Healing Rates and Functional Outcomes After Triple-Loaded Single-Row Versus Transosseous-Equivalent Double-Row Rotator Cuff Tendon Repair

Robert Z. Tashjian,*† MD, Erin K. Granger,† MPH, and Peter N. Chalmers,† MD

Investigation performed at the School of Medicine, University of Utah, Salt Lake City, Utah, USA

Background: Although healing rates and outcomes of arthroscopic single-row rotator cuff repairs have been compared with double-row repairs, none have utilized triple-loaded anchors.

Purpose: To compare healing and function after single-row repairs with triple-loaded anchors versus double-row repairs with a suture-bridge technique.

Study Design: Cohort study; Level of evidence, 3.

Methods: A single surgeon performed arthroscopic rotator cuff repair on 47 consecutive patients with an easily reducible full-thickness rotator cuff tear of medium size (1-3 cm). A retrospective cohort study was performed in which the first 25 patients underwent repair with a double-row suture-bridge (DRSB) technique. The next 22 patients underwent repair with a single-row technique with triple-loaded anchors and simple stitches (SRTL) after a change in technique by the surgeon. Twenty-one DRSB and 18 SRTL repairs were evaluated preoperatively and at a minimum of 12 months postoperatively with a visual analog scale for pain, the American Shoulder and Elbow Surgeons form, and the Simple Shoulder Test. Healing was evaluated with magnetic resonance imaging at a minimum of 12 months.

Results: When DRSB repairs were compared with SRTL repairs, there were no significant differences in patient age (61 vs 65 years), tear size (2.3 vs 2.1 in the sagittal plane; 2.0 vs 1.8 cm in the coronal plane), Goutallier fatty infiltration (supraspinatus grade: stage 0, 38%; stage 1, 38%; stage 2, 19%; stage 3, 5%; vs stage 0, 56%; stage 1, 39%; stage 2, 5%; stage 3, 0%), tendon healing (71% vs 78%), improvement in visual analog scale pain score (3.7 vs 3.2), or improvement in American Shoulder and Elbow Surgeons scores (34.6 vs 36.9), with $P > .05$ in all cases. SRTL repairs had significantly greater improvement in Simple Shoulder Test scores versus DRSB repairs (6.6 vs 4.5; $P = .03$).

Conclusion: DRSB and SRTL repairs have similar improvements in pain and function with equivalent healing rates for arthroscopic repair of mobile full-thickness rotator cuff tears of medium size (1-3 cm).

Keywords: rotator cuff; healing; single row; double row; outcomes

Healing rates after arthroscopic rotator cuff repair are influenced by age, tear size, muscle tendon unit retraction, and rotator cuff muscle quality.[3,13,14,16-18] Repair construct has been reported as having a variable effect on healing, with some series citing improved healing rates in double-row repair, especially in larger tear sizes.[4,11,12,20] A variety of double-row constructs have been described, including separate medial and lateral anchors as well as transosseous-equivalent repairs. Double-loaded anchors are commonly utilized for single-row repairs, and limited data are available on the use of anchors with increased sutures per anchor.

Single-row repairs with triple-loaded suture anchors may provide results equivalent to those of double-row repairs in certain tear patterns. The increased number of sutures per anchor increases the initial biomechanical strength of a single-row rotator cuff repair.[6] Increasing the suture number per repair in single-row repairs has also been shown to increase the ultimate load to failure of repairs in an animal model.[10] Single-row repairs with triple-loaded anchors have further been demonstrated to have superior biomechanical resistance to cyclic displacement as compared with double-row suture-bridge repairs.[2] However, limited clinical data are available evaluating the use of triple-loaded single-row anchor repairs with simple stitches as compared with double-row suture-bridge repairs.[1] The only previously published comparison was between single-row repairs with triple-loaded anchors and

The Orthopaedic Journal of Sports Medicine, 6(11), 2325967118805365
DOI: 10.1177/2325967118805365

double-row suture-bridge repairs augmented with platelet-rich plasma fibrin membrane.[1]

The purpose of the current study was to evaluate and compare healing rates and functional outcomes after single-row rotator cuff repairs with triple-loaded anchors and simple stitches versus double-row suture-bridge repairs without augmentation. Our hypothesis was that healing rates and functional outcomes are similar between repair constructs for tears <3 cm in anteroposterior size.

METHODS

This was a retrospective cohort study. All patients undergoing arthroscopic supraspinatus and/or infraspinatus rotator cuff repair by the senior author (R.Z.T.) at the University of Utah between December 2011 and January 2016 were retrospectively reviewed. Prior to initiation of the study, hospital investigational review board approval was obtained. All patients who underwent primary complete repair of full-thickness medium supraspinatus and/or rotator cuff tears (anteroposterior width, 1-3 cm) were included in the study.[7] Revision repairs, tears of smaller or larger size, partial repairs, isolated subscapularis repairs, open repairs, repairs not performed at the University of Utah, and repairs requiring graft augmentation were excluded. Tears that were medium sized but were not able to be completely mobilized such that the tendon could completely cover the footprint (ie, tears in which the tendon was able to be mobilized only to the anatomic neck or medial aspect of the footprint) were also excluded. Tears in which a concomitant subscapularis repair was performed were included.

A total of 47 repairs meeting the inclusion criteria were performed during this study period. From December 2011 to December 2013, an arthroscopic transosseous-equivalent double-row repair was performed for these injuries. Twenty-five double-row repairs were performed. From January 2014 to January 2016, an arthroscopic single-row rotator cuff repair utilizing triple-loaded suture anchors was performed for these injuries. Twenty-two single-row repairs were performed. During the period, 339 rotator cuff repairs were performed by the primary surgeon (R.Z.T.).

All patients meeting inclusion criteria were contacted by letter and then by phone to return for a postoperative physical examination, questionnaire evaluation, and magnetic resonance imaging (MRI) to document repair integrity. MRI and outcome evaluations were performed at a minimum of 1 year postoperatively. Patient charts were reviewed for age, sex, hand dominance, duration of preoperative symptoms, workers' compensation status, smoking history, history of preoperative trauma to the shoulder, and associated surgical procedures and postoperative complications. Preoperative visual analog scale (VAS) pain scores (0, no pain; 10, severe pain), American Shoulder and Elbow Surgeons (ASES) scores, and Simple Shoulder Test (SST) scores were recorded from preoperative patient intake forms.

Of the 47 patients meeting inclusion criteria, 39 (83%) agreed to follow up and were evaluated in the present study: 21 of 25 patients (84%) who underwent arthroscopic transosseous double-row repair and 18 of 22 patients (82%) who underwent arthroscopic single-row repair. Of the patients undergoing the double-row repairs, 15 were men and 6 were women, and the dominant arm was affected 14 times (67%). Of the patients undergoing the single-row repairs, 13 were men and 5 were women, and the dominant arm was affected 13 times (72%). The mean age of the patients with double- and single-row repairs was 61 years (range, 48-76 years) and 65 years (range, 49-74 years), respectively.

Preoperative MRI was evaluated for coronal tear size (mm), sagittal tear size (mm), and supraspinatus fatty infiltration. Coronal tear size was measured on T2-weighted coronal sections, with retraction measured as the distance from the lateral edge of the greater tuberosity to the tendon end. Sagittal tear size was determined by measuring the anteroposterior length of the exposed rotator cuff footprint of the lateral-most section of the greater tuberosity on the sagittal T2-weighted images. Supraspinatus fatty infiltration was measured with the Fuchs et al[8] classification, as a modification of the Goutallier[9] classification for computed tomography scans. Grading was on the most lateral sagittal T1-weighted image on which the scapular spine was in contact with the scapular body. The stages were identified as follows: stage 0, normal; stage 1, some fatty streaks; stage 2, fatty infiltration throughout with less fat than muscle; stage 3, fatty infiltration with equal muscle and fat; stage 4, fatty infiltration with more fat than muscle.

The mean preoperative sagittal tear size, as measured on MRI for double- and single-row repairs, was 2.3 cm (range, 1.6-3 cm) and 2.1 cm (range, 1.3-3 cm), respectively. The mean preoperative coronal tear size for double- and single-row repairs was 2.0 cm (range, 0.8-3.2 cm) and 1.8 cm (range, 0.8-3.1 cm), respectively. As graded with the Goutallier classification, the preoperative muscle quality of the supraspinatus was as follows: for double-row repairs—stage 0, 38%; stage 1, 38%; stage 2, 19%; stage 3, 5%; for single-row repairs—stage 0, 56%; stage 1, 39%; stage 2, 5%; stage 3, 0%.[9] Eight patients in the double-row repair group and 3 patients in the single-row repair group had subscapularis tears.

*Address correspondence to Robert Z. Tashjian, MD, University of Utah Orthopaedic Center, 590 Wakara Way, Salt Lake City, UT 84108, USA (email: Robert.Tashjian@hsc.utah.edu).

†Department of Orthopaedics, School of Medicine, University of Utah, Salt Lake City, Utah, USA.

One or more of the authors has declared the following potential conflict of interest or source of funding: R.Z.T. receives royalties from Cayenne Medical, Shoulder Innovations, Wright Medical, and Zimmer Biomet; owns stock/stock options in Conextions, Genesis, Intrafuse, and KATOR; and is a consultant for DePuy Mitek and Wright Medical. P.N.C. has received hospitality payments from Tornier. AOSSM checks author disclosures against the Open Payments Database (OPD). AOSSM has not conducted an independent investigation on the OPD and disclaims any liability or responsibility relating thereto.

Ethical approval for this study was obtained from the University of Utah School of Medicine (Institutional Review Board No. 00055731).

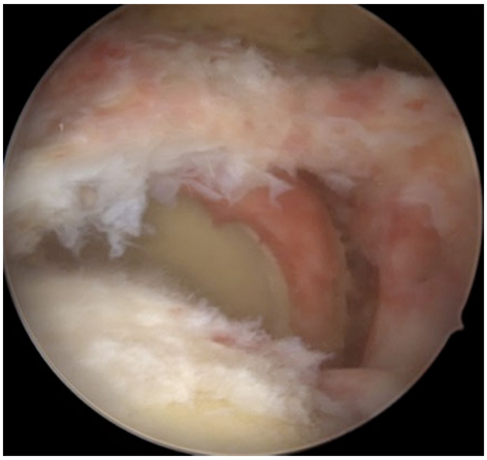

Figure 1. Full-thickness supraspinatus tear viewed from the posterior portal.

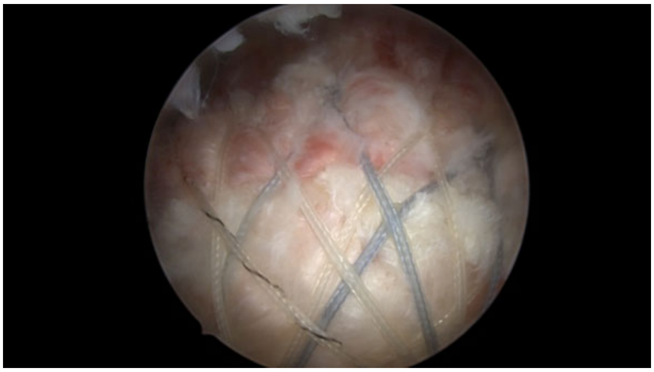

Figure 2. Arthroscopic transosseous-equivalent rotator cuff repair.

Figure 3. Full-thickness supraspinatus tear viewed from the lateral portal.

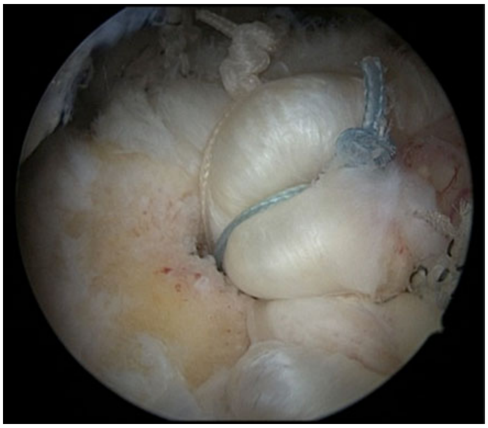

Figure 4. Arthroscopic single-row rotator cuff repair with triple-loaded anchors and simple stitches in which 3 sutures (blue, white, and striped) can be seen originating from the same anchor.

Surgical Procedure

Intra-articular examination and a complete subacromial bursectomy were performed in all cases. Tissue on the undersurface of the acromion extending all the way posterior to the scapular spine was released. A coracoacromial ligament release with subacromial decompression was performed in 12 double-row repairs (57%) and 13 single-row repairs (72%). Subacromial decompressions were performed with a bur, removing only abnormal osteophytes and very little native bone. Associated procedures performed at the time of rotator cuff repair included biceps tenodesis in 12 double-row repairs (67%) and 11 single-row repairs (61%). Biceps tenotomy was performed in 6 double-row repairs (29%) and 2 single-row repairs (11%). Eight patients in the double-row repair group (38%) and 3 in the single-row repair group (17%) had subscapularis tear repairs.

Transosseous-Equivalent Double-Row Repair

Double-row transosseous-equivalent repairs were performed by placing 2 metal 5.5-mm corkscrew suture anchors (Arthrex) loaded with two No. 2 FiberWire sutures (Arthrex). Suture anchors were placed at the anatomic neck of the greater tuberosity, 1 anterior and 1 posterior, separated by at least 1 cm. Sutures were passed in a horizontal mattress fashion a few millimeters lateral to the musculotendinous junction in the posterosuperior rotator cuff. All stitches were then tied. Four tails of these previously tied sutures were then brought over to a 5.5-mm BioComposite SwiveLock anchor (Arthrex) placed at least 1 cm distal to the tip of the greater tuberosity just posterior to the biceps groove. The sutures were tensioned, and the anchor was inserted. Remaining tails were brought over to another 5.5-mm BioComposite SwiveLock anchor (Arthrex) placed at least 1.5 cm posterior to the first anchor. The sutures were tensioned, and the anchor was inserted (Figures 1 and 2).

Single-Row Repair With Triple-Loaded Anchors

Single-row rotator cuff repairs were performed by placing several metal 5.5-mm corkscrew suture anchors (Arthrex)

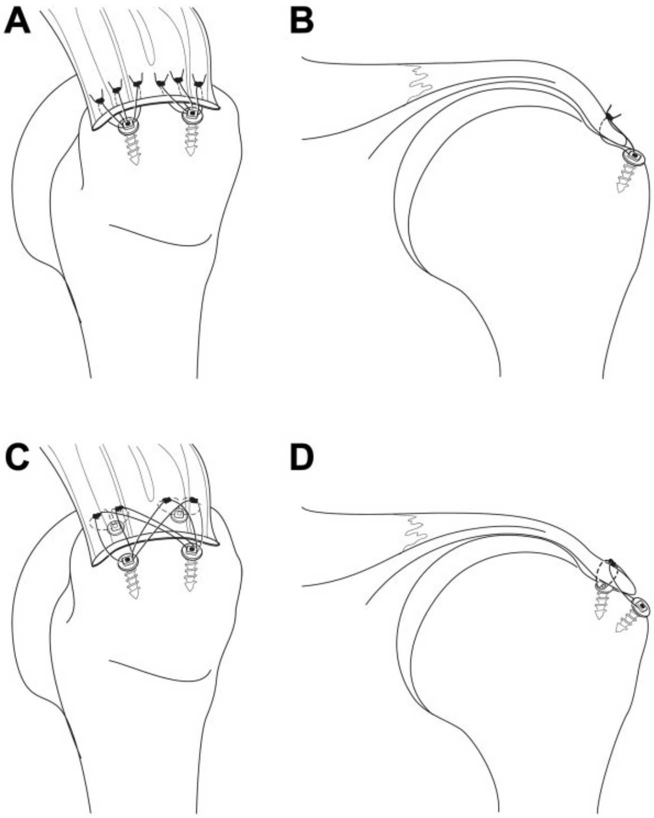

Figure 5. These schematics demonstrate the single-row repair as viewed from the (A) lateral and (B) anterior perspectives and the double-row repair as viewed from the (C) lateral and (D) anterior perspectives.

loaded with three No. 2 FiberWire sutures (Arthrex). Suture anchors were placed at the most lateral aspect of the greater tuberosity to which the tear would mobilize. Either 2 or 3 triple-loaded suture anchors were utilized to repair the tendon. A mean 2.2 anchors were used for the posterosuperior component of the repairs. Sutures were passed as simple stitches in an anterograde fashion, taking an approximately 1.5-cm bite of tissue with each stitch. All stitches were tied with 2 half-hitches on the same post, followed by another half-hitch in the alternate direction on the same post and by 3 half-hitches in alternating directions and alternating posts (Figures 3 and 4). Schematics for both repairs are shown in Figure 5. All subscapularis repairs were upper rolled border tears fixated with a single-row technique with a single anchor and 3 simple stitches.

The arm was immobilized in a sling for the first 6 weeks postoperatively. For small- and medium-sized tears, passive supine forward elevation in the scapular plane was allowed to 130° and external rotation at the side to 30° starting at 2 weeks postoperatively. Passive and active assisted motion in all planes, except internal rotation and extension, was allowed at postoperative 6 weeks for all patients. Isometric and resistive shoulder-strengthening exercises were started at postoperative 3 months, as well as internal rotation and extension stretching. Patients were allowed to return to all activities without restriction at 6 months.

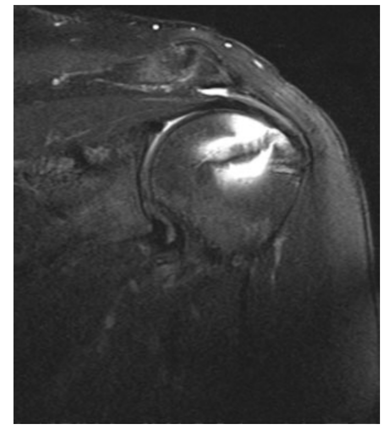

Figure 6. This postoperative magnetic resonance coronal T2-weighted image demonstrates an intact repair.

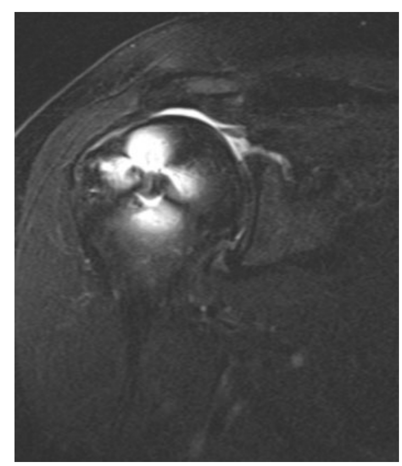

Figure 7. This postoperative magnetic resonance coronal T2-weighted image demonstrates a repair that is not intact.

Patient Follow-up Evaluations

The patients were evaluated with MRI at a minimum of 12 months after surgery for tendon integrity. Postoperative MRI was performed with a 1.5-T Avanto scanner (Siemans AG). Postoperative MRI was evaluated for repair healing (Figures 6 and 7). Anatomic assessment of tendon healing was performed by a shoulder surgeon who did not perform the surgical procedures (P.N.C.), using the grading scale described by Sugaya et al.[14] Grades I through III were considered healed, while grades IV and V were considered unhealed. MRI was also evaluated for retear patterns as defined by Cho et al.[5] Cases were divided into type 1 retears if there was no remaining cuff tissue at the insertion site of the rotator cuff on the greater tuberosity or type 2 retears if a remnant of cuff tissue remained at the insertion site despite the retear.

The patients were evaluated clinically at a minimum of 12 months. Evaluations included a physical examination and completion of an outcome questionnaire. Physical examinations included measurement of active forward elevation in the scapular plane with a handheld goniometer and calibrated forward elevation strength (lb) at 90° of elevation in the scapular plane with an isometer (Innovative Design Orthopaedics).

All patients completed a standardized outcome questionnaire containing a VAS for pain (0, no pain; 10, severe pain), the ASES form, and the SST. Information gathered allowed calculation of pre- and postoperative ASES and SST scores. Finally, 2 yes/no questions were asked of each patient: "Are you satisfied with your surgery?" and "Would you undergo your surgical procedure again?"

Statistical Analysis

A paired Student *t* test or Wilcoxon signed-rank test was used to compare pre- and postoperative VAS pain, SST, and ASES scores for each repair, depending on whether the data were parametric or nonparametric, respectively. An unpaired *t* test or Mann-Whitney *U* test was used to compare age, sagittal tear size, calibrated final elevation strength, final active forward elevation, duration of follow-up for MRI evaluation, duration of follow-up for clinical outcome follow-up, improvement in VAS pain, improvement in ASES scores, and improvement in SST scores between double- and single-row repairs, depending on whether data were parametric or nonparametric, respectively. A Fisher exact test was used to evaluate the effect of repair construct on tendon healing, the presence of subscapularis repairs between double- and single-row repairs, and the type of retear (type 1 or 2) between repair constructs. A chi-square test was used to compare percentages of Goutallier grades between double- and single-row repairs. *P* values <.05 were considered statistically significant.

An a priori power analysis was performed. A prior meta-analysis of randomized clinical trials found a 63% rate of tendon continuity for single-row repairs.[19] We decided a priori that a clinically meaningful difference would exist if the healing rate was altered by half. Given these parameters, 38 patients (19 patients per group) would be necessary to provide statistical power of 90% to detect a significant difference, should one exist.

RESULTS

Fifteen of 21 (71%) double-row and 14 of 18 (78%) single-row repairs had complete healing on postoperative MRI ($P = 0.7$). In the double-row group, there were 6 grade I, 6 grade II, 3 grade III, 2 grade IV, and 4 grade V repairs. In the single-row group, there were 9 grade I, 3 grade II, 2 grade III, 1 grade IV, and 3 grade V repairs. Per Cho et al,[5] there were 2 lateral type 1 failures and 3 medial type 2 failures in the double-row repair group and 1 lateral type 1 and 2 medial type 2 failures in the single-row repair group ($P \geq .999$). MRI was performed at a mean postoperative 1.3 years (range, 1-1.9 years) for double-row repairs and at a mean 1.2 years (range, 1-1.4 years) for single-row repairs ($P = .06$). Age, sagittal tear size, coronal tear size of the supraspinatus, and the addition of a subscapularis repair were similar between the double- and single-row repair groups ($P > .05$) (Table 1). The percentage of patients with each Goutallier grade was similar between double- and single-row repairs ($P = .41$).

Final clinical outcome evaluations were performed at a mean postoperative 2.1 years (range, 1.1-2.6 years) for double-row repairs and at a mean 1.6 years (range, 1.1-2.4 years) for single-row repairs ($P = .001$). Double- and single-row repairs had significant pre- to postoperative improvements in VAS pain, SST, and ASES scores ($P < .001$) (Table 2). Double- and single-row repairs had similar pre- to postoperative improvement in VAS pain (3.7 vs 3.2, $P = .47$) and ASES scores (34.6 vs 36.9, $P = .73$). Single-row repairs had significantly greater improvement in SST scores as compared with double-row repairs (6.6 vs 4.5, $P = .03$). Final postoperative forward elevation strength (mean ± SD) for double- and single-row repairs was 17.8 ± 12.7 kg and 18.6 ± 9.8 kg, respectively ($P = .8$). Final postoperative active forward elevation range of motion for double- and single-row repairs was 160° ± 29° and 168° ± 5°, respectively ($P = .22$).

TABLE 1
Demographic, Magnetic Resonance Imaging, and Surgical Characteristics of Single- and Double-Row Repairs

	Single Row (n = 18)	Double Row (n = 21)	*P*
Mean age, y	65	61	.09
Mean tear size, cm			
Sagittal	2.1	2.3	.25
Coronal	1.8	2.0	.38
Addition of a subscapularis repair, n (%)	3 (17)	8 (38)	.17

TABLE 2
Mean Outcome Scores of Single- and Double-Row Repairs[a]

	VAS Pain			SST Score			ASES Score		
	Pre	Post	*P*	Pre	Post	*P*	Pre	Post	*P*
Single row	3.3	0.08	<.001	5.1	11.7	<.001	59.1	96	<.001
Double row	4.6	0.9	<.001	6	10.5	<.001	52.7	87.3	<.001

[a]ASES, American Shoulder and Elbow Surgeons; Post, postoperative; Pre, preoperative; SST, Simple Shoulder Test; VAS, visual analog scale.

DISCUSSION

Double-row transosseous-equivalent rotator cuff repairs and single-row rotator cuff repairs with triple-loaded suture anchors and simple stitches provide similar healing rates for medium-sized full-thickness rotator cuff tears. These data correspond to prior prospective randomized data comparing single- and double-row repairs with the same techniques but with the addition of platelet-rich plasma.[1] The healing rate in the Barber[1] study for both constructs was 85% and is comparable with that of the current study, with similar repair constructs but without the addition of platelet-rich plasma. Both of the repair constructs provide comparable improvement in functional outcomes and pain levels, although single-row repairs provided a functional advantage, as measured by the SST, and the benefit was clinically meaningful based on the minimal clinically important difference for the SST.[15]

Multiple authors have compared single- and double-row repairs with respect to healing and functional outcomes. Xu et al[20] recently published a meta-analysis between repair techniques and, for double-row repairs, reported improved healing rates for all tear sizes and improved outcomes for large and massive tears. Five studies were utilized in this meta-analysis to evaluate healing rates, and all had single-row repairs performed with double-loaded anchors. A possible reason for the similarity between the healing rates of double- and single-row repair in the current study is either the improved healing rates of the single-row repairs with triple-loaded anchors or the lower healing rates of our double-row repairs. Voigt et al[19] reported a 71% healing rate of suture-bridge repairs for isolated supraspinatus tears among patients averaging 62 years of age, which is identical to our study's healing rate among patients averaging 61 years of age. One potential disadvantage of the single-row technique is the prominence of the knots within the subacromial space; however, within our study, we did not find any change in postoperative outcome associated with these potentially prominent knots.

Limitations of the current study include its retrospective nature, although >80% follow-up was achieved for MRI evaluation and clinical evaluation, both of which were performed at a minimum of 1 year; however, we did not achieve 2-year clinical outcomes for all patients. Finally, this was not a prospective randomized study but a retrospective cohort study. We believe that this comparison is still reasonable, as we elected to perform single-row repairs on those patients for whom we would have performed a double-row repair in the earlier cohort. This is reflected in the similarity in demographics, including age, tear size, muscle quality, and tendon retraction. However, unmeasured residual bias may remain between groups, and certainly the length of follow-up was different between groups. The inclusion of concomitant subscapularis repair could be considered a limitation. However, of the 8 subscapularis repairs in the single-row group, 75% (n = 6) healed, as compared with 71% healing in the overall group. Furthermore, of the 3 subscapularis repairs in the double-row group, 67% (n = 2) healed, as compared with 78% in the overall group. Thus, these patients were not thought to overly influence the results of our study. Finally, we did not include either operative time or cost data, as these were not the focus of this study; future analyses should address these factors.

CONCLUSION

Double-row suture-bridge repairs and single-row repairs with triple-loaded anchors and simple stitches have similar improvements in pain and function, with equivalent healing rates for arthroscopic repairs of mobile medium-sized full-thickness rotator cuff tears (1-3 cm).

REFERENCES

1. Barber FA. Triple-loaded single-row versus suture-bridge double-row rotator cuff tendon repair with platelet-rich plasma fibrin membrane: a randomized controlled trial. *Arthroscopy*. 2016;32(5):753-761.
2. Barber FA, Herbert MA, Schroeder A, Aziz-Jacobo J, Mays MM, Rapley JH. Biomechanical advantages of triple-loaded suture anchors compared with double-row rotator cuff repair. *Arthroscopy*. 2010;26(3):316-323.
3. Boileau P, Brassart N, Watkinson DJ, Carles M, Hatzidakis AM, Krishnan SG. Arthroscopic repair of full-thickness tears of the supraspinatus: does the tendon really heal? *J Bone Joint Surg Am*. 2005;87(6):1229-1240.
4. Chen M, Xu W, Dong Q, Huang Q, Xie Z, Mao Y. Outcomes of single-row versus double-row arthroscopic rotator cuff repair: a systematic review and meta-analysis of current evidence. *Arthroscopy*. 2013;29(8):1437-1449.
5. Cho NS, Yi JW, Lee BG, Rhee YG. Retear patterns after arthroscopic rotator cuff repair: single-row versus suture bridge technique. *Am J Sports Med*. 2010;38:664-671.
6. Coons DA, Barber FA, Herbert MA. Triple-loaded single-anchor stitch configurations: an analysis of cyclically loaded suture-tendon interface security. *Arthroscopy*. 2006;22(11):1154-1158.
7. DeOrio JK, Cofield RH. Results of a second attempt at surgical repair of a failed initial rotator-cuff repair. *J Bone Joint Surg Am*. 1984;66(4):563-567.
8. Fuchs B, Weishaupt D, Zanetti M, Hodler J, Gerber C. Fatty degeneration of the muscles of the rotator cuff: assessment by computed tomography versus magnetic resonance imaging. *J Shoulder Elbow Surg*. 1999;8(6):599-605.
9. Goutallier D, Postel JM, Bernageau J, Lavau L, Voisin MC. Fatty muscle degeneration in cuff ruptures: pre- and postoperative evaluation by CT scan. *Clin Orthop Relat Res*. 1994;304:78-83.
10. Jost PW, Khair MM, Chen DX, Wright TM, Kelly AM, Rodeo SA. Suture number determines strength of rotator cuff repair. *J Bone Joint Surg Am*. 2012;94(14):e100.
11. Mihata T, Fukunishi K, Ohue M, Tsujimura T, Fujiwara K, Kinoshita M. Functional and structural outcomes of single-row versus double-row versus combined double-row and suture-bridge repair for rotator cuff tears. *Am J Sports Med*. 2011;39(10):2091-2098.
12. Millett PJ, Warth RJ, Dornan GJ, Lee JT, Spiegl UJ. Clinical and structural outcomes after arthroscopic single-row versus double-row rotator cuff repair: a systematic review and meta-analysis of level I randomized clinical trials. *J Shoulder Elbow Surg*. 2014;23(4):586-597.
13. Noyes MP, Lederman E, Adams CR, Denard PJ. Triple-loaded suture anchors versus a knotless rip stop construct in a single-row rotator cuff repair model. *Arthroscopy*. 2018;34(5):1414-1420.
14. Sugaya H, Maeda K, Matsuki K, Morishi J. Functional and structural outcome after arthroscopic full-thickness rotator cuff repair: single-row versus dual-row fixation. *Arthroscopy*. 2005;21:1307-1316.
15. Tashjian RZ, Deloach J, Green A, Porucznik CA, Powell AP. Minimal clinically important differences in ASES and simple shoulder test scores after nonoperative treatment of rotator cuff disease. *J Bone Joint Surg Am*. 2010;92(2):296-303.
16. Tashjian RZ, Erickson GA, Roins RJ, Zhang Y, Burks RT, Greis PE. Influence of preoperative musculotendinous junction position on rotator cuff healing after double-row repair. *Arthroscopy*. 2017;33(6):1159-1166.

17. Tashjian RZ, Hollins AM, Kim HM, et al. Factors affecting healing rates after arthroscopic double-row rotator cuff repair. *Am J Sports Med*. 2010;38(12):2435-2442.
18. Tashjian RZ, Hung M, Burks RT, Greis PE. Influence of preoperative musculotendinous junction position rotator cuff healing using single-row technique. *Arthroscopy*. 2013;29(11):1748-1754.
19. Voigt C, Bosse C, Vosshenrich R, Schulz AP, Lill H. Supraspinatus tendon repair with suture-bridging technique: functional outcome and magnetic resonance imaging. *Am J Sports Med*. 2010;38:983-991.
20. Xu C, Zhao J, Li D. Meta-analysis comparing single-row and double-row repair techniques in arthroscopic treatment of rotator cuff tears. *J Shoulder Elbow Surg*. 2014;23(2):182-188.