Review paper

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Role of ultrasound and MRI in the evaluation of postoperative rotator cuff

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Abstract

Rotator cuff tears are common shoulder injuries in patients above 40 years of age, causing pain, disability, and reduced quality of life. Most recurrent rotator cuff tears happen within three months. Surgical repair is often necessary in patients with large or symptomatic tears to restore shoulder function and relieve symptoms. However, 25% of patients experience pain and dysfunction even after successful surgery. Imaging plays an essential role in evaluating patients with postoperative rotator cuff pain. The ultrasound and magnetic resonance imaging are the most commonly used imaging modalities for evaluating rotator cuff. The ultrasound is sometimes the preferred first-line imaging modality, given its easy availability, lower cost, ability to perform dynamic tendon evaluation, and reduced post-surgical artifacts compared to magnetic resonance imaging. It may also be superior in terms of earlier diagnosis of smaller re-tears. Magnetic resonance imaging is better for assessing the extent of larger tears and for detecting other complications of rotator cuff surgery, such as hardware failure and infection. However, postoperative imaging of the rotator cuff can be challenging due to the presence of hardware and variable appearance of the repaired tendon, which can be confused with a re-tear. This review aims to provide an overview of the current practice and findings of postoperative imaging of the rotator cuff using magnetic resonance imaging and ultrasound. We discuss the advantages and limitations of each modality and the normal and abnormal imaging appearance of repaired rotator cuff tendon.

Introduction

Supraspinatus, infraspinatus, teres minor, and subscapularis together constitute the rotator cuff tendons.

1. Supraspinatus tendon: It is the most frequently involved tendon in rotator cuff tears. Tears of the supraspinatus tendon can range from partial to complete tears. This tendon is commonly repaired when indicated, especially in symptomatic or large tears(1).
2. Infraspinatus tendon: It is less frequently torn compared to the supraspinatus tendon, but it is still a common site of rotator cuff pathology. Tears in the infraspinatus tendon can be associated with other rotator cuff tears or occur in isolation. Surgical repair may be considered for larger or symptomatic tears(2).
3. Subscapularis tendon: It is a less frequently torn tendon compared to the supraspinatus and infraspinatus tendons. Certain larger tears are considered for primary repair, especially when conservative treatment does not lead to improvement(3).
4. Teres minor tendon: Teres minor tendon tears are rare, and the tendon is generally intact even in the presence of a massive rotator cuff tear.

Rotator cuff tears are broadly classified into partial and full-thickness tears, and are commonly seen in patients above 40 years of age, causing pain, disability, and reduced quality of life.

Full-thickness tear size definitions:

1. Small tear: Typically involves a partial discontinuity of the tendon, often less than 1 cm in width.
2. Moderate tear: Larger than a small full-thickness tear but not a full-width tear, usually ranging from 1 to 3 cm in width.
3. Large tear: A full-thickness disruption of the tendon, typically measuring more than 3 cm in width.
4. Massive tear: Involves multiple tendons and may extend to more than 5 cm in width. In some cases, it can lead to complete detachment of the rotator cuff from its attachment site.

Implications of tear size and fatty atrophy in rotator cuff repair:

1. Tear size:

- Smaller tears may be amenable to conservative management or arthroscopic repair, with generally better outcomes.

- Moderate tears can often be managed with arthroscopic repair, although success rates may be slightly lower than in smaller tears.
- Large and massive tears usually require surgical intervention due to significant functional impairment and limited healing potential.

2. Fatty atrophy:

- Fatty atrophy r efers to the replacement of muscle tissue with fatty tissue, which can occur when the rotator cuff tears are left untreated. Advanced fatty atrophy may compromise the healing potential and functional outcome following rotator cuff repair. The degree of fatty atrophy is assessed using magnetic resonance imaging (MRI) or ultrasound (US) imaging, and can influence the surgical decision-making process.

Most recurrent rotator cuff tears occur within three months[4]. Rotator cuff repair is performed to restore shoulder function and relieve symptoms. However, 25% of patients experience pain and dysfunction even after successful surgery[5]. Imaging plays an essential role in evaluating patients with postoperative rotator cuff pain. US and MRI are the most commonly used imaging modalities for evaluating rotator cuff. US is often the first-line imaging modality, given its easy availability, lower cost, ability to perform dynamic tendon evaluation, and reduced post-surgical artifacts compared to MRI. It may also be better for earlier diagnosis of smaller re-tears. MRI is superior for assessing the extent of larger tears and for detecting other complications of rotator cuff surgery, such as hardware failure and infection. However, postoperative imaging of the rotator cuff can be challenging due to the presence of hardware and variable appearance of the repaired tendon, which can be confused with a re-tear. This review aims to provide an overview of the current practice and findings of postoperative imaging of the rotator cuff using MRI and US. We discuss the advantages and limitations of each modality, and the normal and abnormal imaging appearance of the repaired rotator cuff tendon.

Types of rotator cuff repair

When imaging postoperative rotator cuff, for an appropriate assessment, one should be aware of the type of surgical repair undertaken. Some of the common techniques are briefly described below.

Open repair

The traditional surgical procedure for rotator cuff tears is an open repair. To reach the torn rotator cuff tendon, a sizable skin incision must be made. The surgeon identifies the ripped tendon in real-time, after which the repaired tendon is reattached to the bone with sutures or anchors. In contrast to arthroscopic procedures, open repair typically involves larger incisions, and prolonged recovery periods, and is associated with more complications[6]. However, it provides good visualization and direct access to the rotator cuff. Tendon transfer surgery, such a latissimus dorsi or pectoralis major transfer, is also undertaken as an open procedure, to fix an irreparable rotator cuff.

Mini-open repair

Repairs of large tears with retracted tendons, and poor tissue quality tendons are sometimes technically challenging to perform arthroscopically. Consequently, these tears can be repaired using a mini-open approach, which involves making a vertical split in the anterolateral deltoid muscle to approach the rotator cuff tear.

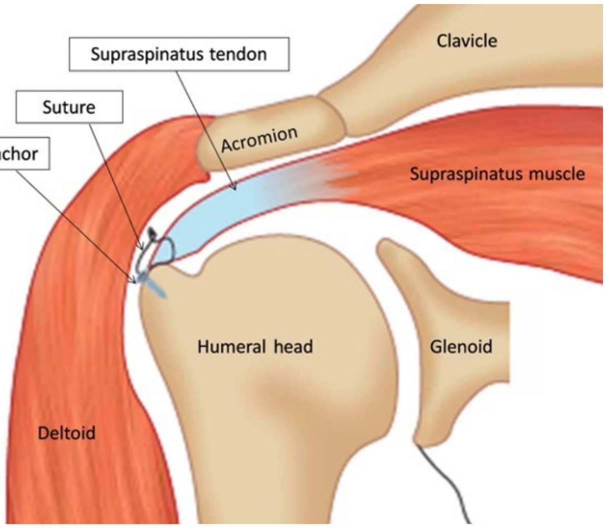

Fig. 1. *Illustration demonstrating the single-row technique of rotator cuff repair*

Arthroscopic repair

This is the most preferred repair option nowadays, and is broadly divided into two types: single-row rotator cuff repair and double-row rotator cuff repair.

Single-row rotator cuff repair

Partial-thickness tears, small full-thickness tears, and subscapularis tears are commonly treated arthroscopically via single-row rotator cuff repair. Following arthroscopic access, the damaged tendon is attended to by removing debris and scar tissue. Then, the tendon is reattached to the greater tuberosity utilizing sutures and anchors arranged in a single row (Fig. 1).

The position of the repaired tendon and the quality of the repair can be evaluated radiologically during the postoperative period. Both MRI and US are utilized to visualize postoperative changes. A well-apposed tendon-to-bone interface, and the absence of fluid collections or gaps at the repair site, are good indicators of good repair and tendon healing on both US (Fig. 2) and MRI (Fig. 3)[7]. However, MRI can be affected to varying degrees by artifacts.

Double-row rotator cuff repair

Larger tears are fixed utilizing a more complex surgical technique called the double-row repair, which seeks to better resemble the natural rotator cuff's architecture. The damaged tendon is repaired by anchoring the tendon in two distinct locations (medial and lateral) instead of a single tendon row (Fig. 4). Improved biomechanical stability is intended to be provided by applying the double bundle approach, which may also lead to improved functional results[8,9]. Like single bundle repairs, the assessment of postoperative double bundle repairs focuses on the location, integrity, and healing of the repaired

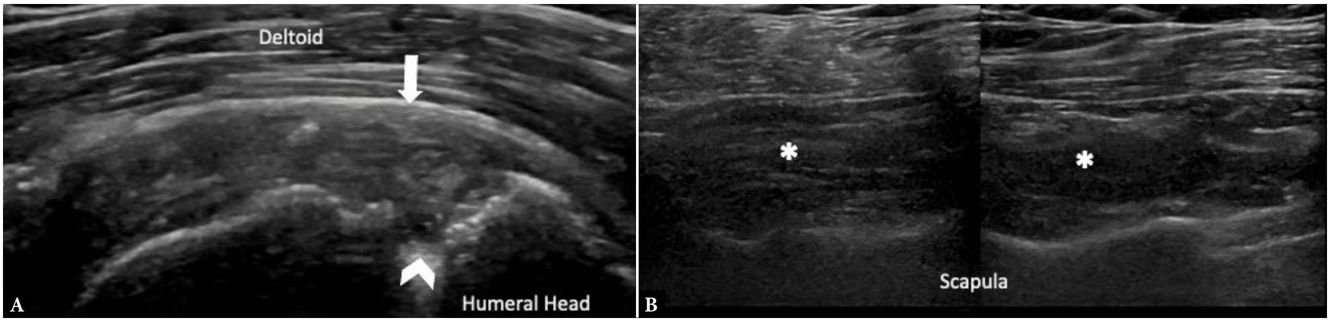

Fig. 2. A. *Long-axis grayscale US image showing intact single-row repaired supraspinatus tendon (arrow). The arrowhead indicates the trough of the greater tuberosity, the site of normally embedded anchor.* **B.** *Short-axis US images of the same shoulder show normal bulk of the supraspinatus (SST) and infraspinatus (IST) muscles indicating normal healing of the repaired tendon*

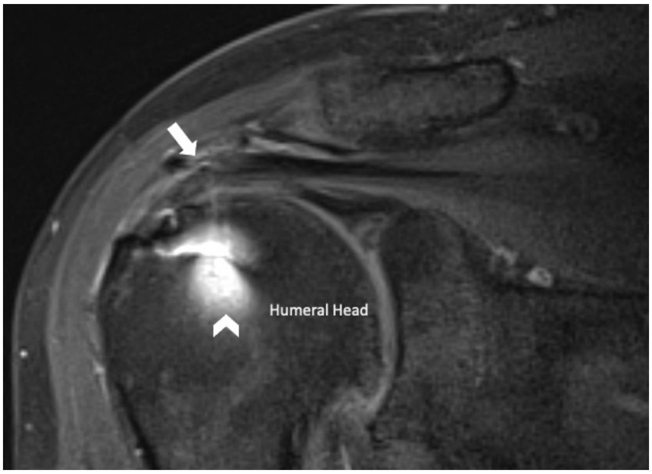

Fig. 3. *Proton density fat-suppressed coronal MR image post single-row rotator cuff repair shows an intact postoperative supraspinatus tendon (arrow). Artifacts by the anchor (arrowhead) can be reduced by applying hardware reduction MRI techniques*

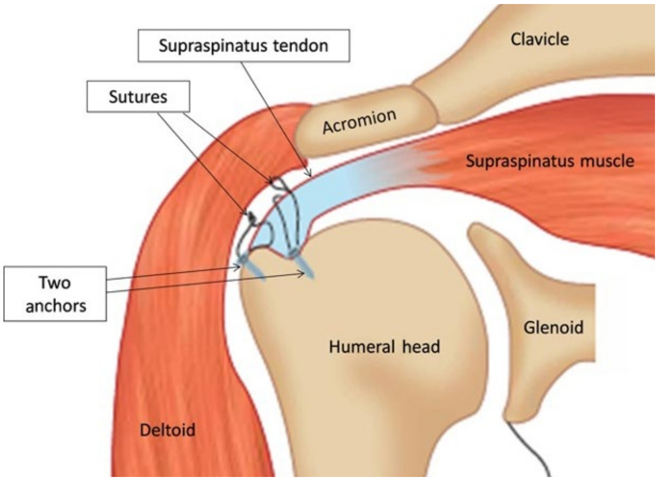

Fig. 4. *Illustration demonstrating the double-row technique of rotator cuff repair*

tendon. Imaging often reveals two suture anchors, or groups of suture anchors, at the repair site for a double-row repair (Fig. 5).

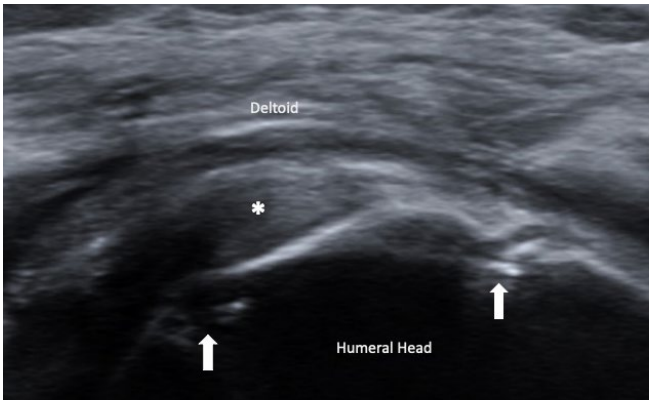

Fig. 5. *Long-axis grayscale US image shows intact double-row repaired supraspinatus tendon, maintaining the expected tendon volume (asterisk). The arrows indicate anchors of double bundle repair. Overlying deltoid muscle is echogenic, making the visualization of the underlying supraspinatus tendon challenging*

Transosseous equivalent repair

A hybrid procedure, known as transosseous equivalent repair, combines the advantages of both open and arthroscopic methods. It tries to mimic the biomechanics of open repair, while achieving the benefits of arthroscopic surgery. The method uses tiny arthroscopy incisions to send sutures through the tendon and tunnels carved out of the humeral head. To replicate the transosseous tunnels utilized in open repair, the sutures are knotted over bone bridges[10] (Fig. 6, Fig. 7).

Postoperative imaging findings/appearance of repairs of massive rotator cuff tears

Massive rotator cuff repairs are defined as full-thickness and full-width tears of two or more tendons of the rotator cuff. Such tears result not only in pain but also in glenohumeral instability, as demonstrated by the high-riding humeral head. These tears are often not amenable to primary repair due to anatomic limitations, chronicity, or extent. In such cases, orthopedic surgeons may elect to proceed with arthroplasty. This is a less-than-ideal option in the younger patient population without glenohumeral arthrosis. Arthroplasty implants have a limited life span, and arthroplasty often results in decreased strength and range of motion compared to the primary repair of the rotator cuff.

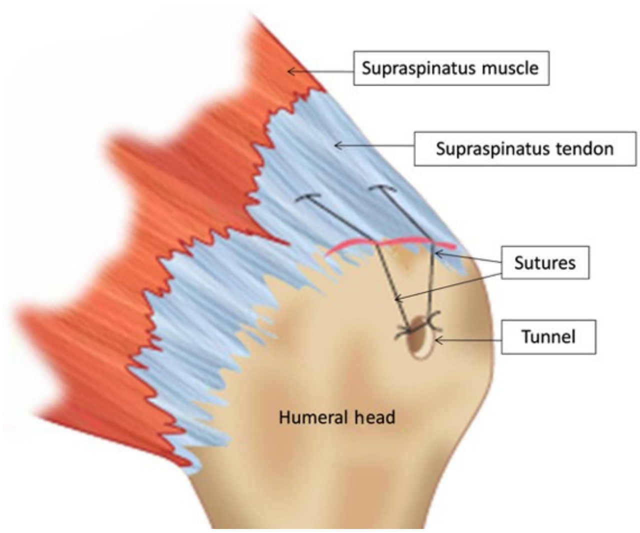

Fig. 6. *Illustration demonstrating transosseous-equivalent rotator cuff repair with suture configurations and bridges that are fixed to the head of the humerus*

In an attempt to avoid arthroplasty, other techniques have been developed, including tendon transfer (most commonly, latissimus dorsi or pectoralis major), patch graft augmentation and bridging, and superior capsular reconstruction.

Tendon transfer

In the tendon transfer method, the choice of tendon is dependent on the functional deficit resulting from the tear in question. The most commonly employed tendon transfers are the latissimus dorsi and the pectoralis major. The latissimus dorsi transfer simulates the function of the posterosuperior rotator cuff and augments external rotation. The pectoralis major tendon transfer may be used to mimic the function of the anterosuperior cuff. The sternal head of the tendon is typically employed and augments internal rotation, acting in a similar fashion to the subscapularis tendon. Different techniques for the transfer of graft tendons are available to the surgeon. It is helpful to be familiar with the specific technique when evaluating the postoperative appearance of the repair. The most common complications in tendon transfers include graft tendon tear, infection, or neurovascular injury[11].

The MRI and US appearance of a normal transferred tendon is similar to primarily repaired rotator cuff tendons. On MRI, graft tendons are typically low to intermediate in signal on T2-weighted and T1-weighted imaging, often with intermediate signal at the attachment of the tendon due to granulation tissue and scar formation. The fluid-filled defect would be consistent with a tear of the graft tendon. Neurovascular injury is a potential complication, and, on MRI, this may manifest with denervation edema and fatty infiltration[12].

Patch graft augmentation and bridging

Patch graft augmentation can be employed to bridge an irreparable tear or defect, or to patch and reinforce a primary repair that may not achieve optimal strength or healing. Patch augmentation may be performed with autografts, allografts (human dermal grafts), xenografts, or synthetic grafts[13]. Graft augmentation uses grafts to reinforce the existing primary repair, with the graft sutured directly to the repaired tendon. Patch graft bridging is used to address an irreparable defect greater than 1 cm, and the graft is sutured to the debrided torn tendon stump and to the insertion site on the bone, forming a bridge between the torn tendon and the original footprint.

On MRI, intact grafts and repaired tendons should be low to intermediate in signal, without fiber discontinuity. Findings such as partial or full-thickness fluid-filled defects, as well as attenuation and laxity of the tendon or graft, are indicative of recurrent tear[14].

Superior capsular reconstruction

For patients with massive rotator cuff repairs and no glenohumeral arthrosis, superior capsular reconstruction has been used to provide glenohumeral stability by preventing superior migration of the humeral head through the torn superior cuff and prevent or reduce the development of rotator cuff arthropathy[15]. Currently, the most com-

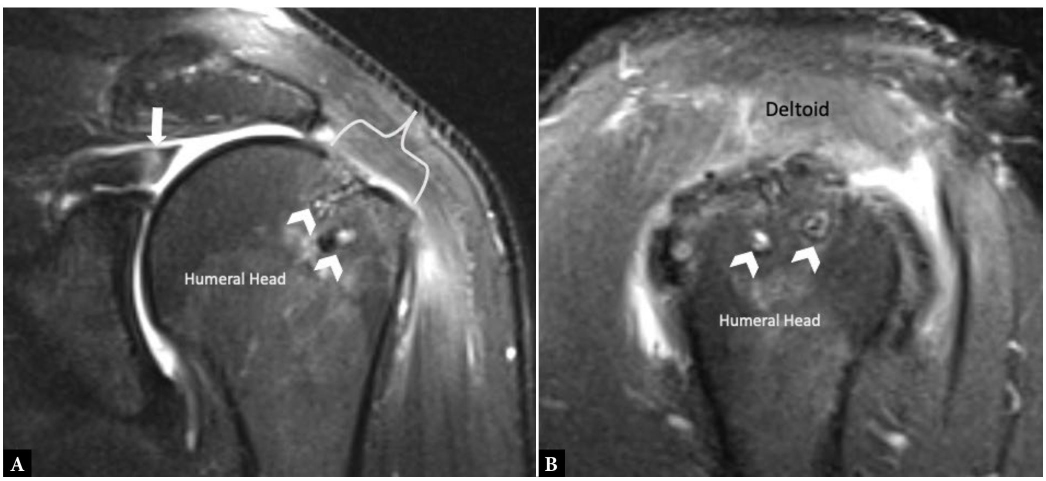

Fig. 7. *Proton density fat-suppressed coronal (**A**) and sagittal (**B**) MR images show complete re-tear of repaired supraspinatus tendon, exposing the trough of the greater tuberosity (bracket). Deltoid muscle overlies the trough. Retracted tendon stump now lies at the level of the glenoid (arrow). Note the anchors of the transosseous-equivalent technique (arrowheads) in the humerus, causing minimal artifact, as expected in this technique*

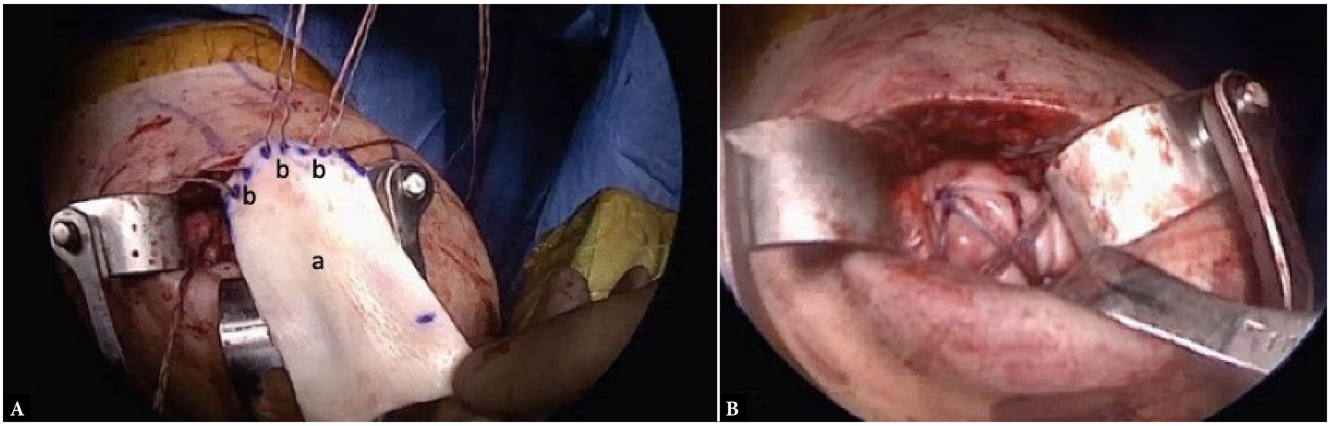

Fig. 8. A. *Clinical photograph of passage of dermal allograft for superior capsule reconstruction. The dermal allograft (a) is secured to the glenoid via suture anchors (b).* **B.** *Clinical photograph of superior capsule reconstruction. Glenoid sutures have been tied and cut (not visualized). The graft is secured to the greater tuberosity via double-row repair. Courtesy: Dr. Christopher Shultz, University of New Mexico*

monly used graft is the dermal allograft (Fig. 8). In superior capsular reconstruction, the graft forms a bridge from the superior glenoid to the greater tuberosity. In addition to the anchoring of the graft to the superior glenoid and the greater tuberosity, the graft is also sutured to the adjacent remnant rotator cuff tendons (Fig. 9). Potential complications of the procedure include tear of adjacent repaired tendons, re-tear of the anastomosis of the graft to adjacent tendons, and graft detachment from the greater tuberosity or the glenoid (Fig. 10).

The normal appearance of an intact graft on MRI is a low-signal structure without laxity or discontinuity[12,15]. Graft detachment may be accompanied by the laxity of the graft, superior migration of the humeral head, and dislodged anchors. On US, the graft is an echogenic linear structure. US findings of graft failure are similar to the appearance on MRI and include laxity due to graft detachment and hypoechoic fluid at the site of tears in the adjacent tendon. One study of 18 patients with superior capsular reconstruction who received a postoperative ultrasound at one-year follow-up showed that the graft might increase in thickness, particularly at the lateral humeral attachment, and might also show neovascularization[16].

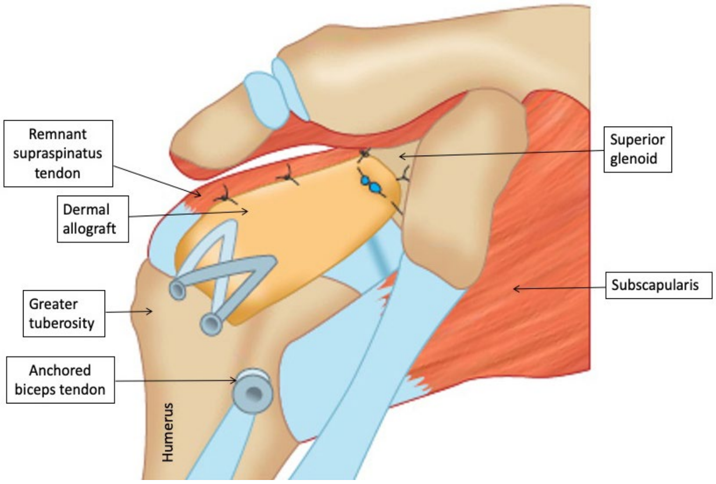

Fig. 9. *Illustration demonstrating superior capsular repair with dermal allograft which is anchored with the superior glenoid, greater tuberosity, and remnant supraspinatus tendon*

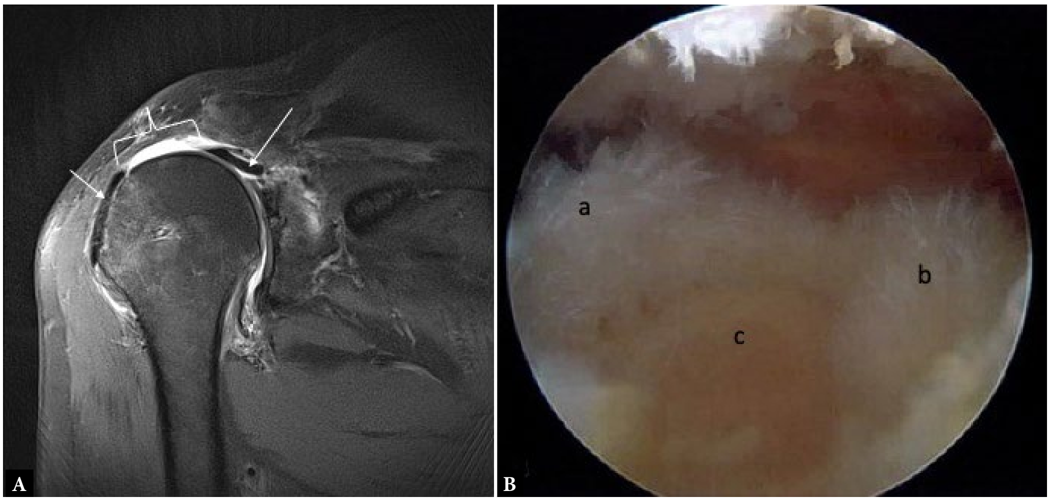

Fig. 10. A. *Coronal proton density fat-suppressed MR image of torn dermal allograft shows medial (long arrow) and lateral (short arrow) portions of split graft with a large gap (bracket).* **B.** *Arthroscopic image of the same patient. Arthroscope is viewing from a posterior portal in the subacromial space. The medial edge (a) of the graft is split from the lateral edge (b). The humeral head is distal to the graft (c). Courtesy: Dr. Christopher Shultz, University of New Mexico*

Subacromial decompression

During subacromial decompression, the undersurface of the acromion is shaved or resected to increase the space and reduce pressure on the rotator cuff tendons. The procedure aims to relieve pain and improve shoulder function in patients with impingement syndrome.

Mumford procedure (distal clavicle resection)

This procedure involves removing a portion of the distal end of the clavicle. The Mumford procedure is commonly performed for patients with acromioclavicular (AC) joint osteoarthritis or AC joint impingement.

Remplissage procedure

The remplissage procedure is performed in conjunction with rotator cuff repair, especially in cases of recurrent shoulder instability with a Hill-Sachs lesion. During the remplissage procedure, the infraspinatus tendon (a rotator cuff tendon) is mobilized and shifted into the Hill-Sachs defect. This action helps to 'fill' the defect, effectively preventing the humeral head from engaging the glenoid (shoulder socket) during shoulder motion and reducing the risk of recurrent instability.

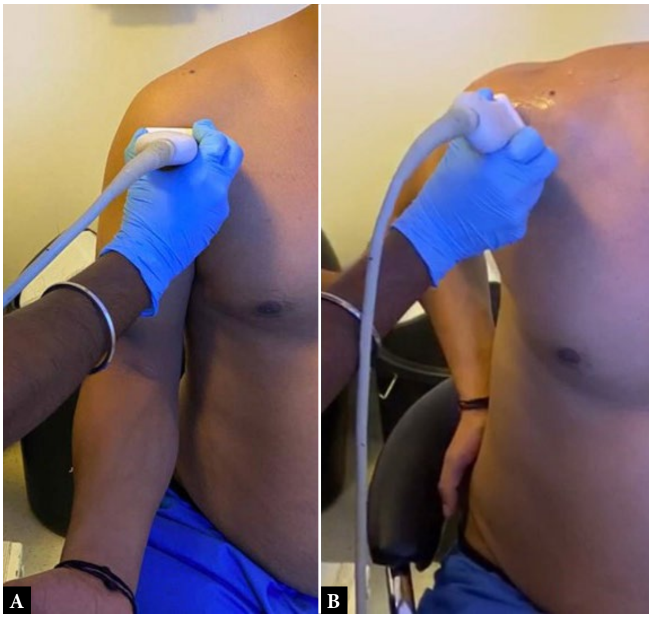

Fig. 11. *US technique for rotator cuff evaluation. (**A.**) Patient is seated, with the elbow flexed and the arm abducted to 90 degrees (**B.**) Modified Crass position to evaluate supraspinatus tendon*

Imaging techniques to evaluate repaired rotator cuff tendon

MRI is a highly sensitive and specific imaging modality that can provide detailed information about the extent of the re-tear and the status of the rotator cuff repair. However, when compared to the US, MRI is more susceptible to surgical hardware artifacts, more expensive, and not readily available. In addition, it is not possible to obtain a dynamic evaluation on MRI.

Ultrasound

The US appearance of postoperative rotator cuff can vary depending on the time after surgery, type of repair performed, and any complications. Since some voluntary shoulder movement is required for an US study, this should be avoided in the immediate postoperative period.

The rotator cuff tendons are imaged using high-frequency linear transducers (6–15 MHz)[17]. Discussed below is a brief overview of the US technique for the assessment of postoperative rotator cuff, which is similar to the protocol used while evaluating the native rotator cuff:
• The patient is seated, with the elbow flexed and the arm abducted to 90 degrees. The supraspinatus tendon is evaluated in either Crass or modified Crass positions (Fig. 11). Based on the position being scanned, the torn tendon morphology can differ, with more separation of the tear in the modified Crass position (Fig. 12).
• The thickness, echogenicity, and continuity of the tendons are assessed. The supraspinatus tendon is the one that is typically repaired; thus, even though other tendons are evaluated as part of the examination, this is the one that is given the most attention. The volume of the rotator cuff muscles is also evaluated.

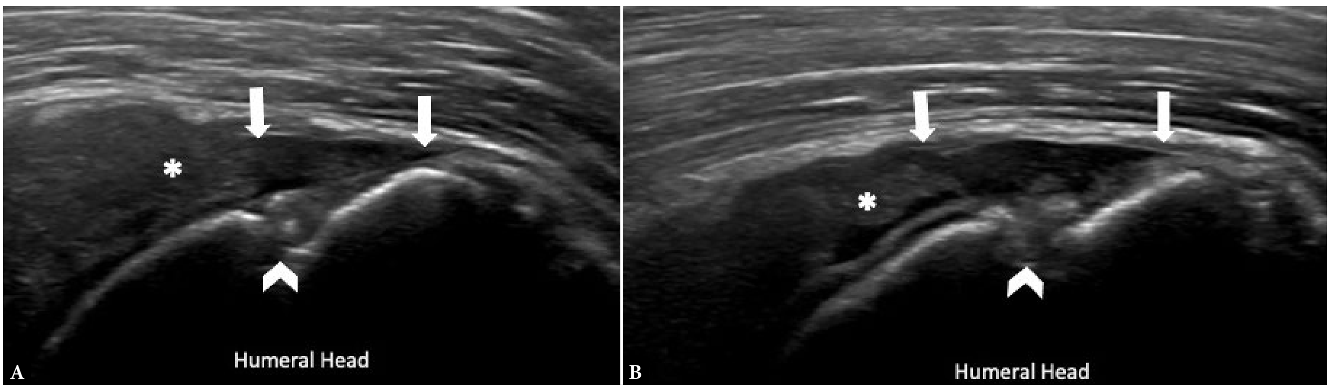

Fig. 12. *Long-axis grayscale US image of a complete re-tear of repaired supraspinatus tendon in Crass (**A**) and modified Crass (**B**) positions show tear gap (arrows) due to tendon retraction which is occupied by fluid. Note that the tear gap is accentuated in modified Crass position, and the bulk of the stump (asterisk) is reduced. Arrowheads indicate normal anchors*

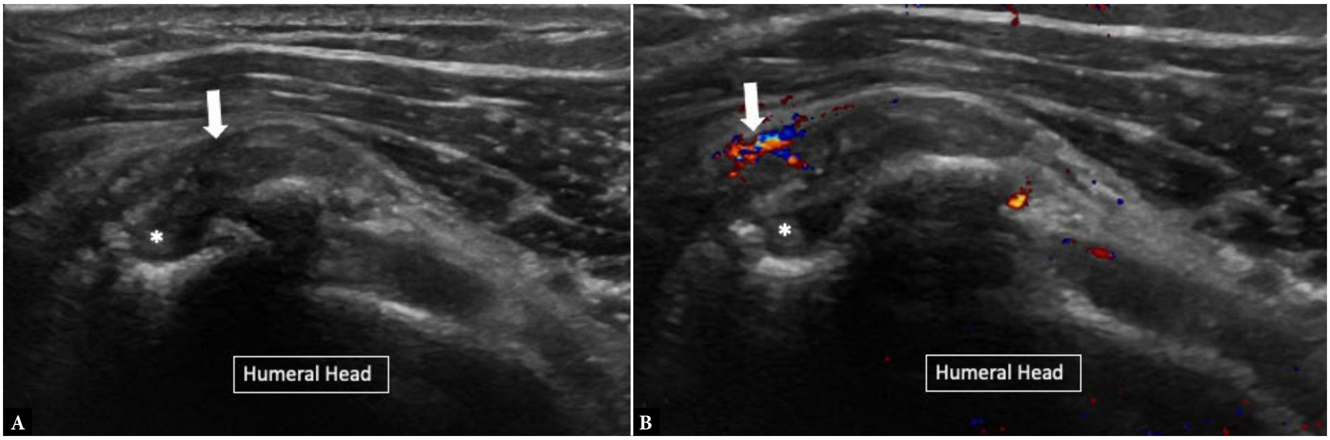

Fig. 13. *Short-axis grayscale (**A**) and power Doppler (**B**) US images show thickening and fluid in subdeltoid bursa with power Doppler signal (arrows) two months after rotator cuff repair, representing inflammation. Long head biceps tendon (asterisks) can be seen within the bicipital groove*

• To evaluate the integrity of the repair, passive dynamic maneuvers, including abduction and external rotation, are conducted, while keeping the patient's comfort in mind.
• Subacromial-subdeltoid bursa and acromioclavicular joint are assessed for the presence of fluid or other post-surgical sequelae.

There can be postoperative inflammation in the bursal space and other soft tissue around the repaired rotator cuff, which can be assessed by color, power, and microvascular Doppler US (Fig. 13).

Shear wave elastography has an added value in the follow-up of repaired rotator cuff By helping to evaluate whether the elasticity of the tendon is having a normal or abnormal progression with duration[17].

MRI

MRI can evaluate the entire length of the rotator cuff tendons in various planes. Repaired rotator cuff commonly demonstrates increased signal intensity due to postoperative granulation tissue and inflammation rather than a re-tear[18]. The protocol used to study postoperative rotator cuff is like that of the preoperative MRI.

Imaging findings of rotator cuff repair

Both US and MRI play vital roles in the imaging evaluation of postoperative rotator cuff. Recent studies have revealed no significant difference between US and MRI for diagnosing tears in repaired rotator cuff[19]. The overall sensitivity, specificity, positive predictive value, negative predictive value, and accuracy for the US in detecting rotator cuff re-tears were 95%, 90%, 97%, 82%, and 94%, respectively[20]. However, the correlation between the structural integrity of rotator cuff repair and the clinical outcome remains controversial, and there are studies indicating that the functional outcome is independent of the structural integrity[21].

Intact postoperative rotator cuff

Imaging evaluation of repaired rotator cuff becomes difficult due to anatomical distortion at the surgical site. Intact repaired tendons appear thickened and heterogeneous on both US and MRI for at least one year to five years postoperatively[18,22,23]. These changes gradually regress with the progression of time, with a return to standard fibrillar patterns. However, the suture material and associated graft patches continue to appear heterogeneous and thickened. MRI usually shows susceptibility artifacts related to anchors and sutures that could impair visualization of the repaired tendon, limiting interpretation (Fig. 3). MRI in the early postoperative period shows intermediate or high signal intensity of the repaired tendon on fluid-sensitive sequences, and may reveal a small amount of fluid in the subacromial-subdeltoid bursa, which is considered a normal spectrum (Fig. 14). US has the excellent advantage of dynamic assessment of the repaired cuff's integrity. This dynamic assessment can be used to evaluate the stability

Fig. 14. *Proton density fat-suppressed coronal MR image shows thinned but intact postoperative supraspinatus tendon (white arrow). There is fluid in subacromial-subdeltoid bursa (black arrow). The tendon-bone interface also appears intact. Note the presence of double-row anchors in the humeral head (arrowheads)*

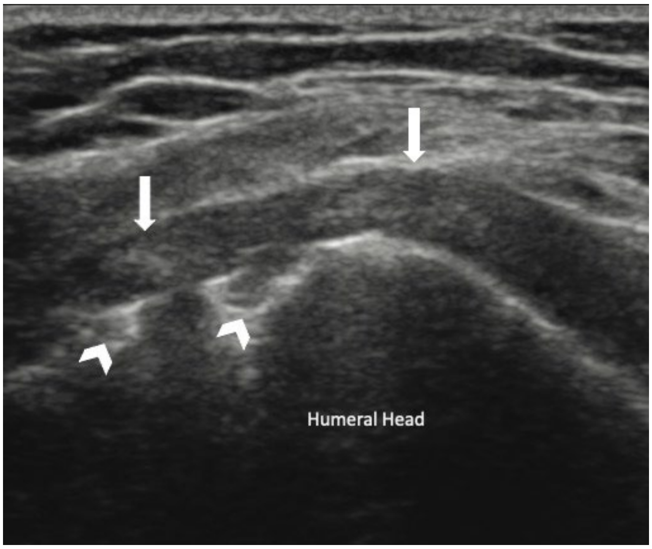

Fig. 15. *Long-axis grayscale US image of intact repaired supraspinatus tendon 12 months after surgery shows normal heterogeneous appearance (arrows). Note the presence of anchors in the humeral head (arrowheads)*

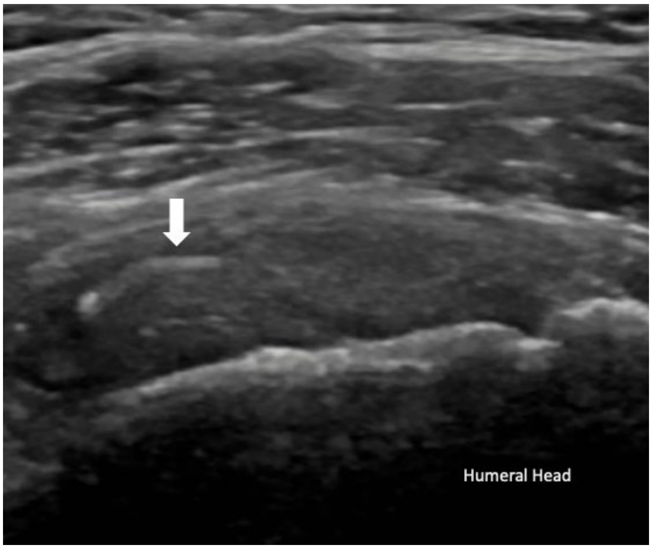

Fig. 16. *Long-axis grayscale US image of intact repaired infraspinatus tendon shows normal echogenic suture material (arrow) within the tendon*

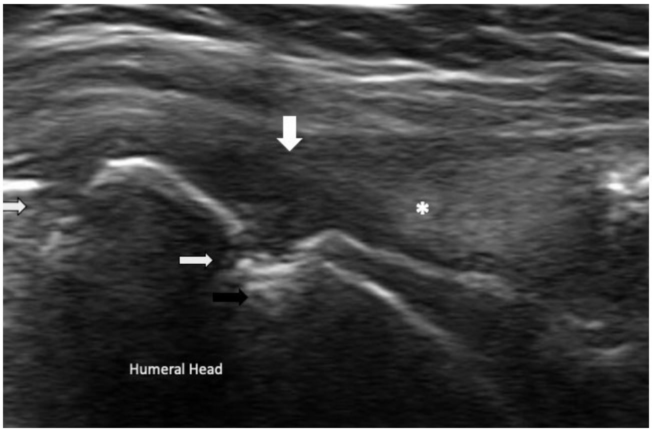

Fig. 17. *Long-axis grayscale US image of repaired supraspinatus tendon shows a full-thickness re-tear with defect and exposed trough (thick white arrow). Positions of the anchors of double bundle repair could be noted in the humeral head (thin white arrows). Note the retracted tendon stump (asterisk)*

and functionality of repaired tendon while in motion. Similarly to MRI, the variable and heterogeneous appearance of the repaired cuff on US may persist for years after surgery (Fig. 15). There can be discontinuity and irregularity of a few of the repaired tendon fibers, which may represent unrepaired torn fibers that were not possible to repair due to poor quality of tendon tissue[24]. Thus, information about the extent and type of surgical repair is needed to avoid overcalling re-tears.

Artifacts due to surgical hardware and postoperative scar tissue can affect how an MRI or US scan looks, and determine its diagnostic capability. Additionally, on US, the patient's body habitus, fatty infiltration of the deltoid, the operator's experience, and the equipment being used may all affect the visibility and interpretation of repaired tendons.

Tendon-bone interface

In intact rotator cuff repair, the distal end of the reconstructed rotator cuff tendon must be firmly fastened to the bone, covering the newly created trough portion in the greater tuberosity. A well-apposed contact between the restored tendon and the bone surface can be seen and assessed on US and MRI, to confirm the integrity of repair (Fig. 2, Fig. 3, Fig. 12).

Suture or anchor depiction

Depending on the surgical approach employed, US and MRI may detect the presence of sutures or anchors, which on US appear as hyperechoic structures either inside or near the healed tendon (Fig. 16). They function as reminders of the repair and might support pinpointing the repair site's position. On T2-weighted MRI sequences, the suture anchors may be seen as small, rounded, or oval structures with low signal intensity.

Subacromial-subdeltoid bursa

The subacromial-subdeltoid bursa may be thickened following rotator cuff repair (Fig. 14), which is thought to be caused by inflammation and scar tissue production. Sometimes the bursa is excised, which can lead to the pooling of fluid in its place, in the immediate postoperative period.

Rotator cuff re-tear

Specific US and MRI findings that may be seen in patients with a postoperative rotator cuff re-tear include[25]:

- Thickening, irregularity, defect, or gap within the rotator cuff tendon (Fig. 17, Fig. 18)
- Empty trough (site of tendon attachment at the greater tuberosity) (Fig. 19)

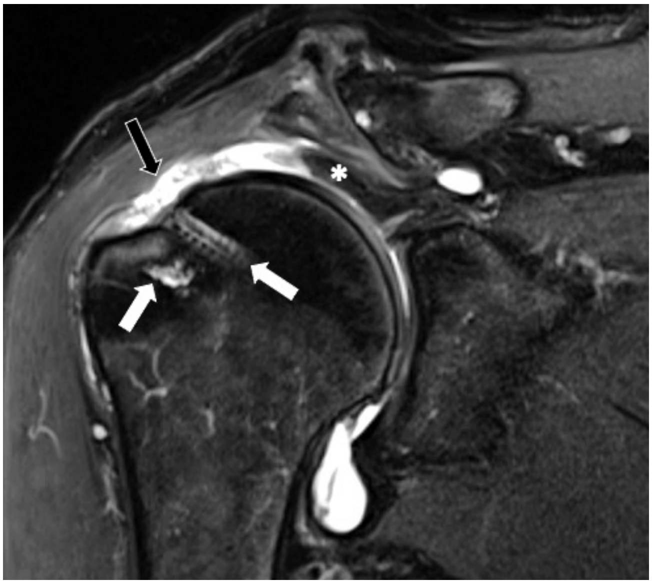

Fig. 18. *Proton density fat-suppressed coronal MR image shows a full-thickness supraspinatus tendon re-tear (asterisk–retracted stump) with complete absence of the tendon fibers at the attachment site and the region of tear occupied by fluid (black arrow). The anchors can be seen in place (white arrows)*

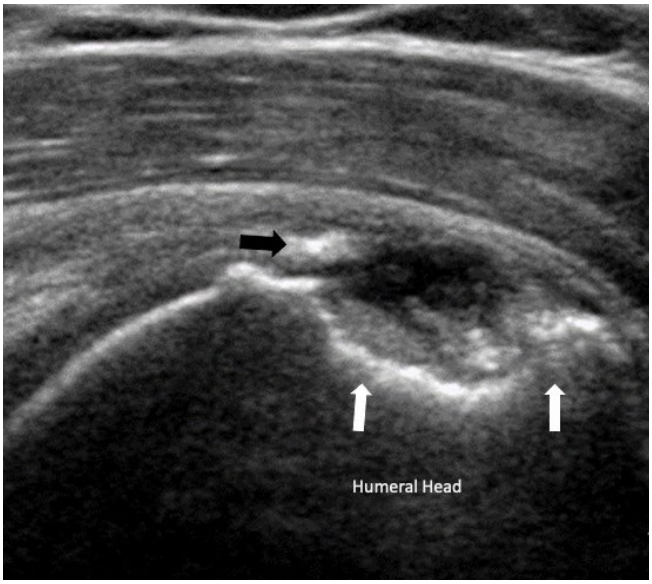

Fig. 19. *Long-axis grayscale US image of repaired supraspinatus tendon shows the absence of fibers at the site of tendon attachment to greater tuberosity – empty trough sign (white arrow). The avulsed suture anchor appears as echogenic foci in the region of repair (black arrow)*

- Recurrent tears tend to get larger and significant
- Completely or partially avulsed or dislodged suture anchor (Fig. 20)
- Fluid or other abnormalities in the subacromial space (Fig. 18)
- Biceps tendinosis

Important US and MRI appearances of a re-tear of rotator cuff repair:

- **Tendon discontinuity:** Like in the original tear, there will be a noticeable interruption or discontinuity in the tendon fibers in the case of a re-tear. The gap is mostly at the newly created tendon-bone repair; however, it can also be at the myotendinous junction proximally, with an intact stump repair at the bone tendon interphase. Hence, it is important to assess the entire length of the tendon. The tendon's previously intact section can develop a fresh gap or separation, signaling a re-tear of the tendon (Fig. 21).
- **Tendon thinning or retraction:** Re-tearing may result in additional tendon thinning or retraction compared to the first repair. The previously healed part of the tendon may thin out or retract, indicating that either the initial repair failed or new tendon fibers were torn (Fig. 17).
- **Tendon edge unevenness:** The edges of a re-tear may be jagged, ragged, or uneven (Fig. 21). The disintegration of the restored tissue can be seen as a rough outline or interrupted contour along the previously treated tendon.
- **Fluid accumulation:** A repeat rotator cuff repair procedure may cause fluid to build up in the subacromial-subdeltoid bursa or at the tear site. A fluid-filled region connected to the re-tear may be visible next to the torn tendon as an anechoic or hypoechoic area on US.
- **Muscle atrophy:** Rotator cuff tears that are chronic or recurring can cause underlying muscle atrophy or wasting (Fig. 22). Compared to the unaffected side, the muscles involved in the re-tear may appear smaller, lose mass, and have more fatty infiltration. This can be assessed by observing the convex outline of the supraspinatus and its volume loss related to the supraspinatus fossa, and increased echogenicity at the myotendinous junction.

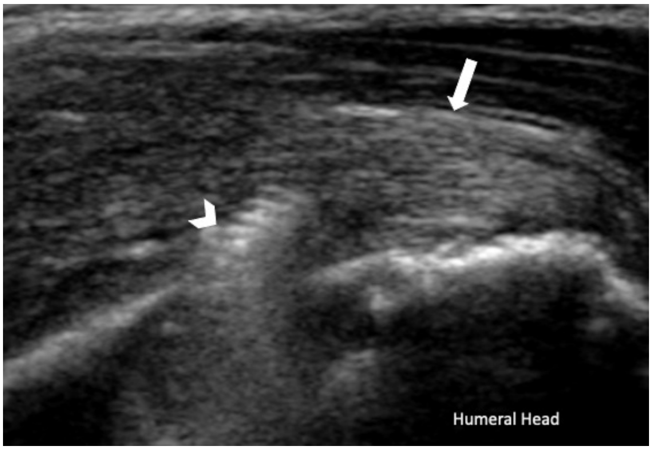

Fig. 20. *Long-axis grayscale US image of repaired supraspinatus tendon (arrow) shows a protruding suture anchor (arrowhead) but intact tendon*

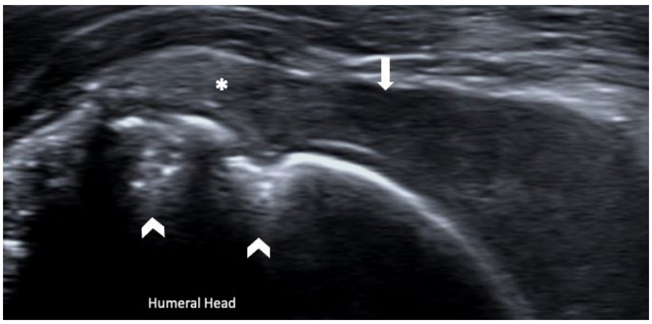

Fig. 21. *Long-axis grayscale US image of repaired supraspinatus tendon shows a full-thickness tear of the mid part of the tendon (arrow) with intact stump (asterisk). There is a clumping of fibers and the edges of the re-tear appear ragged and uneven. Note the anchors in the humeral head (arrowheads)*

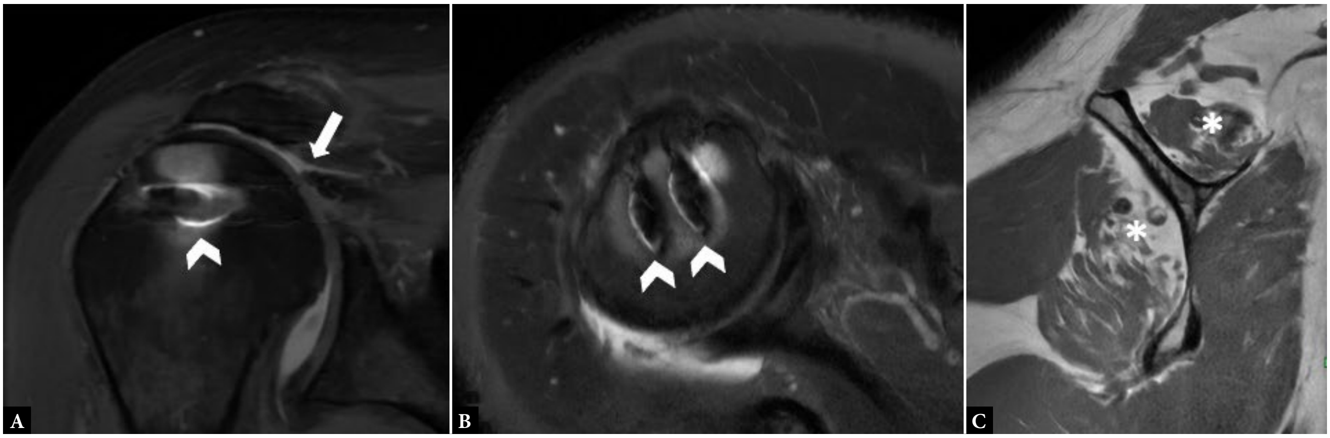

Fig. 22. *Proton density fat-suppressed coronal (***A***) and axial (***B***) and T1 sagittal non-fat suppressed (***C***) MR images post single-row repaired supraspinatus tendon shows a complete re-tear of the tendon (arrow in A). Even in the single-row technique, there are usually two anchors in the same row and orientation (arrowheads in B), and should not be confused with the double-row technique. There is fatty infiltration and atrophy of the supraspinatus and infraspinatus muscles (asterisks in C)*

Imaging findings of long head of biceps tendon in post rotator cuff repair

Sometimes, a rotator cuff tear or repair does not impact the biceps tendon, so the surgeon may repair the rotator cuff without specifically addressing the biceps tendon. In such cases, imaging reveals a continuous and clearly defined biceps tendon, making it seem normal.

Biceps tenotomy

A partially torn long head of the biceps is sometimes totally released from the biceps anchor. On imaging, this is seen as an empty bicipital grove, and with time the biceps musculature shows fatty infiltration and atrophy.

Biceps tenodesis

Biceps tenodesis involves detaching the biceps tendon from its native attachment and reattaching it to another location, usually in the distal bicipital groove or the distal pectoralis major tendon, close to its humeral attachment site (Fig. 23).

The reattached biceps tendon should exhibit a secure and stable position in its new place following successful biceps tenodesis. The tendon is visualized by imaging as rigidly fixed to the proximal humerus, typically with suture anchors or other fixation devices[22]. The tendon should appear whole and uninterrupted, with no signs of tears or breaks.

Suture anchors or other fixation devices used to secure the reattached biceps tendon to the proximal humerus may be visible through imaging. These devices may appear on US as hyperechoic structures or on MRI as signal voids.

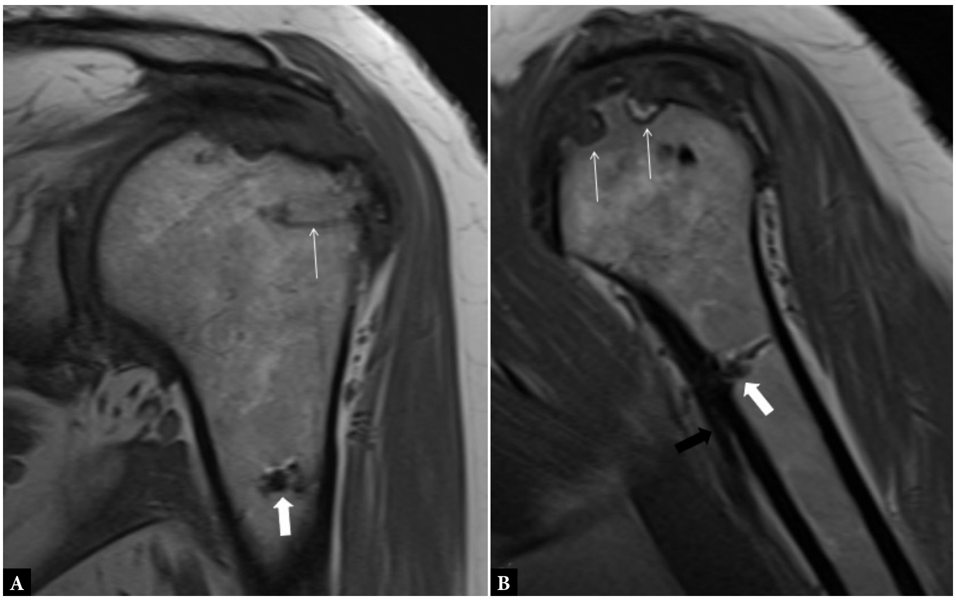

Fig. 23. *Biceps tenodesis. Coronal (***A***) and sagittal (***B***) T1 MR images show anchors (thick white arrows) in the distal bicipital groove. The long-head biceps tendon (black arrow in B) is seen close to the anchor. The anchors (thin white arrows) of the rotator cuff repair can also be seen in the humeral head*

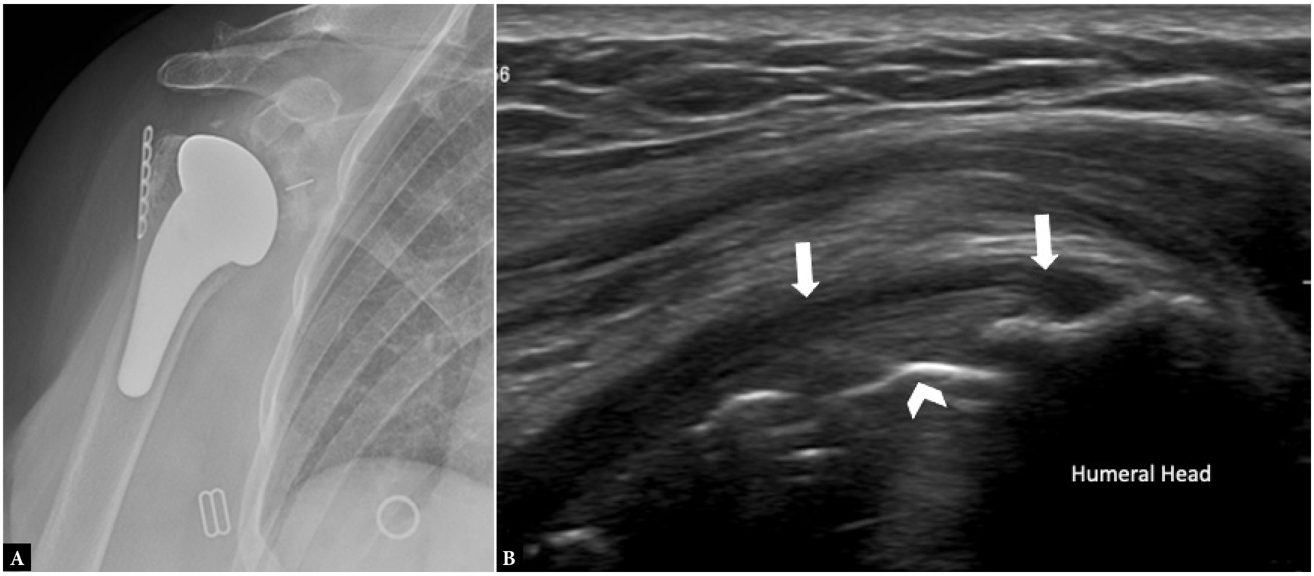

Fig. 24. *Shoulder arthroplasty*. **A.** *Antero-posterior shoulder radiograph demonstrating total shoulder arthroplasty.* **B.** *Long-axis grayscale US image of the same shoulder shows continuous and well-defined undamaged supraspinatus tendon (arrow). Echogenic hardware (arrowhead) is seen deep to the tendon in the humerus head*

Tendon sheath

The biceps tendon is encased in a synovial sheath that lubricates the tendon and makes tendon movement easier. The synovial sheath of the reattached tendon may exhibit alterations in shape and thickness after biceps tenodesis, compared to its preoperative state. These modifications can be seen on both MRI and US.

Imaging of rotator cuff post arthroplasty

Radiography, US, and MRI are the imaging modalities frequently utilized to evaluate the rotator cuff following arthroplasty. The supraspinatus is expected to be intact in total shoulder arthroplasty (TSA) and absent in reverse shoulder arthroplasty (RTSA).

The indications for RTSA include:
1. Massive rotator cuff tears: RTSA is commonly performed in patients with massive, irreparable rotator cuff tears, where the torn tendons cannot be adequately repaired or reconstructed. In such cases, the deltoid muscle, rather than the rotator cuff, is used for shoulder function, allowing for improved stability and function.
2. Rotator cuff arthropathy: The condition occurs when a long-standing rotator cuff tear leads to degenerative changes in the shoulder joint. RTSA is considered when the patient experiences severe pain, loss of function, and poor shoulder mobility.
3. Failed previous shoulder surgery: RTSA may be indicated in patients who have had unsuccessful previous shoulder surgeries, including failed shoulder replacements or rotator cuff repairs.
4. Complex fractures: In elderly patients with complex fractures of the proximal humerus (shoulder bone), where the bone is severely damaged and the surrounding tissues are compromised, RTSA may be a viable treatment option.
5. Proximal humerus tumor: In patients with certain tumors affecting the proximal humerus, RTSA may be used to provide pain relief and functional improvement.
6. Severe glenoid (shoulder socket) deficiency: Patients with significant glenoid bone loss or deformities may be candidates for RTSA, as it can provide better stability and fixation.

Top of form

Several characteristics can be observed when examining the imaging findings of the rotator cuff post-TSA or RTSA[26].

Integrity of the rotator cuff

One of the critical issues for planning TSA and RTSA is the integrity of the supraspinatus and subscapularis, respectively. Post-surgery, imaging examinations can help determine whether the rotator cuff tendon is torn, partially torn, or intact. It may appear thin, but a healthy, undamaged rotator cuff is a continuous, well-defined structure on US or MRI scans, without any signs of rupture or retraction (Fig. 24). Focused abnormalities or disruptions in the tendon fibers can be used to detect partial or complete tears. While an attempt is made to avoid incising subscapularis to approach the joint when performing RTSA, one of the primary challenges in evaluating the subscapularis tendon post-TSA is that the tendon is often incised during the surgical procedure to gain access to the shoulder joint for implant placement. This can result in varying degrees of damage to the tendon, making it difficult to assess its condition accurately. Additionally, the presence of metallic artifacts from the prosthetic implant can obscure the imaging quality in standard radiographic studies, such as radiography. This can limit the visibility of the subscapularis tendon and surrounding structures on MRI.

To overcome these challenges, advanced imaging modalities are often utilized for a more comprehensive assessment of the subscapularis tendon post-TSA and post-RTSA. MRI and US are commonly used, as they offer superior soft tissue visualization compared to CT or radiograph, and can help detect subscapularis tendon tears or pathology more effectively[27] (Fig. 25).

Fig. 25. *Axial T2 MR image demonstrating tear of subscapularis tendon (arrows) eight months after shoulder arthroplasty. Asterisk denotes the implant in the humerus*

Tendon position and movement

The rotator cuff position and movement may vary after arthroplasty. Imaging can be used to determine whether the tendons correctly exhibit the anticipated mobility during dynamic US imaging, indicating proper functioning.

Tendon atrophy or thinning

Surgical intervention or long-term rotator cuff disease can cause tendon atrophy or attritional thinning. Imaging, especially US or MRI, can measure the thickness of the rotator cuff tendons and compare it to the other side or to preoperative imaging scans. Tendon atrophy or thinning may indicate chronic degeneration or persistent disease.

Tendon repair or rebuilding

The rotator cuff may have undergone repair or reconstruction during various arthroplasty procedures. Like the results seen after a primary rotator cuff repair, imaging can help assess the state of repair and integrity of the repaired or reconstructed tendon. It is possible to see sutures, anchors, or other repair tools, which provide visual cues that surgery was previously performed.

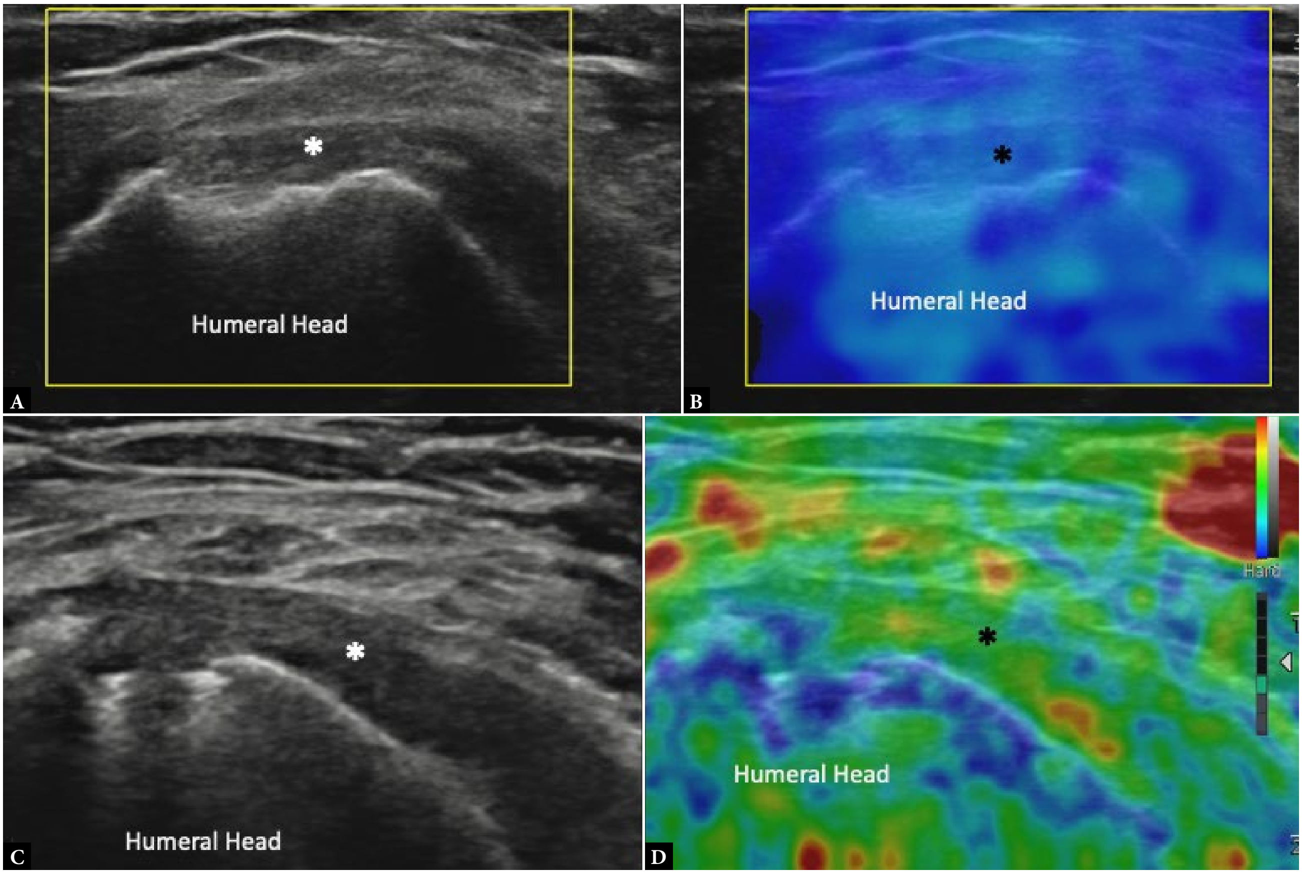

Fig. 26. *Shear wave US elastography of the supraspinatus tendon.* **A.** *Shear wave US elastography long-axis image shows homogenous appearance of the intact postoperative tendon.* **B.** *Strain wave US elastography long-axis images of the same shoulder show the tendon as intermediate in firmness. The patient underwent surgery 12 months prior, and elastography demonstrates the intact tendon to be in the normal healing phase*

Fluid collections or bursal effusions

After arthroplasty, the rotator cuff may experience fluid collections or subacromial-subdeltoid bursal effusions. These could be symptoms of bursitis, synovitis, or surgical inflammation. The fluid accumulations can be seen on US or MRI as hypoechoic or hyperintense regions.

Limitations of imaging in patients with postoperative rotator cuff

- Suture anchors and screws, among other surgical devices, can introduce artifacts in imaging studies, resulting in acoustic shadowing or reverberation on US and signal dropouts or distortion on MRI, making it challenging to visualize and evaluate the integrity of rotator cuff tendons.
- Scar tissue is formed because of healing. It could be challenging to differentiate between scar tissue and recurrent or residual tears because this scar tissue might change the way the healed tendon and its surrounding components look. It may be a challenge to evaluate the mobility of the rotator cuff tendons if they are encased in scar tissue. It is not unusual to see an apparent full-thickness defect or focal cleft in early postoperative rotator cuff, representing a reparative scar rather than a true re-tear[28]. Follow-up US imaging may show the filling of these apparent defects, suggesting routine healing.
- The time interval since surgery can impact postoperative rotator cuff MRI results. Due to inflammation and edema, the rotator cuff tendons may seem swollen and disorganized in the early postoperative period. However, the tendons should eventually appear normal, with expected fibrillar echotexture.
- The rotator cuff tendon margins should be examined the most carefully. The tendon edges ought to be smooth, and the presence of uneven or ragged tendon edges could indicate a tear.

To overcome the limitations, sometimes examining the rotator cuff tendons using both imaging techniques, including MRI and US, may be needed. This can lessen the effect of artifacts and give a more thorough evaluation of the tendons. The patient's medical history is beneficial when evaluating postoperative rotator cuff imaging scans. For instance, the probability of a re-tear rises if the patient has a history of recurrent rotator cuff tears.

Advances in imaging for better evaluation of repaired rotator cuff tendons

There are modifications in MRI sequences that usually help to reduce imaging artifacts, including: using fast spin-echo and short inversion time inversion-recovery sequences, increasing bandwidth and echo train length, increasing the matrix and decreasing section thickness, to name a few.

Shear wave and strain wave US elastography are used to predict the outcomes of repaired rotator cuff based on the elasticity of the tendon tissue and demonstrating promising results (Fig. 26).

Conclusion

Understanding the expected time-bound variation of imaging findings post rotator cuff repair is critical to improving the accuracy of diagnosis and avoiding pitfalls and overdiagnosis. Most recurrent rotator cuff tears happen within three months. Therefore, it is essential to have a high index of suspicion during this period for a re-tear in any patient with persistent pain or weakness after rotator cuff surgery. It is important to note that patients with recurrent tears may be asymptomatic. but large recurrent tears are more likely symptomatic. The ability to perform a dynamic evaluation and reduced limitations from artifacts may favor US over MRI in the initial assessment of postoperative rotator cuff, provided that operator expertise exists.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

Author contributions

Original concept of study: GG. Writing of manuscript: AKS, EKM, GG. Analysis and interpretation of data: EKM, GG. Final acceptation of manuscript: GG. Collection, recording and/or compilation of data: GG. Critical review of manuscript: GG.

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