High-Tension Double-Row Footprint Repair Compared with Reduced-Tension Single-Row Repair for Massive Rotator Cuff Tears

By Benjamin G. Domb, MD, Ronald E. Glousman, MD, Adam Brooks, BA, Matthew Hansen, MD, Thay Q. Lee, PhD, and Neal S. ElAttrache, MD

Introduction

A massive, retracted tear of the rotator cuff poses a unique challenge to the orthopaedic surgeon. All attempts must be made to mobilize the tendons such that they can be repaired to their anatomic insertion sites on the greater tuberosity in a tension-free manner. However, many retracted tears cannot be fully mobilized. In this situation, there is substantial controversy over the most successful repair technique.

The advent of double-row repairs has been a substantial advance in rotator cuff repair. The double-row technique has been shown to be biomechanically superior to single-row and transosseous suture techniques[1-4]. However, the studies comparing these repair constructs have subjected all specimens to the same loads, failing to account for differences in tension between the repair constructs.

In the case of a retracted massive cuff tear that cannot be adequately mobilized, performing a double-row footprint repair as advocated by several authors requires repairing the cuff under tension[1,4]. For this reason, Snyder and others have advocated performing a medialized repair with a single-row technique[5], which may allow for repair under reduced tension. Thus, controversy exists around the question of which approach is biomechanically superior: a double-row technique under tension at the footprint or a reduced-tension medialized repair with a single-row technique. The purpose of the present study was to compare the biomechanical behavior of these two approaches in a cadaver model accounting for differences in tension between the constructs. Our hypothesis was that the double-row footprint repair construct would demonstrate superior biomechanical properties in spite of being subjected to higher load conditions.

Materials and Methods

Preliminary Data

In order to compare the medial repair with the anatomic repair, it was necessary to determine the tension differential between the two sites. Hersche and Gerber studied long-standing ruptures of the supraspinatus and found a 45-N tension differential[6]. To confirm this finding, we performed a preliminary study in vivo.

With informed consent, in vivo data were collected during the arthroscopic repair of massive retracted rotator cuff tears to establish the tension differential between footprint and medialized repair sites. After mobilization of the rotator cuff, a tensioning suture was placed through the rotator cuff tendon. This suture was passed through the lateral portal and was connected to a sterile tensiometer for measuring the tension in the rotator cuff suture. This device is a simple spring-loaded calibrated scale with a hook for connecting the suture. With the arm placed in 45° of abduction, 30° of forward flexion, and neutral rotation (as measured with a sterile goniometer), the surgical assistant (M.H.) manually applied tension to the cuff suture until the senior surgeon (R.E.G.) stated that the cuff was properly reapproximated to the humerus. The force required for this maneuver was recorded. Tension was measured while pulling the cuff to two separate repair sites, the medialized site and the footprint site. The medialized site was located at the articular margin, and the footprint site was located at the lateral margin of the rotator cuff footprint on the greater tuberosity. This procedure was repeated with the arm in 30° of abduction, 0° of forward flexion, and neutral rotation. In vivo tension was measured specifically at the above-mentioned positions to approximate the postoperative immobilization positions in patients with massive rotator cuff

Disclosure: In support of their research for or preparation of this work, one or more of the authors received, in any one year, outside funding or grants in excess of $10,000 from Arthrex and DJ Ortho. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity. A commercial entity (Arthrex) paid or directed in any one year, or agreed to pay or direct, benefits in excess of $10,000 to a research fund, foundation, division, center, clinical practice, or other charitable or non-profit organization with which one or more of the authors, or a member of his or her immediate family, is affiliated or associated.

TABLE I Tension of the Cuff Tendon in Vivo at Medial and Footprint Repair Sites

	Tension *(N)*			
	Arm in 45° of Abduction		Arm in 30° of Abduction	
Case	Medial	Footprint	Medial	Footprint
1	39	78	29	88
3	15	59	29	69
4	33	78	33	89
5	17	37	17	59
Mean	26	63	27	76

tears. After these measurements were obtained, the suture was removed and rotator cuff repair proceeded in the customary fashion. Data collection was attempted for five patients, with actual data being collected in vivo for four patients (Table I). One patient (Case 2) was excluded because the rotator cuff tendon could not be mobilized to reach the footprint site.

The tension differential between medialized and anatomic repair sites was 37 N with the arm at 45° of abduction and 49 N with the arm at 30° of abduction. On the basis of these data and the results obtained by Hersche and Gerber[6], we chose to employ a 50-N load differential in testing of the medialized and footprint repair constructs.

Specimen Preparation

Fifteen matched pairs of fresh-frozen cadaver shoulders (comprising a total of thirty specimens) were used in the present study. All soft tissues were dissected from the specimens, with the infraspinatus and supraspinatus insertions on the proximal part of the humerus being left intact. Specimens with preexisting rotator cuff abnormalities, previous surgery, or fracture were excluded from the study, leaving ten matched pairs (a total of twenty specimens). The supraspinatus and infraspinatus tendons were released sharply from their insertions on the greater tuberosity. In accordance with previous studies, the distal 10 mm of tendon was resected to approximate the tissue loss associated with a chronic tear of the rotator cuff[1,7].

Repair Technique

One shoulder from each matched pair was randomly selected for the double-row footprint repair, whereas the other was assigned to the medialized single-row repair.

Double-Row Footprint Repair (Group I)

As previously described, this technique involved the use of a total of six anchors, three for the medial row and three for the lateral row (Figs. 1, 2, and 3)[1,7]. In the lateral row, three double-loaded 6.5-mm metal corkscrew anchors (Arthrex, Naples, Florida) were inserted 12.5 mm lateral to the articular margin of the humeral head along the lateral edge of the greater tuberosity. These anchors were used to place a total of six simple sutures through the lateral edge of the rotator cuff tendon. For the medial row, three single-loaded anchors were inserted at the articular edge in the footprint and were used to place three horizontal mattress sutures through the rotator cuff tendon. For each horizontal mattress suture in the medial row, the two limbs of suture were passed through the tendon 5 mm from each other and 7.5 mm medial to the lateral row sutures.

Medialized Single-Row Repair (Group II)

This technique involved the use of a total of three double-loaded 6.5-mm metal corkscrew anchors. The anchors were inserted at the articular margin of the humeral head and were used to place six simple sutures through the rotator cuff tendon (Figs. 4, 5, and 6). All sutures were tied with use of a standard arthroscopic knot-tying technique (Tennessee slider knots backed up by three half-hitches)[8].

Biomechanical Testing

The proximal part of the humerus was potted with plaster

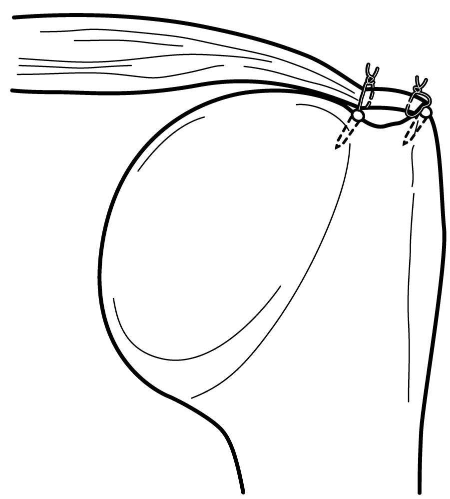

Fig. 1
Schematic illustrating a high-tension double-row footprint repair (anterior view).

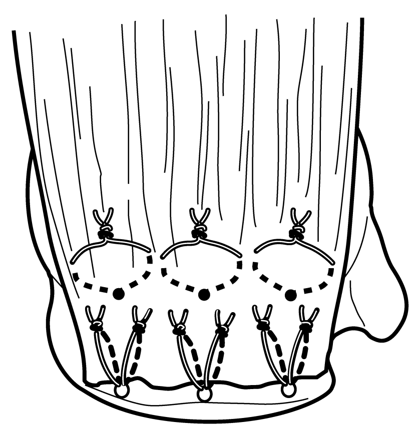

Fig. 2
Schematic illustrating a high-tension double-row footprint repair (superior view).

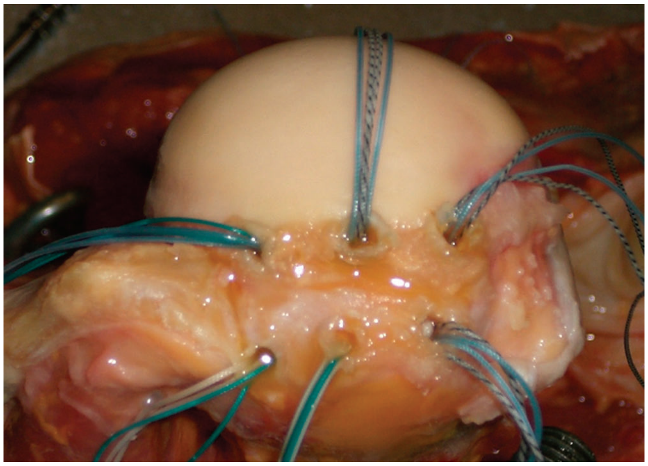

Fig. 3
Photograph showing high-tension double-row footprint repair suture placement.

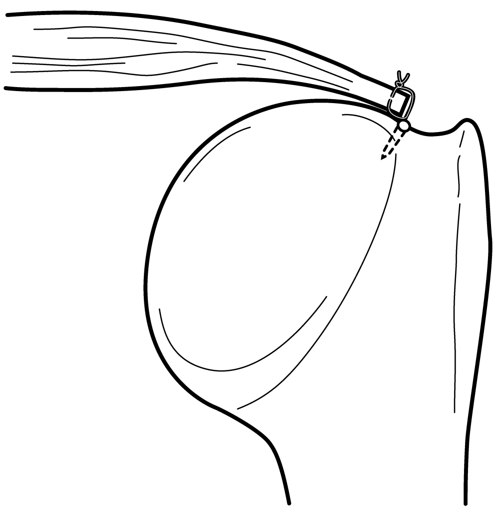

Fig. 4
Schematic illustrating a reduced-tension single-row medialized repair (anterior view).

of Paris and was secured with screws to the testing apparatus in 30° of abduction. The free medial ends of the supraspinatus and infraspinatus tendons were attached to a soft-tissue liquid nitrogen freeze-clamp (Fig. 7). Displacement between the greater tuberosity and a point in the tendon 2 cm from its free ends were measured with use of an external extensiometer.

In order to simulate the tension differential between the footprint and medialized repairs, a load difference of 50 N was chosen on the basis of the preliminary in vivo data described above. All repairs were cyclically loaded for 200 cycles at a rate of 5 mm/s, with forces cycling from 60 to 230 N for the double-row repair and from 10 to 180 N for the single-row repair. These loading conditions reflected the inherent 50-N tension differential between the two repair sites. At the conclusion of cyclical loading, all repairs were loaded to failure. Data collection included displacement and stiffness for the first and final cycles as well as gap formation, defined as the change in displacement between the start of the first cycle and the start of the last cycle. Linear stiffness was calculated as change in force divided by displacement. After 200 cycles of loading, the specimens were loaded to failure at a rate of 1 mm/s, and yield, ultimate failure load, and mode of failure were recorded.

The data were analyzed with use of a paired t test in order to determine which measurements for each type of repair were significantly different.

Results

The mean results are shown in Table II for displacement and stiffness for the first and final cycles, gap formation between the first and final cycles, yield strength, and ultimate failure strength. With use of paired t test analysis, the double-row construct fared significantly better than the single-row

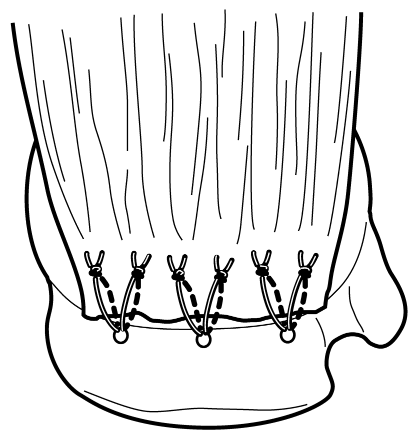

Fig. 5
Schematic illustrating a reduced-tension single-row medialized repair (superior view).

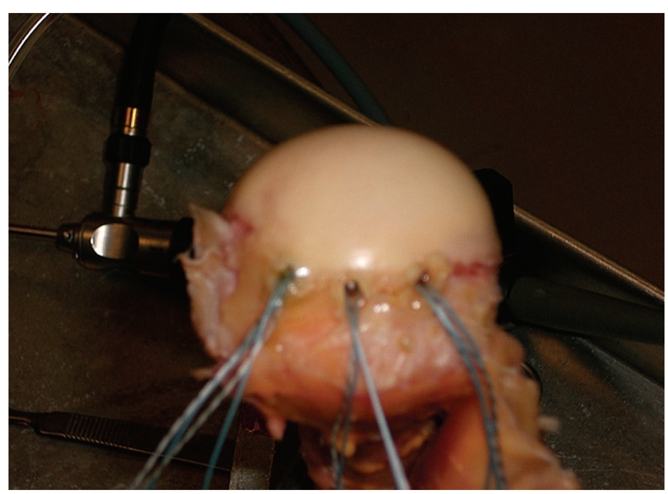

Fig. 6
Photograph showing reduced-tension single-row medialized repair suture placement.

Fig. 7
Photograph showing the humeral head with rotator cuff tendons affixed to the liquid nitrogen freeze-clamp.

construct in terms of displacement in the first cycle (2.1 compared with 5.2 mm; p = 0.0244), stiffness in the final cycle (202.3 compared with 127.1 N/mm; p = 0.0450), and ultimate failure (644.2 compared with 392.3 N; p = 0.0186). There were also trends favoring the double-row construct in terms of displacement in the final cycle (0.8 compared with 1.4 mm; p = 0.1258), stiffness in the first cycle (68.6 compared with 48.6 N/mm; p = 0.1480), gap formation (5.6 compared with 8.7 mm; p = 0.1103), and yield strength (576.8 compared with 307.0 N; p = 0.0757).

In the double-row group, the mode of failure was suture pull-out (seven specimens), suture breakage (one), anchor pull-out (one), or soft-tissue failure (one). In the single-row group, the mode of failure was suture pull-out (seven specimens), anchor pull-out (two), or suture breakage (one).

Discussion

The advent of double-row repair techniques has sparked a growing debate regarding the optimal repair construct for retracted rotator cuff tears. Proponents of the single-row technique for retracted rotator cuff tears argue that a single-row repair in a medialized position at the articular margin places the repair under less tension, allowing for biological healing in a reduced-tension environment. Advocates of the double-row technique cite superior biomechanical characteristics and an increased contact area for healing. This debate has led to several recent studies characterizing the normal anatomy of the rotator cuff tendon insertion[9-11] along with several biomechanical studies[1,12,13] comparing double-row and single-row techniques. None of those studies, however, accounted for the difference in tension on the repair construct between the two techniques.

Much is known about the normal anatomy of the rotator cuff tendon footprint and its interaction with the humerus. Dugas et al. demonstrated the dimensions of and measurement techniques used for the rotator cuff footprint, specifically highlighting the three-dimensional aspects of the site and the broadness of the insertions around the greater tuberosity of the humerus[9]. Subsequent studies have shown that a single-row suture method is inadequate for restoring this footprint site or the medial-to-lateral width of the footprint[14,15], whereas a double-row technique can indeed effectively completely restore both the supraspinatus tendon footprint and the medial-to-lateral width of the footprint, which increases the contact area for healing[3,15].

None of the numerous recent biomechanical comparisons of single-row and double-row repair constructs considered the inherent tension differential between single-row and double-row repair. The most common loading parameters in the biomechanical literature on rotator cuff repair involve cyclic loading to a maximum of 180 N. Kim et al.

TABLE II Results of Double and Single-Row Repair Testing*

	Displacement *(mm)*		Stiffness *(N/mm)*				
	First Cycle	Final Cycle	First Cycle	Final Cycle	Gap Formation *(mm)*	Yield *(N)*	Ultimate Failure *(N)*
Double-row repair	**2.1**	0.8	68.6	**202.3**	5.6	576.8	644.2
Single-row repair	**5.2**	1.4	48.6	**127.1**	8.7	307.0	392.3
P value	**0.0244**	0.1258	0.1480	**0.0450**	0.1103	0.0757	0.0186

*The values are given as the mean. Values shown in bold indicate that the difference between the double and single-row constructs was significant ($p < 0.05$).

compared single-row and double-row techniques for repair of the supraspinatus tendon in a cadaver model[1]. Specimens in both repair groups underwent identical cyclic loading from 10 to 180 N for 200 cycles, followed by testing to failure. Gap formation, stiffness, and ultimate failure measurements were significantly superior in association with the double-row construct.

In a similar study, Smith et al. subjected the repairs to identical static loading conditions followed by cyclic loading to failure and found significantly lesser gap formation and a nonsignificant trend toward higher load to failure in association with the double-row construct[12]. Waltrip et al. had previously described the initial fixation strength of the double-row footprint method in comparison with a single-row method involving either suture anchors or transosseous repair[13]. In addition, a recent clinical study comparing the outcomes of the single-row and double-row repairs demonstrated no difference among patients with small to medium (<3-cm) tears[16]. However, among patients with large to massive (>3-cm) tears, the clinical outcome was superior in the group treated with the double-row repair. The authors concluded that small to medium tears should be treated with the single-row method, whereas large to massive tears should be treated with the double-row footprint method.

The preliminary portion of the present study demonstrated that an in vivo tension differential between the medialized and footprint repair constructs does indeed exist. This tension differential in the present study had an upper limit of 50 N, which is consistent with the findings of previous reports[6]. The present study demonstrated that, in spite of the increased loading conditions designed to simulate a 50-N increase in tension on a double-row repair, the double-row construct fared better in terms of all biomechanical measures. Significant differences were noted with regard to first-cycle displacement, last-cycle stiffness, and load to ultimate failure.

The major limitation of the present study is inherent in the use of cadaver models that cannot account for the biological effects of an in vivo rotator cuff repair. A cadaver model does not account for the effect that the repair might have on healing, vascularity, and strength of scar formation. While biomechanical testing in a cadaver model can provide useful information, the clinical outcome is not always in accordance with experimental findings. In addition, the attempt to account for the tension differential between the two repair constructs led to an experiment in which there were two variables, tension and construct type. This study design is less strong than a design in which there is only one variable. Finally, every rotator cuff tear may have unique size, retraction, and tension differential, and it is therefore difficult to draw broad conclusions with regard to a specific repair technique.

The biomechanical study presented here is the first comparison of double and single-row repair techniques that accounts for the tension differential between the two. The results suggest that, when possible, a double-row repair should be performed for the treatment of retracted tears of the rotator cuff. ■

Benjamin G. Domb, MD
Loyola University Stritch School of Medicine, 1010 Executive Court, Suite 250, Westmont, IL 60559

Ronald E. Glousman, MD
Adam Brooks, BA
Matthew Hansen, MD
Neal S. ElAttrache, MD
6801 Park Terrace Drive, Los Angeles, CA 90065

Thay Q. Lee, PhD
5901 East 7th Street, Long Beach, CA 90822

References

1. Kim DH, Elattrache NS, Tibone JE, Jun BJ, DeLaMora SN, Kvitne RS, Lee TQ. Biomechanical comparison of a single-row versus double-row suture anchor technique for rotator cuff repair. Am J Sports Med. 2006;34:407-14.

2. Ma CB, Comerford L, Wilson J, Puttlitz CM. Biomechanical evaluation of arthroscopic rotator cuff repairs: double-row compared with single-row fixation. J Bone Joint Surg Am. 2006;88:403-10.

3. Meier SW, Meier JD. The effect of double-row fixation on initial repair strength in rotator cuff repair: a biomechanical study. Arthroscopy. 2006;22:1168-73.

4. ElAttrache NS, Snyder SJ. Debate: single-row vs. “transosseous equivalent” arthroscopic rotator cuff repair. Presented at the American Orthopaedic Society for Sports Medicine Specialty Day at the 75th Annual Meeting of the American Academy of Orthopaedic Surgeons; 2007 Mar 8; San Francisco, CA.

5. Snyder SJ. Single vs. double row suture anchor fixation rotator cuff repair. Presented at the American Orthopaedic Society for Sports Medicine Specialty Day at the 75th Annual Meeting of the American Academy of Orthopaedic Surgeons; 2007 Mar 8; San Francisco, CA.

6. Hersche O, Gerber C. Passive tension in the supraspinatus musculotendinous unit after long-standing rupture of its tendon: a preliminary report. J Shoulder Elbow Surg. 1998;7:393-6.

7. Park MC, Tibone JE, ElAttrache NS, Ahmad CS, Jun BJ, Lee TQ. Part II: biomechanical assessment for a footprint-restoring transosseous-equivalent rotator cuff repair technique compared with a double-row repair technique. J Shoulder Elbow Surg. 2007;16:469-76.

8. Snyder SJ. Shoulder arthroscopy. 2nd ed. Philadelphia: Lippincott Williams and Wilkins; 2003. Basic techniques for arthroscopic shoulder reconstruction; p 46-65.

9. Dugas JR, Campbell DA, Warren RF, Robie BH, Millett PJ. Anatomy and dimensions of rotator cuff insertions. J Shoulder Elbow Surg. 2002;11:498-503.

10. Curtis AS, Burbank KM, Tierney JJ, Scheller AD, Curran AR. The insertional footprint of the rotator cuff: an anatomic study. Arthroscopy. 2006;22:609.e1.

11. Mochizuki T, Sugaya H, Uomizu M, Maeda K, Matsuki K, Sekiya I, Muneta T, Akita K. Humeral insertion of the supraspinatus and infraspinatus. New anatomical findings regarding the footprint of the rotator cuff. J Bone Joint Surg Am. 2008;90:962-9.

12. Smith CD, Alexander S, Hill AM, Huijsmans PE, Bull AM, Amis AA, De Beer JF, Wallace AL. A biomechanical comparison of single and double-row fixation in arthroscopic rotator cuff repair. J Bone Joint Surg Am. 2006;88:2425-31.

13. Waltrip RL, Zheng N, Dugas JR, Andrews JR. Rotator cuff repair. A biomechanical comparison of three techniques. Am J Sports Med. 2003;31:493-7.

14. Apreleva M, Ozbaydar M, Fitzgibbons PG, Warner JJ. Rotator cuff tears: the effect of the reconstruction method on three-dimensional repair site area. Arthroscopy. 2002;18:519-26.

15. Lo IK, Burkhart SS. Double-row arthroscopic rotator cuff repair: re-establishing the footprint of the rotator cuff. Arthroscopy. 2003;19:1035-42.

16. Park JY, Lhee SH, Choi JH, Park HK, Yu JW, Seo JB. Comparison of the clinical outcomes of single- with double-row repair in rotator cuff tears. Am J Sports Med. 2008;36:1310-6.