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Treatment options for massive irreparable rotator cuff tears: a review of arthroscopic surgical options

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- While functional reconstruction of massive irreparable rotator cuff tears remains a challenge, current techniques aimed at recentering and preventing superior migration of the humeral head allow for clinical and biomechanical improvements in shoulder pain and function.
- Recentering of the glenohumeral joint reduces the moment arm and helps the deltoid to recruit more fibers, which compensates for insufficient rotator cuff function and reduces joint pressure.
- In the past, the concept of a superior capsular reconstruction with a patch secured by suture anchors has been used.
- However, several innovative arthroscopic treatment options have also been developed.
- The purpose of this article is to present an overview of new strategies and surgical techniques and if existing present initial clinical results.
- Techniques that will be covered include rerouting the long head of the biceps tendon, utilization of the biceps tendon as an autograft to reconstruct the superior capsule, utilization of a semitendinosus tendon allograft to reconstruct the superior capsule, superior capsular reconstruction with dermal allografts, and subacromial spacers.

Keywords

- massive irreparable rotator cuff tear
- superior capsular reconstruction
- margin convergence
- orthobiologics
- LHBT
- BAR
- SCR
- InSpace balloon

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Introduction

The prevalence of rotator cuff tears (RCT) in the literature is reported to be between 22.1% (1) and 34% (2), with one-third of the reported RCTs being symptomatic and approximately one-fourth of these RCTs being massive irreparable rotator cuff tears (MIRCTs) (1). There are numerous clinical presentations of MIRCTs, ranging from pain or decreased range of motion to debilitating pseudoparalysis. First-line therapy for MIRCTs can be either non-operative or operative and is dependent on age, rupture morphology, and patient expectations. Regardless, if non-operative treatment fails, surgical treatment should be considered.

Treatment of MIRCTs remains a challenging dilemma for surgeons. The intricate interaction between an aging population with associated sarcopenia and inferior tissue quality (3) in combination with increasing shoulder functional demands further complicates surgical management. Reverse total shoulder arthroplasty (RTSA) has traditionally been used in cases of MIRCTs, particularly in older patients (1, 2). The number of implanted RTSA has increased over the past years and continues to increase in the future. The number of primary shoulder replacements is set to increase significantly by 2040, reaching at least 37,000 procedures per year. Additionally, the age range of patients receiving RTSAs has expanded to include younger patients (4).

Despite the trend of rapidly increasing numbers of implanted RTSAs, alternative therapeutic options for MIRCTs have become available, as illustrated in the literature (5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17). The general concept of preventing the superior migration of the humeral head is to reduce the painful contact between the humeral head and the acromion and enable the remaining rotator cuff (RC) muscles and the deltoid muscle to be recruited for improved active range of motion. These techniques also seek to minimize glenohumeral joint pressures to reduce the risk of developing cuff arthropathy, reduce pain, and restore function.

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Recently, various autografts/allograft and surgical fixation techniques have been proposed including superior capsule reconstruction (SCR) with a dermal allograft (18), rerouting the long head of the biceps tendon (LHBT), utilization of the biceps as an autograft or the semitendinosus as a tendon allograft, and various subacromial spacers (Fig. 2). Clinically, SCR shows comparable results to RTSA (19) and may be preferable for certain patients. Recently, a consensus was reached on treatment for MIRCTs by the Neer Circle of the American Shoulder and Elbow Surgeons (Fig. 1) (24).

The purpose of this review is to present an overview of innovative surgical techniques for restoring native joint function in MIRCTs and to present available clinical results. A comprehensive search was performed using the PubMed (2019–2021) database. Keywords were as follows: massive rotator cuff tear; massive irreparable rotator cuff tear, superior capsular reconstruction. The queries were performed in October 2021. Inclusion criteria were techniques that provide a treatment option for MIRCTs. Articles involving RTSA, hemiarthroplasty, or muscle/tendon transfers were excluded.

Definition of tear size

If non-surgical treatment fails, preoperative MRI is necessary to assess tear size, degree of retraction, muscle atrophy, and fatty infiltration. Several classification systems with variable criteria for massive RCTs have been proposed. The Patte classification defines a massive RCT as retraction of tendons to the glenoid rim (20), Gerber *et al.* state that two tendons must be completely torn (6), Davidson and Burkhart define type 3 tears as a tear of at least 2 2 cm in the coronal and sagittal dimension (21), and lastly, DeOrio and Cofield define an anterior-posterior or medial-lateral dimension over 5 cm as massive (22). More recently, a Neer Circle Consensus statement determined that a massive RCT should be defined as the retraction of tendon(s) to the glenoid rim in either the coronal or axial plane and/or a tear with 67% of the greater tuberosity exposed measured in the sagittal plane (23). The measurement can be performed either with MRI or intraoperatively (24, 25, 26).

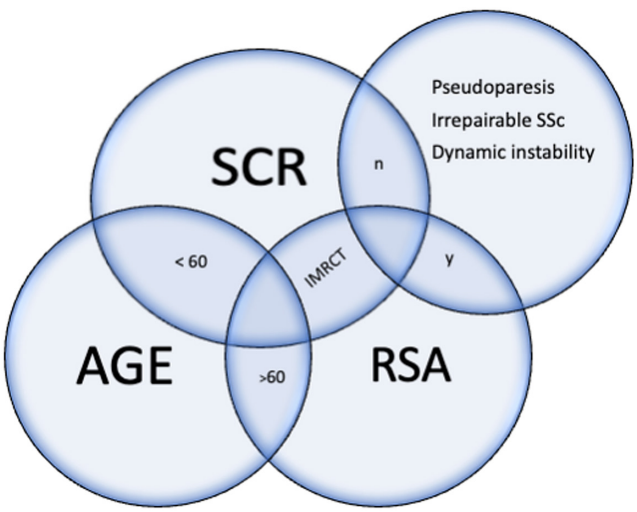

Figure 1
Neer Circle Consensus Paper on the treatment algorithm for MIRCTs: Displayed are the conditions in the patients where consensus was reached on treatment for MIRCTs (24). Starting with the patient's age (bottom left bubble) and adding clinical findings (top right bubble), recommendations for treatment can be seen in this chart.

Indicators of irreparability of RCTs

Preoperative risk factors for irreparability help to anticipate the intraoperative risk of facing irreparable tears. Predictors of irreparability reported in the literature include the following:

- Tear size and age (25).
- Fatty degeneration: over 50% fatty infiltraion of the muscle belly (Goutailler grade 4) (27).
- Muscle atrophy: Tangent sign in sagittal MRI (28) showing less supraspinatus muscle in the supraspinatus fossa.
- Ultrasound assesment of tear size/MRI: anterosuperior (SSC + supraspinatus) or posterosuperior (infraspinatus + supraspinatus) massive tear > 5 cm (25, 29).
- X-ray/CT scan: Moloney's line: harmony arch of shoulder and glenoid, acromiohumeral distance distance less than < 6 mm (30).

Superior capsular reconstruction

The superior capsule is a thin structure from the labrum to the humeral head at the greater tuberosity that covers the footprint of the supraspinatus tendon and serves as a static stabilizer for the glenohumeral joint (31, 32, 33).

Mihata *et al.* studied the biomechanical properties of glenohumeral joints with irreparable supraspinatus tears. Compared to native joints, shoulders with large tears demonstrated superior humeral head translation, increased subacromial contact pressure, and decreased glenohumeral compression force (32, 34, 35). As a surgical solution, they invented the superior capsular reconstruction (SCR) using a facia lata autograft (32, 34, 35). The autograft is fixed onto the superior part of the scapular neck and the greater tuberosity of the humeral head, preventing the cranial migration of the humeral head (32, 34, 35, 36, 37).

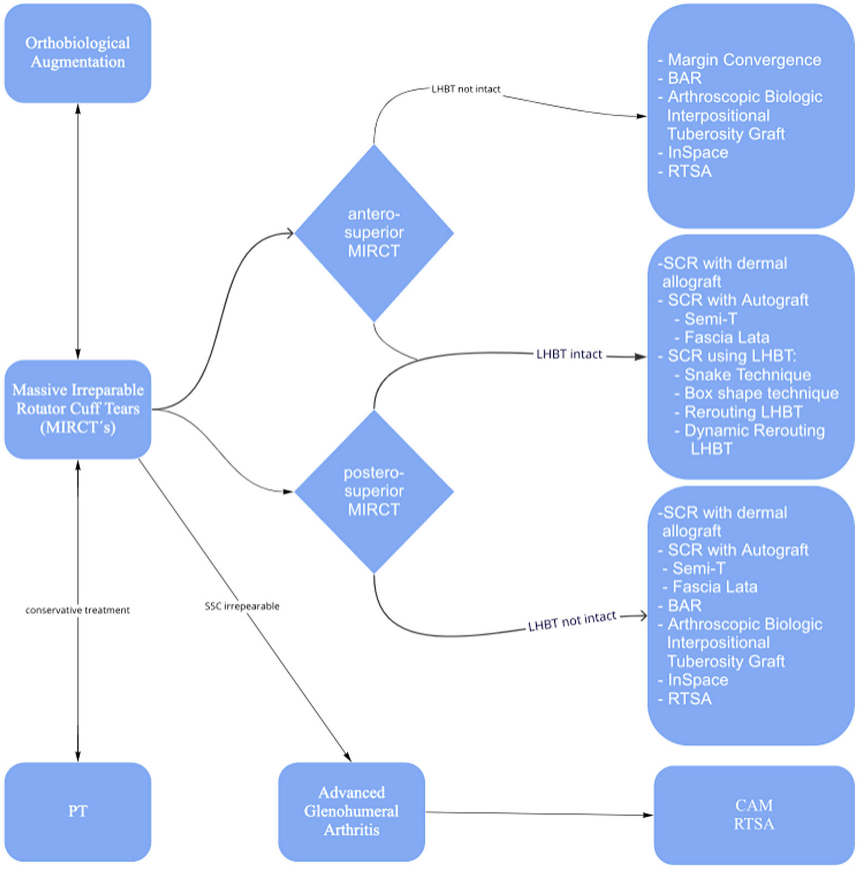

Figure 2
Possible treatment options for massive irreparable rotator cuff tears. This flowchart gives an overview of novel arthroscopic as well as established techniques.

The principle of the SCR is to restore superior capsular stability, which maintains the humeral head in its relocated, native position. This, in turn, allows the deltoid and remaining RC muscles to compensate for the deficient RC function and prevents painful bony contact between the humeral head and the acromion. Mihata *et al.* presented excellent clinical results in both the short- and mid-term follow-up periods. Preoperative compared to postoperative values showed American Shoulder and Elbow Surgeons score improvement from 29 to 83 and 92 at preop, 1-year, and 5-year time points, respectively. Forward elevation also improved from 85° preoperatively to 138° at 1-year and 151° at 5-year follow-up. Improvements in acromiohumeral distance (preoperative: 3.4 mm, 1-year follow-up: 9.1 mm, 5-year follow-up: 8.1 mm) and a decreased visual analog scale (preop: 6.9, 1-year follow-up: 1.3, 5-year follow-up: 0.9) were also seen (37).

Allogenic dermal allografts have been developed as an alternative to the fascia lata autograft, shortening procedure time and reducing donor site morbidity. These allografts have been shown biomechanically to restore the humeral head position after a posterosuperior RCT (38). Clinical 2-year results of 22 patients demonstrated significantly improved clinical scores (39). Postoperative MRI evaluations have shown 100% graft integrity at the tuberosity side, 76% at the midsubstance, and 81% on the glenoid side (39, 40). Table 1 summarizes the clinical and radiographic results of various study groups. Second-look case reports (41, 42) and animal rabbit models (43) have reported histological cell infiltration in the grafts. In these studies, retrieved graft tissue demonstrated a tendon-like structure, neovascularization, and various cell expressions (41, 42, 43).

For the SCR technique (19, 31, 39), the shoulder is positioned in 30° to 40° of glenohumeral abduction. An arthroscopic measuring device is used to define the defect size in the anterior-posterior/medial-lateral directions (Fig. 4A). The 3-mm thick human cellular dermal allograft (Arthroflex, Arthrex, Naples, FL, USA) is sized and cut to include an additional 5–10 mm medially to allow for anchor placement and approximately 15 mm laterally to cover the anatomic footprint of the RC. Next, all four corners are armed with lasso loops *ex vivo*. The graft is then shuttled into the joint and fixed at the glenoid side and on the tuberosity side with a double-row reconstruction. Lastly, the graft is fixed with side-to-side sutures to the subscapularis and infraspinatus muscles, leaving the medial rotator interval open (Fig. 4B) (19, 44). The disadvantages of the SCR technique are the lack of

Table 1 Clinical and radiographic outcomes of superior capsular reconstruction.

Year	Reference	Patients, *n*	Implant	Average follow-up (months)	Pre- to post-op clinical outcomes		Intact graft rate	Failure rate
					ASES	VAS		
2013	Mihata *et al.*(64)	23	Fascia lata autograft	34.1	23.5 → 92.9		83.3%	4.3%
2017	Denard *et al.*(65)	59	Dermal allograft†	17.7	43.6 → 77.5	5.8 → 1.7	45%	18.6%
2017	Hirahara *et al.*(66)	8	Dermal allograft†	32.4	43.5 → 86.5	6.3 → 0.4		21.5%
2018	Lee & Min (67)	32	Fascia lata autograft or allograft‡	24.8	50.3 → 84	5.8 → 1.34	63.9%	36.1%
2018	Lim *et al.* (68)	31	Fascia lata allograft	12.8	54.4 → 73.7	6 → 2.5	71%	29%
2018	Mihata *et al.*(69)							
	No pseudoparalysis	45	Fascia lata allograft	60	43.6 → 96.5		98%	2%
	Moderate pseudoparalysis	28			29.2 → 92.2		96%	4%
	Severe pseudoparalysis	15			20.3 → 91.8		87%	13%
2018	Pennington *et al.* (70)	86	Dermal allograft†	Minimum 12	52.2 → 81.6	4.0 → 1.5		4.5%
2019	Burkhart & Hartzler (71)	10	Dermal allograft†	12.9	52 → 89	4.6 → 0.5		
2019	Burkhart *et al.* (40)	41	Dermal allograft†	34	52 → 90	4.6 → 0.7	85%	5%
2020	Lacheta *et al.* (39)	22	Dermal allograft†	25.2	54.0 → 83.9	4 → 0	Tuberosity: 100% Midsubstance: 76% Glenoid: 81%	3.7%
2021	Okamura *et al.* (72)		Teflon§	42				13%
	1 teflon layer	15			42.4 → 63.2			
	3 teflon layers	20			40.3 → 71.4			0%

†Arthroflex, Arthrex, Naples, FL, USA; ‡MegaDerm® allodermis, L&C BIO, Seoul, Korea; §Bard PTFE Felt, C.R. Bard, Inc., Murray Hill, NJ, USA.
ASES, American Shoulder and Elbow Surgeons score; VAS, visual analog score.

restoration of active function of the supraspinatus muscle and relatively high costs (dermal allograft and multiple anchors). However, the procedure still serves as an effective surgical option to stave off the need for RTSA in patients that are young and/or do not wish to undergo shoulder arthroplasty.

Alternative arthroscopic techniques for superior humeral head stabilization

Long head of the biceps tendon to reconstruct the superior capsule

Recently, the LHBT has been utilized in numerous surgical techniques, often in combination with additional suprascapular nerve releases (11, 12, 15, 24, 33, 45, 46). These techniques can be divided into techniques rerouting the biceps tendon and techniques using the biceps tendon as an autograft (Fig. 3). All of these techniques take advantage of a viable and locally available autograft and require an intact LHBT. Successful clinical outcomes have been reported for these techniques in shoulders with intact LHBTs and intact glenohumeral cartilage.

Rerouting biceps tendon

Kim *et al.* published a technique performing *in situ* SCR using the LHBT (16). In this technique, a mid-substance intraarticular biceps tenotomy is performed without detachment of the LHBT from the superior labral complex.

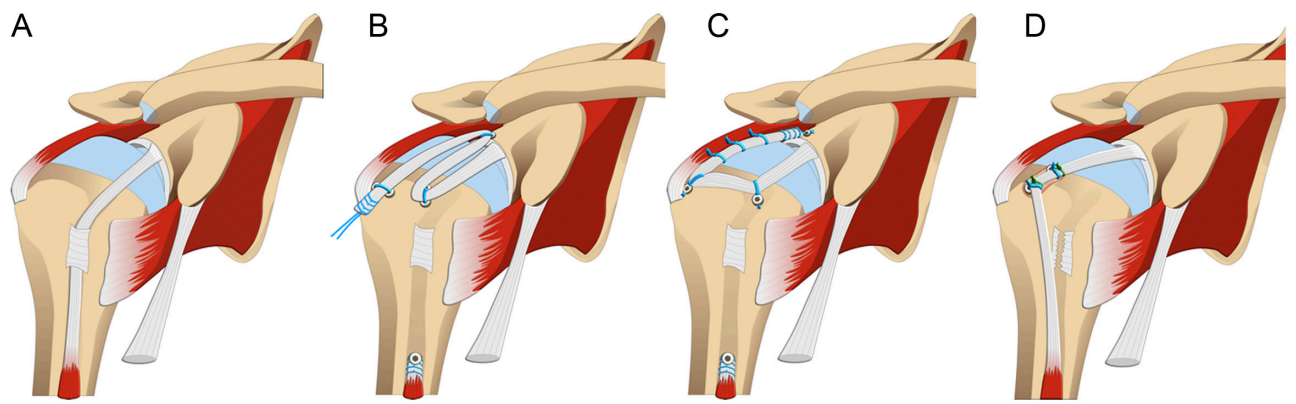

Figure 3
(A) Massive rotator cuff tear. (B) Snake technique by Kim *et al.* using the LHBT in a snake-like formation for SCR. (C) Box shape technique by Denard *et al.* using the LHBT in a box shape for SCR. (D) Biceps rerouting technique by Kim *et al.* using an intraarticular biceps tenodesis for SCR.

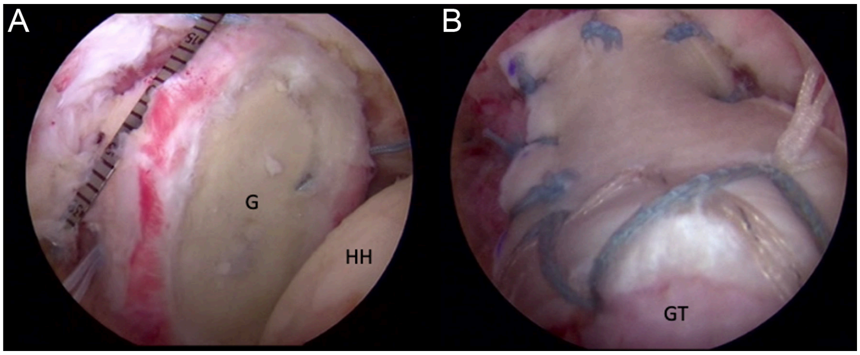

Figure 4
(A) Arthroscopic view of a right shoulder from the posterolateral portal demonstrating a massive irreparable tear of the supraspinatus and infraspinatus prior to capsular reconstruction. (B) Arthroscopic view of the right shoulder showing the completed capsular reconstruction with medial fixation to the superior glenoid and lateral fixation to the greater tuberosity (GT).

The tendon is then fixated at the greater tuberosity with an anchor to reduce humeral head superior migration (Fig. 3D). Optional tenodesis at the distal aspect of the lateral anchor can be performed if needed (47, 48).

Fucai Han *et al.* analyzed the rerouting technique biomechanically in seven fresh frozen cadaveric shoulders in the following states: intact RC, artificially created massive RCT, and modified superior reconstruction using the LHBT. The LHBT was tenotomized at the entrance of the bicipital groove and attached with a transosseous wire suture repair at 30° of glenohumeral abduction. They found that this technique restored shoulder stability by recentering the humeral head with reduced subacromial peak contact pressure and improved range of motion (13). To further support this technique, Sang-Yup Han *et al.* tested eight cadaveric shoulders in unique testing conditions. They found decreased humeral head translation, reduced subacromial contact pressure, and no impairment in total rotational range after LHBT rerouting both with and without RC repair (45). Improved clinical outcomes and low retear rates have been reported for this technique used as an adjunct to arthroscopic RC repair (14, 49, 50). However, data for an isolated biceps rerouting for MIRC's are not available yet (14, 49, 50).

A variation of the technique is the arthroscopic *dynamic* rerouting approach introduced by Tang and Zhao (15). In this technique, a new bicipital groove is shaped lateral to the native bicipital grove within the greater tuberosity without attaching the LHBT to the humeral head. Then, a side-to-side repair of the supraspinatus tendon is performed superior to the new groove carrying/containing the LHBT (15). Clinical or biomechanical data have not been presented yet.

In a systematic review comparing SCR techniques using LHBT, Kitridis *et al.* found the new techniques equal to the traditional techniques and describe them to be cost-effective, easy, and time-efficient (33).

SCR using the LHBT as an autograft

Denard *et al.* introduced a biceps tendon box configuration with a biomechanical study of eight cadaveric shoulders. The technique demonstrated decreased superior translation of the humeral head in massive RCTs but did not restore the translation to native levels (20). In this technique, the biceps tendon is cut at the lateral bicipital groove entrance and is fixed anteriorly at the humeral head with an anchor. The tendon is laid on the humeral head in a vertical orientation to the humeral axis and is then attached posteriorly to the greater tuberosity with a second anchor. Next, the tendon is secured to the upper margin of the infraspinatus as it continues toward the glenoid, where it is attached with a third anchor resulting in a box-shaped form (12). Clinical results for this technique are not available yet. (Fig. 3C)

A variant of this technique proposed by Kim *et al.* uses both the intraarticular and extraarticular portion of the LHBT for the superior capsular repair and is referred to as the Snake/Triple Bundle technique (11). In this approach, the study group used suture tape in addition to an open subpectoral tenodesis. The LHBT was arranged in a snake-like manner, meandering from the humeral head to the glenoid two to three times. This technique leaves the origin intact, and by performing a subpectoral biceps tenodesis in combination with a tenotomy at the incision site for the tenodesis, at least 14 cm of biceps tendon remain. The proximal part of the tendon is brought back to the greater tuberosity and secured with an anchor, then the loose end is brought back to the glenoid where it is fixed with another anchor (Fig. 3B). Once again, it is brought back to the humeral head at the posterior portion of the greater tuberosity. If necessary, a third bundle can be attached to the glenoid. No clinical data have been published so far.

SCR using the semitendinosus tendon as an allograft/autograft

Milano *et al.* published a surgical technique utilizing a semitendinosus tendon autograft. After tendon harvesting, the semitendinosus tendon is debrided and armed with non-absorbable sutures, leaving long suture tails for easier maneuvering. The greater tuberosity is cleaned, and then the graft is shuttled through the lateral portal and attached with anchors at the glenoid leaving

either a box shape, V-shape, or reverse V-shape depending on the graft lengths (51, 52).

The pivot SCR fixation technique presented by Bader and Garcia in 2020 also uses a semitendinosus autograft that enters the joint through the posterior portal, shuttling the tendon through a predrilled hole in the scapular neck from posterior to anterior. The shuttling sutures of the armed autograft are utilized to pull the graft into the joint in an orientation that is parallel to the glenoid articular plane. Through a Neviaser portal, a K-wire is drilled into the upper part of the greater tuberosity, fixating the semitendinosus autograft with an interference screw (53). A biomechanical cadaver study by Berthold *et al.*, published in 2021, showed that the V- shape and box-shape rerouting techniques significantly decreased glenohumeral superior translation and decreased maximum deltoid cumulative forces (54).

InSpace biodegradable implantable balloon (subacromial spacer)

In 2021, the US Food and Drug Administration approved the use of a subacromial spacer in MIRCTs. As described by Savarese and Romeo in 2012, the InSpace balloon gained interest due to its rather simple applicability (55). The InSpace balloon is a pre-shaped spacer consisting of poly-L-lactide-co-ε-caprolactone and is designed to be adsorbed in 12 months (55, 56, 57). After diagnostic arthroscopy and confirmation of the MIRCT, a lateral 1.5 cm arthroscopic portal is established parallel to the supraglenoid tubercle (55). After debridement and bursectomy in the usual fashion, the biodegradable spacer is positioned through the lateral portal and with the help of the application system 0.9% saline solution with a Luer-Lock syringe is inserted (55). The volume of saline solution utilized depends on the balloon size. Balloons are available in small (40 x 50 mm), medium (50 × 60 mm), and large (60 × 70 mm) sizes and are chosen based on shoulder and tear morphology or measurement with an arthroscopic probe (55). After inflating the InSpace Balloon, the application system is removed from the shoulder and the shoulder is moved through a full range of motion for correct implant placement (55).

After the preliminary technical description, Singh *et al.* provided a biomechanical analysis comparing the balloon to the SCR in irreparable RCTs based on superior humeral head migration in a cadaveric model (58). Both constructs showed comparable results at the time point zero regarding decreasing superior humeral head migration during various abduction states (0°, 30°, 60°, 90°). (58).

Since the balloon is biodegradable within 12 months, the mid- and long-term efficacy has been questioned (59). Familiari *et al.* prospectively investigated 51 patients with a mean age of 63 (range: 50–78) with a mean follow-up time of 36 months (range: 24–56 months) (56). The inclusion criteria were no prior shoulder surgery and a minimum of 6 months of physiotherapy preoperatively (56). This prospective study demonstrated total Constant Score (CS) improvement from 27 ± 7.4 to 77 ± 15 ($P = <0.01$), with 46 patients reporting good to excellent satisfaction scores and 5 reporting dissatisfaction with the results (56). A total of six patients needed revision surgery including five RTSAs and one latissimus dorsi transfer (56). Reasons for failure were not described in this study. Interestingly, the study group reported that a high postoperative acromiohumeral interval was associated with worse CS at follow-up, which is unexpected as the InSpace balloon is primarily designed to restore the humeral head position allowing for normal shoulder kinematics (56). Pieekar *et al*. reported similar clinical results as Familiari *et al.* in a cohort that included patients with partial repair. The study reported significant pre- to post-operative improvement in the Oxford Shoulder Score (21.32 to 34.39, range: 29.17–36.70), with an 82% satisfaction rate (57). In the current literature, there are no comparative studies between the InSpace Balloon and other treatment strategies for MIRCTs. Future comparative level 1 studies are needed to adequately compare these treatments.

Bursal acromial resurfacing

In addition to the InSpace balloon, Ravenscroft *et al.* presented another surgical technique based on the subacromial spacer concept. The bursal acromial resurfacing (BAR) technique utilizes an acellular dermal allograft as treatment for irreparable RCTs. The procedure is indicated for patients over the age of 70 with minimal to no osteoarthritic findings. According to the authors, BAR aims to combine the simplicity of the balloon and the longevity of the graft, with the goal of reducing pain and minimizing contact between the humeral head and the acromion. In addition, the procedure is proposed to be more cost-effective due to the reduced use of anchors and the durability of the construct. The BAR technique includes arthroscopic debridement with subacromial decompression to leave a bleeding bed for the autograft as well as a lateral acromioplasty. The graft is armed with six sutures using lasso loops and a cross link pattern. To place the graft, the medial sutures are shuttled into the joint and tied around the acromion, attaching the dermal allograft to the undersurface of the acromion. To date, no clinical outcomes have been presented (60).

Arthroscopic biologic interpositional tuberosity graft

Dermal allografts most commonly fail at the glenoid or in the midsubstance of the graft (39, 64). They rarely fail at the greater tuberosity (39, 64). Mirazayan *et al.* demonstrated in a clinical and imaging study that failed SCR with dermal

allograft can still improve pain and function (67). Better coverage of the greater tuberosity resulted in better clinical outcomes, an observation described (67) as the 'Biologic Tuberoplasty Effect' (67). This led to the idea that an interpositional graft can be utilized to prevent painful contact between the acromion and greater tuberosity.

The biologic interpositional tuberosity graft technique presented by Griffin *et al.* and Mirzayan *et al.* (67, 84) uses an arthroscopic technique in which a dermal allograft is attached to the humeral head with anchors to cover the greater tuberosity. The graft acts like a biologic interpositional spacer between acromion and greater tuberosity preventing painful contact. Clinical results for this technique are not available yet.

Conclusion

There is a myriad of open and arthroscopic techniques to approach MIRCTs that have been developed in recent years. The development of these novel approaches has been driven by the technical challenges that surgeons experience when treating MIRCTs. Clinical results for the newer techniques are still lacking, so evidence-based recommendations cannot be made at this point. Biomechanically, all presented techniques have been shown to partially or fully restore native shoulder biomechanics. Improved shoulder function stems from the prevention of superior humeral head migration, which may stave off RCT arthropathy. This is particularly relevant for younger patients seeking to avoid RTSAs (19).

Despite lacking substantial clinical evidence, it is worth taking these new techniques into consideration as cost-effective alternative options for the treatment of MIRCTs. Future randomized, clinical, large multicenter trials are needed to determine which techniques are most suitable for different patient groups and pathologies.

ICMJE conflict of interest statement
P J Millett has received from Arthrex something of value (exceeding the equivalent of US$500) not related to this manuscript or research. He is a consultant and receives payments from Arthrex and owns stock in VuMedi with stock options in Game Ready. He received IP royalties from MedBridge. R-O Dey Hazra's research fellowship position is supported by Arthrex, Inc. The remaining authors do not have any conflicts of interest to report.

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