The Evolution of the Superior Capsular Reconstruction Technique

After years of research and clinical trials, this procedure has become a valuable and viable option to treat patients with irreparable, massive rotator cuff tears.

Authors

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Introduction

Irreparable, massive rotator cuff tears can result in unacceptable functional deficits in patients. When the supraspinatus tears and retracts medially, the superior capsule is also disrupted, and superior constraint is lost. With no superior restraint to the humerus, the humeral head migrates superiorly, causing a decrease in the acromial-humeral distance. [1-4]

Biomechanical analysis has shown that a defect in the superior capsule results in a minimum 200% greater glenohumeral superior translation and subacromial peak contact pressure compared with an intact capsule. [3] The malposition of the humeral head leads to functional abnormalities and pseudoparalysis.

Numerous proposed treatments for massive rotator cuff tears – including debridement and tenotomy, tendon transfers, and reverse total shoulder arthroplasty – have yielded mixed results and high complication rates. [5-12] In particular, reverse shoulder arthroplasty can result in humeral or glenoid fractures, persistent anterior or posterior instabilities, loosening of the glenoid or humeral cemented components, dislocations, and infection. [5-7]
The superior capsular reconstruction (SCR) was described by Hanada et al [13] in 1993 and by Mihata et al [1] in 2013 as an alternative procedure to increase function and decrease pain by restoring the restraint mechanisms in the shoulder. Using a graft to recreate the superior capsule, the humeral head is centered in the glenoid, allowing the larger muscles (ie, deltoid, latissimus dorsi, and pectoralis major) to function appropriately. Mihata et al [3,4] have found that the SCR reduces glenohumeral superior translation and subacromial contact force.

Mihata et al [1] described their SCR technique using a 6-mm to 9-mm fascia lata autograft. Hirahara et al [14] modified this procedure to use a thinner, 3.5-mm dermal allograft (ArthroFLEX 301; Arthrex, Inc., Naples, Florida) (Figure 1). Many SCR techniques have been described in the literature since the publication of these 2 landmark papers. [15-20]
Rotator cuff tears can be classified as irreparable if the muscle has retracted medially to the extent that it is unable to be pulled and attached back to its anatomic footprint, or if the tissue integrity is so poor that an attempted repair has previously failed or would likely fail. It is often difficult to complete a repair of tissue that has retracted to or past the glenoid rim.

Typically, patients with irreparable supraspinatus and/or infraspinatus tears and minimal arthritis are initially treated conservatively. The SCR is indicated for these patients if:

- Shoulder pain proves intolerable
- The patient feels the dysfunction is unacceptable
- A previously attempted repair has failed

The SCR is contraindicated for patients with moderate to severe arthropathy (Hamada Scale 4 or greater [21]), diminished large muscle function (ie, deltoid, latissimus dorsi, or pectoralis), significant bone defects, or shoulder stiffness.
Outcomes Studies with the SCR

A torn tendon can be reattached to the rotator cuff footprint, but increased tension on the repair may result in failure from the weak tissue and create an environment that is not conducive to healing. [22] Techniques have been described for anterior and posterior “interval slides,” with the goal of reducing tension and increasing the likelihood of a large rotator cuff repair to succeed. [23-26] This method may not be technically feasible for surgeons of all levels.

Another technique for repair of massive, retracted tears of the rotator cuff medializes the attachment of the cuff to the humeral head. [27] This, however, is biomechanically insufficient, as the supraspinatus is known to play a critical role in maintaining the humeral head appropriately in the joint. [1-4] Without restoring the superior restraint to the humerus by spanning the defect from the lateral humerus to the glenoid, the humeral head will still migrate superiorly and lead to the dysfunction and pain.

To date, 2 clinical outcome studies with a minimum 2-year follow-up have shown similar results, [1,28] indicating the SCR is an effective method to decrease pain and increase function in patients with massive irreparable rotator cuff tears.

Hirahara et al [28] found that patients undergoing an SCR had better 2-year outcomes when compared with patients who had massive rotator cuff repairs. Acromial-humeral distance was shown to improve by 3.98 mm (P=< 0.0008) over the 2-year follow-up (Figure 2). They also observed pulsatile vessels on ultrasound appearing between 4 and 8 months in the graft at the insertion site, indicating that the graft was vascularizing and incorporating (Figure 3). [28] These vessels eventually disappeared by the 1-year mark, indicating transformation of the dermal tissue with vessels to connective tissue with capillary flow.
Figure 2. Preoperative anterior-posterior radiograph (A). The decrease in the acromial-humeral distance (yellow line) is an indirect indication of a massive rotator cuff tear and disruption of the superior capsule. Corresponding radiograph of the same patient 13 months after surgery (B). The acromial-humeral distance (green line) can be seen to be increased compared to the preoperative image. This indicates the SCR is holding the humeral head centered in the glenoid.
Figure 3: A short axis ultrasound image of a patient 6 months post-SCR. The color Doppler mode on the ultrasound is used to detect blood flow within the yellow square. The red vessels (white arrow) indicate revascularization within the graft. This suggests the graft is being incorporated into the body.

One of the authors of this article (ESL) had a patient with an SCR that failed after a postoperative fall. The graft was explanted 13 months postoperatively during a debridement surgery (Figures 4 and 5). On analysis, fibroblast-like cells had infiltrated into the graft, and signs of neovascularization were present in the periphery of the graft (Figures 6 and 7). Tendon-like tissue structure was found near the glenoid attachment, while fibrocartilage-like tissue was seen on the articular side of the graft, indicating appropriate changes from pressure of the humeral head (Figures 8).

Figure 4. An external view of the bursal side of the SCR dermal allograft explant.
Figure 5. Histologic analysis of the explanted dermal allograft, showing fibrocartilage deposition within the graft, greater on the articular side versus the bursal side.
Figure 6. Microscopic analysis of the explanted dermal allograft. Fibroblast-like cells (black arrows) can be seen to have infiltrated into the acellular dermal allograft, indicating recellularization.

Figure 7. Microscopic analysis of the explanted dermal allograft. An abundance of capillary vessels can be seen forming within the allograft (black arrows).
These findings indicate that the acellular dermal graft tissue was being incorporated by the body, and that the graft was acting as a stabilizing force as opposed to just a spacer. The finding of fibroblast- and fibrocartilage-like tissue and the disappearance of the vessels support the hypothesis detailed by Hirahara et al [28] that the dermal allograft transforms into capsular ligamentous tissue.

**Implantation and Graft Stability**

The dermal allograft is significantly stronger than the fascia lata autograft but is more elastic. Mihata et al [29] showed that the fascia lata autograft is stiffer and results in diminished range of motion. In another study, Mihata et al [30] suggested attaching an 8-mm fascia lata autograft in 10° to 30° of glenohumeral abduction for greater shoulder stability.

Although the latter technique may work with a fascia lata autograft, it may not work with a dermal allograft: The 2 grafts are different, and when approaching the techniques of implantation, the surgeon must be cautious about applying research from one graft to the other. Dermal allograft elasticity will allow for greater deformation without failure; however, stability is compromised if the graft is too loose when implanted. Conversely, if the graft is implanted too tightly, over-constraint results in increased joint reaction forces, causing greater pain, failure of fixation, or failure of the graft.

Hirahara et al [14] showed that implantation of the graft and stability can be determined by placing the anchors at the edges of the tear and pre-measuring the distances between the anchors with the arm in neutral position. The authors define “neutral” as 0° of flexion-extension.
and 0° of rotation with the patient in resting abduction. The degree of abduction may vary depending on the patient’s body habitus but should generally be considered where the arm sits naturally. This method is believed to be the most reliable technique for graft measuring and tensioning.

Determining the precise distances between the anchors before introduction of the graft, based on the arm position, can help avoid graft tensioning issues (Figure 9). Pre-punching holes in the graft with the appropriate distances from the anchors will pre-set the tension on the graft per the tear size and configuration. The distance between the anchors is determined by tear size and arm position, which will change the distances between the anchors as the arm position changes (Figure 10).

Figure 9. A graphic representation of typical measurements for the SCR dermal allograft. The yellow circles represent the site of the anchors for the medial and lateral attachments. The red circles represent where the anterior and posterior margin convergences will be attached. The distances in the figure are in millimeters (mm). The average size of the SCR graft is 45-50 x 45-50 x 25-40 x 30-40 (Anterior x Posterior x Medial x Lateral).
Figure 10. Diagram of basic shoulder anatomy represents how changes in arm position affect the distance relationships between anchors on the glenoid and greater tuberosity (A). The measurements between the anchors (white circles) are represented by the yellow lines. Diagram of an arm in neutral rotation (left) compared with an arm in internal rotation (right) and the effect on the measurements between the anchors in the anterior and posterior aspect of the shoulder (green and red lines, respectively) (B). Diagram of an arm in neutral abduction (left) compared with an arm in increased abduction (right) (C). Abduction decreases the distance between the medial and lateral anchors (red line).

For example, increasing the abduction angle will shorten the distance between the glenoid and tuberosity anchors, and internal rotation will shorten the anterior distance but lengthen the posterior distance. These mismatches of distances will result in abnormal tensioning of the graft and early failure.

When measuring the distances, the surgeon must take into account that curvilinear distance does not equate to linear distance. The glenoid and humeral head have curved surfaces, so exact measurement is impossible using a straight edge. The linear distance will be shorter than the curvilinear, which will result in an over-constrained graft if used. The senior author of this article (AMH) has developed a technique to measure the curvilinear distance exactly using the sutures from the suture anchors and converting it to linear distance for exact measurement on the graft. [14]

Anterior and Posterior Margin Convergence

Mihata et al [1] originally maintained that anterior margin convergence was unnecessary and that only posterior margin convergence was needed. Hirahara et al [28] found that patients with anterior margin convergences did significantly better than those with only posterior margin convergence. Mihata’s data apply to use of a fascia lata allograft and cannot necessarily
be applied directly to the use of a dermal allograft because of the different biomechanical properties.

Anterior margin convergence should only be performed when rotator interval tissue is present. In the absence of rotator interval tissue, the graft should not be attached medially to the subscapularis, as closure of the interval would result in abnormal increased joint reaction forces; the graft should only be attached laterally to the lesser tuberosity or the lateral subscapularis.

Poisson’s ratio is the ratio of transverse contraction to longitudinal extension in the presence of a stretching force. When performing an SCR, Poisson’s ratio highlights the importance of anterior and posterior margin convergences. By securing the graft and limiting contraction anteriorly and posteriorly, excessive elastic stretch in the medial-lateral directions can be prevented.

This is supported by the concept of the “rotator cable complex,” first introduced by Burkhart et al, [31] which the authors of this article have renamed the “rotator-capsule cable complex.” The normal cable that runs from anterior to posterior along the lateral edge is similar to the constraints in performing margin convergence. This ensures adequate graft tensioning, increases construct stability, and improves clinical outcomes.

**Graft Thickness and Fixation**

Mihata et al [1,30] have maintained that using a 6- to 9-mm thick graft is critical to success of the SCR. This is not necessarily true when using a dermal allograft because the dermal allograft is so much stronger than a fascia lata autograft. Hirahara et al [28] showed that a 3.5-mm thick graft is preferable than a thinner graft when using the dermal allograft, which can rupture if the graft is thinner than 3 mm.

Biomechanical analysis has shown that the maximal load of the 3.5-mm dermal allograft (530 N) exceeds that of a standard double-row SpeedBridge (Arthrex, Inc., Naples, Florida) rotator cuff repair (482 N). The thinner 1.76-mm to 2.25-mm dermal allografts had a lower maximal load (290 N). The maximum loads of both dermal allografts exceeded the maximum loads of 3-mm and 4-mm fascia lata autografts (153 and 181 N, respectively). In a comparison of failure modes, 2 of the 3 3.5-mm dermal allograft samples broke the foam block of the testing construct. The third failed at the knot of the PASTA Bridge. [32] For the other samples (thinner dermal allograft, 3- to 4-mm fascia lata autografts), the graft either tore through or failed at the medial or lateral fixations (data on file, Arthrex, Inc.).

The double pulley system is used for implantation of the graft over the defect. [33] These are 2 independent pulley systems, 1 laterally and 1 medially, that are pulled alternately to ensure the graft does not flip or bunch in the subacromial space. Once the graft has been properly implanted, the sutures from the double pulley [33] and FiberTape sutures (Arthrex, Inc., Naples,
Florida) are used to create a SpeedBridge configuration laterally, which is generally considered to be the best method of lateral fixation at the greater tuberosity. [14-20]

Medial fixation, however, has been widely debated. Research has shown that larger anchors and more anchors, as well as double-row fixation, result in greater strength and fixation. [34] Hirahara et al [14] utilize a PASTA Bridge [32] configuration for glenoid fixation. This uses 2 3.0-mm BioComp site SutureTak anchors (Arthrex, Inc., Naples, Florida) on the glenoid rim, medial to the labrum, with a separate 3.5-mm BioComposite Vented SwiveLock (Arthrex, Inc., Naples, Florida) more medially. The sutures from the SutureTak anchors make up the medial pulley system. The PASTA Bridge [32] utilizes the anchors on the glenoid rim as pivot points and the more medial SwiveLock as the site where most of the stress is distributed. Recent innovations have seen the use of 2 or 3 3.9-mm Knotless Corkscrew anchors (Arthrex, Inc., Naples, FL) for glenoid fixation, backed up with a 3.5-mm BioComposite Vented SwiveLock for double-row fixation.

Mihata et al [2] compared the effect of SCR with and without acromioplasty on subacromial contact pressure, contact area, and superior migration. They found no difference in contact pressure or superior migration, but there was a significant decrease in contact area at 0°, 30°, and 60° of abduction. Although this sounds like a promising addition to the SCR procedure, in the event of a failure, the acromion could be worn and fractured as the humeral head abuts against it. The senior author of this article (AMH) only performs an acromioplasty in conjunction with an SCR if there is significant bone spurring that would create true external impingement.

Rehabilitation after the SCR

Rehabilitation following the SCR is aimed at protecting the integrity of the construct while the patient regains range of motion and begins minimal strength activities early-on. The strength of the dermal allograft and our surgical technique allows the rehabilitation process to begin 1 week postoperatively. Early pain-free passive range of motion is the goal, beginning with flexion, scaption, and external rotation. Allowing early movement can prevent some detrimental effects of prolonged immobilization, including stiffness, adhesions, and atrophy.

Patients use a shoulder sling for comfort for approximately 2 weeks. Submaximal isometrics of the musculature are initiated within 2 weeks to limit atrophy. From 3 to 6 weeks, very light strengthening progresses to active assisted range of motion and, eventually, to active range of motion against gravity.

Most SCR patients return to basic activities of daily living within 8 weeks and gravity-resisted forward flexion above 120°. Long-term strength is expected to be graded as 3+ to 4- since the supraspinatus is not being restored. Repetitive overhead activities (ie, tennis, throwing) may be challenging due to a lack of endurance.
The Future of the SCR

Research on the role of SCR in managing rotator cuff tears is ongoing, with studies currently focusing on:

- Fixation options
- Construct types
- Use of SCR as an internal brace to protect the repair of reparable large to massive rotator cuff tears
- Combining SCR with arthroplasty in patients with severe cuff tear arthropathy, as opposed to a reverse arthroplasty

Thus far, results have been encouraging. The SCR procedure improves the rotator cuff’s mobility, allowing it to be pulled over the tuberosity for easy fixation. SCR reduces the head into position, putting less strain on the rotator cuff repair.

Since its adoption in the United States, the SCR has shown tremendous potential and its popularity has grown. The SCR with a 3.5-mm dermal allograft was first performed in 2014, with 31 total procedures that year. In 2015 and 2016, there were 1629 and 5258 procedures performed, respectively. In North America from January through July 2017, 4780 procedures have been performed using the dermal allograft.

When Dr. Teruhisa Mihata began researching the superior capsule’s properties and role in the biomechanics of the shoulder, he had few options in Japan to treat irreparable, massive rotator cuff tears. After 12 years of research and clinical trials, the SCR has become a valuable option to treat patients with this very difficult problem.

Author Information

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Disclosures

Dr. Hirahara has disclosed that he is a consultant for and receives royalties and research support from Arthrex, Inc.; that he is a consultant for LifeNet Health, Inc.; and that he is a medical advisor for Clarius Mobile Health. Dr. Lederman had disclosed that he is a member of the speakers’ bureau for and receives royalties from Arthrex, Inc. Mr. Andersen and Dr. Yamashiro have no disclosures relevant to this article.
References

1. 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. **Clinical relevance:** The authors detail the first technical note and clinical outcomes of the SCR. They evaluated patients pre- and postoperatively by clinical outcome scores (American Shoulder and Elbow Surgeons), physical examination, radiography, and magnetic resonance imaging. The SCR was shown to improve clinical outcomes and is proven to be a reliable alternative for irreparable rotator cuff tears.


3. Mihata T, McGarry MH, Kahn T, Goldberg I, Neo M, Lee TQ. Biomechanical role of capsular continuity in superior capsule reconstruction for irreparable tears of the supraspinatus tendon. *Am J Sports Med*. 2016; 44(6):1423-1430. **Clinical relevance:** This study by Mihata et al was designed to assess the effects of anterior and posterior continuity after SCR. They found that a defect in the superior capsule results in a minimum of 200% greater humeral superior translation and subacromial peak pressure compared to an intact capsule. Performing a SCR with side-to-side suturing decreases these measurements to normal. Furthermore, they recommend posterior side-to-side suturing to provide additional stability, but express caution for anterior side-to-side suturing as it can result in an over-constrained shoulder and did not add any additional stability when performed in conjunction with posterior side-to-side suturing.

4. 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. **Clinical relevance:** Mihata et al aimed to determine if the SCR is an effective method of restoring the native superior restraints of the humerus. They found that a full-thickness supraspinatus tear increases humeral superior translation and subacromial contact pressure and decreased glenohumeral compression force compared with an intact rotator cuff. The SCR was found to fully restore the superior translation and subacromial contact pressure, but it did not alter the glenohumeral joint force.


14. Hirahara AM, Adams CR. Arthroscopic superior capsular reconstruction for the treatment of massive irreparable rotator cuff tears. *Arthrosc Tech*. 2015; 4(6):e637-e641. **Clinical relevance:** The authors developed an SCR technique that modified the original description by Mihata et al. The report by Mihata et al used a large fascia lata autograft. This technical note utilizes a human dermal allograft to recreate the superior restraint in the shoulder, which centers the humeral head within the glenohumeral joint.


28. Hirahara AM, Andersen WJ, Panero AP. Superior capsular reconstruction: clinical outcomes after a minimum 2-year follow-up. *Am J Orthop*. 2017; 46(6):266-272,278. Clinical relevance: This is the first clinical outcome study of the SCR with dermal allograft with a minimum 2-year follow-up. The results of this study mirrored those of Mihata et al’s landmark clinical outcome paper that used a fascia lata autograft. This study showed the SCR improves functional outcome measures, decreases pain, and increases acromial-humeral distance.


