Double-Row Rotator Cuff Repairs: Biomechanical Rationale and Surgical Techniques

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ABSTRACT
Advances in surgical technique and implants for arthroscopic rotator cuff repair have generated an interest in the indications and application of double- and single-row repairs. Recently, a variation of the double-row technique, known as the transosseous equivalent repair, has also been described. Previous reports of unacceptably high failure rates after arthroscopic repair of large and massive rotator cuff tears have led to the scrutiny of both this technique and the implants used. Biomechanically, double-row techniques are superior to single-row with respect to restoring the anatomic footprint, minimizing gap formation, and providing a greater load to failure at time equals zero. Furthermore, the recently described transosseous equivalent fixation technique provides improved footprint restoration, greater contact pressure across the bone-tendon interface, and an increased load to failure when compared to double-row repair. Although the biomechanical data are encouraging, clinical studies are still in progress to assess the efficacy of double-row versus single-row techniques, particularly with regard to tendon healing. The potential advantages may be offset by the added surgical time, required technical expertise, and potential increase in cost. The purpose of this study is to review the biomechanical, histological, and in vivo results of double-row and transosseous equivalent arthroscopic rotator cuff repairs while also discussing our indications and technique for double-row repairs.

Keywords: rotator cuff, double-row, transosseous equivalent, technique, arthroscopic, biomechanics

The goal of rotator cuff repair is to decrease pain, improve function, and restore strength through restoration of a stable bone-tendon construct. Previous literature has shown that improved outcomes, particularly with regard to restoration of strength, are present when the rotator cuff repair is intact. Gerber and colleagues suggested that the ideal repair should provide high initial fixation strength, minimize gap formation, and maintain mechanical stability until sufficient healing has occurred. Historically, open techniques have generally employed the use of bone tunnels to provide transosseous fixation. With the advent of arthroscopic techniques for rotator cuff repair, suture anchors have replaced the transosseous tunnel as the primary mode of fixation. As proficiency in arthroscopic rotator cuff repair has improved, so have the fixation techniques. Various methods of arthroscopic rotator cuff footprint restoration have been described, including a double-row repair, which simulates the type of fixation achieved with open and mini-open techniques. For the purposes of this article, a double-row construct consists of 2 rows of suture anchors, all placed within the rotator cuff footprint. A transosseous equivalent construct (TOE) is similar to a double-row anchor repair except that the lateral row fixation integrates the medial sutures to provide compression of the rotator cuff to the tuberosity, similar to an open transosseous suture technique (Fig. 1).

Recent studies have demonstrated that double-row fixation is superior to single-row fixation with regard to contact area and pressures, minimizing gap formation, and increasing load to failure. Demirhan et al showed that the strongest biomechanical construct is the combination of medial suture anchors and lateral transosseous bone tunnels, a double-row repair pattern that requires open surgery. However, many surgeons have shifted from open to arthroscopic surgery in order to gain better visualization of the tear pattern, less deltoid disruption, less postoperative morbidity, and an earlier return of motion. Improvement in anchor and suture technology has led to a reduction in implant failures. Currently, with better understanding of optimal techniques for repair based on tear pattern for large and massive tears, the mechanism of failure has shifted to the suture-tendon interface. The arthroscopic TOE repair does not rely on the lateral aspect of the tendon for fixation but rather...
creates a load-sharing construct between the medial and lateral points of fixation, which has been shown to reduce the incidence of suture pullout and may provide improved resistance to shear stress during rotational motion.\textsuperscript{14}

Arthroscopic rotator cuff repair has become an accepted technique with clinical results that approach the outcomes of open and mini-open techniques. Rетear rates for all-arthroscopic repairs have been reported to be between 17\% and 50\% for 1 and 2 tendon repairs\textsuperscript{1,3,4,15} and as high as 94\%\textsuperscript{16} for large and massive tears. However, these studies have demonstrated that clinical outcome does not necessarily correlate with tendon healing. Therefore, there has been considerable debate regarding the adoption of a more technically demanding, longer, and potentially more expensive double-row all-arthroscopic technique. Current studies are underway to determine if double-row or TOE techniques result in improved results with regard to both clinical outcome and tendon healing to justify the increased complexity and expense.

## HISTORICAL PERSPECTIVE

Restoration of the entire footprint is a potentially important factor in cuff repair because it leads to a greater surface area for healing of the tendon. The supraspinatus footprint, on average, measures 12.7 mm (medial to lateral) and 16.3 mm (anterior to posterior) on the superior aspect of the greater tuberosity (Fig. 2).\textsuperscript{17} In a cadaver model, Mazzocca et al\textsuperscript{18} showed that double-row fixation provides a footprint that is identical to that of the intact supraspinatus. An in vivo study showed that only 47\% of the supraspinatus footprint is restored after placement of a single lateral row of suture anchors and confirmed that the entire footprint can be reestablished with the addition of a medial row.\textsuperscript{7} Using three-dimensional digitization of the supraspinatus footprint, a significantly greater percentage of native tendon-bone contact area was found after double-row suture anchor fixation (100\%) when compared to either single-row suture anchor or simple transosseous suture repairs (46 vs 71\%, respectively).\textsuperscript{19} In addition, Park and colleagues\textsuperscript{20} used contact pressure film to show that a significantly greater portion of the supraspinatus footprint can be restored with a 4-suture bridge TOE technique when compared to double-row suture anchor fixation (77.6\% vs 39.6\%, respectively).

Double-row techniques have been shown to have a significantly greater load to failure\textsuperscript{10,21} and mean cycles to failure\textsuperscript{8} with significantly less gap formation\textsuperscript{9,10,21,22} when compared to single-row fixation. Burkhart\textsuperscript{23} determined that the maximal contraction force generated by the supraspinatus is equal to approximately 302 N. The actual load that a rotator cuff tendon repair must withstand in vivo, however, may be greater than that predicted by the maximal contraction force generated by the supraspinatus tendon because of the overlap of infraspinatus and supraspinatus tendon fibers on the greater tuberosity.\textsuperscript{24} Fortunately, during the early phases of repair, however, rehabilitation is restricted to passive range of motion limiting muscle activity to 10\% to 20\% and decreasing stress across the repair site.

Early biomechanical studies have demonstrated that 6 simple sutures placed in a single-row has a load to failure of 273 N,\textsuperscript{5} and 5 single-loaded suture anchors in a double-row configuration has a load to failure of 336 N.\textsuperscript{25} More recently, Park and colleagues\textsuperscript{14,26} described a TOE technique that has a load to failure of 443 N. Gap formation, at time equals zero, is significantly reduced with double-row when compared to single-row fixation\textsuperscript{9,21} but is similar to that achieved with TOE fixation.\textsuperscript{14} The TOE repair technique does, however, provide greater compression of the tendon against the bone\textsuperscript{20} and higher load to failure than does double-row fixation with suture anchors.\textsuperscript{14} Furthermore, gap formation with shoulder rotation simulating passive motion during the
early rehabilitation phase is less with TOE repair than with single- or double-row repair. The biomechanical rationale is that with a TOE repair, the lateral fixation is oriented 90 degrees to the vector of the supraspinatus muscle and thus provides more stability.26

**HISTOLOGY/ANIMALS MODELS**

Once the anatomy of the supraspinatus footprint has been restored, the biological properties of the tissues must be maximized to ensure adequate healing of the repair. The goal of biological healing is to restore a normal bone-tendon interface because this will provide long-term stability of the repair. During the early postoperative period, failure uniformly occurs at the repair site because bone-tendon healing does not reach adequate strength until approximately 12 weeks postoperatively. During this phase, the repair must be protected to ensure adequate tendon to bone healing.

Previous studies have examined the histological properties and biological contribution of different tissues to the healing response.27–31 Following rotator cuff repair in a rabbit model, Uthoff et al. described increased cellularity in the bony footprint and bursal tissues but decreased cellularity in the stump. Their conclusion was that the biological contribution of the tendon is minimal in the early preoperative period and that preservation of bursal tissue and adequate bone debridement to improve vascularity at the repair site when reestablishing the tendon footprint is important for successful bone-tendon healing. In addition, another rabbit model has been used to show that motion at the tendon-bone interface may impair graft incorporation after anterior cruciate ligament reconstruction.32 Extrapolation of these data suggests that motion and gap formation may impair healing at the bone-tendon interface after rotator cuff repair.

**INDICATIONS**

Several factors must be considered, such as tear configuration and tissue quality, as part of the preoperative plan when deciding whether a tear is appropriate for a double-row or TOE repair. Because crescent-shaped tears are generally smaller and more mobile and can often be repaired directly to the humerus with a single-row of suture anchors. Furthermore, the intact anterior and posterior cables limit tension on the repair and prevent tear retraction. In our experience, tears that are large (greater than 3 cm) or have poor tissue quality are generally good candidates for double-row or TOE repair. Furthermore, patient factors such as age, tobacco use, and inflammatory or comorbid conditions that may impede tendon healing may be considered in selecting double row techniques. In addition, L-shaped and reverse L-shaped tears are generally amenable to double-row fixation because the apex of the L-shaped tear can usually be reduced back to the lateral margin of the footprint. Massive tears often require additional side-to-side fixation using the principle of margin convergence to minimize the tension at the bone-tendon interface. With sufficient tendon mobility and reduction to the anatomic footprint, larger and massive tears (U-shaped and others) may also be fixed with double-row fixation techniques. These guidelines, based on our experience and extrapolation of biomechanical data, are in agreement with a previously published treatment algorithm.26 Future studies are necessary, however, to validate this algorithm based on clinical results.

**TECHNIQUES**

Under either general anesthesia or a regional block, the patient is placed in the beach chair position with the surgical arm draped-free. Correct portal positioning is critical for performing a successful double-row or TOE repair. With a 30-degree arthroscope in the glenohumeral joint via a standard posterior portal, an anterosuperior portal is established in the superior aspect of the rotator interval. A standard diagnostic arthroscopy is performed to identify any concomitant glenohumeral pathology. The anterior portion of the rotator cuff is placed under tension with glenohumeral flexion and external rotation and the rotator cuff insertion lateral to the edge of the articular surface is carefully probed and examined for undersurface tears (Fig. 3). Any undersurface tear is gently debrided and marked with a number 1 polydioxone monofilament absorbable (Ethicon, Somerville, NJ) suture through a spinal needle placed from the subacromial space (Fig. 4).

Next, the subacromial space is accessed using a blunt trochar through the posterior portal, which will serve initially as the viewing portal. At this time, the lateral viewing portal is established approximately 2 to 3 cm inferior to the

**FIGURE 3.** Undersurface view of a full-thickness tear of the supraspinatus tendon as viewed from posterior portal with the arthroscope in the glenohumeral joint.
inferior edge of the acromion corresponding to the anterior-posterior midportion of the acromion (the “50-yard line”). The position of this portal can also be adjusted to correspond to the midpoint of the rotator cuff tear. A 5-mm cannula should then be inserted into this portal in order to minimize fluid extravasation. Through this lateral portal, a shaver and radiofrequency device can be used to debride the subacromial bursa and related tissues to provide adequate visualization and working space. Care should be taken at this time to thoroughly debride the lateral gutter to ensure adequate visualization of the tuberosity for lateral fixation. This can be accomplished with the arm in neutral position and a slight downward traction using dynamic internal and external rotation to help identify and differentiate rotator cuff tissue from bursal tissue. If a subacromial decompression is desired, then acromioplasty is performed at this time. The deltoid fascia should not be violated in order to minimize bleeding and fluid extravasation into the soft tissues.

With the 30-degree arthroscope in the lateral subacromial portal, better visualization of the morphology of the tear pattern can be achieved and allows proper classification to direct surgical management (Fig. 5). The tear is prepared in standard fashion, performing releases as needed to assess rotator cuff mobility. A second lateral portal is made (with a 7-mm cannula) directly adjacent to the anterolateral edge of the acromion and serves as a working portal, with the arthroscope in the lateral portal (posterior to this new anterolateral portal). A grasper is inserted through this anterolateral portal to assess tear mobility and ability to be reduced to the tuberosity. By using a grasper from the anterosuperior portal, a surgeon can assess the mobility of the tendon and develop a plan for the number and position of suture anchors. Additional releases may be performed at this point to allow sufficient tear mobility for reduction to the tuberosity. For larger tears, a temporary reduction stitch in the most anterior part of the tendon (L-shaped, posterior part for reverse L-shaped) can aid in the orientation of the tear and prevent overdistraction, which may result in restriction of postoperative shoulder range of motion.

It is critical to establish a bleeding bony bed at the site of the entire tendon footprint to maximize the surface area of biologic healing at the bone-tendon interface (Fig. 6). However, only a light partial decortication (via bone cutting shaver or burr lightly on the reverse setting) is usually necessary to create adequate bleeding, and care must be taken to prevent complete decortication, which may impair anchor fixation.

The medial row of fixation should be addressed first using a double-loaded suture anchor placed 1 to 2 mm lateral to the articular cartilage margin corresponding to the posterior edge of the tendon footprint (Fig. 7). The
humerus should be abducted 20 to 30 degrees during this step to ensure proper trajectory of the suture anchors (Deadman’s angle of 45 degrees as advocated by Burkhart). Using arthroscopic suture passers, the sutures should be passed through the tendon approximately 10 to 14 mm from the lateral edge of the tendon in the mattress pattern approximately 4 to 5 mm apart. This point is located just lateral to the musculotendinous junction. Suture passage through the tendon can be achieved using either anterograde or retrograde suture-passing methods. A retrograde method uses either a straight or angled retrograde suture-passing device such as a penetrator inserted from the posterior portal (Fig. 8). The tendon is penetrated with the suture-passing device; the suture is grasped and withdrawn through the tendon exiting through the posterior portal. For accessing more central portions of the tendon, an anterograde suture-passing device such as the ExpressSew (Johnson & Johnson, Raynham, Mass) or Scorpion (Arthrex, Naples, Fla) may be used. The suture-passing device is first loaded with suture and then inserted through the anterolateral portal. The tendon is grasped with the device, which is then “fired,” thus passing the suture through the tendon at the desired location. The suture can then be brought out through the anterosuperior portal using a suture grasper. Alternatively, a variety of retrograde passers may be used to complete the entire repair.

In general, we prefer to place all medial anchors before suture tying (Fig. 9), and the sutures then should be stored temporarily in the posterior portal. The next anchor should be placed again at the lateral aspect of the articular surface at the anterior extent of the footprint approximately 20 mm from the posterior anchor. Passage of the suture through the tendon is again performed. At this point, all medial sutures are tied sequentially, but the sutures are not cut. Rather, the limbs are shuttled through the anterosuperior portal for storage.

At this point, attention is drawn to the lateral transosseous equivalent fixation. The authors’ prefer the 3.5- or 4.5-mm Bio-Pushlock device (Arthrex, Naples, Fla) for this step, with a larger sized option for decreased bone quality. A suture-bridge is established by taking one limb of the anterior anchor and one limb of the posterior anchor and mating them through the Pushlock eyelet, which is then securely placed on the lateral aspect of the tuberosity in line with the anterior suture anchor (Fig. 10). Of note, up to 3 suture limbs can be secured with each device to allow for even greater contact area. Care should be taken to maintain tension on the sutures while inserting the anchor into bone. After completion of anchor insertion, an optional nonsliding arthroscopic
knot can then be tied directly down to the surface of the anchor, without past pointing, to provide a restraint to suture slippage past the eyelet of the Bio-Pushlock device. This step is again repeated but this time in line with the posterior anchor and using one limb from both the posterior and anterior anchors (Fig. 11). All suture limbs can now be cut.

**POSTOPERATIVE PROTOCOL**

Postoperatively, the patient is placed into an abduction-immobilizing sling for the first 6 weeks. During this time, the patient is restricted to only passive external rotation with the elbow at the side and pendulum exercises. Between 6 and 12 weeks, active range of motion exercises are begun with forward flexion and external rotation at the side; however, lateral abduction is to be avoided at this time. After 12 weeks, muscle strengthening is to begin with focus on scapular stabilization and rotator cuff musculature. Six months after surgery, the patient is cleared for full, unrestricted activity.

**CLINICAL RESULTS**

Historically, the rates of nonhealing events after rotator cuff surgery have ranged from 13% to 94%.\(^1\text{,3,16,35\text{--}39}\) Galatz reported on the long-term results of open rotator cuff repair in 33 patients examined at 2 years and again at 10 years postoperatively.\(^40\) The results showed no significant changes with regard to physical examination and subjective patient questionnaires between the 2- and 10-year follow-up. Their conclusion was that the results of open technique for rotator cuff repair do not deteriorate over time. With the advancement of arthroscopic capabilities, arthroscopically assisted mini-open and all-arthroscopic rotator cuff repair techniques have been described.

Several studies examined the outcomes of open and mini-open versus all-arthroscopic repairs looking at subjective outcomes scores as well as advanced imaging to identify rates of rerupture.\(^1\text{,3,41\text{--}44}\) The short-term clinical outcome scores for pain, function, and patient satisfaction are similar,\(^1\text{,3,42\text{--}44}\) or significantly improved for arthroscopic and mini-open repairs in the literature based on subjective patient outcome. Furthermore, these scores are not significantly correlated with an intact repair.\(^1\text{,3}\) Bishop et al. prospectively compared the outcomes and rerupture rates in 72 consecutive patients undergoing open and mini-open versus arthroscopic rotator cuff repair at their institution. At 1-year follow-up, American Shoulder and Elbow Society patient assessment and Constant scores were significantly improved in both groups, and the tendon rerupture rate for the open group was 31% versus 47% for the arthroscopic group, with the retear rate significantly higher after arthroscopic repair of tears greater than 3 cm. This study concluded that although an intact repair provides significantly increased postoperative strength in forearm elevation and external rotation, clinical outcome did not correlate with tendon integrity.

Verma and colleagues\(^3\) reported that at 2-year follow-up, there was no significant difference between mini-open and all-arthroscopic repairs of small and large tears with regard to American Shoulder and Elbow Society patient assessment, simple shoulder test, L’Insalata scale, and visual analog scale. Based on ultrasound imaging, the incidence of retear was 24% in the arthroscopic group and 27% in the open group (not significant). When stratified based on original tear size, repair of a tear greater than 3 cm in size had a 7 times
greater likelihood for retear. However, those patients found to have a retear did not differ significantly with regards to pain or outcome scores when compared to those with intact repairs. Consistent with previous reports, an intact tendon did have significantly greater strength in forward elevation and external rotation.

Galatz and colleagues\textsuperscript{16} reported on the all-arthroscopic repair of large and massive tears using a single row with simple suture configuration. The retear rate in this group was 94\%, suggesting that an all-arthroscopic technique for the repair of large and massive tears might be inadequate. The ability to place 2 rows of fixation to restore the tendon footprint and provide added fixation strength and suture redundancy is potentially advantageous when faced with repairing a massive tear arthroscopically. Fealy and colleagues\textsuperscript{35} reported their results of mini-open repairs using a medial row of suture anchors and a lateral transosseous fixation based on tear size: small, medium, and large. Their results showed no significant difference between groups with regard to functional outcome scores. Finally, Jost and colleagues\textsuperscript{6} recently reported on long-term results of patients who had failed repair on postoperative imaging but clinically successful surgery based on improved pain and functional outcome. In their study of 20 patients, they reported a significant improvement in Constant scores, pain, function, and strength when compared to preoperative scores. At an average of 7.6 years of follow-up, the scores were not significantly different when compared to the scores at an average of 3.2 years of follow-up, and no tear increased in size. Smaller tears, however, did show evidence of healing.

To date, the only report on all-arthroscopic repairs of single-tendon tears using a double-row suture anchor configuration identified a 17\% retear rate at an average of 30 months based on ultrasound imaging.\textsuperscript{4} Consistent with previous studies, the authors found a significant increase in postoperative functional scores, active range of motion in all planes, and strength in forward elevation, external rotation, and internal rotation. Furthermore, no significant difference in functional scores was found based on tendon integrity, but strength in forward elevation and external rotation were significantly correlated with an intact repair. Although the clinical results are too early and inconclusive, yet to recommend routine use of either double-row or TOE type repairs, the biomechanical evidence is compelling. Addition clinical follow-up is necessary to ascertain the overall healing differences between various biomechanical fixation techniques.

**SUMMARY**

The biomechanical literature has clearly demonstrated that double-row and transosseous repairs more appropriately recreate the anatomic footprint of the supraspinatus tendon and provide a stronger biomechanical construct. Arthroscopic TOE repairs are advantageous because the surgeon can provide adequate biomechanical stability and maximize the biological healing response with compression at the bone-tendon interface while maintaining the many advantages of arthroscopic surgery. Choosing which method of fixation to use is not limited to the biomechanical results described above but should also involve consideration of the surgical cost. With biomechanical data suggesting that a double-row or TOE repair provides superior fixation and a potential improvement in bone-tendon healing, a surgeon may be tempted to use these techniques in all repairs. Because of the significant increase in surgical cost associated with double-row and transosseous repairs and that not all tears require the added fixation, these techniques should be considered primarily for the repair of tears at greatest risk of rerupture. However, cost may eventually be justified if lower clinical failures are demonstrated. The use of single-row fixation is adequate for smaller tears, whereas for large and massive tears, double-row and TOE fixation offers additional fixation strength, footprint compression, and a theoretically improved biological healing response. Although an intact tendon repair has been shown to be associated with a significant increase in strength and active range of motion, overall patient satisfaction does not correlate with an intact tendon. Additional clinical data are necessary to address the long-term efficacy of these techniques.

**REFERENCES**


