Technical Note

Arthroscopic Linked Triple Row Repair for Large and Massive Rotator Cuff Tears

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Abstract: Recently, many arthroscopic techniques have been described to improve the outcomes in rotator cuff repair of large and massive tears; these include conventional double-row, suture bridge, and triple-row techniques, in an effort to optimally reconstruct the rotator cuff footprint and improve fixation. This report describes a modified triple-row repair technique that links the double-row and suture-bridge techniques in one construct, merging the advantages of both to maximize the footprint contact area and contact pressure, which may lead to better healing and faster rehabilitation.

Large and massive rotator cuff tears are still a major challenge for shoulder surgeons to the extent that it can be difficult to restore the rotator cuff to its anatomic position. This leads to limited rotator cuff footprint contact area with decreased healing potential and greater retear rates; hence, a more effective repair is imperative.[1] Recent arthroscopic techniques are described to improve the outcomes of rotator cuff repair; these include double-row (DR) and transosseous-equivalent techniques in an effort to improve fixation and repair.[1-6]

Although studies have proven biomechanical superiority of the DR repair compared with the single row, yet there is no definitive difference in clinical outcomes between the 2 repair constructs.[5-7] In addition, retear rates of 10% to 30% have been reported in DR techniques (DR and suture bridge [SB]) with even greater rates (40%-64%) in patients with large-to-massive tears (≥3 cm).[3,4,6,8-11]

A triple-row modification of SB technique was proposed by Ostrander et al.[12,13] in which an additional middle row was inserted independent of medial and lateral rows. It has been demonstrated that this technique results in significantly more footprint contact area and contact pressure compared with the DR and transosseous-equivalent techniques. This report describes in details a linked triple-row technique in which the middle row is linked to the repair construct. This technique blends the best of both techniques, the conventional DR and SB techniques, into a single construct for the management of large and massive cuff tears.

Surgical Procedure (With Video Illustration)

The indication, advantages and contraindications are presented in Table 1. The pearls, pitfalls, and limitations are shown in Table 2. The procedure steps are presented in Video 1.

Preoperative Assessment

Patients are assessed preoperatively for supraspinatus and infraspinatus weakness. Patients' preoperative range of motion is determined both active and passive. Magnetic resonance imaging is done to evaluate the degree of tendon retraction and fatty infiltration. Patients with irreparable rotator cuff tears, fatty infiltration more than Goutallier grade III, rotator cuff arthropathy, and stiff shoulders should not be submitted to this repair.

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The authors report that they have no conflicts of interest in the authorship and publication of this article. Full ICMJE author disclosure forms are available for this article online, as supplementary material.

Received June 9, 2020; accepted September 20, 2020.

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2212-6287/201096

https://doi.org/10.1016/j.eats.2020.09.017

Table 1. Indication, Advantages, and Contraindications for the Triple-Row Rotator Cuff Repair

Indication	Reparable large and massive rotator cuff tears in symptomatic patients.
Advantages	Anatomic restoration of rotator cuff footprint. Increased points of fixation. Greater contact area with the bone. Decreased dog-ear formation. Linking both DR and SB techniques in one construct. Load sharing construct, decreasing the tension on the medial row and subsequent failure. Safer and faster rehabilitation
Contraindications	Irreparable rotator cuff tears. Rotator cuff arthropathy. Partially reparable massive cuff tears. Goutallier fatty infiltration more than GIII Osteoporotic bone

DR, double-row; SB, suture bridge.

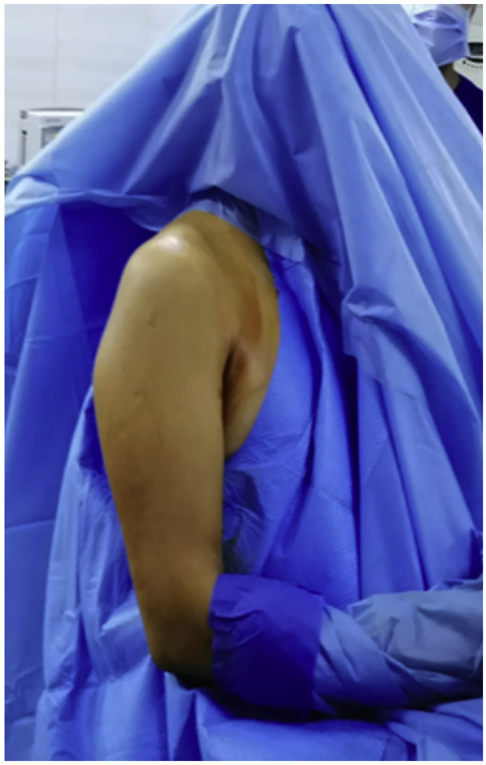

Fig 1. Patient positioning and draping of the right shoulder in the modified beach chair position.

Patient Positioning and Preparation

The procedure is performed with the patient under general anesthesia with ultrasound-guided regional interscalene nerve block. The patient is positioned in a modified beach chair position (semi-setting). A team-based approach is used to ensure that the patient is in the appropriate position (Fig 1). Care should be taken to maintain the head and neck of the patient in neutral position. Examination under anesthesia of the operated shoulder is performed to confirm the free passive range of motion and stability of the shoulder.

The patient's skin is disinfected with povidone iodine and sterile drapes are applied. An arthroscopic pump is used starting with pressures around 40 mm Hg with hypotensive general anesthesia.

Table 2. Pearls, Pitfalls, and Limitations of the Triple-Row Rotator Cuff Repair

Pearls	The middle row anchor should anatomically reduce the rotator cuff tendon to the lateral edge of footprint. A cannula should be used at the final step for better suture management. Adequate tendon mobilization is crucial before attempting this repair. Crucial anchor site and trajectory insertion. Middle anchor insertion site should allow anatomic reduction according to tear type (crescent, L, inverted L). Use same color of all sutures during lateral row insertion to avoid suture entanglement.
Pitfalls	Incorrectly placed anchors near to each other may lead to anchors' failure. Poor anchor trajectory may lead to bone violation or anchor pullout. Many anchors (5) may lead to suture entanglement.
Limitations	Relatively increased cost compared with the double-row repair technique. Increased operative time, this decreases as more the surgical skills increase. A steep learning curve.

Portal Placement and Diagnostic Arthroscopy

A posterior portal is established 2 cm distal and 1 cm medial to the posterolateral corner of the acromion, and a 30° arthroscope (Stryker Endoscopy, San Jose, CA) is introduced. Systematic diagnostic shoulder arthroscopy is performed, and any intra-articular pathology is addressed.

Preparation of the Rotator Cuff Tear Footprint

With the arthroscope in the posterior portal, cuff inspection is performed intra-articularly (Fig 2). A lateral portal is created using an outside-in technique with an 18-gauge spinal needle under direct visualization toward the center of the tear. A 4.5-mm shaver blade (Stryker Endoscopy) is used to debride tissues, adhesions, tendon edges, and footprint (Fig 3). A radiofrequency ablation device (VAPR; DePuy Mitek, Raynham, MA) is introduced through the lateral portal to clear the footprint over the greater tuberosity from all soft tissues. An arthroscopic 5-mm burr (Stryker Endoscopy) is then introduced through the lateral portal to debride the footprint till reaching bleeding bone surface. It is important not to breach the cortical

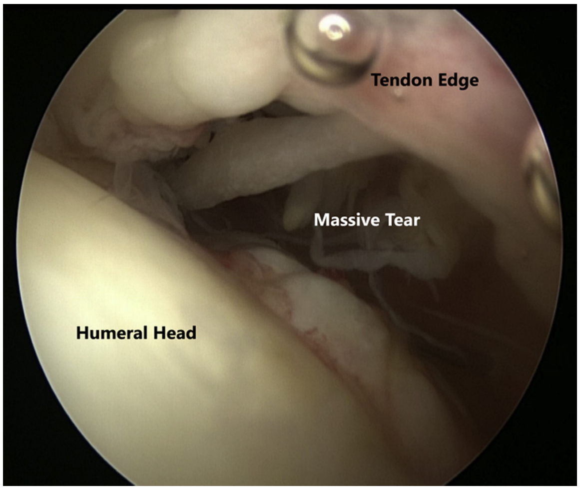

Fig 2. Arthroscopic view from the posterior portal of the right shoulder in a modified beach chair position, showing a full-thickness massive tear of the supraspinatus and infraspinatus tendons.

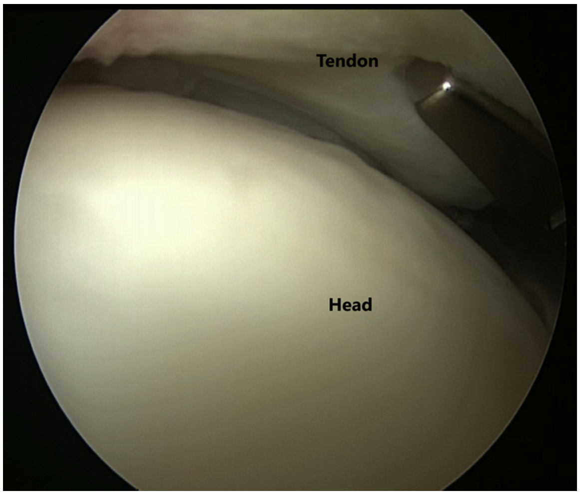

Fig 4. Arthroscopic view of the right shoulder through posterior portal in a modified beach chair position. Tendon reduction to its footprint using grasper forceps after adequate debridement and tendon mobilization.

bone with the burr, as it may compromise anchor purchase (Fig 3).

Tendon Mobilization

Intra- with or without extra-articular mobilization of the retracted and scarred tendon is then followed using a soft-tissue liberator, arthroscopic shaver, and/or radiofrequency ablation device. Tendon reduction is checked using grasper or ring forceps (Fig 4).

Subacromial Decompression and Bursectomy

The scope is then shifted to the subacromial space in which the bursal side of the rotator cuff is inspected, and the tear morphology is determined (Fig 5). Arthroscopic subacromial decompression is performed using radiofrequency ablation device and 5.5-mm motorized burr if there is a spur at the undersurface of the acromion.

First Step: Medial Row Anchors' Insertion

Once the tendon is fully mobilized and its free end can be brought to the lateral edge of the footprint, the repair can be initiated. First, 2 titanium double-loaded 5-mm anchors (Twinfix; Smith & Nephew, Andover, MA) are placed just lateral to the articular cartilage 1 cm apart through separate portals that are established

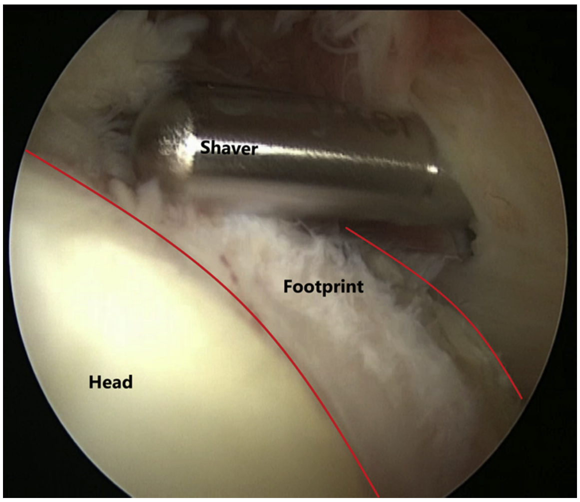

Fig 3. Arthroscopic view of the right shoulder through posterior portal in a modified beach chair position. Preparation of the tear footprint (between the 2 red lines) through the lateral portal using a 4.5-mm shaver blade.

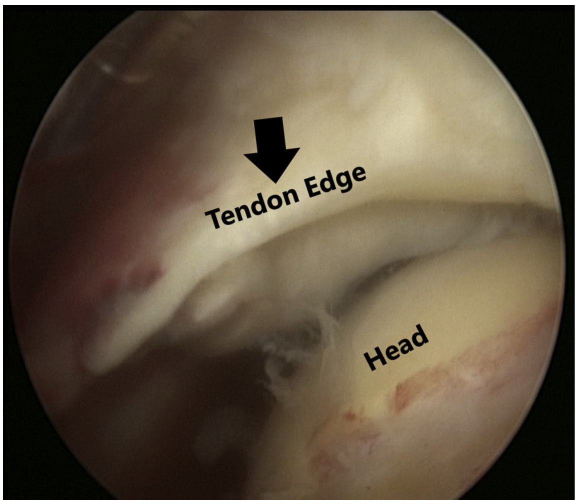

Fig 5. Arthroscopic view of the subacromial space of the right shoulder through the lateral portal in a modified beach chair position showing the free tendon edge. Tear configuration and tendon reduction are assessed to determine anchor positions. Arrow indicates the tendon edge.

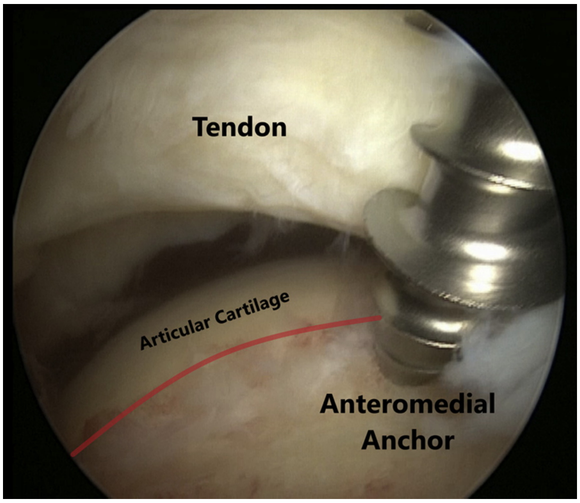

Fig 6. Arthroscopic view of the right shoulder subacromial space through the lateral portal in a modified beach chair position. Anteromedial anchor insertion just behind the articular cartilage (red line represents the articular cartilage edge).

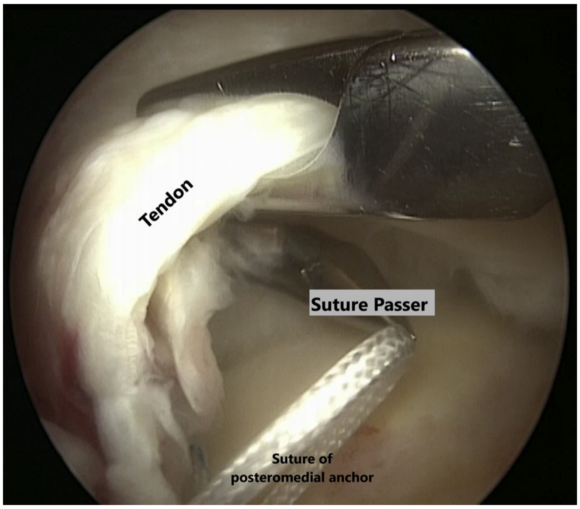

Fig 8. Arthroscopic view of the right shoulder subacromial space through the lateral portal in a modified beach chair position. Suture passing instrument is introduced through posterior portal to suture the tendon layers.

under direct visualization using an 18-gauge spinal needle. The anteromedial anchor is placed first (Fig 6) then the posteromedial anchor. (Fig 7).

Second, a suture retriever forceps is used to pass all the strands of both medial anchors independently through the cuff as mattress sutures (Fig 8). A modified lasso loop stitch can be used in the medial row for better tissue holding and tendon reduction (Fig 9).

If needed, an intra-articular biceps tenodesis is done using the sutures of the anteromedial anchor (Fig 10). Strands of these 4 mattress sutures will not be tied at this stage.

Second Step: Middle Row Anchor's Insertion: "Reduction Step"

A repositioning central titanium double-loaded anchor "middle row" is then placed (Twinfix; Smith & Nephew) at the lateral edge of the footprint. The placement of this anchor is very crucial, as it reduces the lateral edge of the cuff back to its anatomical site before tying the medial row (Figs 11 and 12).

One limb of each color of the suture threads is passed through the cuff in a simple fashion to anatomically reduce the cuff to its footprint using TRUEPASS suture passer (Smith & Nephew). These 2 simple sutures are tied first to adjust the tension of the tendon before tying

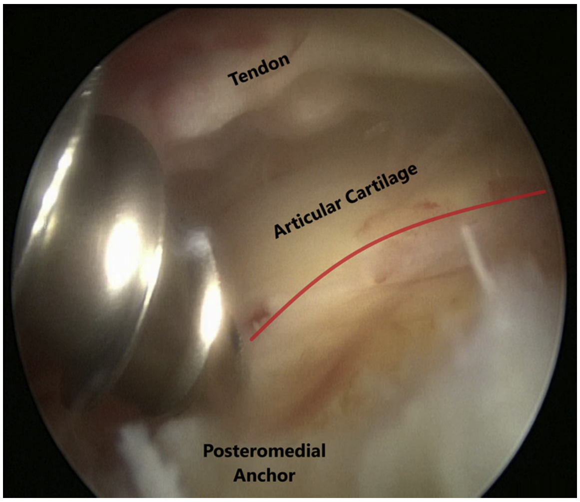

Fig 7. Arthroscopic view of the Rt shoulder subacromial space through the lateral portal in a modified beach chair position. Posteromedial anchor insertion just behind the articular cartilage (red line represents the articular cartilage edge).

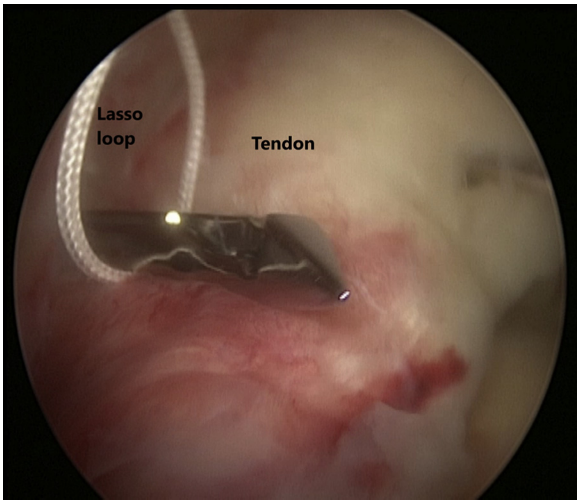

Fig 9. Arthroscopic view of the right shoulder subacromial space through the lateral portal in a modified beach chair position. Suture passers can be used to make lasso loop stitch.

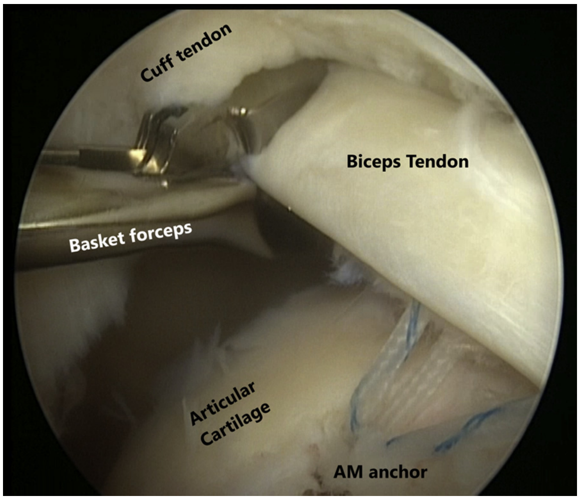

Fig 10. Arthroscopic view of the right shoulder subacromial space through lateral portal in a modified beach chair position. A straight basket forceps is used to cut the biceps tendon through the lateral portals after passing the sutures of anteromedial anchor into the biceps.

the medial row. This allows tension-free knotting of the medial row anchors (Fig 13). A suture cutter is used to cut one limb only from each suture color for later loading to the lateral row along with the medial row sutures.

Third Step: Tying of the Medial Row Sutures

The medial row mattress sutures are tied, which will result in 4 mattress sutures at the medial row. A suture cutter is then used to cut one strand from each mattress suture, leaving 4 strands from the medial row (2 white and 2 tiger) and 2 strands of the middle row (1 white and 1 tiger) (Fig 14).

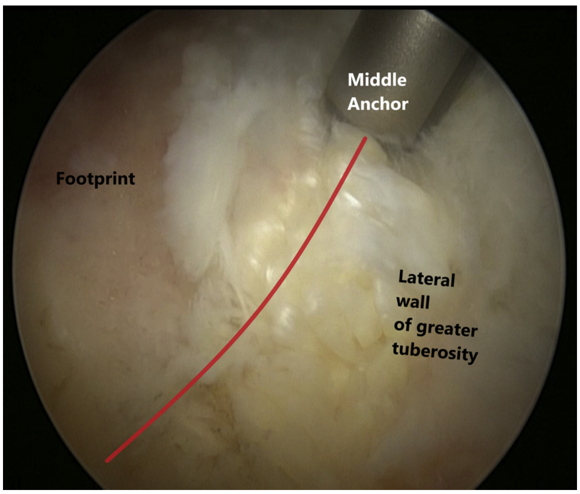

Fig 11. Arthroscopic view of the right shoulder subacromial space through the posterior portal in a modified beach chair position. The middle repositioning anchor is placed at the lateral edge of the footprint (red line represents the lateral edge of the footprint).

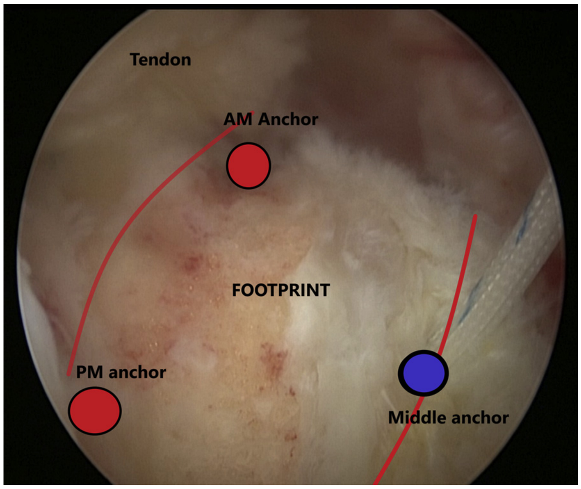

Fig 12. Arthroscopic view of the right shoulder subacromial space through the posterior portal in a modified beach chair position. The middle repositioning anchor is placed at the lateral edge of the footprint. The footprint is the area between the 2 red lines. The 2 red circles indicate the medial anchors and the blue circle indicates the middle anchor. (AM, anteromedial; PM, posteromedial.)

Final Step: Lateral Row Anchors' Insertion: "Linking Step"

The lateral wall of the greater tuberosity is then prepared using shaver blade and radiofrequency device. A PassPort Cannula (Arthrex Inc, Naples, FL) is then inserted for better suture management. Afterwards, 2 PEEK (polyether ether ketone) 5.5-mm knotless anchors (FOOTPRINT 5.5 mm; Smith & Nephew) are placed lateral to the greater tuberosity one cm apart as a lateral row. Each knotless anchor is loaded with 3 suture threads of the same color: one from the

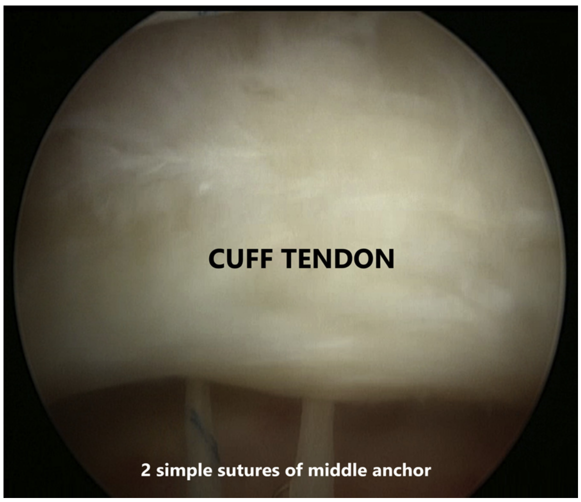

Fig 13. Arthroscopic view of the right shoulder subacromial space through the lateral portal in a modified beach chair position. The middle anchor sutures are passed in a simple fashion through the lateral edge of the tendon.

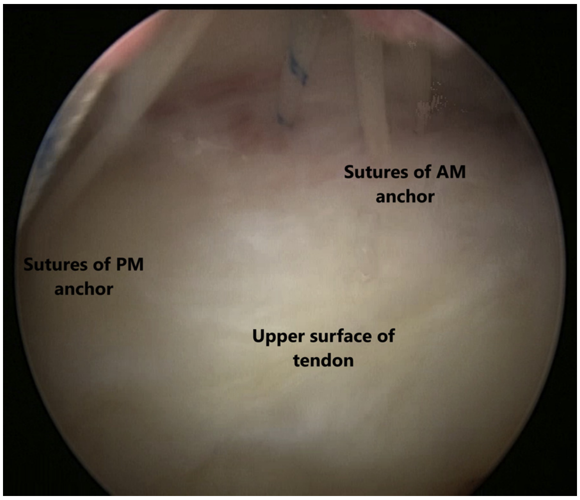

Fig 14. Arthroscopic view of the right shoulder subacromial space through the posterior portal in a modified beach chair position. The strands of the double loaded titanium medial row anchors are passed through the medial part of the cuff in a mattress fashion. They are tied after tying the middle repositioning anchor.

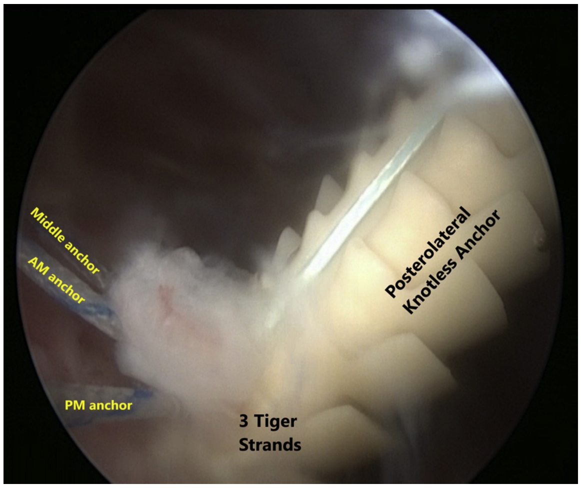

Fig 16. Arthroscopic view of the right shoulder subacromial space through the posterior portal in a modified beach chair position. The posterolateral anchor is inserted holding the other 3 tiger strands from the 3 anchors (one strand from anteromedial anchor, one strand from posteromedial anchor, and another strand from middle anchor).

anteromedial anchor, one from the posteromedial anchor, and the last one from the middle anchor. To avoid suture entanglement, it is better to combine the sutures tails of the same color together. The linking of the medial, middle, and lateral rows should allow more cuff compression and less gap formation (Figs 15 and 16).

Check Repair Extra- and Intra-Articularly

Finally, the arthroscope is shifted to the lateral portal to assess the adequacy of cuff compression without any dog ear formation. Then the scope is switched intra-articularly through the posterior portal to evaluate the competency of the repair from inside the joint. (Figs 17-21).

Discussion

Large and massive rotator cuff tears represent a major challenge for shoulder surgeons. It is difficult to mobilize and anatomically reduce a scarred retracted tendon; however, it is even harder to achieve a tension-free repair. Biomechanically, the goal of a rotator cuff

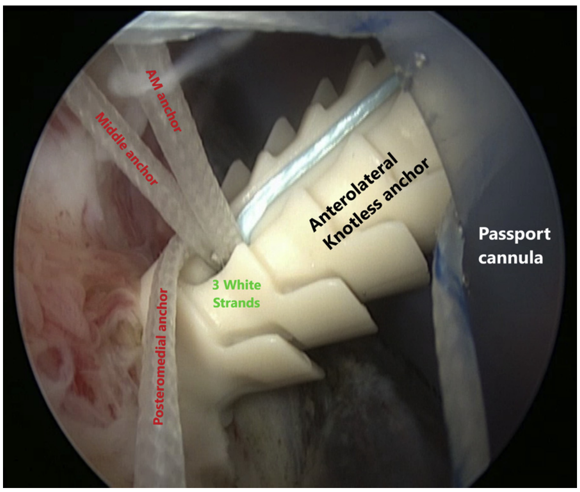

Fig 15. Arthroscopic view of the right shoulder subacromial space through the posterior portal in a modified beach chair position. The anterolateral anchor is inserted holding the 3 white strands of the 3 anchors (one strand from anteromedial anchor, one strand from posteromedial anchor and another strand from middle anchor).

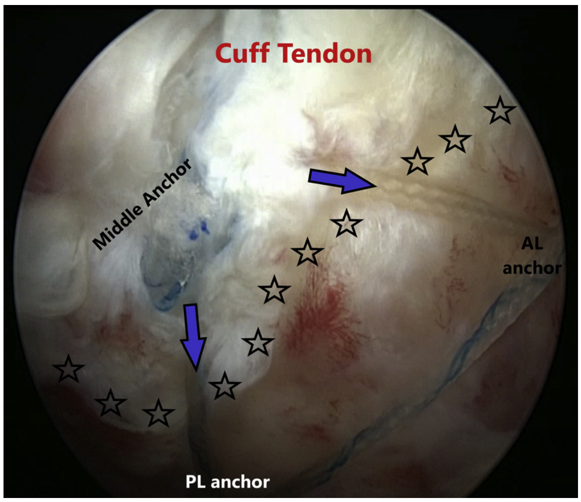

Fig 17. Arthroscopic view of the right shoulder subacromial space through the lateral portal in a modified beach chair position. Linking of the middle row anchor's sutures to the 2 lateral row knotless anchors. The stars in the figure define the tendon edge. (AL, anterolateral; PL, posterolateral.)

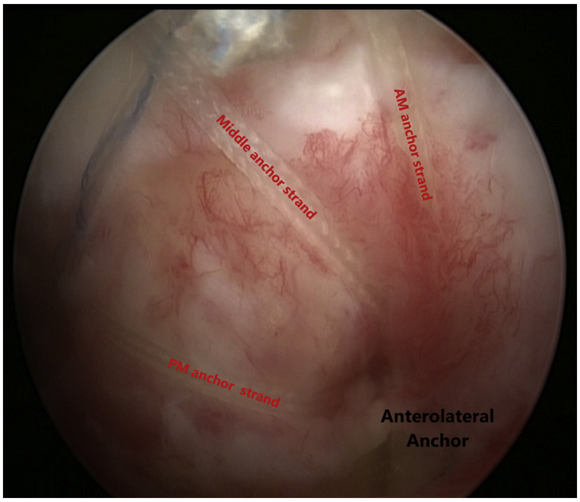

Fig 18. Arthroscopic view of the right shoulder subacromial space through the lateral portal in a modified beach chair position. Anterolateral anchor holding the 3 white strands compressing the cuff anteriorly.

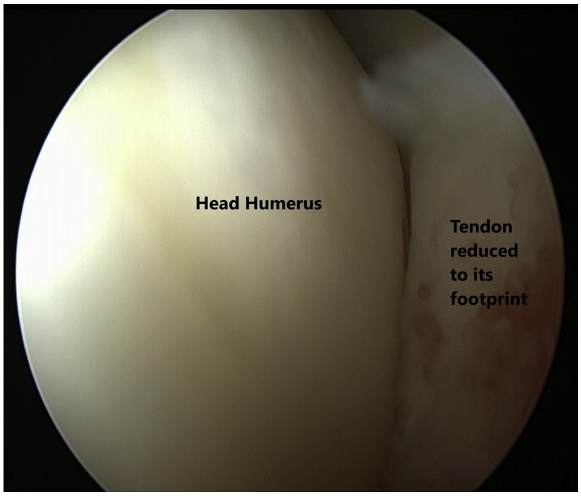

Fig 20. Intra-articular arthroscopic view of the right shoulder through the posterior portal in a modified beach chair position. The tear is sealed completely and anatomically reduced back to its footprint.

repair is to achieve high initial fixation strength, minimize gap formation, and maximize footprint contact area. In fact, rotator cuff repair represents a race between tissue healing and biomechanical failure. Therefore, ideally the repair should be optimized by the surgeon intraoperatively to provide the best chance for tendon healing.[14]

Different repair techniques have evolved for the management of large and massive cuff tears to improve success rates. Studies have shown the biomechanical superiority of linked DR repair technique (SB) over single or unlinked conventional DR repairs. Linking allows more tendon to bone compression, thus improving healing rates.[15]

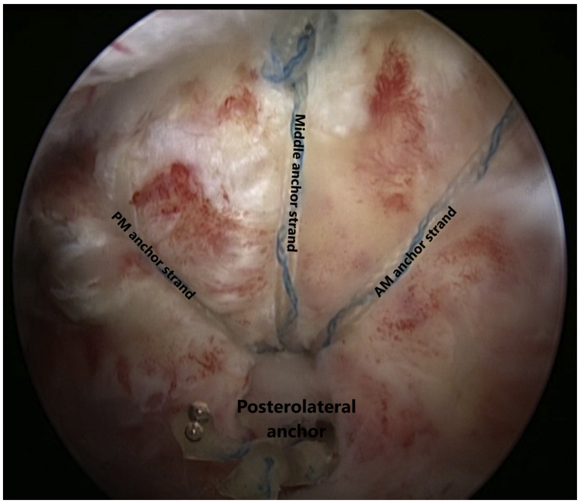

Fig 19. Arthroscopic view of the right shoulder subacromial space through the lateral portal in a modified beach chair position. Posterolateral anchor holding the 3 tiger strands compressing the cuff posteriorly.

Nevertheless, this biomechanically advantageous repair construct may still have some drawbacks in large and massive tears, as it may exert high load forces over the medial row sutures which may lead to type II failure (medial row failure). Moreover, excessive pressure on tendon may lead to local tissue devascularization and failure to heal. This high stress concentration may clarify the increased re-tear rates specifically around the medial anchors that had been reported during the past decade with linked DR technique.[16]

Kim et al.[17] and Hein et al.[18] reported retear rates after SB technique to be about 42% in large and massive tears, of which were mainly due to the medial cuff failure. A lot of tension exerted on the medial row during suture tightening was postulated by Trantalis et al.[19] as the main cause of this retear.

A recent study by Park et al.[20] found that the repair tension was the most important factor for the integrity of rotator cuff repair. Consequently, a medial row sutures tied over an anatomically reduced tendon without over tension is the main goal. This could be achieved through adequate release of the retracted tendon in addition to adding a repositioning or a reducing anchor before even tying the medial row sutures (triple-row concept)[12,13]

Triple row cuff repair was introduced by Ostrander and McKinney[12] in 2012 as a modification of the transosseous equivalent repair. They found that the lateral part of the cuff was anatomically reduced without an over tensioned cuff medially. This independent additional row of fixation reduced the cuff before tying the medial row sutures, which allowed for decreased load over the medial anchors and

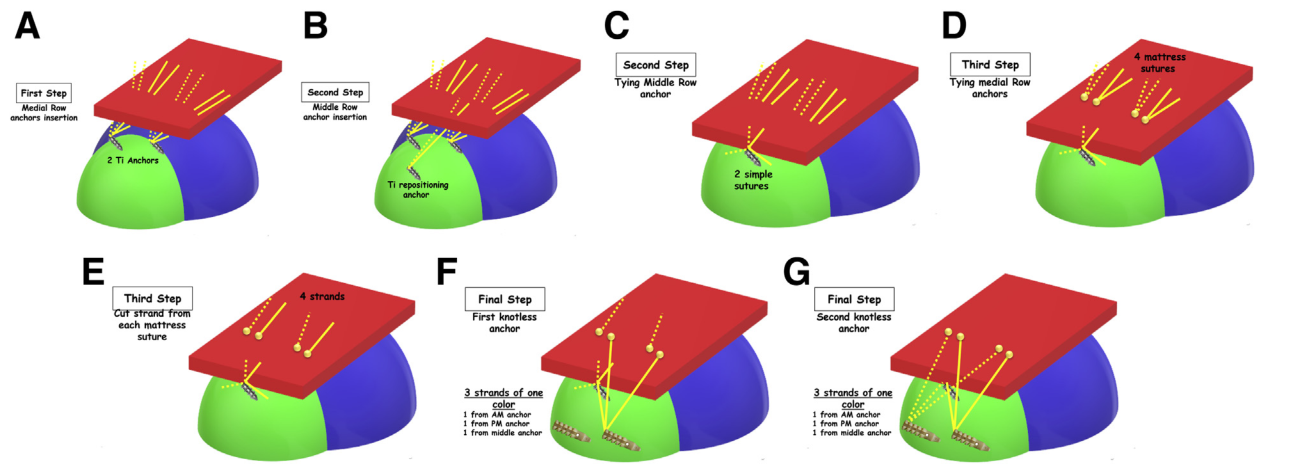

Fig 21. Step-by-step linked triple row technique. (A) First step, medial row anchors insertion; (B, C) Second step, inserting and tying of the middle row anchor. (D,E) Third step, tying of medial row mattress sutures. (F,G) Final step, lateral row anchor insertion.

subsequently failure of repair. Hence, the position of this middle anchor is crucial; it should be placed at a site that restores the normal anatomy of the footprint. Replicating the normal footprint anatomy can maximize the contact area and contact pressure as well as ultimate load to failure without deleterious impact on the biology.[13] The main advantage of the triple-row technique is a tension-free knotting of the medial anchors. The potential for tension-free repair was confirmed by tendon mobilization with the grasper to the lateral border of the native footprint. In contrast, in the standard SB technique, the medial row anchors were tied first; this maximizes peak suture-tissue forces medially, which may lead to medial cuff failure.[12,13]

The linked triple-row technique presented in this report has many theoretical advantages compared with the DR and the SB techniques. Unlike the SB, in the conventional DR technique the tendon footprint is restored anatomically but with no competent contact pressure.[21] However, the whole repair construct would fail in the SB technique if the medial row failed. Moreover, in the conventional triple-row technique, if the medial row failed, the construct will act as a single row, but in the linked triple-row presented in this study, the construct will still act as a DR if the medial row failed. Thus, linking the DR with the SB in the linked triple row proposed in this study, a triple effect can be achieved. First, an anatomical restoration of the footprint resembles the DR repair. Second, a better contact pressure and tendon compression are similar to the SB technique. Finally, a "tension-free" repair is a unique feature of the triple row construct with decreased load per suture and uniform load sharing for all sutures.

In contrast to the original unlinked triple-row repair, the middle row anchor is linked and loaded to the lateral row in this technique. This shall give the construct more stability and superior performance. This secured tight repair may permit an accelerated rehabilitation program with earlier range of motion exercises postoperatively. Pearls and pitfalls of the technique are presented in Table 2.

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