arm extended forward 30° to 45° from the midline. External rotation strength was included in this analysis as many of the tears included the infraspinatus. These digital dynamometric strength analyses and functional range of motion assessments were obtained preoperatively as well as at 6 months, 1 year, and 2 years postoperatively.

All data collected were recorded, maintained, and analyzed in a database (Excel, Microsoft) with subsequent statistical analysis involving normally distributed, unpaired 1-way t tests to the level of $P < .05$. In evaluation of parameters for correlation we use the Pearson correlation coefficient test. For purposes of this report, 1-year data are being used for outcome analysis of our early results. χ-Square goodness of fit analysis performed on our data confirmed normal distribution of our data.

Surgical Technique

We perform all of these cases in the lateral decubitus position with general anesthesia and a single-shot interscalene block or single-shot block with indwelling pain catheter. The shoulder is examined to assess range of motion and stability and then the patient is placed in the lateral decubitus position with the arm positioned in 45° of abduction, 10° of forward flexion, and neutral rotation. A posterior glenohumeral viewing portal is created along with an anterior outflow/working portal, and diagnostic arthroscopy is performed. Any intra-articular pathology is assessed and addressed appropriately (glenohumeral debridement or biceps tenotomy as needed). Specific attention is given to the rotator cuff as it is assessed for degree of retraction, mobility, tissue quality, and atrophy. The majority of these tears were U-shaped and were unable to be re-approximated to the tuberosity despite multiple attempts in mobilization with margin convergence and release techniques. The patients included in this outcome analysis were patients who had completely irreparable rotator cuff tears of the supraspinatus and infraspinatus tendons. The tears were determined to be irreparable after a thorough diagnostic arthroscopy was performed, and any residual rotator cuff tissue was completely mobilized through release techniques such as the interval slide technique with attempts in multiple vectors to attempt reapproximation of the torn rotator cuff to the native footprint. There were no partial rotator cuff repairs and no patients with a torn subscapularis or teres minor requiring repairs in this analysis. After any intra-articular pathology is addressed, the arthroscope is then reconfigured into the subacromial space and a midlateral portal is created. Arthroscopic visualization is typically performed using the midlateral portal, with anterior, posterior, and juxta-acromial working portals being used.

The undersurface of the acromion and the coracoacromial ligament is assessed for evidence of impingement. Any evidence of abrasion on the undersurface of the acromion is addressed with an arch sparing/gentle subacromial smoothing procedure. The acromioclavicular joint is assessed, and if required (acromioclavicular joint tenderness), a distal clavicle excision is performed (n = 23). The rotator cuff is evaluated for reparability, and when it is deemed to be irreparable because of retraction and atrophy, the joint is prepared for arthroscopic SCR. We performed biceps tenotomy prior to performing SCR on all of these patients. Any atrophic rotator cuff tissue is debrided and the arthroscopic shaver is used to expose the superior glenoid.

Our surgical technique for arthroscopic superior reconstruction largely mimics the technique described by Adams et al.[4] with modification to the glenoid fixation technique and graft passage. Our technique favors an advancement technique rather than double pulley used by Adams et al. As stated previously, we use the lateral decubitus position with 4 portals: anterior, posterior, midlateral and a juxta-acromial portal such that is used in a standard rotator cuff repair (Fig 3). The juxta-acromial portal is placed to facilitate appropriate anchor placement in the superior glenoid rim as well as anchor placement to the proximal humerus for standard arthroscopic transosseous equivalent double-row fixation technique of the graft to the humerus. This portal is similar to a standard rotator cuff repair portal used for anchor placement and is placed with the assistance of visualization with a spinal needle. After

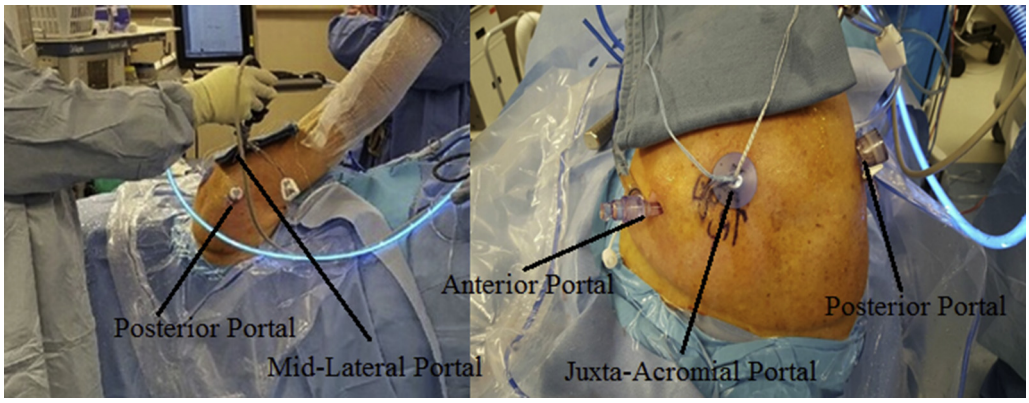

Fig 3. Portals used in the lateral decubitus position: anterior and posterior working portals, midlateral viewing portal, and a juxta-acromial portal similar to that used in a standard rotator cuff repair for anchor placement in the glenoid and humerus as well as graft advancement.

abrasion of the superior glenoid rim and the footprint of the greater tuberosity of the humerus, drill holes are placed in the superior glenoid rim in preparation for graft fixation. The 2 medial row anchors (biocomposite 4.75 × 19.1 mm; Arthrex) on the humerus are placed with associated suture tapes. Graft dimensions are obtained medially on the superior glenoid rim, laterally on the humeral footprint between remnant rotator cuff tissue, and anteriorly and posteriorly between the superior glenoid and the humerus.

A 3.0-mm (2.75-3.25 mm)-thick acellular dermal allograft is prepared using the dimensions obtained. Three suture tapes to be used for glenoid fixation are placed in the medial aspect of the graft. We mark the middle suture tape with a surgical marker at the graft/suture tape interface as well as at the free ends to facilitate identification during graft advancement and fixation. Two holes of sufficient diameter are placed in the lateral aspect of the graft to allow passage of the medial row suture tapes that are in the rotator cuff anchors.

Glenoid fixation modification in our technique uses a push-in anchor technique (biocomposite 2.9 × 12.5 mm, Arthrex) that allows us to use the anchor suture tape configuration to push the graft in through the juxta-acromial portal and securely fix the graft to the glenoid adjacent to the articular margin immediately medial to the superior articular surface of the glenoid. In our hands, this fixation is favored over the double pulley technique due to ease of graft advancement using the anchor to advance the graft, as well as the fixation provided by the anchor being placed in the typically strong subchondral bone of the glenoid immediately adjacent to the superior glenoid rim. This technique is also knotless, providing strong, smooth fixation of the medial aspect of the graft. Typically we advance the graft through the juxta-acromial portal with the suture tape and anchor of the posterior superior glenoid fixation site, followed by fixation of the graft to the middle anchor of the superior glenoid, and lastly the anterosuperior glenoid anchor. All cases that we have performed use 3 push-in anchors on the glenoid. After this is performed, the humeral side of the graft is fixed using the suture tapes in the 2 medial row anchors and an additional 2 screw-in anchors laterally to the greater tuberosity of the humerus. This is analogous to the arthroscopic double-row transosseous equivalent technique described by Park et al.[17] Typically, 2 margin sutures were placed suturing the posterior aspect of the graft to the intact posterior rotator cuff musculature as well as a single margin suture between the anterior aspect of the graft and the superior margin of the intact subscapularis tendon. Postoperatively, we treat all of these patients with a similar rehabilitation protocol with which we treat our rotator cuff repairs. This includes sling immobilization for comfort with passive range of motion for 4 weeks. Active assisted motion is commenced at 4 weeks with progression to active motion by 8 weeks postoperatively.

Results

There were 88 shoulders in 86 consecutive patients (59 male and 27 female) with an average age of 59.4 years (range, 27-79 years) at the time of surgery for this retrospective review. Each presented with symptoms of rotator cuff arthropathy manifested by severe weakness and pain. Of these patients, 41% failed 1 or more previous surgical attempts to treat their rotator cuff pathology. The majority (78%) presented as pseudoparalytic, defined as the inability to abduct or having forward flexion of less than 90 with normal passive range of shoulder motion and the absence of neurologic impairment. No patients were determined to have severe glenohumeral arthritis or acetabularization of the acromion on preoperative imaging. All patients presented with massive rotator cuff tears (Cofield classification >5 cm), retraction (>5 cm), and Goutalier

Table 1. Outcome Data at 1-Year Follow-up

	ASES Score	VAS Pain
Preoperation	52.22 ± 19.29	4.0306 ± 2.5478
1 year	81.56 ± 10.21	1.51 ± 1.21

NOTE. The outcome data above show significant improvement at 1-year follow-up for ASES and VAS scores ($P = .005$).

ASES, American Shoulder and Elbow Surgeons; VAS, visual analog scale.

grade 3 or 4 atrophy as classified on preoperative MRI scan. The tears involved the supraspinatus or typically both the supraspinatus and infraspinatus tendons with the anteroposterior extension of the graft being 15 mm and 23 mm for the glenoid and tuberosity respectively. There were no tears involving the subscapularis or teres minor in these patients.

Clinical Results

One-year follow-up (range, 16-28 months) is available on all 86 patients in this outcome analysis, with 23 patients having 2-year follow-up data. Clinical results, as evaluated by the Internet-based outcome scoring systems, revealed statistically significant improvements ($P = .005$) in all clinical outcome measures. Specifically, the mean preoperative VAS score was 4, which improved to a mean VAS score of 1.5 at the 1-year follow-up. Similarly, ASES scores (52 preoperation to 82 at 1-year follow-up) showed statistically significant improvements maintained at 1-year follow-up (Table 1) ($P = .005$). A patient satisfaction of 90% was found on post-op surveys.

Range of motion evaluations postoperatively revealed improvement in both abduction and forward flexion. At 1-year follow-up, shoulder active range of motion improved significantly by 39° for forward flexion ($P = .04$) and 56° for abduction ($P = .007$) (Table 2). Shoulder strength also improved significantly at the 1-year follow-up (forward flexion: 4.8-9.8 pounds; abduction: 4.1-9.2 pounds; external rotation: 7.7-12.3 pounds) ($P = .0005$; $P = .01$; $P = .02$) (Table 3). At the 1-year follow-up, there was no statistical difference in strength between the surgical and nonsurgical extremities.

Radiographic Evaluation

The mean preoperative measurements were 7.1 mm for the acromiohumeral interval and 52.9 mm for the superior capsular distance. Our analysis showed significant changes at the 1-week, 6-month, and 1-year points with a 2.6-mm increase in the acromiohumeral interval ($P = .049$) and 6.7-mm decrease in superior capsular distance ($P = .011$) from the preoperative to 1-year follow-up dates (Table 4).

Failures

Currently, we are obtaining advanced imaging of all of our patients to evaluate graft incorporation; however, we have had 3 radiographically revealed graft failures on MRI in patients reporting dissatisfaction. One additional patient reported dissatisfaction due to pain and lack of function, but the MRI revealed an intact graft. This patient was the only one who proceeded with revision to reverse total shoulder arthroplasty. These patients represent a failure rate of 4.5% (4/88 shoulders). All 3 radiographic failures we observed occurred at the greater tuberosity of the humerus attachment site.

Patients With 2-Year Follow-up

We do have a subset of 38 patients with 2-year follow-up. Two of our failures are in this subset of patients leaving 36 patients included in analysis of 2-year results. VAS scores in this subset of patients showed significant improvement with a mean of 4.26 preoperatively to 1.24 at 2-year follow-up ($P < .05$) and ASES scores showed significant improvement as well with preoperative mean ASES score of 49.5 and 2-year mean ASES score of 85.3 in these 36 patients without evidence of failure at 2-year follow-up. Radiographic follow-up revealed a similar improvement with mean acromiohumeral interval of preoperation of 7.3 mm improved to 9.9 mm 2-year postoperatively ($P = .0492$) and mean SCD improvement from 53.4 to 45.8 mm postoperatively ($P = .01$). Range of motion improvement in these patients showed improvement in mean forward flexion from 123° preoperatively to 162° at 2 years postoperatively ($P = .041$) and mean abduction of 106° preoperatively to 160° at 2 years postoperatively ($P = .006$). Strength measures improved in forward flexion from 4.7 lb preoperatively to 9.8 lb at the 2-year follow-up ($P = .46$) abduction from 4.0 lb preoperatively to 9.4 lb at the 2-year follow-up ($P = .40$), and external rotation 7.6 to 12.6 lb at 2-year follow-up ($P = .05$).

Discussion

The principal findings in this study show that SCR using an acellular dermal allograft produces patient satisfaction, including reduced pain and improved functionality, on par with Mihata's original report using fascia lata autograft. Historically, the younger, active

Table 2. Range of Motion (Degrees)

	FF	ABD
Preoperation	121 (10-180)	103 (15-180)
6 months	145 (60-180)	137 (45-175)
	$P = .0283$	$P = .00941$
1 year	160 (70-180)	159 (68-180)
	$P = .0436$	$P = .00678$

NOTE. This table reveals a statistically significant improved range of motion in forward flexion ($P = .0436$) and abduction ($P = .00678$) in these patients through a minimum of 1-year follow-up.

ABD, abduction; FF, forward flexion.

Table 3. Dynamometric Strength Measurements (lb)

	FF		ABD		EXT	
	Surgical	Nonsurgical	Surgical	Nonsurgical	Surgical	Nonsurgical
Preoperation	4.8 (0-11.5) $P = .00051$	14.1	4.1 (0-11.9) $P = .000013$	13.9	7.7 (0-19.2) $P = .018$	16.5
6 months	6.2 (0.5-18.0) $P = .016$	13.0	5.8 (0.5-17.0) $P = .0022$	11.1	9.3 (3.2-20) $P = .011$	15.2
1 year	9.8 (3.0-18.1) $P = .44$	11.5	9.2 (0.5-16.1) $P = .39$	10.1	12.3 (2.0-20.3) $P = .060$	14.7

NOTE. Results of dynamometric strength measurements (in pounds) taken on the surgical extremity and nonsurgical extremity are depicted. Measurements are statistically different until 1 year postoperation, when there is no significant difference between the surgical and nonsurgical extremity.

ABD, abduction; EXT, external rotation; FF, forward flexion.

patient with massive, irreparable rotator cuff pathology coupled with significant functional and motion impairment has been a difficult patient subset to predictably treat with arthroscopic methods.

The younger, active patient with massive, irreparable rotator cuff pathology coupled with significant functional and motion impairments has been a historically difficult patient to predictably treat with arthroscopic methods. When nonsurgical and arthroscopic treatment options fail in these patients with a nonarthritic shoulder and massive rotator cuff tear with chronic rotator cuff insufficiency, historically they have often been salvaged with open procedures such as latissimus dorsi, pectoralis major, or teres major muscle transfer procedures. These transfer procedures are performed to correct joint kinematics, decrease pain, and restore shoulder function with favorable results reported in the literature.[6-9] Other arthroscopic surgical treatment options have been described, including simple arthroscopic debridement with or without biceps release or tenodesis, arch-sparing subacromial smoothing with further capsular releases and debridement as necessary, partial rotator cuff repair, and bridging of defects with graft material.[10-14,18] In our experience, the results of these arthroscopic procedures in these patients are largely unpredictable and can be short-lived because of the continued altered mechanics from rotator cuff insufficiency and loss of superior capsular integrity. More recently, Mihata et al. introduced the arthroscopic SCR as a procedure that has shown promising clinical results in this problematic patient population. In Mihata's initial published report describing his clinical results, this procedure had clinical results on par with open muscle transfer procedures in terms of pain relief and function restoration. Mihata's original case series described this procedure being performed with fascia lata autograft. Subsequently, Hirohara and Adams described a technique using acellular dermal allograft to decrease the graft site morbidity associated with the harvesting of fascia lata in these patients.[5] All patients treated in our series received an acellular dermal allograft.

As previously mentioned, treatment of these patients with open procedures to attempt to restore joint function, kinematics, and strength with muscle transfer procedures have been shown to yield favorable results. Specifically, the latissimus dorsi transfer procedure to restore function in patients with chronic posterosuperior rotator cuff insufficiency and pectoralis major transfer for patients with chronic anterosuperior rotator cuff insufficiency have been described as salvage procedures to restore function and relieve pain in these patients.[6-9] Gerber et al. reported 10-year results in treating younger nonarthritic patients with chronic irreparable rotator cuff tears with posterosuperior rotator cuff insufficiency treated with latissimus dorsi transfer. In Gerber's series, the patients had improvements in forward flexion from 118° preoperatively to 132° postoperatively and abduction from 112° preoperatively to 123° postoperatively. Although the results in our report are short-term, 1 to 2 years' follow-up, our series of arthroscopic SCR had range of motion improvements in forward flexion of 120° to 160° and abduction of 103° to 159°. These shorter-term improvements are certainly at least equally favorable to those seen in Gerber's series, revealing a favorable functional result with this procedure. Mihata's clinical results also showed functional motion improvements similar ot those in his original case series.[3] Longer-term follow-up is essential to ascertain whether these short-term improvements are maintained. In a more recent

Table 4. Radiographic Measurements (mm)

	AHI	SCD
Preoperation	7.1	52.9
1 week	10.8 ($P = 3.22E{-}07$)	49.2 ($P = 5.25E{-}05$)
6 months	9.0 ($P = .00872$)	48.7 ($P = .00932$)
1 year	9.7 ($P = .0487$)	46.2 ($P = .01052$)

NOTE. The results of acromiohumeral interval (AHI) ($P = .049$) and superior capsular distance (SCD) ($P = .011$) from standing anteroposterior radiographs show improvements maintained over the 1-year follow-up.

AHI, acromiohumeral interval; SCD, superior capsular distance.

series of patients reported by Kanatli et al., patients with pseudoparalysis and rotator cuff arthropathy were treated with arthroscopic assisted latissimus dorsi transfer. In their short-term follow-up of minimum of 24 months (24-31 months), they reported improvements in forward flexion of 58° to 130°, abduction of 51° to 129°, and acromiohumeral distance improvement of 3.13 mm to 5.67 mm postoperatively. The patients in our series and Mihata's series reveal similar improvements when treated with arthroscopic SCR, again validating this procedure's efficacy as a comparable procedure to muscle transfer in treating this problematic patient population.[2]

The loss of superior stability present with the absence of the superior capsule has been theorized as a reason for the higher failure rate in reparable massive rotator cuff tears.[4,19] The presence of superior capsular instability in irreparable rotator cuff tears has been implicated in pain associated in these patients due to abrasion on the undersurface of the acromion. These observations lead to the implementation of bridge grafting of larger, irreparable rotator cuff tears to restore superior stability of the shoulder, decrease pain and increase function. Previous clinical reports have documented soft tissue augmentation with bridging patch graft surgery as a viable option for these irreparable rotator cuff tears.[10-13] In their cadaveric biomechanical study, Mihata et al. compared SCR versus rotator cuff patch grafting and rotator cuff and superior capsular patch grafting. This analysis showed that although rotator cuff patch grafting did reduce the superior translation of the humerus, it was not able to fully restore glenohumeral joint stability. When an SCR was performed in this model, normal restraint of the glenohumeral joint was achieved.[2] Consequently, this led to their conclusion that theoretically a higher retear rate for patch grafts secured medially to the rotator cuff could be higher than those attached medially to the glenoid due to less superior stability and possible abrasion of the patch graft on the undersurface of the acromion.[2] The implication of this analysis is that the superior capsule is essential to glenohumeral joint stability. Restoring superior capsular integrity helps recenter the humeral head in the glenoid and provide superior stability, thereby preventing contact between the humeral head and the undersurface of the acromion.[2-5,20] Shoulder function is theoretically maintained through this restoration of superior capsular integrity and re-establishment of the rotator cable as described by Burkhart et al.[19,21]

Radiographic analysis of our series revealed significant improvement at the 1-week, 6-month, and 1-year time points for an increase in the acromiohumeral interval (mean 7.1 mm preoperatively to mean 9.7 mm at 1 year) ($P = .049$). In evaluating these patients radiographically, we also presented and used the superior capsular distance, which we believe can help quantify the degree of initial improvement, as well as maintenance, of superior capsular stability provided by SCR as it reveals the correction of the superior migration of the humeral head in respect to the superior aspect of the glenoid. We have also noticed clinically that some massive rotator cuff tears that are unable to be reapproximated to the native rotator cuff footprint initially, are able to be advanced over the rotator cuff footprint after SCR is performed. We believe that this may be due to the decreased length that the rotator cuff needs to be advanced because of a theoretical decrease in the superior capsular distance provided by the restoration of superior stability and reduction of the humeral head in relation to the glenoid provided by the SCR. In our series, superior capsular distance improved significantly from a mean of 52.9 mm preoperatively to a mean 46.2 mm at the 1-year follow-up ($P = .011$). The maintenance of this reduction through the postoperative period can also be used to quantify continued superior capsular stability over time. Recognizing the role of superior capsular stability provided by concomitant SCR and rotator cuff repair may prove beneficial in providing decreased failure rates in massive rotator cuff repairs. We theorize this may be due to decreased tension on the repair after SCR, maintenance of superior capsular stability, and soft tissue augmentation of poor-quality native rotator cuff tissue. We have a series of patients ($n = 48$) treated with concomitant SCR and rotator cuff repair of massive tears with advanced atrophy who have had similar favorable short-term (1-2 year) clinical and radiographic results that are reported in a separate case series. We also hypothesize that the measurement of superior capsular distance may be a more accurate measure of actual restoration of superior stability postoperatively as it is a reflection of the anatomic recentering of the humeral head within the glenoid. Second, factors such as concomitant subacromial decompression or subacromial smoothing changing the acromial morphology on anteroposterior radiograph can affect acromiohumeral measurement.

In Mihata et al.'s initial clinical case series, they reported the clinical outcome after SCR using a fascia lata autograft. Their postoperative ASES shoulder index was 92.9 points, with other positive outcomes such as a 95.0 Japanese Orthopaedic Association score and 32.9 University of California—Los Angeles Shoulder rating.[4] The outcome analysis of our case series showed similar improvements. Clinical outcome measures included improvements in outcome scores evaluated such as VAS scores (4.0-1.5) and ASES scores (52-82) at 1-year follow-up. All of these clinical outcome measures were improved to a level of statistical significance ($P < .05$).

The initial clinical presentation of our patients included severe weakness, pain, and pseudoparalysis in

the most severe cases. Most previously described arthroscopic methods of treatment in these patients effectively relieve the shoulder pain, but patients found it difficult to recover muscle strength in the long term. In the patients in our series treated with arthroscopic SCR, the preoperative range of motion and shoulder muscle strength had severe deterioration when compared against the nonsurgical extremity. Preoperatively, the mean range of motion was 120° of forward flexion and 103° of abduction while mean strength measures with dynamometric evaluation yielded mean values of 4.8 pounds forward flexion, 4.1 pounds abduction, and 7.7 pounds external rotation. One-year follow-up data revealed statistically significant improvement in forward flexion ($P = .044$) and abduction ($P = .007$) measures to 160° and 159°, respectively (Table 4). A similar improvement of forward flexion range of motion to 157° was also noted by Mihata et al.[3] Strength measures in all motion planes evaluated revealed similar significant improvements in all measures. Notably at the 1-year follow-up, no significant strength difference between operative and non-operative extremity was found. Forward flexion, abduction, and external rotation strength increased to 9.8, 9.2, and 12.3 lb, respectively.

Limitations

We recognize admitted limitations of this outcome analysis. As this is a short-term follow-up analysis, we are continuing to follow these patients and will soon be able to have all reach the 2-year postoperative point. Those patients who have made it to the 2-year point of follow-up have shown maintenance of clinical and radiographic improvement at the 2-year point as well. We had no exclusion criteria, and thus minimal selection bias as every patient who underwent SCR from our institution was included in the study. In terms of recording bias, the acromiohumeral distance and superior capsular distance measurements were determined by a research assistant under the supervision of the lead author. By supervising and double-checking these measurements, we believe recording bias was minimized in this study. Lastly, we only obtained MRI scans in those patients who were dissatisfied or who sustained trauma.

Conclusions

This analysis reveals that arthroscopic SCR with acellular dermal allograft has been successful in decreasing pain and improving function in this patient subset. Radiographic analysis has also shown a consistent and lasting decrease in superior capsular distance and increase in acromiohumeral interval, indicating maintenance of superior capsular stability.

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