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A Biomechanical Comparison of Transosseous–Suture Anchor and Suture Bridge Rotator Cuff Repairs in Cadavers

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Background: Several biomechanical studies comparing open and arthroscopic rotator cuff repair methods have shown inferior performance of arthroscopic repairs. Suture anchor–augmented transosseous repairs and suture bridge repairs have shown superior biomechanical performance when compared with other methods, but these 2 repair methods have not been directly compared.

Hypothesis: There will be no difference in the biomechanical performance of the transosseous–suture anchor and suture bridge techniques.

Study Design: Controlled laboratory study.

Methods: Eight paired cadaveric shoulder specimens (16 specimens) had creation followed by repair of a complete tear of the supraspinatus, with the first member of each pair undergoing repair by a transosseous–suture anchor technique and the second member undergoing repair by the suture bridge technique. Specimens were then cycled from 10 to 180 N for 200 cycles, followed by testing to failure at 33 mm/s. Elongation was measured during cyclic testing, and failure load and stiffness were obtained during load-to-failure testing. Failure method was recorded.

Results: There was no significant difference between transosseous–suture anchor repairs and suture bridge repairs for elongation (4.0 ± 1.60 mm vs 3.5 ± 1.1 mm, *P* = .31), failure load (408 ± 93 N vs 419 ± 62 N, *P* = .70), or stiffness (58 ± 10 N/mm vs 58 ± 14 N/mm, *P* = .94). The most common mode of failure with each method was suture cutting through tendon.

Conclusion: The suture bridge repair exhibited similar biomechanical performance during cyclic and load-to-failure testing as a transosseous–suture anchor repair, which historically has been performed in open or mini-open fashion.

Clinical Relevance: Arthroscopic rotator cuff repairs can be performed that are as strong as open or mini-open repairs.

Keywords: rotator cuff; suture bridge; transosseous; shoulder

Rotator cuff repair has evolved from an open procedure with detachment of the deltoid through a mini-open deltoid-preserving approach to an all-arthroscopic approach. The advantages of arthroscopic surgery include diminished postoperative pain and better visualization of lesions.[20] Ideally, arthroscopic rotator cuff repair would also result in a construct that is at least as strong as that performed in open fashion. Recent studies that have compared open repair methods to arthroscopic repair methods demonstrated inferior performance with the latter[5,19,23]; however, the methods used for arthroscopic repair in those studies were different from the methods currently used.

Transosseous repair of the rotator cuff has been used with the open approach for decades and, when combined with suture anchor fixation, has been shown to exhibit superior biomechanical performance when compared with early arthroscopic methods.[23] The introduction of newer sutures and implants has allowed the performance of transosseous-equivalent repairs to be done arthroscopically.[15] These repairs have been compared with other methods of arthroscopic repair[16,18] but have not been compared directly with the transosseous–suture anchor technique.

The purpose of the present study was to compare the biomechanical performance of an open repair method that has been shown to exhibit superior biomechanical performance in a comparative study[23] with the biomechanical performance of an arthroscopic repair method that has been shown to exhibit superior biomechanical performance in a different comparative study.[18] Our hypothesis was that there would be no difference between a transosseous–suture

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anchor repair and a transosseous-equivalent repair of the rotator cuff during cyclic and load-to-failure performance testing.

MATERIALS AND METHODS

Sample Size Calculation

Previous authors have found that a suture bridge repair displaces 3.74 ± 1.51 mm after 30 cycles performed from 10 to 180 N.[18] We decided a priori that a clinically significant difference in gap formation between repair methods after cyclic loading would be 2 mm. Calculation of the number of specimens needed to detect a difference of 2.0 ± 1.50 mm with an alpha of .05 indicated that 7 pairs of specimens (14 shoulders) would do so with a power of .83. We chose 8 pairs to account for any problems encountered during testing.

Specimen Preparation and Repair

Eight pairs of shoulder specimens (16 total) with no grossly visible evidence of rotator cuff damage were obtained from our university's Department of Anatomy. The specimens were from 2 male and 6 female donors, with a mean age of 74.5 years (range, 57-87). The supraspinatus was dissected free from the infraspinatus posteriorly and the rotator interval anteriorly and then sharply detached from its insertion on the greater tuberosity. One member of each pair then underwent repair of the detached tendon using a combination of 3 No. 2 FiberWire sutures (Arthrex Inc, Naples, Florida) and 2 suture anchors. The sutures were placed 1 cm apart in Mason-Allen configuration, 1 cm medial to the free edge of the tendon. They were then passed through osseous tunnels placed 1 cm apart on the greater tuberosity, starting at the lateral edge of the supraspinatus footprint and exiting approximately 15 mm distal to the top of the tuberosity. This was followed by the placement of 2 titanium Corkscrew anchors (5.5 mm, Arthrex Inc) 1 cm apart at the medial edge of the supraspinatus footprint, with the suture limbs from the anchors being passed through the tendon 1 cm from the free tendon edge, 8 mm apart, and tied in horizontal mattress fashion (Figure 1A). These 2 suture anchors were placed between the sites of the transosseous Mason-Allen sutures to avoid interference or potential damage to the Mason-Allen sutures by the sutures from the anchors. The transosseous sutures were tied after the anchor sutures were passed and tied. Cortical augmentation of the lateral aspect of the greater tuberosity was not performed, to remain consistent with other recent studies using a transosseous repair method combined with suture anchors.[5,23,24] The second member of each pair underwent repair using 3 titanium Corkscrew anchors (5.5 mm) placed 1 cm apart at the articular edge of the supraspinatus footprint, with 2 suture limbs from each anchor passed through the tendon 1 cm from the free edge, 8 mm apart, and tied in horizontal mattress fashion. This was followed by fixation of the suture limbs into the lateral aspect of the greater tuberosity using 3 bioabsorbable push-lock anchors (3.5 mm, Arthrex Inc)

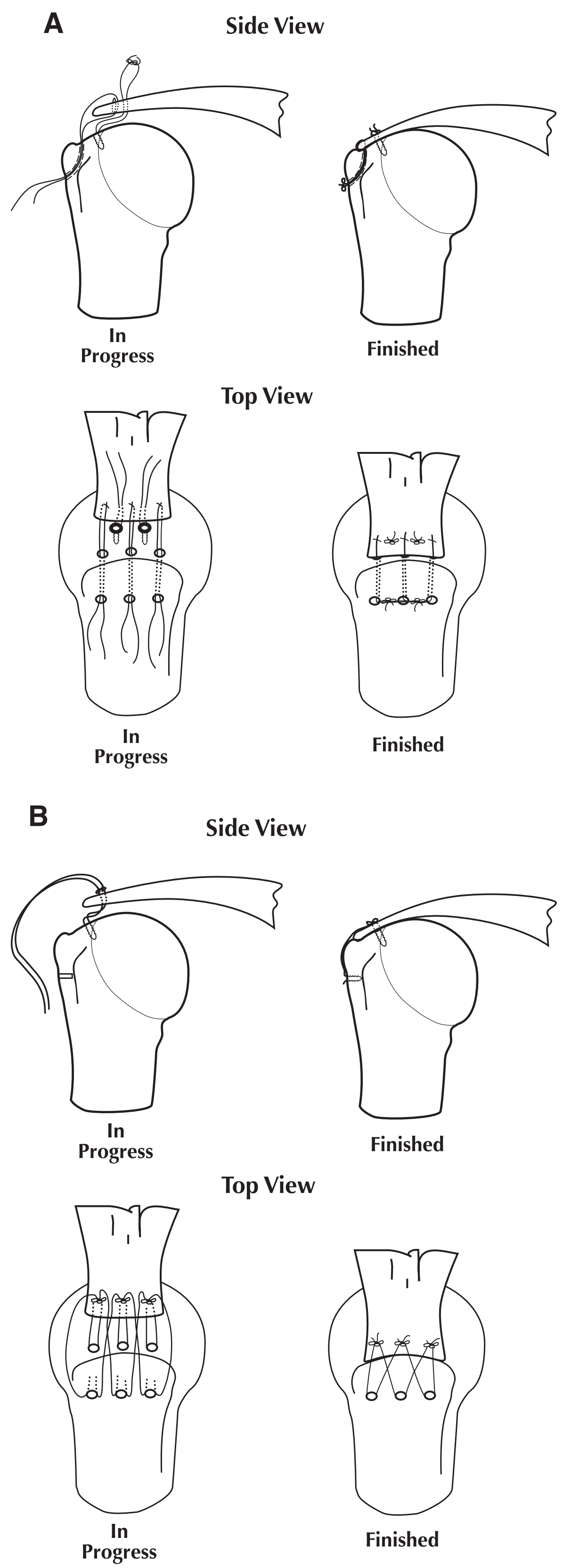

Figure 1. Repair methods used in the study: A, the transosseous–suture anchor repair; B, the suture bridge repair.

TABLE 1
Comparing the Biomechanical Performance of 2 Repair Methods[a]

	Transosseous	Suture Bridge	*P*
Elongation, mm	4.0 ± 1.60	3.5 ± 1.11	.311
Load to failure, N	408 ± 93	419 ± 62	.705
Stiffness, N/mm	58 ± 10	58 ± 14	.935

[a]Values given as mean ± standard deviation.

TABLE 2
Sites of Failure During Load-to-Failure Testing for 2 Repairs, n

	Transosseous-Suture Anchor Repair	Suture Bridge Repair
Suture-tendon interface failure	3	4
Suture breakage	1	3
Bone failure	2	0
Anchor pullout	2	1

placed approximately 15 mm from the top of the greater tuberosity (Figure 1B).

Biomechanical Testing

The proximal humerus of each specimen was fixed in a vise in a Bionix Mini-MTS machine (MTS Systems Corp, Eden Prairie, Minnesota), and the medial edge of the supraspinatus tendon was grasped approximately 1 cm medial to the sutures in a thermally cooled grip (Electroforce Division, Bose Corp, Eden Prairie, Minnesota), with the angle between the humeral shaft and the tendon kept at 45° to avoid interference of the humeral head with the ability of the thermal clamp to grasp the specimen. The grip is designed to freeze only the segment of tendon within the clamp, leaving the remainder of the tendon unaffected. Care was taken to ascertain that the site of thermal grip placement on each tendon was consistent between pairs. All specimens were kept moist with saline spray, as necessary, during testing. The specimen was cycled from 10 to 180 N at 1 Hz for 200 cycles, held to 10 N for 5 seconds, and then loaded to failure at 33 mm/s. Other investigators have used a similar cyclic loading protocol for testing rotator cuff repair.[9,18] Conditioning elongation was defined as the load cell displacement recorded at 180 N for cycle 200 minus the load cell displacement recorded at 180 N for cycle 1. Failure load was defined as either (1) the highest load recorded during load-to-failure testing for specimens that failed before 1 cm of displacement or (2) the load recorded at 1 cm of displacement for those specimens that failed at greater than 1 cm of displacement. One centimeter of displacement has been used as the definition of failure in other rotator cuff repair studies.[23] Stiffness was calculated from the slope of the linear portion of the load-displacement curve. Mode of failure was recorded by direct observation of the specimen during testing.

Statistical Testing

Paired *t* testing was used to determine the effect of repair method on the biomechanical behavior of the specimen. Statistical comparison of conditioning elongation, failure load, and stiffness was performed. *P* values less than .05 were considered significant. All statistical analyses were performed using SPSS 14 (SPSS Inc, Chicago, Illinois).

RESULTS

Table 1 summarizes the results of cyclic and load-to-failure testing. There were no significant differences between repair methods in conditioning elongation, failure load, and stiffness. Table 2 shows mode of failure. The most common method of failure for both repairs was suture cutting through tendon (3 specimens in the transosseous–suture anchor repair group and 4 in the suture bridge repair group). Only 2 specimens in the transosseous–suture anchor repair group failed because of bone bridge failure. To determine whether the lack of cortical augmentation influenced the results of our study, we reanalyzed our data excluding these 2 pairs and again found no significant differences in conditioning elongation, stiffness, and failure load for the 6 remaining pairs.

DISCUSSION

Few biomechanical studies have directly compared arthroscopic and open methods of rotator cuff repair, and those have suggested that arthroscopic methods exhibit inferior performance in the laboratory.[5,19,23] Despite these studies, arthroscopic rotator cuff repairs have shown satisfactory performance in clinical studies with relatively short follow-up.[1,2,6,10,22] Transosseous methods of rotator cuff repair have a long clinical history and, when combined with suture anchors, have been shown to exhibit superior performance in biomechanical studies.[23] The suture bridge method of rotator cuff repair can be done arthroscopically relatively easily, and it has been shown to perform well in biomechanical tests and to reproduce the supraspinatus footprint with excellent contact characteristics.[16,18] However, it has not been directly compared with the transosseous method. The hypothesis of our study was that there would be no difference in the biomechanical performance of the suture bridge repair and that of the transosseous repair combined with suture anchors, and our study verified this hypothesis, within the limits of our power analysis.

Two choices were made during performance of the study that deserve explanation. First, the lateral aspect of the greater tuberosity was not augmented in the transosseous–suture anchor repairs. Early studies of transosseous repair demonstrated that augmentation of the repair with a device placed at the greater tuberosity improved the biomechanical performance of isolated transosseous repairs when compared with that of the unaugmented state.[4,7] However, authors of more recent biomechanical studies have chosen to augment their transosseous repairs with suture anchors rather than a device placed on the lateral aspect of the greater tuberosity, and they have shown satisfactory performance using this type of augmented transosseous repair.[5,23,24] Use of suture anchors, rather than a device placed laterally on the greater tuberosity, may therefore be considered an alternative form of augmentation of a transosseous repair. To determine whether the lack of cortical augmentation affected the results of our study, we reanalyzed our data excluding the 2 pairs for which the transosseous–suture anchor repair member failed owing to bone bridge failure, and again, we found no significant differences in conditioning elongation, stiffness, or failure load for the 6 remaining pairs. This finding suggests that augmentation at the site of the greater tuberosity would not have substantially changed the results of our study. Finally, we should note that the values we obtained for failure load with our suture anchor–augmented transosseous repair were greater than those obtained in studies using cortical augmentation.[4,7]

Second, we chose to place only 2 suture anchors in our transosseous–suture anchor repairs, as opposed to 3 anchors in the suture bridge repair. We did so to reflect the technique that the senior author has used when clinically performing transosseous repair. When performing this repair for an isolated supraspinatus tear, he typically places 3 Mason-Allen sutures (which are later passed through the greater tuberosity for the transosseous component of the repair) at the anterior, middle, and posterior part of the tendon, and passes them approximately 8 to 10 mm medial to the edge of the tendon, to grasp better tissue. Two suture anchors are then placed at the medial border of the supraspinatus footprint, adjacent to the articular surface, with the first anchor placed between the site of the anterior and middle Mason-Allen sutures and the second anchor placed between the site of the middle and posterior Mason-Allen sutures (see Figure 1A). From a purely comparative biomechanical standpoint, it may be more desirable in the laboratory to use 3 suture anchors placed directly medial to the Mason-Allen sutures in the transosseous–suture anchor repair; however, we have found that doing so often results in an overcrowding of the sutures from the anchors and the Mason-Allen sutures, with the risk of damage to the Mason-Allen sutures as the sutures from the anchors are passed through the rotator cuff. As can be seen in Figure 1A, if 3 anchors were placed in line with the previously placed Mason-Allen sutures and the anchor sutures were then passed, there could have been laceration of the Mason-Allen sutures by the needles from the anchor sutures. We therefore chose clinical relevance over scientific perfection when designing the study. Furthermore, although some studies have demonstrated better biomechanical performance from double-row rotator cuff repairs, at least 2 studies have shown no advantage to a double-row repair when the medial and lateral anchors are aligned with the direction of shortening of the supraspinatus.[13,14] This is a second reason that we staggered the Mason-Allen sutures and the sutures from the suture anchors. We believe that this modification may actually make the repair biomechanically stronger. We do admit, however, that this has not been directly studied.

We should also emphasize that both repair methods exhibited quite high failure loads (greater than 400 N for each method), which is approximately half that of the intact supraspinatus tendon.[8] Regardless of failure site (suture-tendon interface, anchor pullout, suture breakage, or bone failure), all failures occurred at loads of approximately 400 to 450 N, making that value a possible biologic limit using the sutures and techniques currently available. As a matter of interest, other authors studying the biomechanics of human rotator cuff repair have been unable to create repairs that exceed this limit.[†] The addition of more suture anchors or cortical augmentation may therefore have changed the site of failure in our study but would have been unlikely to increase the failure load of the construct. In fact, the failure load obtained with each repair method was equal to or higher than that obtained by any other biomechanical study of rotator cuff repair published to date.[‡] The values obtained for elongation, stiffness, and failure load suggest that future clinical studies on early motion after selected repairs using these methods may be appropriate.

Our study has several strengths, including our use of a single investigator to perform all the repairs. We compared 2 repair methods that are clinically relevant and commonly used. The relatively narrow standard deviations that we obtained for our values attest to the reproducibility of our technique. Our results are quite close to those obtained for the suture bridge technique in other laboratories.[17,18] Finally, we were able to obtain paired specimens without any gross evidence of damage to the supraspinatus.

There are limitations of our study that deserve mention. First, this was a cadaveric study and therefore measured performance at time zero only. It was done with grossly normal rotator cuffs, which may have properties different from those of degenerative, torn tendons. Second, as performed in this study, the transosseous method pulls the supraspinatus down onto the greater tuberosity, whereas the suture bridge technique presses the tendon onto the tuberosity. Animal and human studies are necessary to determine if doing so results in different rates of healing. We did not measure differences in contact area or pressure, which may also contribute to the healing of the tendon and to the ultimate clinical results. Third, we did not use a video system to determine the site of the elongation; therefore, the measured elongation may have occurred at sites other than the edge of the tendon. However, we did not find any difference in elongation between the 2 repair methods, again supporting our conclusion that these methods are biomechanically equivalent. We also did not detect any visible slipping of the tendon within the cryoclamp during biomechanical testing. Finally, although the suture bridge repair is commonly used arthroscopically, we performed it using an open technique. Arthroscopic methods of repair may lead to different results.

In conclusion, we compared a mini-open rotator cuff repair method with an arthroscopic rotator cuff repair method and found no differences in conditioning elongation, failure load, or stiffness. This is the first biomechanical

[†]References 3, 5, 7, 9, 11, 12, 14, 18, 21, 24.
[‡]References 3, 5, 7, 9, 11, 12, 14, 18, 21.

study of human rotator cuff repair to show equivalence of arthroscopic and open repair methods.

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REFERENCES

1. Anderson K, Boothby M, Aschenbrener D, van Holsbeeck M. Outcome and structural integrity after arthroscopic rotator cuff repair using 2 rows of fixation: minimum 2-year follow-up. *Am J Sports Med.* 2006;34(12):1899-1905.
2. Buess E, Steuber KU, Waibl B. Open versus arthroscopic rotator cuff repair: a comparative view of 96 cases. *Arthroscopy.* 2005;21(5): 597-604.
3. Busfield BT, Glousman RE, McGarry MH, Tibone JE, Lee TQ. A biomechanical comparison of 2 technical variations of double-row rotator cuff fixation: the importance of medial row knots. *Am J Sports Med.* 2008;36(5):901-906.
4. Caldwell GL, Warner JP, Miller MD, Boardman D, Towers J, Debski R. Strength of fixation with transosseous sutures in rotator cuff repair. *J Bone Joint Surg Am.* 1997;79(7):1064-1068.
5. Demirhan M, Atalar AC, Kilicoglu O. Primary fixation strength of rotator cuff repair techniques: a comparative study. *Arthroscopy.* 2003; 19(6):572-576.
6. Flurin PH, Landreau P, Gregory T, et al. Cuff integrity after arthroscopic rotator cuff repair: correlation with clinical results in 576 cases. *Arthroscopy.* 2007;23(4):340-346.
7. Gerber C, Schneeberger AG, Beck M, Schlegel U. Mechanical strength of repairs of the rotator cuff. *J Bone Joint Surg Br.* 1994;76(3):371-380.
8. Itoi E, Berglund LJ, Grabowski JJ, et al. Tensile properties of the supraspinatus tendon. *J Orthop Res.* 1995;13(4):578-584.
9. 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.* 2006;34(3):407-414.
10. Lee E, Bishop JY, Braman JP, Langford J, Gelber J, Flatow EL. Outcomes after arthroscopic rotator cuff repairs. *J Shoulder Elbow Surg.* 2007;16(1):1-5.
11. Lorbach O, Bachelier F, Vees J, Kohn D, Pape E. Cyclic loading of rotator cuff reconstructions: single-row repair with modified suture configurations versus double-row repair. *Am J Sports Med.* 2008;36(8): 1504-1510.
12. 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(2):403-410.
13. Mahar A, Tamborlane J, Oka R, Esch J, Pedowitz RA. Single-row suture anchor repair of the rotator cuff is biomechanically equivalent to double-row repair in a bovine model. *Arthroscopy.* 2007;23(12):1265-1270.
14. 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(12):1861-1868.
15. Park MC, Elattrache NS, Ahmad CS, Tibone JE. “Transosseous-equivalent” rotator cuff repair technique. *Arthroscopy.* 2006;22(12): 1360, e1361-1365.
16. Park MC, Elattrache NS, Tibone JE, Ahmad CS, Jun BJ, Lee TQ. Part I: footprint contact characteristics for a transosseous-equivalent rotator cuff repair technique compared with a double-row technique. *J Shoulder Elbow Surg.* 2007;16(4):461-468.
17. Park MC, Idjadi JA, Elattrache NS, Tibone JE, McGarry MH, Lee TQ. The effect of dynamic external rotation comparing 2 footprint-restoring rotator cuff repair techniques. *Am J Sports Med.* 2008;36(5):893-900.
18. 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(4):469-476.
19. Schneeberger AG, von Roll A, Kalberer F, Jacob HA, Gerber C. Mechanical strength of arthroscopic rotator cuff repair techniques: an in vitro study. *J Bone Joint Surg Am.* 2002;84(12):2152-2160.
20. Severud EL, Ruotolo C, Abbott DD, Nottage WM. All-arthroscopic versus mini-open rotator cuff repair: a long-term retrospective outcome comparison. *Arthroscopy.* 2003;19(3):234-238.
21. Smith CD, Alexander S, Hill AM, et al. A biomechanical comparison of single and double-row fixation in arthroscopic rotator cuff repair. *J Bone Joint Surg Am.* 2006;88(11):2425-2431.
22. Verma NN, Dunn W, Adler RS, et al. All-arthroscopic versus mini-open rotator cuff repair: a retrospective review with minimum 2-year follow-up. *Arthroscopy.* 2006;22(6):587-594.
23. Waltrip RL, Zheng N, Dugas JR, Andrews JR. Rotator cuff repair: a biomechanical comparison of three techniques. *Am J Sports Med.* 2003;31(4):493-497.
24. Zheng N, Harris HW, Andrews JR. Failure analysis of rotator cuff repair: a comparison of three double-row techniques. *J Bone Joint Surg Am.* 2008;90(5):1034-1042.