Skeletal Radiology (2019) 48:47–55
https://doi.org/10.1007/s00256-018-3015-4

REVIEW ARTICLE

Graft use in the treatment of large and massive rotator cuff tears: an overview of techniques and modes of failure with MRI correlation

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Received: 9 May 2018 / Revised: 12 June 2018 / Accepted: 17 June 2018 / Published online: 5 July 2018

Abstract
Despite technical advances, repair of large or massive rotator cuff tears continues to demonstrate a relatively high rate of failure. Rotator cuff repair or superior capsular reconstruction (SCR) using a variety of commercially available grafts provides a promising option in patients with tears that may be at high risk for failure or otherwise considered irreparable. There are three major graft constructs that exist when utilizing graft in rotator cuff repair or reconstruction: augmentation at the rotator cuff footprint, bridging, and SCR. Each construct has a unique appearance when evaluated using postoperative magnetic resonance imaging (MRI), and each construct has unique sites that are predisposed to failure. Understanding the basic principles of these constructs can help the radiologist better evaluate the postoperative MRI appearance of these increasingly utilized procedures.

Keywords Rotator cuff repair · Superior capsular reconstruction · Rotator cuff graft · Rotator cuff augmentation · Rotator cuff interposition

Introduction

Rotator cuff repair is one of the most frequently performed orthopedic procedures, with utilization rates continuing to increase across the United States [1, 2]. Despite numerous technological advances, the rate of radiographic retear or loss of structural integrity of the repair for large or massive rotator cuff tears remains high, ranging from 20 to 90% in published studies [3–9]. Although much has been made about improving the biomechanical characteristics of the rotator cuff repair construct [10–14], there has been a more recent focus on augmenting the biological environment to improve healing after rotator cuff repair [15–18].

Augmentation of rotator cuff repair with autograft, allograft, xenograft, or synthetic grafts allows surgeons to better address rotator cuff tears that exhibit poor tissue quality or tendon retraction that otherwise would lead to a high rate of failure [19–25]. Although the majority of reported clinical results are short-term, grafts provide an option in patients with tears that would otherwise be considered irreparable or only amenable to partial repair or reverse shoulder arthroplasty, all of which may impose significant postoperative limitations or risk in an otherwise active patient population [19, 26–30]. Still, it is important to understand that not all grafts or graft constructs are the same. Whereas the term "augmentation" is often used ubiquitously when referring to graft constructs, this may cause confusion when attempting to interpret the literature or radiographically assess a patient postoperatively. More specifically, grafts can be used to augment a repair at the rotator cuff footprint on the greater tuberosity of the humerus when the native rotator cuff is unable to cover the entire footprint or is deemed to have poor tissue quality, bridge a defect if the native tendon is retracted and unable to be mobilized to any portion of the rotator cuff footprint on the greater tuberosity, or reconstruct the superior capsule in the form of superior capsular reconstruction (SCR) when the rotator cuff tendons are deemed irreparable.

As graft use in the setting of rotator cuff repair and SCR increases, it is important for the radiologist to be familiar with currently utilized techniques to aid in the interpretation of postoperative imaging [31]. The purpose of the following review is to provide radiologists with familiarity with the variety

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of graft constructs used during rotator cuff repair and SCR. By providing an overview of the surgical techniques and modes of failure, we hope to provide radiologists with a better understanding of the magnetic resonance imaging (MRI) appearance of the relevant anatomy, graft integrity, and complications in the postoperative setting.

MRI assessment of rotator cuff repairs

Patients with persistent pain and weakness after adequate rehabilitation following rotator cuff repair or a history of an acute injury postoperatively may undergo advanced imaging to assess the repair. MRI remains a valuable and cost-effective tool in the evaluation of patients with a suspected rotator cuff tear [32]. It is important for those interpreting these images to understand that the appearance of the repaired tendon differs from that of the native tendon, particularly on fluid-sensitive sequences, and evolves over time [33, 34]. Historically, MR arthrograms were believed to provide greater sensitivity when assessing the rotator cuff postoperatively. However, recent studies have suggested no superiority of MR arthrography over MRI without intra-articular contrast medium when using 1.5-T or 3.0-T MRI units [35].

It is important for the radiologist to understand the basic details of the surgical procedure when evaluating an MRI postoperatively, as evolving techniques have led to distinct modes of failure that should be carefully scrutinized. For example, the widespread use of the double-row repair technique, utilizing anchor fixation at the articular margin and lateral aspect of the rotator cuff footprint on the greater tuberosity of the humerus [36], has led to increased recognition and classification of medial row failures [37, 38]. As an evolving technique, there remains a paucity of literature on the postoperative MRI appearance of rotator cuff repair and SCR using grafts. Because of this, it is important for the radiologist to understand the basics of repair constructs utilizing grafts. In these scenarios, it is particularly important for the radiologist to appreciate the secondary signs of repair failure, including visualization of a free tendon stump, superior migration of the humeral head, a decrease in the acromiohumeral interval, increasing fatty infiltration of the muscle belly of the affected tendon compared with preoperative or serial images, and loose bodies consistent with dislodged anchors, all of which can be helpful in distinguishing an intact construct from a repair failure when the local anatomy has been altered by the use of a graft.

Graft techniques

The three most commonly employed graft techniques for rotator cuff repair include graft augmentation at the rotator cuff footprint and graft bridging technique, whereas SCR serves to reconstruct the superior capsule when the native rotator cuff is deficient (Fig. 1). The indication for each technique is based primarily on the quality of the tissue and/or the mobility of the tissue. This is often determined at the time of surgery, but several MRI findings, including the degree of fatty infiltration of the involved rotator cuff musculature, as originally described by Goutallier using computed tomography and later modified by Fuchs using MRI, may provide some insight into the quality of tissue and subsequent risk for repair failure (Fig. 2) [39, 40]. The following serves to briefly describe the relevant portions of the operative technique for each graft construct, in addition to the normal appearance on postoperative MRI.

Graft augmentation technique at the rotator cuff footprint

Indications and operative technique

Graft augmentation at the rotator cuff footprint on the greater tuberosity of the humerus is considered when the native rotator cuff tendon can be adequately mobilized to the rotator cuff footprint but is deemed to be of poor tissue quality. Additionally, graft augmentation may be considered when the native rotator cuff tendon can only be mobilized to the medial-most portion of the footprint at the articular margin, thus leaving a portion of the native rotator cuff footprint uncovered unless a graft is used.

Graft augmentation at the rotator cuff footprint is most analogous to a standard rotator cuff repair when compared with the other graft construct techniques. As with standard rotator cuff repair, the procedure can be performed via arthroscopic or mini-open techniques with equivalent clinical results [41], although the approach may affect the appearance of adjacent tissues on postoperative MRI [31]. The end of the torn native rotator cuff tendon is mobilized to reach at least the medial border of the rotator cuff footprint at the articular margin of the humeral head cartilage. Most typically, a double-row repair construct is utilized to maximize coverage and contact area for healing to the native footprint [36]. Suture anchors are placed directly adjacent to the articular margin, creating the medial row, and sutures from these anchors are then passed through the native tendon in addition to the medial edge of the appropriately-sized graft [42]. The native tendon and graft are secured to the medial footprint by tying knots, and then an additional row of anchors, creating the lateral row, are placed at the lateral edge of the rotator cuff footprint to secure the lateral edge of the graft and, if able to be adequately mobilized, any residual native rotator cuff tendon. In this fashion, the graft is superimposed over the native rotator cuff tendon with poor tissue quality or used to cover the bare footprint if the rotator cuff cannot be adequately mobilized before being fixed laterally (Fig. 3). The graft serves to provide biomechanical strength in addition to a scaffold for biological healing.

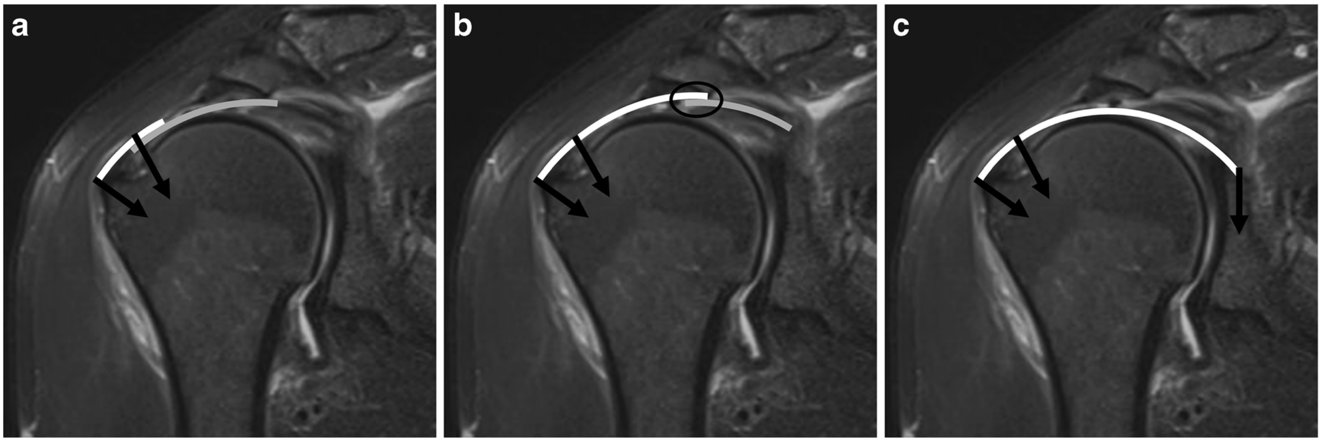

Fig. 1 Various rotator cuff repair and reconstruction graft constructs graphically demonstrated on a coronal oblique T2-weighted fat-saturated image including **a** graft augmentation at the rotator cuff footprint, **b** graft bridging technique, and **c** superior capsular reconstruction. The graft is represented by the superimposed *white line* whereas the native rotator cuff, when present, is represented by the superimposed *gray line*. *Black arrows* represent typical locations of anchors for fixation to bone. The *black circle* represents the suture interface between native tendon medially and the graft laterally

Postoperative MRI appearance

Magnetic resonance imaging of the shoulder after graft augmentation at the rotator cuff footprint is most similar to a standard double-row rotator cuff repair without graft. Following graft augmentation, the tissue at the rotator cuff footprint may appear thickened owing to the superimposed graft, which may measure anywhere from 1–3 mm in thickness. Outside of the variable thickness of commercially available grafts, the MRI appearance of various allografts, autografts, xenografts, and synthetic grafts frequently utilized for graft augmentation appear similar. Like standard rotator cuff repairs, the appearance of the graft evolves over time, having homogeneously low signal on fluid-sensitive sequences as the graft matures. Understanding anchor position and associated artifact is also important, particularly with commonly utilized double-row repair techniques. An intact graft augmentation construct displays complete coverage of the rotator cuff footprint with soft

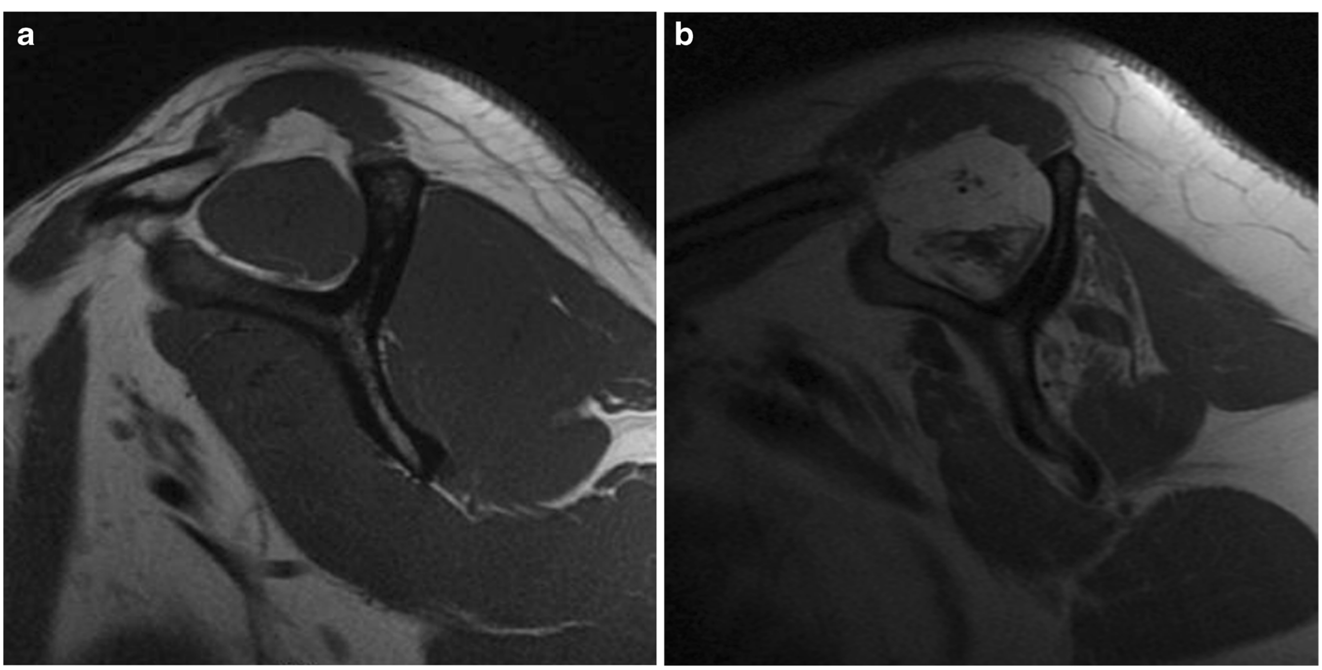

Fig. 2 Sagittal oblique T1-weighted images at the level of the scapular spine with **a** normal appearance of the supraspinatus and infraspinatus musculature without fatty infiltration and **b** severe fatty infiltration (Goutallier grade 4) of the supraspinatus and infraspinatus musculature

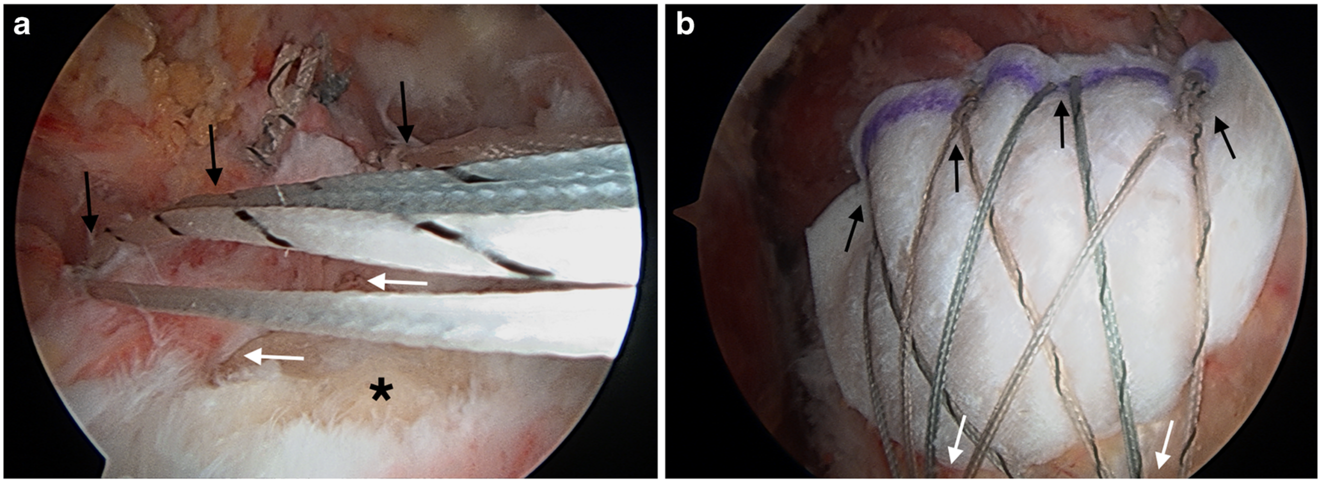

Fig. 3 Arthroscopic images of a right shoulder viewing from the posterolateral portal with **a** medial row anchors passed through the native tendon (*black arrows*) with the lateral edge of the native tendon (*white arrows*) unable to cover the bare footprint (*asterisk*). **b** Graft augmentation at the footprint allows complete coverage of the footprint with medial (*black arrows*) and lateral (*white arrows*) row fixation

tissue that is intact medially without evidence of native tendon retraction or significantly increased signal within the tendon (Fig. 4).

Graft bridging technique

Indications and operative technique

Graft bridging technique is considered when the native rotator cuff cannot be adequately mobilized to the medial aspect of the rotator cuff footprint at the articular margin or when attempting to do so would put undue tension on the repair, thus setting up a situation with a high likelihood of biomechanical and biological failure. In this scenario, using a graft interposed between the immobile native tendon stump and the rotator cuff footprint becomes a viable option.

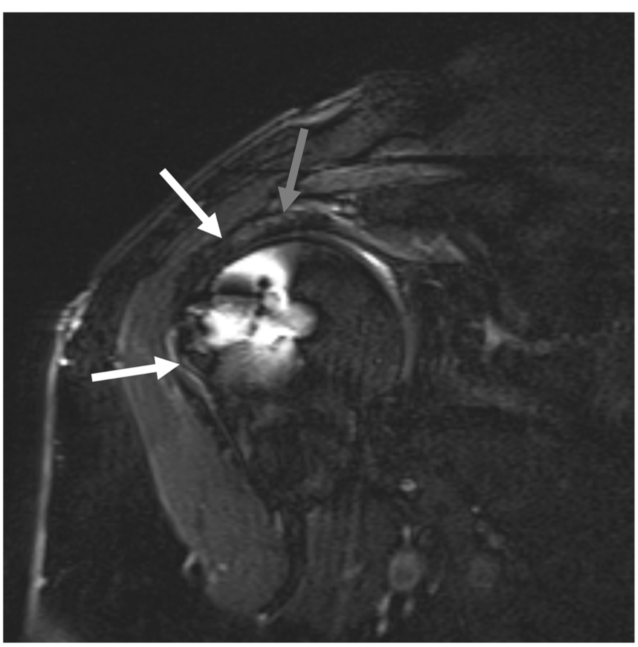

Fig. 4 Coronal oblique T2-weighted fat-saturated image of a rotator cuff repair with graft augmentation at the footprint. The thickened appearance at the greater tuberosity between the medial and lateral row fixation (*white arrows*) is the graft, with the native tendon visible medially (*gray arrow*)

Graft bridging can again be achieved through an arthroscopic or mini-open approach. After mobilization of the native tendon, the distance between the tendon end and the rotator cuff footprint is measured and an appropriately sized graft selected. Sutures are first passed through the free end of the torn rotator cuff tendon and then again through the medial aspect of the graft, passing sutures approximately 5 mm from the graft edge to allow some overlap between the native tendon and the graft while preventing sutures from pulling out of the graft [29]. With the graft secured to the tendon, the graft alone is then secured to the rotator cuff footprint, again using a double-row suture anchor configuration to provide complete coverage of the native footprint with the graft. The procedure creates an interposition graft, which serves to effectively lengthen the tendon back to the footprint without undue tension. The graft provides a biological matrix for tenocyte infiltration and eventual tendon-to-bone healing.

Postoperative MRI appearance

The intact graft bridging construct should demonstrate continuity at the tendon–graft and graft–bone interfaces, consistent with integration of the graft with both the native tendon medially and the rotator cuff footprint laterally (Fig. 5). The interposed graft typically displays low signal intensity initially, becoming more homogeneous in appearance as the graft matures over time. However, there is often suture artifact and persistent signal increase directly at or

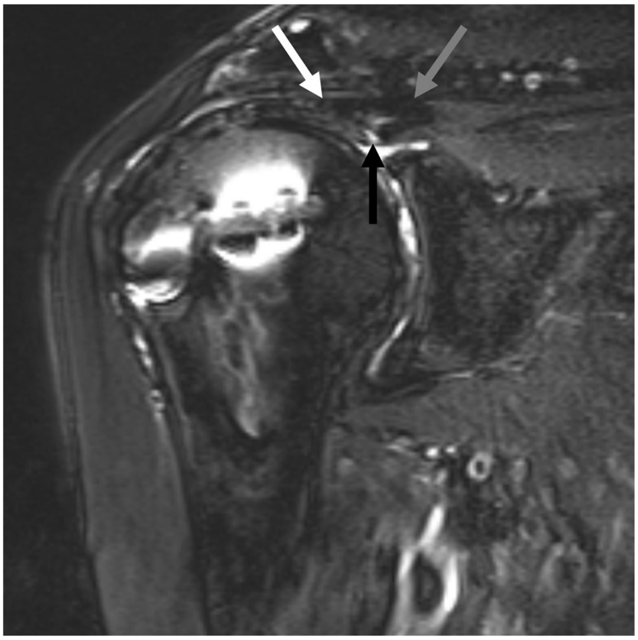

Fig. 5 Coronal oblique T2-weighted fat-saturated image of a bridging graft construct. The native tendon is visible medially (*gray arrow*) with a clear suture interface (*black arrow*) between the native tendon and the graft (*white arrow*), which is fixed laterally to the footprint on the greater tuberosity

Fig. 6 Coronal oblique T2-weighted non-fat-saturated image of a massive rotator cuff tear with supraspinatus tendon retraction to the level of the glenohumeral joint (*white arrow*) and a high-riding humeral head with a decreased acromiohumeral interval

adjacent to the tendon–graft interface, but there should not be discontinuity at the interface on adjacent MRI slices. Laterally, soft tissue should cover the entire rotator cuff footprint, as the graft incorporates into the bone without evidence of a fluid layer between the graft and bone, while acknowledging adjacent suture anchor artifact.

Superior capsular reconstruction technique

Indications and operative technique

In patients with massive rotator cuff tears that are retracted to the level of the glenoid or more medially and with poor tissue quality and excursion (Fig. 6), SCR is a viable option that serves to limit superior migration of the humeral head, thus maintaining concentric articulation of the glenohumeral joint. It is not uncommon for patients, particularly young patients, to have failed one or multiple previous attempts at standard rotator cuff repair before meeting indications for SCR. The procedure is particularly attractive in young patients with massive rotator cuff tears where alternative procedures, such as reverse total shoulder arthroplasty, may result in significant postoperative limitations and poor survivorship.

As with the other graft constructs, SCR can be performed via an arthroscopic or mini-open approach. Inadequate excursion of the torn rotator cuff tendon is confirmed, thus providing the indication for the procedure. Suture anchors, typically two to three in number, are placed along the superior glenoid and associated sutures are passed through the medial aspect of an appropriately-sized graft [43]. Knots are tied to fix the graft medially to the superior glenoid. The remaining graft is then pulled laterally to the rotator cuff footprint at the greater tuberosity. Anchors are again placed in a double-row configuration to cover the entire rotator cuff footprint and the graft affixed to the footprint. When anchoring the graft laterally, enough tension is applied through the graft to reduce the high-riding humeral head. Once fixed medially and laterally, the graft is sutured side-to-side to any remaining adjacent anterior (subscapularis) and posterior (infraspinatus) rotator cuff tissue to create a watertight seal and thus a reconstruction of the superior capsule.

Postoperative MRI appearance

Grafts used for SCR are typically a minimum of 2.5 mm thick and may appear thicker than other types of grafts used in augmentation or bridging techniques. An intact SCR graft demonstrates a low signal, homogeneous appearance on fluid-sensitive sequences (Fig. 7). The graft should be clearly attached medially to the superior glenoid and laterally to the rotator cuff footprint on the greater tuberosity of the humerus without any increased signal between the graft and bone at both locations. Owing to the commonality of previous operative procedures in the SCR patient population, there can often be a large amount of artifact at the humeral footprint that must be appropriately interpreted. A functioning graft should appear well-tensioned without undulations. A secondary finding for a well-tensioned, functioning graft is the concentric

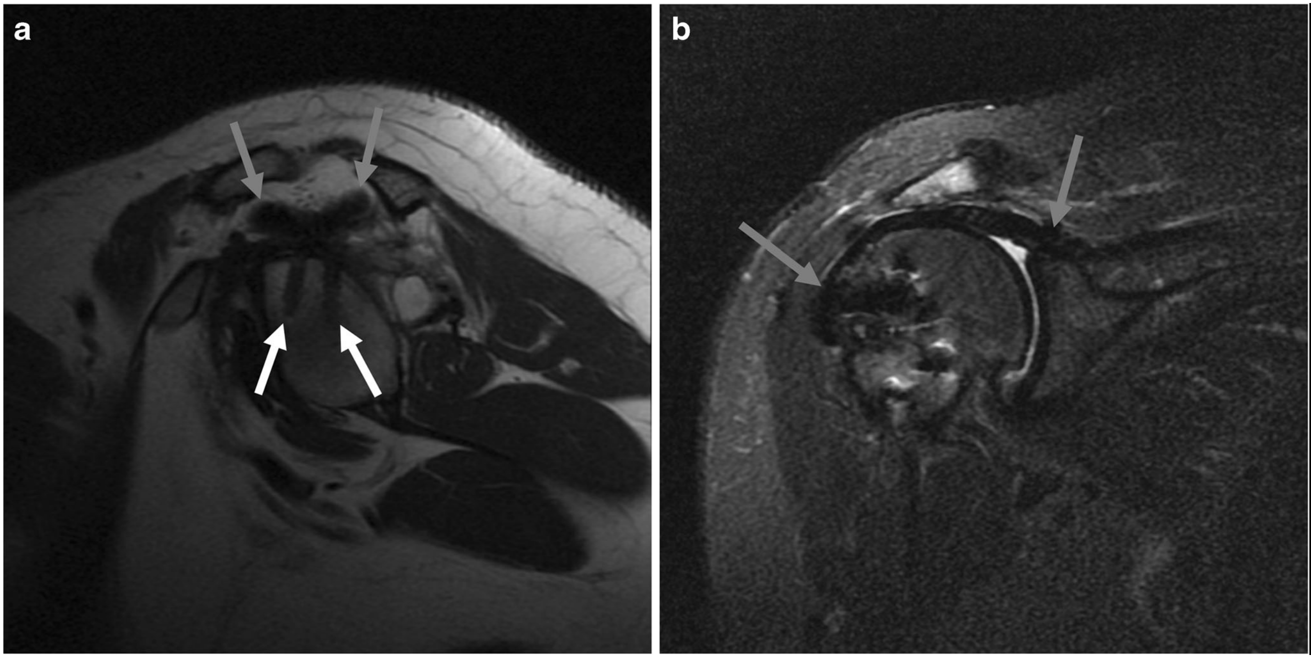

Fig. 7 Intact superior capsular reconstruction with **a** medial fixation of the graft (*gray arrows*) with anchors in the glenoid (*white arrows*) on sagittal oblique T2-weighted non-fat-saturated images. **b** Coronal oblique T2-weighted fat-saturated image demonstrates the intact graft medially and laterally (*gray arrows*) with typical, low signal, homogeneous appearance of the graft between the two points of fixation

appearance of the glenohumeral articulation with appropriate inferior translation of the humeral head and restoration of the acromiohumeral interval.

Modes of failure

Rotator cuff repairs and SCR using graft fail in similar ways to standard rotator cuff repairs, including anchor pullout, suture cutout, suture failure, intrasubstance graft failure, or developing a tear in a new location. Suture cutout through soft tissue is the single most common mode of failure [44], and thus all interfaces, including the tendon-bone, graft-bone, and graft-tendon interfaces, must be carefully evaluated, where applicable, as they serve as the weak link in the repair or reconstruction. This reiterates the importance of understanding the basic concepts of rotator cuff repair and reconstruction techniques to localize areas that are at risk for failure.

Graft augmentation technique at the rotator cuff footprint

Failures following rotator cuff repair with graft augmentation occur at the rotator cuff footprint on the greater tuberosity of the humerus. The currently described techniques for graft augmentation utilize a double-row suture anchor construct [25, 42], and as such, medial row failures may occur at the articular margin, leaving a remnant layer of rotator cuff tissue and graft at the footprint with the rest of the native tendon retracted medially. In double-row repairs, this is the most frequent mode of failure (Fig. 8) [38]. Less commonly, the entire tendon and graft construct can pull off the footprint on the greater tuberosity, leaving the footprint bare of any soft tissue.

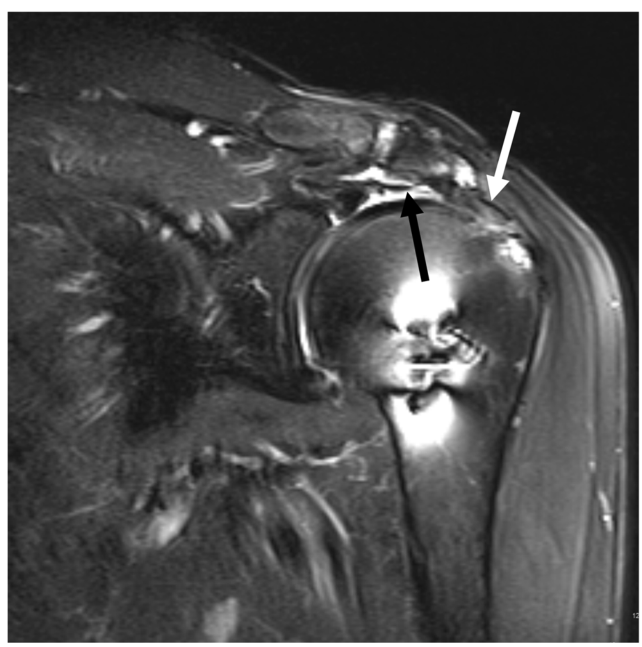

Fig. 8 Coronal T2-weighted fat-saturated image demonstrating a failed rotator cuff repair with augmentation at the footprint. The native tendon is retracted medially (*black arrow*) and persistent low signal at the footprint (*white arrow*) is consistent with residual graft and tendon

Graft bridging technique

There are two interfaces to scrutinize when evaluating a rotator cuff repair with use of a graft bridging technique. The medial interface between the native tendon and graft is a common site of failure. There is often clear discontinuity of the graft–tendon interface with retraction of the native tendon medially and loss of tension within the residual graft (Fig. 9). Although anecdotally less common, the lateral interface between the graft and bone is another potential site of failure. As previously discussed in the context of double-row repair techniques, the graft–bone interface may fail at the medial border or pull completely off the footprint, leaving the entire footprint bare. Although theoretically possible, intra- or midsubstance tears through the graft itself have not been described with the bridging technique.

Superior capsular reconstruction technique

Following SCR, the most common site of graft failure is at the lateral graft–bone interface at the rotator cuff footprint on the greater tuberosity of the humerus [45]. In this scenario, the graft often has an undulating appearance due to the lack of tension within the graft. Unique failures specific to the double-row repair construct still apply with lateral graft–bone interface failures. Although less common, medial failures may occur at the graft–bone interface at the superior aspect of the glenoid (Fig. 10). Intra- or midsubstance failures have also been described following SCR, typically secondary to an attenuated graft. In this setting, it is often useful to look for secondary signs of graft failure, namely a high-riding humeral head or a decrease in the acromiohumeral interval.

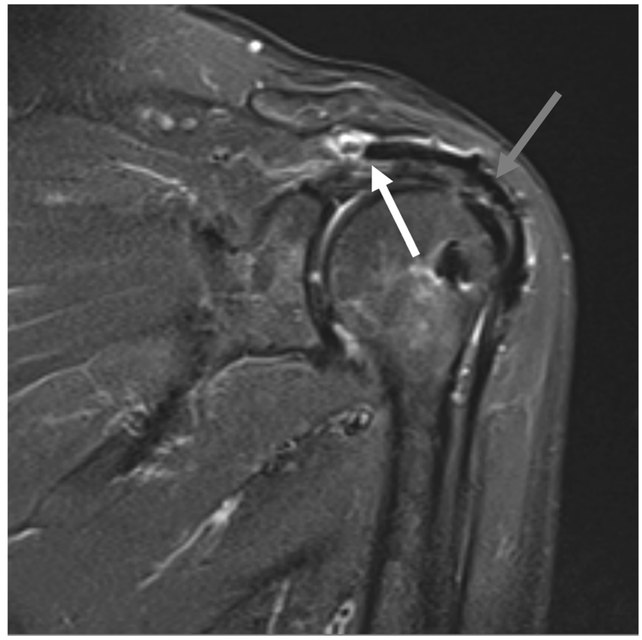

Fig. 10 Coronal oblique T2-weighted fat-saturated image with medial failure at the graft–bone interface following superior capsular reconstruction. The medial aspect of the graft (*white arrow*) is no longer continuous with the superior aspect of the glenoid, whereas graft is seen coursing laterally (*gray arrow*) to the rotator cuff footprint

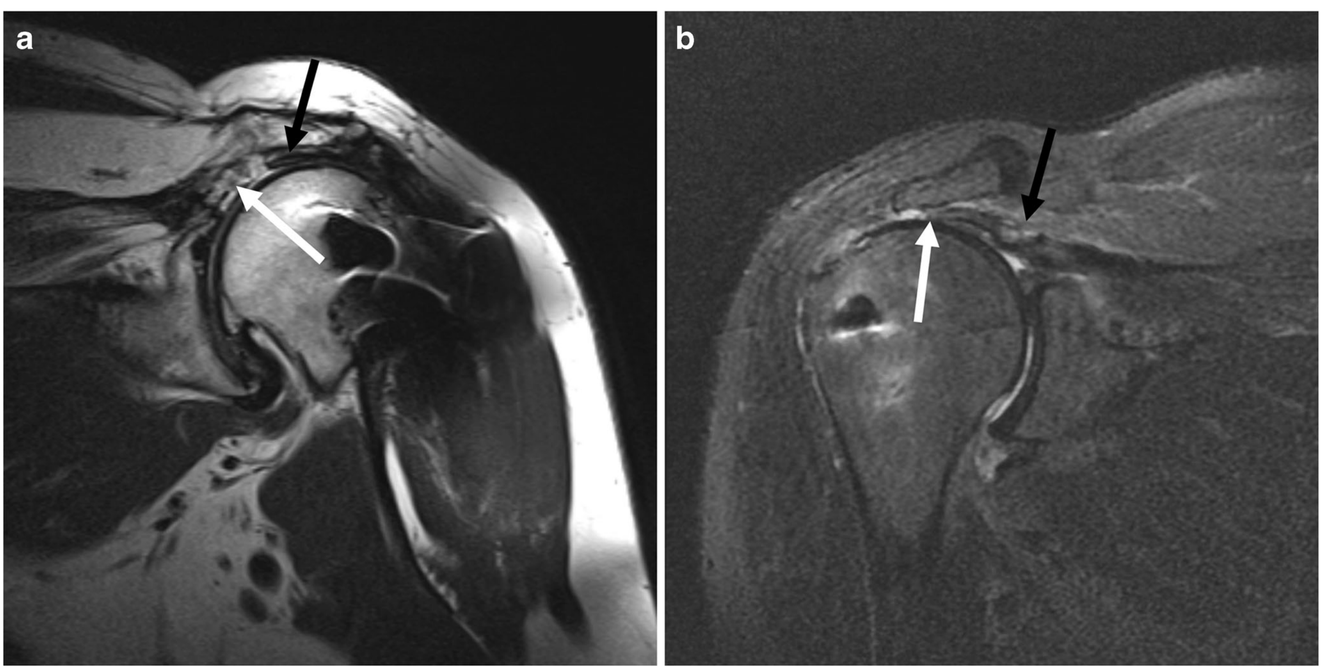

Fig. 9 Failed graft bridging construct **a** medially with discontinuity of the graft–tendon interface, retraction of the native rotator cuff tendon (*white arrow*), and residual graft (*black arrow*) still adhered to the lateral footprint on coronal T2-weighted non-fat-saturated imaging. **b** Lateral failure is demonstrated with retraction of the graft medially (*white arrow*) with the graft–tendon interface still intact (*black arrow*) on coronal oblique T2-weighted fat-saturated imaging

Conclusion

Rotator cuff repair and SCR techniques utilizing grafts to treat large and massive rotator cuff tears provide a promising option for patients with tears that may otherwise be considered irreparable or at significant risk for failure. Graft augmentation at the rotator cuff footprint, bridging, and SCR are currently the most frequently employed constructs utilizing graft. As with standard rotator cuff repair, the interfaces between different tissue types are the most common sites of failure. Specifically, graft augmentation techniques typically fail at the lateral graft–bone or tendon–bone interface, bridging techniques typically fail at the medial graft–tendon or lateral graft–bone interface, and SCR techniques fail at either the medial graft–bone interface on the superior glenoid or the lateral graft–bone interface at the rotator cuff footprint. Although there remains a paucity of literature on the MRI interpretation of these constructs postoperatively, understanding the basic principles of these three techniques should aid the radiologist who may otherwise be unfamiliar with these evolving techniques.

Funding No external funding was utilized for the published content.

Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

Informed consent Informed consent was obtained from all individual participants included in the study.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

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