Arthroscopic Repair of Medium to Large Rotator Cuff Tears with a Triple-Loaded Medially Based Single-Row Technique Augmented with Marrow Vents

Brian D. Dierckman, M.D., Petros Frousiakis, D.O., Joseph P. Burns, M.D., F. Alan Barber, M.D., Ross Wodicka, M.D., Mark H. Getelman, M.D., Ronald P. Karzel, M.D., and Stephen J. Snyder, M.D.

Purpose: The primary purpose of this study was to evaluate the repair integrity on magnetic resonance imaging (MRI), and secondarily, clinical outcomes, of medium to large (2-4 cm) rotator cuff tears treated using an arthroscopic triple-loaded medially based single-row repair technique augmented laterally with bone marrow vents. **Methods:** This is a retrospective outcomes study of patients with full-thickness medium to large (2-4 cm) rotator cuff tears repaired by 4 surgeons at a single institution over a 2-year period with a minimum of 24 months' follow-up. A single-row repair with tension-minimizing medially based triple-loaded anchors and laterally placed bone marrow vents was used. Patients completed a satisfaction and pain survey, the Western Ontario Rotator Cuff index questionnaire, and a Short Form-36 version 2 survey to evaluate clinical outcomes. MRI was obtained at a minimum of 24 months follow-up to assess repair integrity. **Results:** A total of 64 males and 27 females with a mean age of 59.7 (range, 34-82) were included. The mean tear size was 2.6 cm in anteroposterior dimension, treated with a mean of 2.2 anchors. Eighty-three of 91 shoulders (91%) reported being completely satisfied with their result. The median Western Ontario Rotator Cuff score was 95.2% of normal, with a significant difference found between those with an intact repair and those with a full-thickness recurrent defect (median, 95.9% vs. 73.8%; $P = .003$). Postoperative MRI obtained at a median of 32 months (range, 24-48) demonstrated an intact repair in 84 of 91 shoulders (92%), with failure defined as a full-thickness defect of the tendon. **Conclusions:** Arthroscopic repair of medium to large rotator cuff tears using triple-loaded medially based single-row repair augmented with marrow vents resulted in a 92% healing rate by MRI and excellent patient-reported outcomes **Level of Evidence:** Level IV, retrospective case series.

Symptomatic rotator cuff tears are common in the active aging population, and recent clinical results of arthroscopic rotator cuff repair have been promising.[1-10] However, achieving consistent radiologic healing of larger full-thickness rotator cuff tears remains a challenge, with retear rates ranging from 20% to 94%.[4,6] Both patient- and surgeon-related factors can affect healing after rotator cuff repair.[11-21] Patient-related factors include advancing age, chronicity of symptoms, tissue quality, amount of fatty

From the Elite Orthopedics and Sports Medicine (B.D.D.), Nashville, Tennessee, U.S.A.; Ocean Orthopedics (P.F.), Ventura, California, U.S.A.; Southern California Orthopedic Institute (J.P.B., M.H.G., R.P.K., S.J.S.), Van Nuys, California, U.S.A.; Plano Orthopedic and Sports Medicine Center (F.A.B.), Plano, Texas, U.S.A.; and Holy Cross Orthopedic Institute (R.W.), Fort Lauderdale, Florida, U.S.A.

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Address correspondence to Brian D. Dierckman, M.D., 2004 Hayes Street, Ste 200, Nashville TN 37203. E-mail: bdierckman@eliteorthopaedic.com

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infiltration, and tear size.[11,13-16] Two factors influenced by the surgeon are the surgical construct used[22] and the amount of tension applied to the muscle-tendon unit during repair.[16] Traditionally, arthroscopic rotator cuff repair has used a single-row (SR) technique.[13] The detrimental effects of excessive tension on cuff repairs have long been recognized, although few studies have directly evaluated these effects.[16,23,24]

Recent biomechanical research has focused on repair designs to improve rotator cuff tendon repair strength, and, ultimately, healing rates. These efforts have led to the development of various double-row (DR) repair techniques in which reestablishment of the tendon footprint is achieved by extending the rotator cuff tendon toward the lateral margin of the greater tuberosity. One row of anchors is placed at the medial border of the footprint and a second attachment site is established at the lateral footprint. Through a combination of anchors and sutures, the rotator cuff is reduced and compressed to the greater tuberosity. The transosseous-equivalent (TOE) technique was developed to improve compression of the rotator cuff tendon to the tuberosity by linking these 2 anchor rows with bridging/crossing sutures. Several biomechanical studies have shown that the TOE technique provides the strongest biomechanical fixation, although tension in the tendon is higher in these DR and TOE techniques.[25-28]

Despite the newer techniques, recent reports continue to note suboptimal healing rates especially for larger tears.[11,29-32] Adding a third suture to each anchor, medializing the fixation points on the greater tuberosity to minimize tension, and adding the potentially positive effects of bone marrow vents to the healing environment are 3 potential areas of improvement. These are relatively simple and cost-effective modifications to commonly published SR techniques. The primary purpose of this study was to evaluate the repair integrity on magnetic resonance imaging (MRI), and, secondarily, clinical outcomes, of medium to large (2-4 cm) rotator cuff tears treated using an arthroscopic triple-loaded medially based single-row repair technique augmented laterally with bone marrow vents. The hypothesis of this study was that an SR repair technique that theoretically minimizes tension and maximizes repair strength would provide high healing rates on MRI and excellent patient-reported outcomes.

Methods

A consecutive series of patients who underwent arthroscopic rotator cuff repair between January 1, 2008, and December 31, 2009, by 1 of the 4 senior authors (S.J.S., R.P.K., M.H.G., J.P.B.) at a single institution were considered for study inclusion. The inclusion criteria were full-thickness rotator cuff tendon tear measured at time of arthroscopy to be at least 2 cm but not greater than 4 cm in anteroposterior (AP) length, an arthroscopic triple-loaded, single-row tension-minimizing repair and a minimum of 24 months follow-up. Exclusion criteria were: any history of ipsilateral shoulder surgery including previous cuff repair, irreparable tears, tears requiring interval slides or any margin convergence sutures for adequate reduction, instability, adhesive capsulitis requiring lysis of adhesions, subscapularis tendon tears requiring repair, Outerbridge grade 4 glenohumeral arthrosis, significant biceps pathology requiring tenotomy or tenodesis, significant acromioclavicular joint disease requiring distal clavicle excision, worker's compensation claim, or the inability to tolerate MRI examination. Interval slides or margin convergence sutures were used (and tears were thus excluded) when the tendon could not be reduced to the medial tuberosity using a grasper without undue tension after basic mobilization techniques and releases were performed. The specific indications for surgery included functionally limiting pain and disability unresponsive to conservative treatment including physiotherapy, activity modifications and medications, with a full-thickness rotator cuff tear on MRI. All patients had an MRI no more than 6 months before surgery per our institutional standard. Because this was a consecutive series of patients, we included a mix of acute, acute-on-chronic, and chronic tears; duration of symptoms before surgery was not routinely recorded.

Preoperative demographic information was obtained including any history of diabetes mellitus, smoking, or alcohol usage.

Surgical Technique

All procedures were performed with the patient in the lateral decubitus position under general anesthesia with the arm suspended in 45° of abduction and neutral rotation. An interscalene block was offered to all patients to be performed before general anesthesia. A standard diagnostic arthroscopy of the glenohumeral and subacromial spaces was performed. Concomitant pathology was identified and treated at this time. Subacromial decompression was performed on any patient with signs of mechanical abrasion on the undersurface of the coracoacromial ligament.

With the arthroscope in the lateral portal, the pattern and size of the tear was assessed. The posterior edge of the bicipital groove was used as the landmark for measuring the anterior tear edge. The rotator cuff tendon was debrided to a stable edge in preparation for repair and the anatomic footprint was debrided of any remaining soft tissue. The size of the tear was measured in the AP dimension using a suture marked every 5 mm, as previously described.[33] Depending upon the tear size and pattern, 2 or 3 triple-loaded polyether ether ketone (PEEK) or metal anchors (Healix PEEK anchors, DePuy Mitek, Raynham, MA; CrossFT PEEK

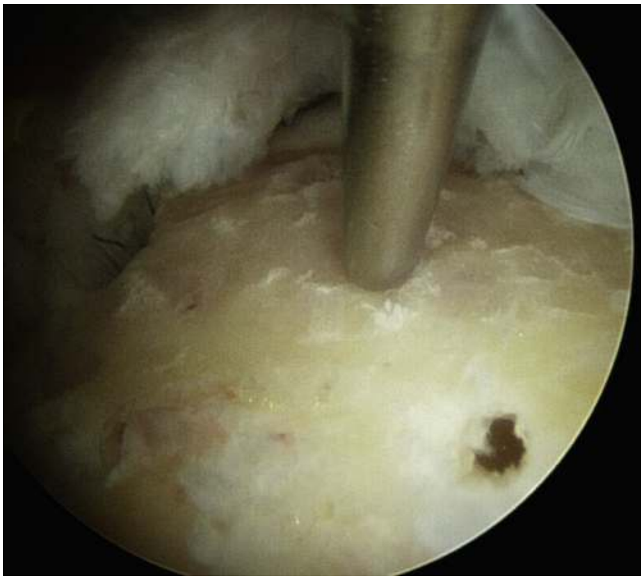

Fig 1. Arthroscopic view with camera in lateral portal showing bone marrow vents being created in the greater tuberosity lateral to the suture anchor and repair site.

and ThreeVo metal anchors, CONMED Linvatec, Largo, FL) were used for the repair. Each anchor was loaded with 3 ultra-high-molecular-weight polyethylene-containing sutures and inserted into the prepared bone at a Deadman angle.[34] The anchors were placed between 3 and 5 mm lateral to the articular cartilage to minimize tension on the torn tendon.[24]

After anchor insertion the sutures were placed as simple stitches in a fan-like array through the rotator cuff tendon using a suture hook and suture shuttling technique in an antegrade fashion.[33] All sutures were tied with sliding-locking knots reinforced with 3 reversed half-hitches on alternating posts. Bone marrow vents roughly 5 to 7 mm deep were placed lateral to the repair in the greater tuberosity using a 1.9-mm diameter bone punch, with 3 to 5 mm separating the bone vents (Fig 1). Per our institution standard, this technique is used for all repairable tears.

Postoperatively patients were immobilized in a neutral-rotation abduction sling (Ultra Sling III, DonJoy Orthopaedics, Carlsbad, CA) for 4 weeks. All patients followed a standardized, supervised physiotherapy program. On postoperative day 1, patients began active elbow, wrist, and hand exercises as well as shoulder shrugs, with passive supine external rotation and pendulum exercises beginning after the first week. Strengthening was initiated at 8 weeks postoperatively, and patients were allowed to resume full, unrestricted activities around 20 weeks postoperatively.

All patients were evaluated at a minimum 24 months postoperatively with MRI for tendon repair integrity as the primary outcome measure, whereas patient-reported outcome measures were secondary. For clinical outcomes, all patients answered patient-reported outcome questionnaires in person at time of MRI administered by an assistant, or by survey via mail or internet within 30 days following their MRI. Clinical outcomes were assessed using the Western Ontario Rotator Cuff Index (WORC). This validated outcome measure correlates well with other outcome tools′ and is more responsive (sensitive to change) than the UCLA, DASH, ASES, Constant, and Rowe scores for rotator cuff disease.[19] A visual analog scale modified to use 0 to 10 integer options was used as was the Short-Form 36, version 2, mental and physical scores. Additionally, patients were asked the nonvalidated yes or no question, “Are you completely satisfied with the results of this procedure AND would you recommend this procedure to others?” to assess for the patient’s overall satisfaction with the surgery.

Tendon repair integrity was assessed using MRI. MRI scans were performed in 1 of 3 1.5-Tesla MRI scanners using current software and a dedicated shoulder coil. The following sequences were obtained on all patients: proton-density fat-saturation T1- and T2-weighted in the oblique coronal plane, T1-weighted in the axial plane, and T1- and T2-weighted in the oblique sagittal plane. An independent fellowship-trained musculoskeletal radiologist blinded to the nature of the study interpreted all scans. Pre- and postoperative supraspinatus muscle atrophy was graded according to the Goutallier classification.[35] Repairs were graded according to the Sugaya criteria as either “healed” (types I-III) or “retear” (types IV-V).[36] MRI interpretation was performed after all patients had completed their survey, and both patient and surgeon were blinded to the MRI result.

Any complications were recorded during the study period.

Statistical Analysis

The Wilcoxon rank sum test was used to compute *P* values for comparing outcome scores between patients with healed versus torn cuff repairs because these scores did not have a normal distribution. Means and standard deviations or medians and interquartile ranges (IQR = Q3-Q1) are reported as indicated. Multivariate Cox regression or linear regression was used to

Table 1. Results of Patient-Reported Outcome Measures Following Rotator Cuff Repair

	Median	IQR	Mean	Range
WORC	95.2	87.3-98	90.5	27.6-100.0
SF-36 PS	51.0	43.0-57.0	49.3	29.0-62.0
SF-36 MS	58.0	54.0-62.0	56.5	29.0-66.0
VAS Pain	1	0-2	1.4	0-9

Mean US normal values of 45.90 PS and 51.05 MS.

IQR, interquartile range; MS, mental score; PS, physical score; SF-36, Short Form Health Survey Scale; VAS, visual analog scale; WORC, Western Ontario Rotator Cuff Index.

Table 2. Results of Postoperative MRI Following Rotator Cuff Repair Surgery Stratified by Sugaya Classification Type

Sugaya Classification	No. (% of total) of Patients
I	51 (56.0)
II	24 (26.4)
III	9 (9.9)
IV	5 (5.5)
V	2 (2.2)
Total	91 (100.0)

Grades I-III considered "healed" (n = 84), grades IV-V considered a "retear" (n = 7).

simultaneously assess the association of age, tear size, number of anchors, surgeon, tobacco and/or alcohol use, and history of diabetes with healing rate or WORC score, respectively. WORC score was transformed using a logit transformation (logit = log(y/(1-y)). A P value (alpha) of <.05 was considered significant. Analyses were carried out using R 3.3.2 (The R Foundation for Statistical Computing).

Results

During the 24-month study period, 102 patients qualified for inclusion. Ninety-one of 102 (89%) patients were available for follow-up at a minimum of 24 months. The mean age of these 91 patients was 59.7 years (range, 34-82) including 64 males and 27 females. The mean follow-up was 33.4 months (range, 24-58; median, 32.0). The mean tear size was 2.6 cm (range, 2-4) and a mean of 2.2 anchors (range, 2-3) were used.

The satisfaction survey revealed that 83 of 91 (91%) patients were satisfied with the result of the surgery. The overall results of the WORC score, visual analog scale pain score, and the Short Form-36 (SF-36) physical and mental scores are shown in Table 1.[37]

Postoperative MRI demonstrated an intact repair (Sugaya types I-III) in 84 of 91 shoulders (92%). In the remaining 7 shoulders (8%), the recurrent tears (Sugaya types IV-V) were all noted to be Cho type 1 failures (retear at the footprint) (Table 2).[38]

Both univariate and multivariate analyses failed to demonstrate any correlation between repair integrity or WORC score and the following variables: age, sex, size of tear, number of anchors, surgeon, diabetes, alcohol use, and smoking (5 of the 6 smokers healed). In univariate analysis, however, a significant difference in WORC scores was seen between those with a healed repair compared with those who demonstrated a retear (median, 95.9; IQR 90-98 in healed vs. median, 73.8; IQR 62.5-79.4 in torn [$P = .003$]) (Table 3). Also, patients with Goutallier pre- and postoperative grades of 0 had significantly higher WORC scores than those patients with higher Goutallier grades ($P = .0004$ and $P < .0001$). In multivariate analysis, the multivariate regression on (logit) WORC score showed that dominant side (yes or no) and postoperative Goutallier grade are simultaneously significant predictors of WORC score as given by

$$\text{Logit (WORC)} = 3.875 - 0.805 \times \text{dominant} - 0.821 \times \text{Goutallierpost}$$

where "dominant" is 1 for dominant and 0 otherwise. The P values are .0083 for dominant side and <.0001 for Goutallier grade.

A total of 3 complications were recorded in the 91 patients. Two of the 7 retears required revision rotator cuff repair within 12 months of the index procedure. One patient developed postoperative subacromial fibrosis and adhesive capsulitis requiring manipulation under anesthesia, lysis of adhesions, and subacromial debridement 7 months following the initial surgery. In this patient, the rotator cuff tendon repair was arthroscopically found to be intact with complete footprint tissue coverage lateral to the repair site (Fig 2).

Discussion

An arthroscopic triple-loaded, medially-based tension-minimizing single-row rotator cuff repair of medium to large tendon tears (2-4 cm in AP length) augmented laterally with marrow vents demonstrated intact tendons in 92% of patients at a median of 32 months postsurgery. A total of 91% of patients were completely satisfied with their treatment and WORC and SF-36 scores were high as well. Preoperative supraspinatus atrophy correlated with significantly lower WORC scores and with retear, consistent with recent reports in the literature; atrophy and fatty infiltration have been shown to be associated with poor function and outcomes of tendon repair and have been shown to be mostly irreversible after tendon repair.[13,39-43]

The principles involved with this repair construct are felt to minimize tension in the tendon and maximize the biomechanics and biology of healing. Specifically, there are 3 core features which accomplish this. First is

Table 3. Demographic Information Stratified by "Healed" Versus "Retear" Following Rotator Cuff Repair Surgery

Variable	Healed (n = 84)	Retear (n = 7)	P Value
Age at surgery, y	60.0 (51.8-66.3)	66.0 (60.5-67.0)	.18
Sex	29.8% F	28.6% F	.99
Dominant side	76.2% Y	85.7% Y	.91
Tear size	2.59 ± 0.53	2.64 ± 0.58	.16
Number of anchors	19.0% with 3	14.3% with 3	.99
Goutallier grade preoperatively	0.23 ± 0.56	0.43 ± 0.49	.21
Goutallier grade postoperatively	0.35 ± 0.68	1.86 ± 0.35	<.0001

Means ± standard deviations presented for sex, tear size, Goutallier grade preoperatively and postoperatively. Median and interquartile ranges presented for age at surgery.

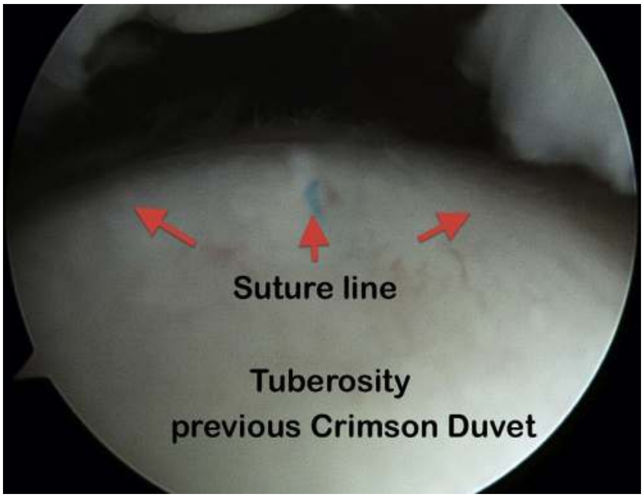

Fig 2. Arthroscopic view at time of second-look arthroscopy with camera in lateral portal showing complete coverage of the tuberosity with tissue. Note the labeled suture strands from the previous medially based repair.

use of a single row of screw-in, fully threaded suture anchors that are triple-loaded with high-strength No. 2 sutures passed as simple stitches in a "fan-like" array and tied securely with sliding-locking knots. Second, this single-row repair minimizes tension on the repair by being fixed medially near the articular cartilage margin on the greater tuberosity. Finally, bone marrow vents placed in the greater tuberosity lateral to the repair allow egress of bone marrow elements, including mesenchymal stem cells and platelets with their growth factors, and establish new vascular channels for ongoing cuff vascularization. This was shown by Milano to improve rotator cuff tendon healing, especially in larger tears.[44]

Although early time 0 biomechanical studies demonstrated higher load to failure strength in DR constructs compared with SR constructs, few studies compared suture-bridging DR constructs with SR constructs using triple-loaded anchors.[45-55] Coons et al.[56] found that by adding a third suture per anchor, cyclical gapping was reduced by a factor of 2.6 compared with a double-loaded anchor. Barber et al.[57] reported comparable biomechanics between a construct using 2 triple-loaded anchors and a TOE construct. During cyclical loading, the SR constructs allowed significantly less gap formation than the TOE constructs. Also, they reported no differences in ultimate loads to failure between the various constructs.

The weakest link in a rotator cuff tendon repair is the suture tendon interface. Consequently, the suture often pulls through the degenerative, compromised tendon before the bone-anchor interface "fails."[58,59] Biomechanical studies have shown that the number of fixation points between the tendon and anchor-bone interface, not the number of anchors, is the most important factor affecting the strength of the repair.[59,60] Recently, Jost and colleagues published their biomechanical results comparing several SR and DR repairs with varying numbers of suture. They found no difference in cyclic gap formation between a 4-suture SR repair and a 4-suture DR repair, and no difference in mean load to failure between these constructs (362N vs. 386N, $P = .58$). In the SR group, increasing the number of sutures from 2 to 4 to 6 decreased the cyclic gap formation by 6 mm and 7 mm, respectively.[59]

Repair tension is a critical factor affecting rotator cuff repair healing. Although no in vivo studies have evaluated a correlation between repair tension and healing rates, Davidson et al.[16] showed that repairs requiring higher tension to reduce the tendon to the tuberosity had significantly lower outcome scores. Several animal studies have evaluated the effects of tension on rotator cuff repairs. Gerber et al.[61] reported that the amount of force required to produce 1 cm of sheep supraspinatus tendon excursion increased from 6.8 N to 47.8 N (a 7-fold increase) when tested 40 weeks after tendon tear. Coleman et al.[62] compared the modulus of elasticity in sheep supraspinatus tendon after 6 weeks and 18 weeks of detachment, reporting a 60% and 70%

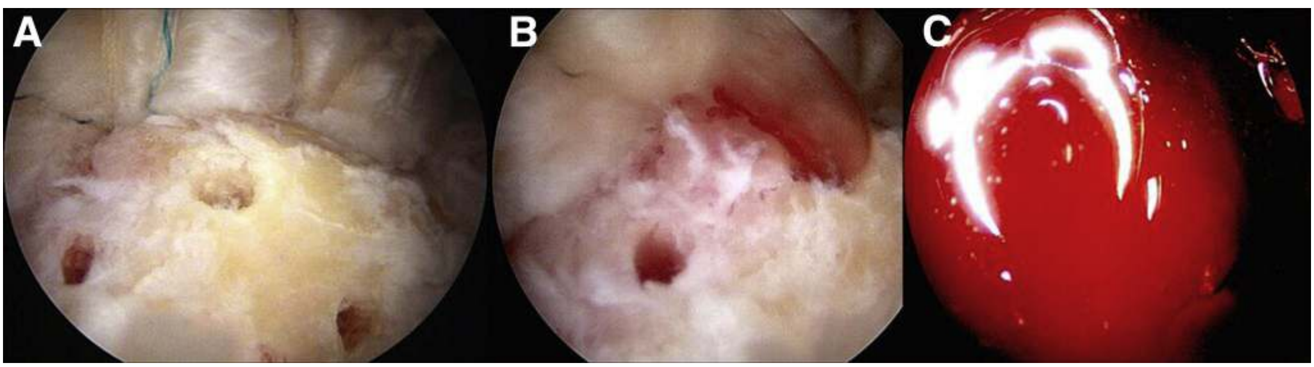

Fig 3. Arthroscopic views with the camera in the lateral portal showing bone marrow vents in the greater tuberosity. (A) After placement of bone marrow vents. (B) Once pump pressure is reduced, blood flowing from the bone marrow vents can be visualized. (C) Final view showing the "crimson duvet" with blood blanketing the rotator cuff repair.

increase, respectively. Gimbel et al.[63] showed that in a rat model, "the repair tension rapidly increased initially after injury followed by a progressive, but less dramatic, increase with additional time."

Clinically, rotator cuff tendon repairs placed at the medial portion of the greater tuberosity have significantly lower construct tensions. Dierckman et al.[24] evaluated cuff tension in vivo when the torn tendon was placed at a medial or lateral footprint position. They found a significant 5.4-fold increase in tension when the tendon was reduced to the lateral compared with the medial footprint. Hersche and Gerber[64] measured the amount of tension required to pull the tendon various distances across its footprint. They found a 2.2-fold increase in tension between 10 mm and 20 mm of displacement across the tuberosity. Domb et al.[23] reported on their results in 4 patients, finding a 2.8-fold increase in tension required to reduce the torn tendon from the medial to the lateral footprint.

In addition, a stump of cuff tissue often remains attached to the tuberosity when the tendon tears. Most tears occur in the hypovascular region of the tendon, 5 to 15 mm from the tuberosity. Debridement of this avascular stump leads to a shortened tendon by necessity.[65] Combining a shortened tendon with stiff, less compliant muscle tissue typically seen in chronic tears, it is reasonable to expect more tension would be required to pull this tendon back to its original attachment point. This is the primary biomechanical advantage of a medially based repair, attaching the tendon to the medial footprint minimizes the tension within the muscle-tendon unit.

Tashjian and colleagues[66] investigated tendon length and muscle-tendon junction (MTJ) position and its correlation with healing following an SR repair. They used AP tear size to stratify tears, but also compared this with the MTJ position relative to the glenoid face on coronal MRI. They found an overall healing rate of 76%, with healing in 26 of 30 small/medium tears (87%). Furthermore, they found a 93% healing rate for tears with a preoperative MTJ position lateral to the glenoid face. They also evaluated for muscle-tendon unit lengthening and found that, on average, "In patients who healed, 70% of the lateralization of the muscle-tendon unit could be attributed to lengthening of the tendon whereas only 30% of the lateralization was due to a change in position of the MTJ…Both preoperative tendon length and preoperative MTJ position likely have a significant correlation with the possibility of post-operative tendon healing." Tashjian et al.[66] went on to postulate that, "However, in chronic retracted tears, muscle elongation may be limited, and the native tendon may be short because of tendon loss. If healing is to occur, tendon lengthening with scar in continuity may be the mechanism that is needed to fill the defect." Further studies are clearly needed to better understand the elasticity of the muscle-tendon unit and its correlation with healing, along with the histological and biomechanical aspects of the "tendon lengthening" that occurs during healing.

Clinically, there is concern that tensioning a stiff, retracted, and chronically torn cuff tendon to the lateral footprint and then compressing it with a TOE construct can have consequences. Double-row constructs have been shown to have a tendency to fail at the musculotendinous junction (Cho type 2), whereas SR constructs typically fail at the footprint (Cho type 1).[38,58] This can be important because musculotendinous junction failures present a more complex and challenging revision scenario from excessive tendon shortening and tissue loss. In our study, all 7 failures were type 1 failures. In a medially based SR repair, the sutures are placed relatively more lateral within the tendon, further from the musculotendinous junction, likely reducing the risk of type 2 failures.

The primary sources of vascularity to the healing cuff tendon are the peribursal tissues and the rotator cuff footprint, with the largest contribution coming from the peribursal tissues.[67] To improve the vascularity of the healing cuff tendon and to augment the local biologic environment, several authors have begun to place vents or channels in the tuberosity.[44,67-70] These vents allow for egress of blood as well as bone marrow cells and other elements and contribute to the formation of a "super clot," akin to the early clot involved in fracture healing. The bone marrow is rich in mesenchymal stem cells as well as platelets with their various growth factors, which supplement and stimulate healing.[68,71,72]

Kida and colleagues[73] published a recent study detailing the kinetics of bone marrow-derived cells during rotator cuff repair in a chimeric rat model engineered to express green fluorescent protein in bone marrow-derived cells only. In 1 shoulder, they created bone marrow vents by drilling into the cuff footprint and then performed a cuff repair, whereas the other shoulder served as a control undergoing a standard repair only. There were significantly more bone marrow-derived cells within the tendon in the cuff repair/drilling group at all time points compared with the control group, and the repairs with bone marrow-derived cells had significantly higher loads to failure as well. This intrinsic "super clot" from the bone marrow not only augments the local biologic milieu but enhances healing (Fig 3).

Bone marrow vents have a beneficial effect on rotator cuff repair healing in vivo. Jo et al. were the first to report clinical outcomes using this technique. They performed a retrospective review of consecutive patients undergoing cuff repair. DR repairs (n = 31) were compared with DR repairs (n = 25) with "multiple channels" placed in the greater tuberosity before anchor placement. A significant decrease in dye leakage on computed tomography arthrograms at follow-up was observed with 35.5% failure without channels compared with 16% with channels. Their technique differs from the technique of the current study because our SR bone marrow vents were placed lateral to the repair.[69] Milano et al. published a prospective randomized study of 80 patients randomized into 2 groups. Group 1 underwent a medially based SR repair with double-loaded anchors, whereas group 2 received microfractures in the footprint in addition to the SR repair. MRI results at final follow-up revealed no significant difference in overall healing rates between groups (53% vs. 66%); however, for larger tears, there was a significant increase in healing rate for those with microfractures (60% vs. 12.5%).[44]

To fully appreciate the 92% healing rate for the arthroscopic triple-loaded medially based single-row tension-minimizing marrow vent augmented rotator cuff repair, a comparison to the historical control is necessary. A recent systematic review of rotator cuff repair techniques published between 2003 and 2014 suggests that there is no difference in rerupture rates regardless of suture technique or tear size.[30] A mean failure rate of 24% (range, 8%-55%) was reported in the 10 publications cited using various SR constructs. The most common technique used double-loaded suture anchors. Only 2 publications reported failure rates comparable to the current study. Mihata et al. reported a cohort study in which 65 of the 206 rotator cuff repairs used a SR construct. Their SR repair consisted of double-loaded titanium screw anchors placed at the lateral edge of the footprint. An average of 1.7 anchors were used for each repair. Fifty-seven of the 65 tears were smaller than those of the current study (mean 1.2 mm in AP length). Mihata's large to massive tears in this study averaged 4.3 cm in AP length and a 62.5% failure rate.[74] The report by Franceschi et al. reported an 8% SR failure rate. This study included 26 SR repairs using an average of 1.9 double-loaded biodegradable screw anchors placed just inside the lateral edge of the footprint with mattress stitches. Their group included 18 3- to 5-cm cuff tears and 8 cuff tears >5 cm. Postoperative magnetic resonance arthrography at a 2-year follow-up found 14 intact tendons, 10 partially torn tendons, and 2 fully torn tendons (8%). Had the Sugaya classification been used, some of these partial tears would have been reclassified as full tears, leading to a higher failure rate.[75]

More recently, 2 prospective randomized studies have been published using a technique similar to the one used in our study. Barber compared an SR construct to a TOE construct for tears up to 3 cm in AP size and augmented all repairs with a platelet-rich plasma fibrin membrane.[76] The SR technique used in that study was similar to the SR technique in our study, with a single row of medially placed triple-loaded anchors augmented laterally with bone marrow vents. He reported an 85% healing rate for both groups, using MRI criteria based on Sugaya's classification. Also of note, all TOE failures were Cho type 2 failures, whereas all SR failures were type 1 failures. Yamakado also compared an SR construct similar to ours to a TOE construct for 1- to 3-cm tears and reported a 97.9% healing rate for SR and 93.5% for TOE.[77] However, mean tear size was not reported and the 1- to 3-cm range is smaller than the 2-to 4-cm range we included. Interestingly, Yamakado noted partial or complete footprint restoration on MRI in 93% of patients and referred to this tissue lateral to the medialized repair as "neotendon" (Fig 2). With the exception of this study, our triple-loaded, medially based tension-minimizing single-row, marrow vent augmented repair demonstrated superior intact cuff healing to all other published SR repairs.

Limitations

There are limitations of our study. This is a retrospective review of a consecutive series of patients without a control group, and selection bias was introduced from the specific inclusion and exclusion criteria. Specifically, these data cannot be applied to larger or more complex tears often requiring interval slides or margin convergence sutures. Furthermore, we did not measure coronal plane retraction or MTJ position, which has more recently been shown to significantly impact repair integrity.[66] As discussed previously, more complex tear patterns, including L-shaped and reverse L-shaped tears, have larger coronal plane tear size than AP size. Additionally, had we included up to 5-cm AP tears, and thus complete 2 tendon supra- and infraspinatus tears, we would have likely seen a higher failure rate as well.

Another inherent limitation of this study is the inability to differentiate the individual effects, or lack thereof, of the several technical variables: triple- versus double-loaded anchors, tuberosity vents and subacromial decompression, medialization of the repair, and thus minimization of tension, or surgeon technical ability. Therefore, any conclusion about the value of any 1 variable over the others would be unfounded.

The historical control may not be exactly comparable, as the selection of tears between 2 cm to 4 cm in length is somewhat different from the more common classification system in which tears in this range are often evaluated as being <3 cm and 3 to 5 cm. Several recent studies have looked at this specific range of 2- to 4-cm tears, believing it is a range that is "an ideal basis for comparison of SR and DR repairs."[21,47,78,79]

Preoperative SF-36 and WORC scores were not available in a sufficient number of patients. This is a significant limitation because it is now the standard to report preoperative clinical scores, and the associated minimal clinically important difference, patient acceptable symptomatic state, and substantial clinical benefit. In addition, we did not perform physical examination on patients at final follow-up. We elected to use the WORC score as our secondary outcome measure because it does not involve physical examination by a medical professional. We felt this would better accommodate our patients to improve follow-up and compliance.

We only measured fatty atrophy of supraspinatus. In hindsight, it would have been beneficial to assess for infraspinatus atrophy as well, but that was not routinely performed when this study was completed. More recent studies have shown that infraspinatus atrophy and fatty infiltration also correlate with healing rates and outcomes following repair.[43,80]

Conclusions

Arthroscopic repair of medium to large rotator cuff tears using triple-loaded medially based single-row repair augmented with marrow vents resulted in a 92% healing rate by MRI and excellent patient-reported outcomes.

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