How to Use a Graft in Irreparable Rotator Cuff Tears: A Literature Review Update of Interposition and Superior Capsule Reconstruction Techniques

Kevin C. Wall¹ · Alison P. Toth² · Grant E. Garrigues²

Published online: 11 January 2018

© Springer Science+Business Media, LLC, part of Springer Nature 2018

Abstract

Purpose of Review To introduce the challenges in addressing irreparable rotator cuff tears and examine the surgical options, specifically interposition grafting and superior capsule reconstruction.

Recent Findings Interposition grafting of rotator cuff tears shows promising results in reducing pain and improving function postoperatively and one study demonstrated that it performs significantly better than partial repair alone. Superior capsule reconstruction has become popular rapidly, but given the novelty of the procedure, there is currently a paucity of outcomes data to review.

Summary Irreparable rotator cuff tears are a challenging condition with a variety of surgical options available. Two such options—interposition and superior capsule reconstruction—both employ grafts in an attempt to restore joint stability and function. In the past 3 years, literature discussing interposition grafting has explored the different types of grafts, and mostly employed pre-post analysis. The recent superior capsule reconstruction articles strictly used human dermal allograft and offer a variety of surgical techniques without quantitative data.

Keywords Shoulder · Rotator cuff tear · Irreparable · Graft · Interposition · Superior capsule reconstruction

Introduction

A rotator cuff tear (RCT) is a common pathology characterized by the tear of any one of the four tendons that compose the rotator cuff. The supraspinatus tendon, which inserts at the greater tuberosity, is most commonly affected, and a complete tear of the supraspinatus often results in pain, loss of function in arm abduction, and superior destabilization of the glenohumeral joint [1]. With an overall RCT incidence of 20%, and an incidence of 50% among individuals over 80 years of age [1, 2], this condition and the resultant pain,

weakness, and impaired function represent a significant burden of disease in our society.

While many tears are asymptomatic, symptomatic tears not responsive to nonoperative treatment are frequently repaired, with approximately 250,000 repairs performed annually in the USA [3, 4]. Retear rates are high, 5–94% [5–7], with risk factors such as age over 65, fatty degeneration of over 50% of the rotator cuff muscle, tendon retraction, tobacco use, diabetes mellitus, and the size of the tear all predictive of structural failure of the repair [8, 9]. Counterintuitively, even in the setting of a re-tear, up to 90% of patients experience pain relief and functional improvement [1, 8]. Purported causes of this structural failure are mechanical forces at the repair site, and often specifically in relation to the poor healing environment and microanatomical changes that occur during the healing process [1, 9, 10].

Many treatment options exist for managing the irreparable RCT, including corticosteroid injections [11], tubero-plasty with biceps tenotomy and debridement [12, 13], partial rotator cuff repair [14], tendon transfers [15, 16], reverse total shoulder arthroplasty [17, 18], and even glenohumeral joint

---

This article is part of the Topical Collection on *Rotator Cuff Repair*

✉ Grant E. Garrigues
grant.garrigues@duke.edu

¹ Duke University School of Medicine, Duke University Health System, Durham, NC, USA

² Section for Shoulder Reconstruction, Department of Orthopaedic Surgery, Duke University Medical Center, Box 3639, Durham, NC 27710, USA

arthrodesis [19]. The focus of this review is to examine research within the last 3 years on the use of two types of grafting procedures for treatment of irreparable RCT: “interposition grafting” (IG), synonymous with gap-bridging, where the graft is used to bridge an irreparable gap between rotator cuff tendon and the rotator cuff footprint—not as an augment (which is frequently an “off-label” use); and “superior capsule reconstruction” (SCR) [9]. Each procedure can be used with a variety of graft materials including autograft, allograft, xenograft, and a variety of synthetic options available.

The most significant variations between the graft types involves their strength and antigenic properties; allografts and xenografts are more likely to be antigenic than synthetic or autografts, but are less available and have less potential for modification of their biomechanical properties than synthetic ones [9]. Unfortunately, even with the promise of biologic modification, the synthetic grafts currently available on the market generally are able to replicate either the biologic properties of the RC tendon or the mechanical properties, but not both, and have a retear rate as high as 62% [9, 20].

The focus of this review is the irreparable RCT, defined as a RCT with a gap between the rotator cuff tendon and the rotator cuff footprint that persists after a complete surgical attempt at tendon mobilization. This situation occurs frequently in massive RCT which have a defect of at least 5 cm and involvement of at least two tendons. The primary function of the rotator cuff is to dynamically maintain the joint center of rotation and avoid superior subluxation of the humeral head by resisting the upward vector of the deltoid muscle [21, 22]. Rotator cuff repair with IG attempts to restore this dynamic restraint to superior translation. With full thickness tears of the supraspinatus, the superior capsule is also damaged and its restraining effect against superior translation is compromised [1, 3]. SCR is a recently described technique that is designed to recreate the static superior stability imparted by this structure. As augmentation grafting is possible only in the subset of massive RCT that are repairable to some portion of the tuberosity, this technique, where a graft is placed on top of a RC repair to fortify its mechanical and biologic properties, will not be discussed here.

Interposition

A PubMed search was conducted for terms related to “rotator cuff, repair, massive, irreparable, interposition, gap-bridging, bridge, patch, graft, scaffold, augmentation,” and was filtered by results only published between October 1, 2014 and October 1, 2017 for this update. Only human, clinical studies, in the English language were included. Using these parameters, a total of 19 relevant results that pertain to IG in massive or irreparable RCT were returned [9, 11, 14, 23•, 24, 25•, 26•, 27•, 28•, 29–38]. Both types of RCT were included as massive

and irreparable are occasionally used interchangeably in the literature. Publications on animal models were excluded from this section and are discussed separately below. Of note, only six clinical studies [23•, 24, 25•, 26•, 27•, 28•] were published during these prior 3 years on IG with one additional case report [37] and one strictly surgical technique paper [36]. The majority of articles returned were reviews that explored various repair options and outcomes that included massive and irreparable RCT [9, 11, 14, 29–35, 38]. As these reviews report largely on publications that occurred prior to this review’s time range, they are not discussed in detail below.

Prior to October 2014, many studies indicated that in massive and irreparable RCT repaired with grafts in the interposition configuration, that there is postoperative improvement in pain, various subjective measures, and range of motion (ROM) [14, 39–47]. Allografts, xenografts, and synthetic grafts all demonstrated some degree of improved postoperative functional status and high rates of healing (74–90%, 73–100%, 60–90%, intact at follow-up, respectively) [26•, 34, 42, 43, 48–56]. Autografts were found to be more likely to be structurally intact than partial primary repairs, with fascia lata (79%) more likely to be intact at 12 months than biceps tendon grafts (58%) [49, 50]. In reviews evaluating graft interposition versus augmentation studies, healing rates were found to be 78–88% when grafts were used in the interposition configuration and 64–66% when used in augmentation [30, 38].

Interposition Allografts

In 2014, Kokkalis et al. [25•] published a retrospective case series of 21 patients with massive RCT who were treated with an open repair utilizing interposition human dermal allograft. After an average follow-up interval of 29 months, all patients had significantly less postoperative pain, decreasing from 7.6 to 1.8 on a 0–10 visual analog scale (VAS) and improved forward flexion (77° to 139°), abduction (67° to 126°) and external rotation (ER) (9° to 47°). American Shoulder and Elbow Surgeons Shoulder Score (ASES) similarly improved from 25.2 to 74.3.

Dimitrios et al. [24] reported a prospective case series of 68 patients with interposition allografts in 2015, in which all subjects had irreparable RCT repaired operatively with fascia lata. At 12 months postoperatively, there was an increase in Constant Score (CS) from 32.5 preoperatively to 88.7, with a notable improvement in the pain subscore from 2.4 to 14.1. Postoperative MRI was performed on 10 patients with equivocal results, though ultrasound examination of 30 other patients at 12 months showed retear in only 3 of them. Statistical significance tests are not reported in this article and there was no comparison control group.

In 2017, Pandey et al. [23•] published a prospective, non-randomized cohort study of 26 patients with symptomatic, irreparable RCT who failed nonoperative management. The

first 13 patients enrolled had only partial repair and the subsequent 13 patients underwent partial repair with an interposition GraftJacket dermal allograft. In keeping with prior literature, both procedures improved postoperative pain and function at 2 years. Partial repair significantly improved the Oxford Shoulder Score (OSS) from 17.8 to 37.1 and the CS from 43.1 to 70.8. The addition of the GraftJacket to the procedure also demonstrated postoperative benefit (14.9 to 43.9 for OSS and 41.2 to 83.9 for CS) but the postoperative scores for the allograft cohort were significantly higher than the partial repair alone on both measures. Three patients in the allograft cohort did retear, though no significant loss of function was noted in these patients when compared to the remaining 10 in their cohort.

Interposition Autografts

Fatty infiltration of muscle is a known risk factor in repairing RCT [8]. In 2013, Mori et al. found clinical improvement over partial repairs when interposition fascia lata grafts were used in RCT with Goutallier stage 1 or 2 fatty degeneration [50]. Building on this foundation, Mori and his colleagues [26•] recently conducted a cohort study in irreparable RCT patients with high-grade (Goutallier stage 3 or 4) supraspinatus fatty degeneration and any Goutallier stage (1–4) infraspinatus. They were divided into low grade, Goutallier stage 1 or 2 infraspinatus, and high grade, stage 3 or 4 infraspinatus, and all treated with an interposition fascia lata autograft. At 24 months postoperatively, significantly more low-grade shoulders (73.1%) were intact than the high-grade ones (10.6%), where 89.4% of the retears that occurred were of the infraspinatus. Both groups showed significant functional improvement in CS, ASES scores and ROM, though the low-grade cohort again consistently outperformed the high-grade shoulders.

The second interposition autograft study in the past 3 years was a small case series by Mihara et al. [27•] in which five irreparable RCT patients received an interposition iliotibial band with a Gerdy's tubercle bone block [57]. They hypothesized that the bony autograft would provide more reliable healing than grafts solely composed of soft tissue. At 24 months postoperatively, statistically improved pain and subjective scores were noted, as measured by UCLA Shoulder Rating Scale, ASES, and the simple shoulder test. ROM improved postoperatively, but not significantly. Radiologically, bone block to greater tuberosity union on CT was confirmed at 3–4 months and intact repairs were noted in all five patients on MRI at 24 months. There was no donor site morbidity.

Interposition Xenografts

Neumann et al. [28•] used porcine cellular dermal matrix grafts to repair 61 irreparable RCT. This report is the first prospective study examining subjective and objective

variables in this specific procedure, and has strengths of a lengthy follow-up (mean 50.3 months) and a large sample size for this type of study. They found that, postoperatively, there were significant improvements in pain, from 4.0 to 1.0 on VAS, forward flexion, ER and internal rotation (IR), supraspinatus and infraspinatus strength, and modified ASES score. 91.8% of cuffs were intact on ultrasound at follow-up as well, with 3.3% partially intact and only 4.9% not intact. However, following the Wright Medical-Tornier merger, this xenograft, which had been sold by Tornier, has been taken off the market in favor of Wright Medical's Graftjacket. Of note, this decision was driven by post-merger corporate sales strategy, and not by any adverse events observed among these grafts.

Superior Capsule Reconstruction

A PubMed search was conducted for terms related to “rotator cuff, superior capsular reconstruction, SCR, massive, irreparable” and was filtered by results only published between October 1, 2014 and October 1, 2017. Twenty relevant results [3, 9, 11, 14, 31, 58–69, 70•, 71•, 72•] were returned, with animal models again excluded from this section. Again, for this update only human, clinical studies, in the English language were included. Ten of the articles revealed by the search were technique articles, nine of which detailed different SCR surgical techniques (see Table 1) [3, 11, 60–64, 66, 67], and one which elaborated on rehabilitation following SCR [59]. The remainder consisted of review articles [9, 14, 31], a case report [58], a cadaveric, radiologic study [65], and a series of biomechanical studies and two editorials on them [68, 69, 70•, 71•, 72•]. No clinical studies were identified during this 3-year period. This is perhaps a function of the relative novelty of SCR; it was only in 2012 that Mihata et al. published their seminal paper on the biomechanics and technique of SCR [73] and, in 2013, on its clinical outcomes [74].

In Mihata et al.'s original case series [74], outside the time frame of this review update, the authors completely repaired the subscapularis tendon, partially repaired the infraspinatus and teres minor tendons, then performed SCR using a folded, 6–8-mm thick fascia lata autograft. Two suture anchors were used for medial fixation to the superior glenoid and lateral fixation was done with the compression double-row technique. Their final step was to suture the graft posteriorly to the infraspinatus tendon and anteriorly to the residual supraspinatus or subscapularis tendons to improve force-coupling. At the final follow-up (24–51 months, mean 34.1 months), this approach yielded a postoperative increase in mean ASES, Japanese Orthopedic Association, and UCLA scores—23.5 to 92.9, 48.3 to 92.6, and 9.9 to 32.5, respectively. ROM and strength were similarly improved at 2 years, with significant benefit seen in elevation, ER and IR. Postoperative

Table 1 Surgical technique SCR publications 10/2014–10/2017

Article	Acromioplasty	Biceps tenodesis/ tenotomy	Partial repair	Arm positioning	Graft dimensions	Graft introduction technique	Anterior fixation
Hirahara and Adams (2015) [60]	/	Y	Y	0° Abd 0° Rot	+ 5 mm A/P/M/L	2 double-pulley systems	Anterior with caution
Petri, Greenspoon and Millett (2015) [61]	/	/	/	/	/	Traction on single glenoid anchor	Anterior to subscapularis
Tokish and Beicker (2015) [62]	Y	Y	/	20–30° Abd 0° Rot	+ 5 mm A/P/M + 12 mm L	Double-pulley	Anterolateral to subscapularis tendon
Katthagen, Tahal and Millet (2016) [63]	/	/	/	/	/	Arthroscopic knot pusher	Anterolateral to subscapularis
Thorsness and Romeo (2016) [11]	Y	/	Y	/	+ 5 mm A/P/M/L	Double-pulley	Advise against
Burkhart et al. (2016) [64]	Y	Y	Y	20–30° Abd 20° FF	+ 5 mm A/P/M + 10 mm L	Zip-line shuttle	Anterior to residual comma tissue
Narvani et al. (2016) [66]	Y	/	/	/	+ 5–10 mm A/P/M/L	Pull-over	/
Adams et al. (2016) [67]	Y	Y	Y	20–30° Abd 20–30° FF	+ 5 mm A/P/M + 10 mm L	Double-pulley	Anterior to residual comma tissue
Sutter, Godin and Garrigues (2017) [3]	/	/	Y	30° Abd 20° FF 10° ER	+ 5 mm A/P/M + 15 mm L	Double-pulley	Advise against

Key: /, not specified in article; Y, used by authors; *graft dimensions*, the number of millimeters added to graft beyond distances measured in vivo; *graft introduction technique*, how graft is introduced to shoulder and guided to superior glenoid; *anterior fixation*, refers to author decision to fix the anterior graft to adjacent tissue; *Abd*, abduction; *Rot*, rotation; *A*, anterior; *P*, posterior; *M*, medial; *L*, lateral; *FF* forward flexion; *ER*, external rotation

imaging revealed an increased acromiohumeral distance from 4.6 to 8.7 mm, indicative of reversal of superior humeral subluxation [64], and an 83.3% rate of intact repairs throughout the follow-up.

Since this time, multiple variations on this theme have emerged, and are detailed below, as are the recent publications that further examine the biomechanics of this relatively new technique. While the criteria for electing to perform SCR have not been completely codified, these repairs generally are used in the massive, irreparable, posterosuperior RCT among young or active patients who do not have arthritis. In the practices of the senior authors (APT, GEG), this typically represents patients between 50 and 70 with supraspinatus or infraspinatus tears retracted to, or just medial to, the glenoid, with at least Goutallier stage 3 fatty infiltration. The primary contraindication to this procedure is a fixed, high-riding humeral head. However, it should be noted that if radiographs demonstrate an acromiohumeral interval (AHI) of > 7 mm, or if the AHI is narrowed but can be reduced to a normal station with sulcus maneuver, then there is sufficient mobility for humeral head reduction and use of a stabilizing SCR graft.

Surgical Techniques

All nine SCR surgical technique articles stayed mostly true to Mihata's original approach with no change to the basics of graft fixation—medially to the superior glenoid, laterally to

the greater tuberosity, and finally posteriorly to the infraspinatus tendon. However, no other authors have used fascia lata as Mihata did; instead, recent reports have opted for a human acellular dermal allograft with a thickness of 3.0–3.5 mm, with the potential benefits of eliminating any donor site morbidity and reducing operative time [3, 67]. The authors all also performed diagnostic arthroscopy upon entering the shoulder, but after this point in the operation, the techniques vary until the relatively similar lateral double-row fixations. The various steps and operative decisions that authors describe in these technique articles are detailed in Table 1, and further elaboration on some of the more significant differences and proposed advantages are below. The lack of published postoperative outcomes makes comparisons between these technique variations impossible and all advantages and disadvantages are thus theoretical.

The decision to perform acromioplasty, biceps tenodesis or tenotomy, and/or partial repair appear, to date, to be matters of surgeon preference in SCR operations, with little commentary offered in the literature on why each author made the decision to perform any one of these specifically during SCR beyond their standard indications. Arm position when fixing the graft laterally, while also seemingly a matter of preference, is described by Sutter and his colleagues as critical for ensuring the graft is taut under low degrees of abduction [3]. They achieve this by putting the patient's arm at 30° abduction, 20° forward flexion, and 10° external rotation. The other authors who

mention position usually follow a similar set-up, with the range for abduction between 0° and 30°, as supported by Mihata's biomechanical studies below, forward flexion 20–30° and rotation neutral to 10° [70•].

Nearly all grafts have 5 mm added to the anterior, posterior, and medial dimensions to prevent suture pullout. A caveat to these measurements is that while some authors measure the corners of the prepared glenoid and greater tuberosity footprints [62], others place anchors first, then measure the distances between them [3, 11, 60, 64, 67]. Hirahara argues that use of the latter method creates a more accurate graft size that better matches the defect [60]. On the lateral edge of the graft, a range of 5–15 mm is described [3, 60, 62, 64, 67], with greater sizes being used to more adequately cover and interface with the prepared greater tuberosity footprint.

The greatest differentiator in published techniques was in the method used by the authors to introduce the graft to the shoulder and bring the medial edge to the superior glenoid. Some authors simply push the graft into place with an arthroscopic knot pusher [63] while others follow Mihata's example and use the double-pulley technique [3, 11, 62, 67]. In this method, a limb of each suture—anterior and posterior—running from the glenoid anchors through a lateral portal and to the medial graft are tied together. Thus, when the remaining free limbs are pulled, the glenoid anchors act as two pulleys that slide the graft into place. Hirahara and Adams introduced a modification of this system by using two double-pulleys. In this, they again passed two limbs from the medial anchors through the graft then tied them together, but then also repeated this with two limbs from the greater tuberosity anchors. The graft may then be introduced with traction on each double-pulley system's remaining free limb, theoretically leading to more accurate graft placement and less graft and suture tangling [60].

Burkhart et al. [64] also modified the double-pulley system with their “zip-line shuttle,” which was originally designed for large grafts that become trapped or meet enough resistance in the cannula that the force on the double-pulley system will pull out a glenoid anchor. The authors first place a third, central glenoid anchor, a step shown in a radiographic study to be at low risk of damaging the suprascapular nerve or disrupting the glenoid fossa [65]. This anchor sits between the standard anterior and posterior ones, with one end of its suture limbs passing through a modified Neviaser portal and the others through a lateral portal. The lateral portal suture limbs are then tied to the graft, while the anterior and posterior anchor suture limbs are passed through their respective holes in the graft, but not tied together; these serve as the zip-lines that the graft may slide down when traction is applied to the central anchor suture limbs exiting the modified Neviaser portal.

Burkhart et al.'s procedure is comparable to Narvani et al.'s pull-over technique [66], in which traction on sutures passing through a Neviaser portal is also used to introduce the graft,

though Narvani et al. use only two standard glenoid anchors. In this technique, anterior and posterior suture limbs from the glenoid anchors are passed out of the lateral portal, through their respective holes in the graft, then shuttled back into the shoulder using polydioxanone suture and out of the Neviaser portal so that upwards traction, directly above the glenoid anchors, will pull over the graft into place. The suggested advantage is that this approach mitigates some of the technical difficulty of pushing the graft into place, suture tangling, and graft rotation.

The final graft introduction variation was proposed by Petri, Greenspoon, and Millet [61] in which a third, central glenoid anchor is placed at 12 o'clock. Its suture is fixed to the center of the graft's edge and traction on the remaining free limbs and an arthroscopic knot pusher are used to introduce the graft. From there, a permanent braided suture tape that already passed through the centromedial graft is loaded into the anterior glenoid anchor along with a braided loop of permanent suture already in the anteromedial graft, thus fixing the graft to the glenoid anteromedially. The same steps are then repeated for posteromedial fixation.

The final step in most SCR procedures involves some degree of side-to-side fixation where the posterior aspect of the RCT is sutured to posterior edge of the graft. As Mihata demonstrated in biomechanical studies, this posterior fixation helps SCR achieve its goal of stabilizing the humeral head and preventing superior subluxation [70•]. Anterior fixation to the subscapularis muscle remains controversial. Multiple authors recommend against this [3, 11], as it has the potential to close the rotator interval and thus restrict ROM [3] but some authors however (see Table 1), do advocate for anterolateral fixation to the subscapularis tendon or to residual “comma” tissue [62, 64, 67].

Ultimately, despite the numerous permutations of these approaches, no SCR data beyond Mihata's original case series was found in the literature, though two surgical technique papers allude to unpublished data demonstrating improvement in pain and functional outcomes [63, 67]. Additional data are needed, whether that is in case series or in comparative studies, for validation of SCR as an effective technique for irreparable RCT, and for evidence to support each variation. Indeed, the only publication highlighting a failure of SCR in the past 3 years of literature is a case study published in 2017 by Zerr et al. which documented one occurrence of allograft detachment from its glenoid anchor at approximately 6 months post-SCR that presented with pain and limited ROM [58]. The patient underwent repeat SCR with graft reattachment to new anchors but pain and an unchanged physical exam persisted at the time of publication, 7 weeks postoperatively. While certainly not the sole case of SCR failure, this limited report highlights the field's need for further research on this rapidly evolving technique.

Biomechanical Studies

Between 2015 and 2016, Mihata and his colleagues conducted a series of cadaveric, biomechanical studies on irreparable tears and SCR that now inform the techniques of this approach. Not only was the tendency of the humerus to translate superiorly and have increased subacromial contact pressure in the presence of irreparable supraspinatus tears demonstrated, thus providing the rationale behind SCR [70•, 71•], but methods for correcting this were also investigated. The authors used fascia lata in 4 or 8-mm thickness to perform SCR with the arm between 0° and 30° abduction. They noted that both graft sizes decreased contact pressure, with the 8 mm graft paradoxically reducing this pressure more so than the 4 mm graft, while also preventing superior translation [70•]. It was also shown that fixing the graft posteriorly to residual infraspinatus tendon similarly decreased contact pressure and prevented superior translation when compared to SCR without this posterior side-to-side suturing [72•]. Finally, they demonstrated that in this irreparable supraspinatus tear population, adding acromioplasty to SCR will decrease subacromial contact area, though not pressure [71•]. In this fashion, the risk of the graft being damaged by the acromion is theoretically reduced. As the literature from the prior 3 years shows, the field has followed the path laid by Mihata: acromioplasty is frequently, albeit not always, used, arms are positioned around 30° for graft measurement and placement, and posterior fixation to the infraspinatus is universal.

Animal Studies

Three animal studies, all comparative, were found that were relevant to interposition grafts or SCR [75–77]. In the first two, interposition grafts were used in simulated irreparable RCT and then underwent biomechanical testing alongside direct repair with native tendon—possible because the “irreparable RCT” in these models were not truly irreparable. Mckeown et al. found that while a physiologic ovine tendon-bone unit had a higher load-to-failure than the two grafts they used—polytetrafluoroethylene and expanded polytetrafluoroethylene—both grafts were stronger than the native tendon and bone once they had been separated and directly repaired [75]. Smith et al. similarly found that a graft consisting of demineralized bone matrix hydrated in platelet-rich plasma showed improved strength, and appearance both histologically and on MRI when compared to direct repair in canine infraspinatus tendon tears [76]. Finally, Lee et al. also utilized growth factor-laden grafts, albeit in augmentation, not in interposition or as part of SCR. They coated human acellular dermal grafts, which are widely used in SCR and thus why this study was included in this review, with BMP-2 which demonstrated improved tensile strength over grafts without

BMP-2 and additionally promoted new bone formation better with newly differentiated fibrochondrocytes present at the graft-bone interface [77]. These studies, while affected by the limitations of the animal models, provide a tantalizing glimpse into potential future options for grafts, including biologically active ones, for irreparable RCT.

Conclusion

Restoring the irreparable RCT is an important clinical issue and a difficult surgical challenge. Basic science literature and animal models suggest a role for using growth factors as an adjunct to grafts to create a more favorable milieu for healing. Clinically, our review of the last 3 years showed no known literature comparing interposition and superior capsule reconstruction, and most studies on the individual technique variations do not use a control group or a randomized design. Thus, it is difficult to definitively assess the outcomes of interposition grafting and superior capsule reconstruction. Structured research with appropriate control populations will be necessary to determine if the added expense, operative time, and potential morbidity of these procedures is indeed justified.

Compliance with Ethical Standards

Conflict of Interest Alison Toth reports a grant and personal fees from Tornier, both of which ended in 2015.

Grant Garrigues reports personal fees from Tornier/Wright medical and DJO/Encore medical, and grants and fellowship support from Arthrex and Smith and Nephew.

Kevin Wall declares that he has no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:

- Of importance

1. McCormack RA, Shreve M, Strauss EJ. Biologic augmentation in rotator cuff repair should we do it, who should get it, and has it worked? *Bull NYU Hosp Jt Dis*. 2014;72:89–96.
2. Yamamoto A, Takagishi K, Osawa T, Yanagawa T, Nakajima D, Shitara H, et al. Prevalence and risk factors of a rotator cuff tear in the general population. *J Shoulder Elb Surg*. 2010;19(1):116–20. <https://doi.org/10.1016/j.jse.2009.04.006>.
3. Sutter EG, Godin JA, Garrigues GE. All-arthroscopic superior shoulder capsule reconstruction with partial rotator cuff repair. *Orthopedics*. 2017;40(4):e735–8. <https://doi.org/10.3928/01477447-20170615-01>.

4. Mather RC, Koenig L, Acevedo D, et al. The societal and economic value of rotator cuff repair. *J Bone Joint Surg Am.* 2013;95(22):1993–2000. <https://doi.org/10.2106/JBJS.L.01495>.
5. Parnes N, DeFranco M, Wells JH, Higgins LD, Warner JJP. Complications after arthroscopic revision rotator cuff repair. *Arthrosc J Arthrosc Relat Surg.* 2013;29(9):1479–86. <https://doi.org/10.1016/j.arthro.2013.06.015>.
6. Rhee YG, Cho NS, Yoo JH. Clinical outcome and repair integrity after rotator cuff repair in patients older than 70 years versus patients younger than 70 years. *Arthrosc J Arthrosc Relat Surg.* 2014;30(5):546–54. <https://doi.org/10.1016/j.arthro.2014.02.006>.
7. Galatz LM, Ball CM, Teefey SA, et al. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. *J Bone Joint Surg Am.* 2004;86–A:219–24.
8. Chung SW, Oh JH, Gong HS, Kim JY, Kim SH. Factors affecting rotator cuff healing after arthroscopic repair: osteoporosis as one of the independent risk factors. *Am J Sports Med.* 2011;39(10):2099–107. <https://doi.org/10.1177/0363546511415659>.
9. Flury M. Patch augmentation of the rotator cuff a sensible alternative or a waste of money? *Orthopade.* 2016;45(2):136–42. <https://doi.org/10.1007/s00132-015-3211-z>.
10. James R, Kesturu G, Balian G, Chhabra AB. Tendon: biology, biomechanics, repair, growth factors, and evolving treatment options. *J Hand Surg Am.* 2008;33(1):102–12. <https://doi.org/10.1016/j.jhsa.2007.09.007>.
11. Thorsness R, Romeo A. Massive rotator cuff tears: trends in surgical management. *Orthopedics.* 2016;39(3):145–51. <https://doi.org/10.3928/01477447-20160503-07>.
12. Fenlin JM, Chase JM, Rushton SA, Frieman BG. Tuberopecty: creation of an acromiohumeral articulation—a treatment option for massive, irreparable rotator cuff tears. *J Shoulder Elb Surg.* 2002;11(2):136–42. <https://doi.org/10.1067/mse.2002.121764>.
13. Walch G, Edwards TB, Boulahia A, Nové-Josserand L, Neyton L, Szabo I. Arthroscopic tenotomy of the long head of the biceps in the treatment of rotator cuff tears: clinical and radiographic results of 307 cases. *J Shoulder Elb Surg.* 2005;14(3):238–46. <https://doi.org/10.1016/j.jse.2004.07.008>.
14. Anley CM, Chan SK, Snow M. Arthroscopic treatment options for irreparable rotator cuff tears of the shoulder. *World J Orthop.* 2014;5(5):557–65. <https://doi.org/10.5312/wjo.v5.i5.557>.
15. 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;51–61.
16. Elhassan BT, Wagner ER, Werthel JD. Outcome of lower trapezius transfer to reconstruct massive irreparable posterior-superior rotator cuff tear. *J Shoulder Elb Surg.* 2016;25(8):1346–53. <https://doi.org/10.1016/j.jse.2015.12.006>.
17. Boileau P, Gonzalez JF, Chuinard C, Bicknell R, Walch G. Reverse total shoulder arthroplasty after failed rotator cuff surgery. *J Shoulder Elb Surg.* 2009;18(4):600–6. <https://doi.org/10.1016/j.jse.2009.03.011>.
18. Mulieri P, Dunning P, Klein S, Pupello D, Frankle M. Reverse shoulder arthroplasty for the treatment of irreparable rotator cuff tear without glenohumeral arthritis. *J Bone Joint Surg Am.* 2010;92(15):2544–56. <https://doi.org/10.2106/JBJS.L.00912>.
19. Cofield RH, Briggs BT. Glenohumeral arthrodesis. Operative and long-term functional results. *J Bone Jt Surg Am.* 1979;61(5):668–77. <https://doi.org/10.2106/00004623-197961050-00005>.
20. Aurora A, McCarron JA, van den Bogert AJ, Gatica JE, Iannotti JP, Derwin KA. The biomechanical role of scaffolds in augmented rotator cuff tendon repairs. *J Shoulder Elb Surg.* 2012;21(8):1064–71. <https://doi.org/10.1016/j.jse.2011.05.014>.
21. Deutsch A, Altchek DW, Schwartz E, Otis JC, Warren RF. Radiologic measurement of superior displacement of the humeral head in the impingement syndrome. *J Shoulder Elb Surg.* 1996;5(3):186–93. [https://doi.org/10.1016/S1058-2746\(05\)80004-7](https://doi.org/10.1016/S1058-2746(05)80004-7).
22. Paletta GA, Warner JJP, Warren RF, Deutsch A, Altchek DW. Shoulder kinematics with two-plane x-ray evaluation in patients with anterior instability or rotator cuff tearing. *J Shoulder Elb Surg.* 1997;6(6):516–27. [https://doi.org/10.1016/S1058-2746\(97\)90084-7](https://doi.org/10.1016/S1058-2746(97)90084-7).
23. Pandey R, Tafazal S, Shyamsundar S, Modi A, Singh HP. Outcome of partial repair of massive rotator cuff tears with and without human tissue allograft bridging repair. *Shoulder Elb.* 2017;9(1):23–30. **This non-randomized cohort study of 26 irreparable RCT patients who received either partial repair or partial repair with an interposition, acellular human dermal allograft. Both cohorts showed postoperative improvement in pain and function but the dermal allograft cohort performed better than the control as measured by Oxford Shoulder Score and Constant Score, suggesting that using these grafts in this fashion may be a better treatment option than partial repair alone for irreparable tears.** <https://doi.org/10.1177/1758573216665114>.
24. Dimitrios V, Athanasios P, Eleni A, Xenofon P, George F, John F. Results of reconstruction of massive irreparable rotator cuff tears using a fascia lata allograft. *Indian J Orthop.* 2015;49(3):304–11. <https://doi.org/10.4103/0019-5413.156202>.
25. Kokkalis ZT, Mavrogenis AF, Scarlat M, Christodoulou M, Vottis C, Papagelopoulos PJ, et al. Human dermal allograft for massive rotator cuff tears. *Orthopedics.* 2014;37(12):e1108–e1116. **This retrospective case series demonstrated evidence that using interposition human dermal allografts in massive RCT will improve pain, range of motion, and function postoperatively.** <https://doi.org/10.3928/01477447-20141124-59>.
26. Mori D, Funakoshi N, Yamashita F, Wakabayashi T. Effect of fatty degeneration of the infraspinatus on the efficacy of arthroscopic patch autograft procedure for large to massive rotator cuff tears. *Am J Sports Med.* 2015;43(5):1108–1117. **In this cohort study, all patients had irreparable rotator cuff tears and supraspinatus stage 3 or 4 Goutallier fatty degeneration of the supraspinatus, and were subsequently treated with an interposition fascia lata autograft. They were analyzed in two cohorts: low-grade shoulders (Goutallier stage 1 or 2 of the infraspinatus) and high-grade shoulders (Goutallier stage 3 or 4 of the infraspinatus), with the low-grade shoulders proving more likely to be intact and showing significant improvement in function and range of motion at 24 months postoperatively than the high-grade shoulders. Such findings may perhaps allow the orthopedic surgeon to better predict postoperative outcomes, and thus counsel patients, given the preoperative infraspinatus condition.** <https://doi.org/10.1177/0363546515569680>.
27. Mihara S, Fujita T, Ono T, Inoue H, Kisimoto T. Rotator cuff repair using an original iliotibial ligament with a bone block patch: preliminary results with a 24-month follow-up period. *J Shoulder Elb Surg.* 2016;25(7):1155–1162. **This small case series of five patients with irreparable RCT received an interposition autograft of iliotibial band with attached Gerdy's tubercle bone block. The harvested bone block was fixed to the greater tubercle footprint to theoretically enhance healing over the use of a solely soft-tissue graft. At 24 months postoperatively, the authors demonstrated improved pain and function. Despite its small sample size, we believe this study to be important as it is unique in its use of autografted bone for lateral fixation.** <https://doi.org/10.1016/j.jse.2015.11.015>.
28. Neumann JA, Zgonis MH, Rickert KD, Bradley KE, Kremen TJ, Boggess BR, et al. Interposition dermal matrix xenografts: a successful alternative to traditional treatment of massive rotator cuff tears. *Am J Sports Med.* 2017;45(6):1261–1268. **This is the largest clinical study that reports statistical significance that was found during this review. Neumann et al. describe here the use of**

- porcine cellular dermal matrix xenografts to repair irreparable RCT, and the resulting postoperative improvements in pain, function and range of motion, thus suggesting this type of graft is a viable interposition option.** <https://doi.org/10.1177/0363546516683945>.
29. Thangarajah T, Pendegress CJ, Shahbazi S, Lambert S, Alexander S, Blunn GW. Augmentation of rotator cuff repair with soft tissue scaffolds. *Orthop J Sport Med*. 2015;3:2325967115587495.
  30. Steinhaus ME, Makhni EC, Cole BJ, Romeo AA, Verma NN. Outcomes after patch use in rotator cuff repair. *Arthrosc J Arthrosc Relat Surg*. 2016;32(8):1676–90. <https://doi.org/10.1016/j.arthro.2016.02.009>.
  31. Petri M, Greenspoon JA, Moulton SG, Millett PJ. Patch-augmented rotator cuff repair and superior capsule reconstruction. *Open Orthop J*. 2016;10(Suppl 1: M7):315–23. <https://doi.org/10.2174/1874325001610010315>.
  32. Ferguson DP, Lewington MR, Smith TD, Wong IH. Graft utilization in the augmentation of large-to-massive rotator cuff repairs. *Am J Sports Med*. 2016;44(11):2984–92. <https://doi.org/10.1177/0363546515624463>.
  33. Gillespie RJ, Knapik DM, Akkus O. Biologic and synthetic grafts in the reconstruction of large to massive rotator cuff tears. *J Am Acad Orthop Surg*. 2016;24(12):823–8. <https://doi.org/10.5435/JAAOS-D-15-00229>.
  34. Lewington MR, Ferguson DP, Smith TD, Burks R, Coady C, Wong IH-B. Graft utilization in the bridging reconstruction of irreparable rotator cuff tears: a systematic review. *Am J Sports Med*. 2017;36354651769435.
  35. Ono Y, Dávalos Herrera DA, Woodmass JM, Boorman RS, Thornton GM, Lo IKY. Can grafts provide superior tendon healing and clinical outcomes after rotator cuff repairs? *Orthop J Sport Med*. 2016;4(12):232596711667419. <https://doi.org/10.1177/2325967116674191>.
  36. Castricini R, Galasso O, Riccelli DA, Familiari F, De Benedetto M, Orlando N, et al. Arthroscopic partial repair of irreparable, massive rotator cuff tears. *Arthrosc Technol*. 2017;6(1):e143–7. <https://doi.org/10.1016/j.eats.2016.09.020>.
  37. Skedros J, Henrie T. Latissimus Dorsi tendon transfer with GraftJacket® augmentation to increase tendon length for an irreparable rotator cuff tear. *Case Rep Orthop*. 2017;2017:1–6.
  38. Ono Y, Dávalos Herrera DA, Woodmass JM, Boorman RS, Thornton GM, Lo IKY. Graft augmentation versus bridging for large to massive rotator cuff tears: a systematic review. *Arthrosc J Arthrosc Relat Surg*. 2017;33(3):673–80. <https://doi.org/10.1016/j.arthro.2016.08.030>.
  39. Neviaser JS, Neviaser RJ, Neviaser TJ. The repair of chronic massive ruptures of the rotator cuff of the shoulder by use of a freeze-dried rotator cuff. *J Bone Joint Surg Am*. 1978;60(5):681–4. <https://doi.org/10.2106/00004623-197860050-00017>.
  40. Nasca RJ. The use of freeze-dried allografts in the management of global rotator cuff tears. *Clin Orthop Relat Res*. 1988;228:218–26.
  41. Venouziou AI, Kokkalis ZT, Sotereanos DG. Human dermal allograft interposition for the reconstruction of massive irreparable rotator cuff tears. *Am J Orthop (Belle Mead NJ)*. 2013;42(2):63–70.
  42. Bond JL, Dopirak RM, Higgins J, Burns J, Snyder SJ. Arthroscopic replacement of massive, irreparable rotator cuff tears using a GraftJacket allograft: technique and preliminary results. *Arthrosc J Arthrosc Relat Surg*. 2008;24(4):403.e1–8. <https://doi.org/10.1016/j.arthro.2007.07.033>.
  43. Gupta AK, Hug K, Berkoff DJ, Boggess BR, Gavigan M, Malley PC, et al. Dermal tissue allograft for the repair of massive irreparable rotator cuff tears. *Am J Sports Med*. 2012;40(1):141–7. <https://doi.org/10.1177/0363546511422795>.
  44. Wong I, Burns J, Snyder S. Arthroscopic GraftJacket repair of rotator cuff tears. *J Shoulder Elb Surg*. 2010;19(2):104–9. <https://doi.org/10.1016/j.jse.2009.12.017>.
  45. Ito J, Morioka T. Surgical treatment for large and massive tears of the rotator cuff. *Int Orthop*. 2003;27(4):228–31. <https://doi.org/10.1007/s00264-003-0459-4>.
  46. Modi A, Singh HP, Pandey R. Management of irreparable rotator cuff tears with the GraftJacket allograft as an interpositional graft. *Should Elb*. 2013;5(3):188–94. <https://doi.org/10.1111/sae.12021>.
  47. Moore DR, Cain EL, Schwartz ML, Clancy WG. Allograft reconstruction for massive, irreparable rotator cuff tears. *Am J Sports Med*. 2006;34(3):392–6. <https://doi.org/10.1177/0363546505281237>.
  48. Ricchetti ET, Aurora A, Iannotti JP, Derwin KA. Scaffold devices for rotator cuff repair. *J Shoulder Elb Surg*. 2012;21(2):251–65. <https://doi.org/10.1016/j.jse.2011.10.003>.
  49. Cho NS, Yi JW, Rhee YG. Arthroscopic biceps augmentation for avoiding undue tension in repair of massive rotator cuff tears. *Arthrosc J Arthrosc Relat Surg*. 2009;25(2):183–91. <https://doi.org/10.1016/j.arthro.2008.09.012>.
  50. Mori D, Funakoshi N, Yamashita F. Arthroscopic surgery of irreparable large or massive rotator cuff tears with low-grade fatty degeneration of the infraspinatus: patch autograft procedure versus partial repair procedure. *Arthrosc J Arthrosc Relat Surg*. 2013;29(12):1911–21. <https://doi.org/10.1016/j.arthro.2013.08.032>.
  51. Giannotti S, Ghilardi M, Dell'osso G, Magistrelli L, Bugelli G, Di Rollo F, et al. Study of the porcine dermal collagen repair patch in morpho-functional recovery of the rotator cuff after minimum follow-up of 2.5 years. *Surg Technol Int*. 2014;24:348–52.
  52. Badhe SP, Lawrence TM, Smith FD, Lunn PG. An assessment of porcine dermal xenograft as an augmentation graft in the treatment of extensive rotator cuff tears. *J Shoulder Elb Surg*. 2008;17(1):S35–9. <https://doi.org/10.1016/j.jse.2007.08.005>.
  53. Jones CR, Snyder SJ. Massive irreparable rotator cuff tears: a solution that bridges the gap. *Sports Med Arthrosc*. 2015;23(3):130–8. <https://doi.org/10.1097/JSA.0000000000000064>.
  54. Rhee YG, Cho NS, Lim CT, Yi JW, Vishvanathan T. Bridging the gap in immobile massive rotator cuff tears: augmentation using the tenotomized biceps. *Am J Sports Med*. 2008;36(8):1511–8. <https://doi.org/10.1177/0363546508316020>.
  55. Sano H, Mineta M, Kita A, Itoi E. Tendon patch grafting using the long head of the biceps for irreparable massive rotator cuff tears. *J Orthop Sci*. 2010;15(3):310–6. <https://doi.org/10.1007/s00776-010-1453-5>.
  56. Scheibel M, Brown A, Woertler K, Imhoff AB. Preliminary results after rotator cuff reconstruction augmented with an autologous periosteal flap. *Knee Surg Sport Traumatol Arthrosc*. 2007;15(3):305–14. <https://doi.org/10.1007/s00167-006-0173-z>.
  57. Mihara S, Ono T, Inoue H, Kisimoto T. A new technique for patch augmentation of rotator cuff repairs. *Arthrosc Tech*. 2014;3(3):e367–71. <https://doi.org/10.1016/j.eats.2014.02.007>.
  58. Zerr J, McDermott JD, Beckmann NM, Fullick RK, Chhabra A. Case study: failure of superior capsular reconstruction using dermal allograft. *Radiol: Skelet*. 2017.
  59. Pogorzelski J, DelVecchio BM, Hussain ZB, Fritz EM, Godin JA, Millett PJ. Superior capsular reconstruction for massive rotator cuff tears—key considerations for rehabilitation. *Int J Sport Phys Ther*. 2017;12:390–401.
  60. Hirahara AM, Adams CR. Arthroscopic superior capsular reconstruction for treatment of massive irreparable rotator cuff tears. *Arthrosc Tech*. 2015;4(6):e637–41. <https://doi.org/10.1016/j.eats.2015.07.006>.
  61. Petri M, Greenspoon JA, Millett PJ. Arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. *Arthrosc Tech*. 2015;4(6):e751–5. <https://doi.org/10.1016/j.eats.2015.07.018>.
  62. Tokish JM, Beicker C. Superior capsule reconstruction technique using an acellular dermal allograft. *Arthrosc Tech*. 2015;4(6):e833–9. <https://doi.org/10.1016/j.eats.2015.08.005>.

63. Katthagen JC, Tahal DS, Millett PJ. Arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. *Orthop Today*. 2016.
64. Burkhart SS, Denard PJ, Adams CR, Brady PC, Hartzler RU. Arthroscopic superior capsular reconstruction for massive irreparable rotator cuff repair. *Arthrosc Tech*. 2016;5(6):e1407–18. <https://doi.org/10.1016/j.eats.2016.08.024>.
65. Schon JM, Katthagen JC, Dupre CN, Mitchell JJ, Turnbull TL, Adams CR, et al. Quantitative and computed tomography anatomic analysis of glenoid fixation for superior capsule reconstruction: a cadaveric study. *Arthrosc J Arthrosc Relat Surg*. 2017;33(6):1131–7. <https://doi.org/10.1016/j.arthro.2016.10.016>.
66. Narvani AA, Consigliere P, Polyzois I, Sarkhel T, Gupta R, Levy O. The “pull-over” technique for arthroscopic superior capsular reconstruction. *Arthrosc Tech*. 2016;5(6):e1441–7. <https://doi.org/10.1016/j.eats.2016.08.016>.
67. Adams CR, Denard PJ, Brady PC, Hartzler RU, Burkhart SS. The arthroscopic superior capsular reconstruction. *Am J Orthop (Belle Mead NJ)*. 2016;45(5):320–4.
68. Rossi MJ. Editorial commentary: superior capsular reconstruction for irreparable supraspinatus tear reveals improved biomechanics with a thicker graft placed in 15° to 45° of shoulder abduction. *Arthrosc J Arthrosc Relat Surg*. 2016;32(3):427. <https://doi.org/10.1016/j.arthro.2015.12.032>.
69. Rossi MJ. Editorial commentary: results of biplanar fluoroscopy with 3-dimensional analysis in patients with rotator cuff tears challenge the concept of superior translation of the humeral head and must be interpreted with caution. *Arthrosc J Arthrosc Relat Surg*. 2016;32(3):452. <https://doi.org/10.1016/j.arthro.2015.12.031>.
70. • Mihata T, MH MG, Kahn T, Goldberg I, Neo M, Lee TQ. Biomechanical effect of thickness and tension of fascia lata graft on Glenohumeral stability for superior capsule reconstruction in irreparable supraspinatus tears. *Arthrosc - J Arthrosc Relat Surg*. 2016;32(3):418–426. **In this cadaveric study, Mihata et al. demonstrate superior humeral translation and increased subacromial contact pressure in irreparable supraspinatus tears. They then show the ability of SCR performed with the shoulder between 0 and 30 of abduction to reduce this pressure and limit superior translation. The importance of this study resides in its use as the guideline for arm positioning during SCR procedures.** <https://doi.org/10.1016/j.arthro.2015.08.024>.
71. • Mihata T, McGarry MH, Kahn T, Goldberg I, Neo M, Lee TQ. Biomechanical effects of acromioplasty on superior capsule reconstruction for irreparable supraspinatus tendon tears. *Am J Sports Med*. 2016;44(1):191–197. **This study, similar to reference 70, also serves as a guideline in SCR operations. Mihata et al. here showed that the addition of acromioplasty to SCR operations will decrease subacromial contact area, though not subacromial contact pressure. As such, acromioplasty is now a frequently addition to these operations.** <https://doi.org/10.1177/0363546515608652>.
72. • 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. **This biomechanical, cadaveric study additionally outlines the best SCR practices. Mihata et al. demonstrated in this article the significance of posterior graft fixation to residual infraspinatus tendon will reduce subacromial contact pressure and superior humeral translation when compared to SCR without this fixation. As such, posterior fixation has become a mainstay of SCR.** <https://doi.org/10.1177/0363546516631751>.
73. Mihata T, McGarry MH, Pirolo JM, Kinoshita M, Lee TQ. Superior capsule reconstruction to restore superior stability in irreparable rotator cuff tears. *Am J Sports Med*. 2012;40(10):2248–55. <https://doi.org/10.1177/0363546512456195>.
74. Mihata T, Lee TQ, Watanabe C, Fukunishi K, Ohue M, Tsujimura T, et al. Clinical results of arthroscopic superior capsule reconstruction for irreparable rotator cuff tears. *Arthrosc J Arthrosc Relat Surg*. 2013;29(3):459–70. <https://doi.org/10.1016/j.arthro.2012.10.022>.
75. McKeown AD, Beattie RF, Murrell GA, Lam PH. Biomechanical comparison of expanded polytetrafluoroethylene (ePTFE) and PTFE interpositional patches and direct tendon-to-bone repair for massive rotator cuff tears in an ovine model. *Should Elb*. 2016;8(1):22–31. <https://doi.org/10.1177/1758573215601815>.
76. Smith MJ, Pfeiffer FM, Cook CR, Kuroki K, Cook JL. Rotator cuff healing using demineralized cancellous bone matrix sponge interposition compared to standard repair in a preclinical canine model. *J Orthop Res*. 2017.
77. Lee KW, Lee JS, Kim YS, Shim YB, Jang JW, IL LK. Effective healing of chronic rotator cuff injury using recombinant bone morphogenetic protein-2 coated dermal patch in vivo. *J Biomed Mater Res B Appl Biomater*. 2017;105(7):1840–6. <https://doi.org/10.1002/jbm.b.33716>.