

Single-Row Suture Anchor Repair of the Rotator Cuff is Biomechanically Equivalent to Double-Row Repair in a Bovine Model

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Purpose: The purpose of this study was to determine biomechanical differences in cyclic elongation and ultimate strength between double-row rotator cuff repair and single-row repair for partial rotator cuff repairs. **Methods:** We randomly assigned 18 immature bovine specimens (aged 12 to 16 weeks) to 3 repair groups (6 per group). A 1 × 2-cm defect was created at the infraspinatus tendon insertion site. Two suture anchors were implanted 1 cm apart at the anatomic insertion area for the lateral row. Two suture anchors were implanted 1 cm medial to the lateral row and 1 cm apart from each other for the medial row. Repair groups were constructed as follows: single-row repair with double-loaded suture anchors (group 1), double-row repair with single-loaded medial row and double-loaded lateral row (group 2), and double-row repair with single-loaded medial row and single-loaded lateral row (group 3). Specimens were cyclically loaded from 10 N to 90 N for 500 cycles and then loaded at 0.5 mm/s to failure. Data for cyclic elongation, with loads at 3 mm, 5 mm, and 10 mm, were analyzed via a 1-way analysis of variance ($P < .05$). **Results:** There were no significant differences for peak elongation after cyclic loading between groups. There were no significant differences between repair groups for loads at 3 mm, 5 mm, and 10 mm of elongation. Constructs typically failed by knot slippage (83%), with a single sample having tendon-suture failure (17%). **Conclusions:** Double-row repair did not show a biomechanical advantage compared with single-row repair. With this result in mind, the theoretic advantage of a potentially larger footprint must be balanced against the added surgical time, complexity, and cost of double-row repair. **Clinical Relevance:** Arthroscopic surgeons should choose the best form of fixation for a given patient, without undue emphasis on single-row repair versus double-row repair. The clinical and biologic impact of footprint restoration was not addressed in this study. **Key Words:** Arthroscopic rotator cuff repair—Double row—Single-tendon tear—Suture anchors—Biomechanical stability.

Arthroscopic rotator cuff repair techniques continue to evolve. Recent reports have shown the results of arthroscopic rotator cuff repairs to be as good, if not better than, the results of open rotator cuff

repair.¹ The benefits of arthroscopic rotator cuff repair compared with open procedures include less postoperative pain, less risk of deltoid-related complications, and improved cosmesis.^{2,3}

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However, concerns still exist regarding the efficacy of arthroscopic rotator cuff repair. Galatz et al.³ recently reported the results of 18 patients who had complete arthroscopic rotator cuff repairs of tears measuring greater than 2 cm. The patients showed excellent clinical results despite 17 of 18 having recurrent tears at 1 year of follow-up. Clinical results deteriorated at a minimum follow-up of 2 years. Apreleva et al. studied the restoration of the supraspinatus footprint by 4 different rotator cuff repair types.⁴ By use of human cadavers and a 3-dimensional digitizer, they found that single-row suture anchor repairs restored only 67% of the original supraspinatus footprint whereas transosseous simple suture repairs restored 85% of the footprint. They concluded that restoration of the original insertion of the rotator cuff would provide a larger area for healing and this could improve long-term mechanical strength and function. Therefore attention should be given to the ability of a procedure to restore the original tendon insertion site.

In an attempt to improve results of arthroscopic rotator cuff repairs, Burkhart and Lo¹ described a technique using a double row of suture anchors. The technique involved the use of a medial and lateral row of suture anchors to better approximate the original rotator cuff footprint. The medial suture anchors were tied with a mattress configuration, and the lateral suture anchors were tied with a simple configuration. They concluded that using a double-row repair may result in greater strength and improved rotator cuff healing.

Recent biomechanical tests have proven inconclusive as to whether the double-row technique is better than,^{5,6} or equal to,⁷ the single-row construct for complete tears. An important element of experimental study design in this area includes the use of a completely detached cuff apparatus (modeling a tear of all 4 tendons of the cuff) versus examination of limited cuff detachment (modeling an isolated tear of a single cuff tendon). These design alternatives may explain some of the discrepancy observed in the literature.

The purpose of this investigation was to compare the performance of the double-row repair technique against single-row repairs for a single-tendon tear model subjected to cyclic loading and failure tests. Our hypothesis was that arthroscopic double-row repair would have greater resistance to elongation and higher failure loads compared with single-row repair.

METHODS

Eighteen immature bovine shoulders (aged 12 to 16 weeks) were sectioned at the mid humerus and cleaned of all soft tissues excluding the infraspinatus tendon. This model has been used previously to evaluate various methods of rotator cuff repair.^{8,9} A scalpel was used to create a 1 × 2-cm defect at the tendon insertion (1 cm in line with the tendon fibers and 2 cm in transverse width), as used previously for in vitro biomechanical investigations (Fig 1).^{10,11} Each cuff defect was repaired under direct vision. Arthroscopic suture-passing and knot-tying were not used so as to minimize variability related to these factors and to focus attention on the specific variables of concern (repair configuration). One sports medicine fellowship-trained orthopaedic surgeon (J.T.) performed all repairs using Smith & Nephew TwinFix metal anchors (Smith & Nephew Endoscopy, Andover, MA) that were double-loaded by the manufacturer with No. 2 Ultrabraid suture (Smith & Nephew Endoscopy). All anchors were inserted 45° to the bone surface with the eyelet flush with the bone. Specimens were randomly assigned to 3 repair groups (n = 6 per group) and repaired as described later. An example of the double-row technique is shown in Fig 2. The sutures were secured with a series of 5 half-hitches while balancing tension between medial and lateral constructs. The first 2 hitches were placed in the same direction, followed by 3 alternating half-hitches. These knot groups were selected based on surgeon preference at our institution.

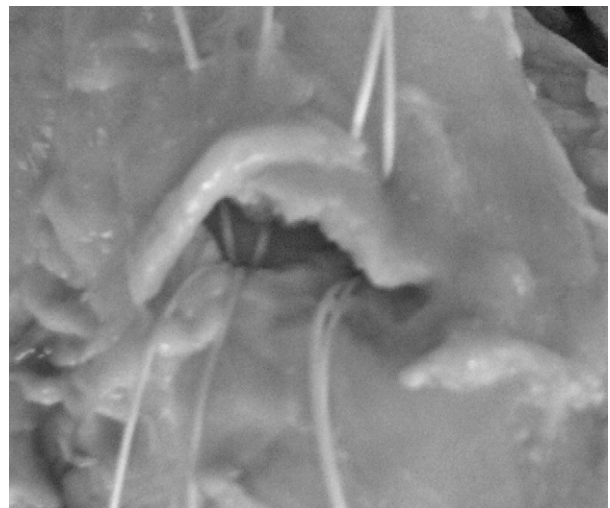


FIGURE 1. Example of cuff defect at tendon insertion with 1-cm resection in line with fibers and 2-cm transverse resection.

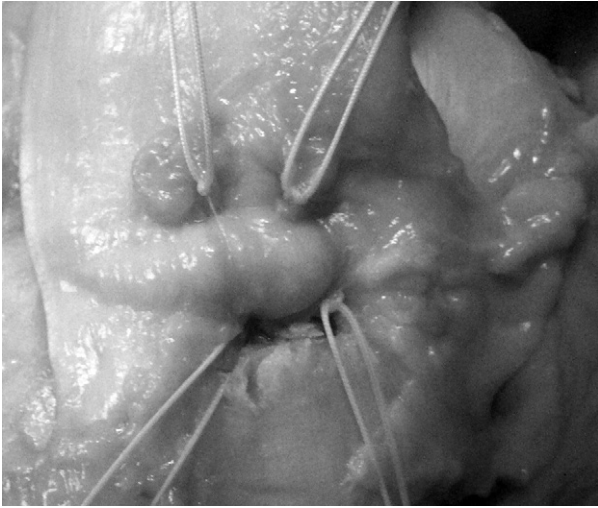


FIGURE 2. Example of double-row repair technique via single-suture fixation.

Repair Configurations

Group 1: Single Row (Four Sutures Total): In group 1, for the lateral row, 2 double-loaded anchors, with simple sutures, were used to fix the rotator cuff.

Group 2: Double Row (Six Sutures Total): In group 2, for the medial row, 2 single-loaded anchors, with mattress sutures, were used to fix the medial aspect of the rotator cuff. For the lateral row, 2 double-loaded anchors, with simple sutures, were used to fix the lateral aspect of the rotator cuff.

Group 3: Double Row (Four Sutures Total): In group 3, for the medial row, 2 single-loaded anchors, with mattress sutures, were used to fix the medial aspect of the rotator cuff. For the lateral row, 2 single-loaded anchors, with simple sutures, were used to fix the lateral aspect of the rotator cuff.

Mechanical Testing

The diaphysis of the humerus was potted in a 2-part epoxy resin (Bondo Mar-Hyde, Atlanta, GA) and fixed to the actuator of an MTS 858 servohydraulic test machine (MTS Systems, Eden Prairie, MN) with a custom-designed rig (Fig 3). The infraspinatus tendon was fixed to the load cell via a soft-tissue clamp. The load cell was rated to ± 10 kN with 12-bit data acquisition resolution. The actuator displacement transducer was rated to 0 to 100 mm with similar data acquisition resolution. This mechanical configuration has been used previously and found to be structurally sound beyond 1,000 N.^{8,9} Care was taken to preserve the anatomic orientation and loading axis of the ten-

don. The specimen was preloaded to 10 N with the actuator displacement transducer set to 0 mm. The pretension was applied for 2 minutes before cyclic loading. Each specimen was cyclically loaded from 10 N to 90 N at 1 N/s for a maximum of 500 cycles and then, if still intact, loaded at 0.5 mm/s to failure. The loading direction was in line with the tendon and perpendicular to the angle of anchor insertion. Gap formation at the repair site was measured directly with digital calipers accurate to within 0.01 mm (Chicago Brand, Chicago, IL). The number of cycles to 3 mm of gap formation, measured by direct visualization, was recorded. Data for force (in Newtons) and displacement (in millimeters) were recorded at 10 Hz for the duration of the test. The load at 3 mm, 5 mm, and 10 mm of elongation was calculated during the failure test. The location and mode of failure after testing were recorded and identified by direct visualization. Data regarding the number of cycles to the predetermined 3-mm elongation and loads at the prescribed elongation points were compared by use of a 1-way analysis of variance ($P < .05$) with a Tukey post hoc correction test for multiple comparisons.

RESULTS

During cyclic loading, group 1 had 2 specimens reach 3-mm failure at a mean of 90.5 ± 116.67 cycles. Group 2 had 1 specimen reach 3-mm failure at 224 cycles. Group 3 had 3 specimens reach 3-mm failure at a mean of 253.33 ± 99.40 cycles. Because group 2 had a single specimen that reached 3 mm, statistical tests were not used on these specific data.

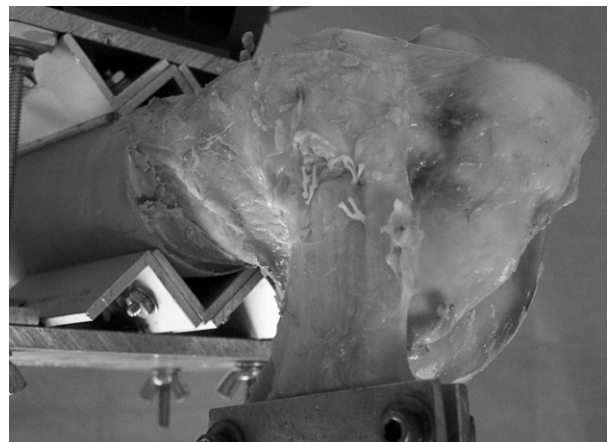


FIGURE 3. Mechanical testing setup in which the humeral diaphysis is rigidly fixed to the machine actuator and a soft-tissue clamp rigidly fixes and distributes load directly to the repaired tendon.

TABLE 1. Mean Loads With Increasing Elongation During Failure Testing

	Mean Load (N)		
	3 mm	5 mm	10 mm
Group 1	100.5 ± 27.2	281.1 ± 44.5	607.7 ± 14.9
Group 2	79.5 ± 48.6	280.1 ± 63.8	567.6 ± 83.1
Group 3	95.5 ± 65.7	302.9 ± 64.4	586.4 ± 70.1

The peak-to-peak elongation data from cyclic loading (cycle 1 to cycle 500) were not significantly different between groups. At the end of the cyclic loading protocol, group 1 had the greatest elongation (3.07 ± 1.68 mm) whereas group 2 had the lowest elongation (2.47 ± 0.64 mm), with group 3 roughly halfway between (2.86 ± 0.87 mm).

There were no significant differences in loads required to induce the 3 elongation levels between groups (Table 1). As expected, increasing elongation required a concomitant increase in applied load (Fig 4). In terms of the mode of ultimate failure, group 1 failed by knot slippage and suture loosening in 66% of specimens whereas fixation failure at the tendon-suture interface occurred 33% of the time. Group 2 failed exclusively by knot slippage and suture loosening. Group 3 failed primarily by knot slippage and suture loosening (83%), with a single sample (17%) failing at the tendon-suture interface.

DISCUSSION

This study showed no significant biomechanical differences between the repair groups tested when fixing a single-tendon rotator cuff tear. These results are contrary to our original experimental hypothesis, although some important design issues should be discussed. Our experimental model used young and relatively robust bovine tissues. A major advantage of this model is the consistency of rotator cuff dimensions and tissue quality, which helps from the perspective of experimental consistency. These tissue characteristics are probably similar to relatively young human rotator cuff tendons (e.g., a middle-aged traumatic tear) as compared with an older patient population with osteoporotic bone or degenerative tendinopathy. In addition, by using this particular model, the common failure modes of anchor pullout and suture cutting through tendon were eliminated. We wanted to focus our attention on the specific effects of single-row versus double-row fixation mechanics on

single-tendon cuff repairs, which could be difficult to decipher given the wide variability of bone and tissue quality encountered in elderly human cadaveric tissue. However, it is possible that a different pattern of findings would be observed with double-row fixation of more compromised tissues or of complete rotator cuff repairs. However, previous biomechanical studies using human cadaveric shoulders have been inconsistent as to which is the best repair construct for biomechanical stability.⁵⁻⁷ This biomechanical perspective does not address the potential biologic implications of footprint restoration on the tuberosity.

Previous studies of single-row versus double-row biomechanics are not consistent. Costic et al.¹² performed biomechanical testing of single-row versus double-row repairs on human cadavers. They found no significant difference between the 2 repairs. Examination of the footprint did show a 90% restoration with the double-row repair, whereas the single row only restored approximately 40% of the footprint. Millett et al.¹³ described a surgical technique using 2 anchors connected by a suture termed the *mattress double-anchor footprint repair*. Linking of the anchors requires use of an anchor with a suture eyelet, which is necessary to allow for passage of a suture loop via No. 2 FiberWire (Arthrex, Naples, FL). Biomechanical testing of this repair technique showed no difference between the single- and double-row repairs.⁷

Meier and Meier¹⁴ compared biomechanical properties of single-row, double-row, and transosseous repair configurations of rotator cuff tears in human cadavers. They found that the double-row repair was significantly stronger than the single-row and transosseous repairs. They also reported that the double-row repair had significantly less motion at the repair

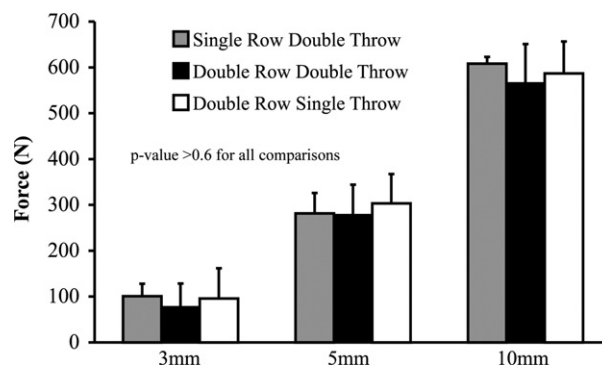


FIGURE 4. Forces at increasing elongation. Note that with increasing elongation, each repair requires a concomitant increase in load.

site compared with the single-row and transosseous repairs.¹⁴ Kim et al.⁵ tested single-row versus double-row repairs using human cadaveric shoulders. They found the double-row repair to be significantly stronger and stiffer than the single-row repair. Ma et al.⁶ compared the biomechanical properties of single-row, arthroscopic Mason-Allen suture, massive cuff stitch, and double-row repair. In this study, double-row repair had a significantly higher ultimate tensile load to failure than the single-row and arthroscopic Mason-Allen groups but was not stronger than the massive cuff stitch configuration. Sugaya et al.¹⁵ retrospectively compared single-row versus double-row arthroscopic rotator cuff repair in 80 patients. They compared functional outcomes and structural outcomes between the 2 groups. The functional outcomes, which were based on the University of California, Los Angeles and American Shoulder and Elbow Surgeons shoulder scores, did not show significant differences between the 2 groups. Structural outcomes were based on follow-up magnetic resonance imaging results. Their results showed the double-row repairs to have significantly greater cuff integrity than the single-row repairs.

There are some important technical issues and design limitations that affect interpretation of our study. Although this study used a sample size similar to that used in previous studies,⁷⁻⁹ it did not achieve a statistical power above 0.8 for comparisons between groups. In other words, with a greater sample size, statistical differences might have been shown. However, even if statistical differences were established, it is unlikely that those differences would have substantial clinical impact, given the small absolute differences in all of the parameters measured in our study.

Some of the variability in our observed data could have been related to subtle differences in suture tension during knot-tying and thus could have been technique-dependent. However, this mimics the reality of the surgical condition. We did note that with repair of a single-tendon tear with this model, slight overlap could be created at the margins between the intact tendon and the torn tendon at the medial and lateral edges (a very subtle “dog ear”). Thus, during initial tension, the suture loops withstand 100% of the input stress, and then with subsequent loading, the medial and lateral margins probably settle to achieve load-sharing with the adjacent intact tendon. In addition, not only is the tension at which the sutures are tied an issue, but where they are placed in the tendon is also an issue. If the spacing between the medial and lateral rows in the tendon is greater than the anchors in bone,

then both the medial and lateral sutures do not see load until the medial row has begun to fail. This may be a critical biomechanical difference between a single-tendon tear versus a multiple-tendon tear configuration. However, isolated supraspinatus tears are very common in human patients, making experimental examination of single-tendon tears clinically relevant.

If one is to believe that 3 mm of tissue separation may prevent biologic healing of the cuff, then the differences between group 1 and group 2 for cyclic elongation may be clinically relevant. Although we did not find biomechanical differences in elongation between group 1 (3.07 ± 1.68 mm) and group 2 (2.47 ± 0.64 mm), the 0.6-mm difference between groups may show a clinical effect on biologic healing and functional outcomes. These were not addressed in this in vitro study, however.

CONCLUSIONS

On the basis of our experimental results, it is not clear whether there are major purely biomechanical advantages of a double-row rotator cuff repair. Double-row repair did not show a biomechanical advantage compared with single-row repair. With this result in mind, the theoretic advantage of a potentially larger footprint must be balanced against the added surgical time, complexity, and cost of double-row repair. Despite these considerations, there may be clinical situations in which double repair is both feasible and advantageous, and surgeons should strive to optimize repair methods for each individual patient.

In Memoriam: This study was co-authored by Jeffrey Tamborlane, M.D. (1972–2007) and the article is now dedicated to his memory. We acknowledge his energy, passion, and desire for excellence, and we will miss him.

REFERENCES

1. Burkhart SS, Lo IKY. Double-row arthroscopic rotator cuff repair: Re-establishing the footprint of the rotator cuff. *Arthroscopy* 2003;19:1035-1042.
2. Gartsman GM. Arthroscopic management of rotator cuff disease. *J Am Acad Orthop Surg* 1998;6:259-266.
3. Galatz LM, Ball CM, Teefey SA, Middleton WD, Yamaguchi K. The outcome and repair integrity of completely arthroscopically repaired large and massive rotator cuff tears. *J Bone Joint Surg Am* 2004;86:219-224.
4. 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;18:519-526.
5. Kim DH, ElAttrache NS, Tibone JE, et al. Biomechanical comparison of a single-row versus double-row suture anchor

- technique for rotator cuff repair. *Am J Sports Med* 2005;34:407-414.
6. 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;88:403-410.
 7. Mazzocca AD, Millett PJ, Guanche CA, Santangelo SA, Arciero RA. Arthroscopic single-row versus double-row suture anchor rotator cuff repair. *Am J Sports Med* 2005;33:1861-1868.
 8. Bynum CK, Lee S, Mahar A, Tasto J, Pedowitz R. Failure mode of suture anchors as a function of insertion depth. *Am J Sports Med* 2005;33:1030-1034.
 9. Petit CJ, Boswell R, Mahar A, Tasto J, Pedowitz RA. Biomechanical evaluation of a new technique for rotator cuff repair. *Am J Sports Med* 2003;31:849-853.
 10. Burkhart SS, Diaz-Pagan JL, Wirth MA, Athanasiou KA. Cyclic loading of anchor-based rotator cuff repairs: Confirmation of the tension overload phenomenon and comparison of suture anchor fixation with transosseous fixation. *Arthroscopy* 1997;13:720-724.
 11. Burkhart SS, Fischer SP, Nottage WM, et al. Tissue fixation security in transosseous rotator cuff repairs: A mechanical comparison of simple versus mattress sutures. *Arthroscopy* 1996;12:704-708.
 12. Costic RS, Brucker PU, Smolinski PJ, Gilbertson LG, Fu FH, Rodosky MW. Biomechanical evaluation of rotator cuff repair complex: Single vs double row repair. Presented at the 52nd Meeting of the Orthopaedic Research Society, Chicago, IL, 2006.
 13. Millett PJ, Mazzocca AD, Guanche CA. Mattress double anchor footprint repair: A novel, arthroscopic rotator cuff repair technique. *Arthroscopy* 2004;20:875-879.
 14. Meier SW, Meier JD. The effect of double-row fixation on initial repair strength in rotator cuff repair: A biomechanical study. *Arthroscopy* 2006;22:1168-1173.
 15. Sugaya H, Maeda K, Matsuki K, Moriishi J. Functional and structural outcome after arthroscopic full-thickness rotator cuff repair: Single-row versus dual-row fixation. *Arthroscopy* 2005; 21:1307-1316.