Initial Fixation Strength of Massive Rotator Cuff Tears: In Vitro Comparison of Single-Row Suture Anchor and Transosseous Tunnel Constructs

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Purpose: The purpose of this study was to compare the in vitro repair integrity of massive rotator cuff tears fixed with transosseous tunnel and single–lateral row suture anchor techniques. Methods: A 5 × 2–cm crescent-shaped rotator cuff tear was created in 6 matched pairs of cadaveric shoulders. Paired shoulders were repaired with 3 transosseous tunnels and 6 Mason-Allen sutures or with 3 screw-in suture anchors and 6 simple sutures. The repairs were cyclically loaded at physiologic forces along the respective directions of pull when the arm was in 90° of scapular plane elevation. Gap formation and repair displacements were monitored with digital video imaging at 3 sites for each repair. Results: There was no significant difference between the maximal gapping of the repair constructs. After 4,000 cycles, the mean maximal gapping at any position along the repair was 6.2 ± 2.99 mm in the transosseous tunnel construct and 4.9 ± 1.27 mm in the suture anchor repair construct (P = .40). Gapping was significantly less in the anterior region when compared with the posterior region of the repair (P = .015). Conclusions: There is no difference in cyclic loading of transosseous and single-row suture anchor repair techniques. Significantly greater gap formation occurs at the posterior aspect of repairs of massive rotator cuff tears in this in vitro model. Clinical Relevance: Initial fixation strength of single-row suture anchor repairs is equivalent to that of transosseous repairs. Further research is required to determine the unknown clinical significance of increased posterior repair gap formation. Key Words: Rotator cuff tear—Massive—Suture anchor—Tendon fixation—Biomechanical—Cadaver.
These studies have used a variety of experimental models. Generally, cyclic loading (as opposed to load to failure) is considered to be more representative of in vivo failure mechanics. Studies comparing cyclic loading response between open and arthroscopic techniques have produced conflicting results. Several studies have compared transosseous tunnels and suture anchors in a cyclic loading model. Burkhart et al. found a significantly higher number of cycles to failure using a suture anchor construct compared with transosseous tunnels. Other authors found no significant difference in the number of cycles to failure between transosseous tunnels and a single row of suture anchors. Most biomechanical studies have used high physiologic forces (unlike those applied during postoperative rehabilitation) and have only loaded supraspinatus tendon repairs. These studies only evaluated small- and medium-sized tears (i.e., tears between 1 and 3 cm). The application of current techniques to larger rotator cuff tears has not been well studied. Increasing experience with arthroscopy has led surgeons to repair larger tears completely with an arthroscopic technique.

The purpose of this study was to comparatively evaluate the initial biomechanical strength of two different rotator cuff repair techniques (transosseous tunnels and a single lateral row of suture anchors) to repair a massive rotator cuff tear under cyclic loading by use of a cadaveric model. We wanted to determine whether the initial construct strength is the reason for higher failure rates with arthroscopic repairs, compared to open repairs, of larger rotator cuff tears. We hypothesized that gapping at the repair site after a single–lateral row suture anchor technique would be greater than that after a transosseous tunnel repair.

METHODS

Six matched pairs of fresh-frozen human cadaveric shoulders were used in this study. The mean age of the specimens was 56 years (range, 50 to 60 years). All had intact rotator cuffs. The specimens were maintained at −20°C until approximately 12 hours before testing. The shoulders were dissected to isolate the humerus from all of the soft tissue except for the subscapularis, supraspinatus, and infraspinatus muscles and tendons. The humeri were cut proximal to the epicondyles and potted in 51-cm-long and 12.7-cm-diameter sections of plastic pipe by use of Smooth Cast 300 (Smooth-On, Easton, PA). The individual specimens were prepared and tested during the same day to avoid refreezing and thawing.

A 5-cm-long (anterior-to-posterior dimension) by 2-cm-wide (lateral-to-medial dimension) rotator cuff tear was created in each shoulder, starting anteriorly at the rotator cuff interval and extending posteriorly along the greater tuberosity into the infraspinatus tendon (Fig 1). An ellipse of rotator cuff tendon was excised with a knife blade to create a broad crescent-shaped tear, simulating a massive rotator cuff tear with tendon loss and retraction. The shoulders were then block-randomized so that each repair technique (transosseous tunnels vs single lateral row of suture anchors) was evaluated within each pair.

The single–lateral row suture anchor repair was completed by use of 3 Linvatec SuperRevo 5.5-mm suture anchors (Linvatec, Largo, FL) loaded with 2 strands of No. 2 braided nonabsorbable polyester sutures. The rotator cuff footprint was lightly decorticated with a bur. Each anchor was placed at the lateral edge of the rotator cuff insertion footprint, separated by 10 mm, and inserted at a 45° angle to the surface of the bone. One limb of each pair of the sutures from the anchor was passed through the tendon 10 mm medial to the free edge and tied with a slipknot followed by 3 alternating half-hitches to the other end of the suture strand (Fig 2A).

The transosseous tunnel repair was performed by use of 3 tunnels separated by 10 mm, which were created via a 1.5-mm drill bit and a large Mayo needle. The medial holes of the tunnels were placed just lateral to the articular surface of the humeral head.
The lateral exit of the transosseous tunnels was 10 mm beyond the tip of the greater tuberosity. Two strands of No. 2 braided polyester suture were placed in each tunnel. One free end of each suture was placed in the rotator cuff tendon 10 mm medial to the free edge of the cuff with a modified Mason-Allen technique and then tied to the other end of the suture over the bone bridge (medial to lateral) of the greater tuberosity (Fig 2B).

The subscapularis, supraspinatus, and infraspinatus tendons were individually attached to 2.5-cm-wide nylon straps as previously described by Goradia et al. Each tendon was then attached to a pneumatic piston that was oriented along the lines of action for each muscle-tendon unit (Fig 3). The tendons were loaded in the respective directions of pull as though the arm was positioned in 90° of scapular plane elevation. This position was chosen because it has been determined that normalized shoulder muscle forces peak around 90° of abduction. Rotator cuff forces (which we define as low loading levels in this experiment) that are required to actively raise the arm from a position of 0° to 90° of abduction were applied to each tendon for this position (supraspinatus, 45 N; infraspinatus, 79 N; and subscapularis, 109 N). Maximal rotator cuff forces were based on isometric Cybex measurements (Lumex, Ronkonkoma, NY) taken in 90 healthy subjects. Because in vivo rotator cuff tendon forces cannot be directly measured, we assumed in our model that maximal isometric strength values in healthy subjects are an accurate measure of maximal cuff forces. The maximal forces (high loading levels) were applied at 1 Hz for 2,000 cycles or until system failure (complete loss of repair fixation, proximal humeral fracture).

Gap formation at the repair site was evaluated at anterior, middle, and posterior regions of the tear by use of a digital video imaging technique as described by Ma et al. Digital video markers were placed on either side of the repaired tears at 3 locations (1 cm, 2.5 cm, and 4 cm posterior to the anterior edge of the tear). Twelve cycles of position data were recorded every 100 cycles for the first 500 cycles, then every 250 cycles for the next 1,000 cycles, and then every 500 cycles for the next 2,500 cycles. Custom MATLAB code (The MathWorks, Natick, MA) was used to calculate the distances between the respective markers along the repair for the first 4,000 cycles of loading. Gap formation was not recorded during the high loading levels because we were interested specifically in how the specimens ultimately failed.

Comparisons in gap distance (“gapping”) were made between constructs and location sites (anterior, middle, and posterior) after 4,000 cycles of loading by use of a 2-way factorial analysis of variance. Pairwise comparisons were performed by use of the Schefé
The study was 80% powered to detect a difference in gap size of 5 mm as a result of either construct type or location.

**RESULTS**

The mean displacement values (±SD) for maximal gapping at any position along the repair in the transosseous tunnel and single–lateral row anchor repair constructs after the initial 4,000 cycles (low loading levels) were 6.2 ± 2.99 mm and 4.9 ± 1.27 mm, respectively. There were no significant differences between the mean gap formation of the constructs ($P = .401$). For the transosseous tunnel repair, the gaps at the anterior, middle, and posterior locations after 4,000 cycles were 2.9 ± 1.37 mm, 5.1 ± 2.36 mm, and 5.1 ± 3.04 mm, respectively. For the single–lateral row anchor repair, the gaps at the anterior, middle, and posterior locations after 4,000 cycles were 2.1 ± 0.92 mm, 3.0 ± 1.31 mm, and 4.7 ± 1.20 mm, respectively (Fig 4). There were no statistically significant differences in the gap formation between the 2 techniques at the anterior ($P = .36$), middle ($P = .12$), and posterior ($P = .82$) sites (Fig 4).

After the initial 4,000 cycles (low loading levels), the mean gap formation values for all of the samples combined at the anterior, middle, and posterior locations were 2.5 ± 1.19 mm, 4.07 ± 2.13 mm, and 4.89 ± 2.21 mm, respectively. There was a statistically significant difference between the 3 sites ($P = .011$). Gap formation was significantly less at the anterior site when compared with the posterior site of the repair ($P = .015$) (Fig 5).

A substantial amount of gap formation occurred during the initial 500 cycles of low loading levels for
both repair constructs. The largest change in gapping of both constructs in the initial 500 cycles occurred during the first 25 cycles. Repair gapping in the suture anchor construct then plateaued for the remainder of the low load cycling. Gapping in the transosseous tunnel construct plateaued at 500 cycles and then began to increase substantially at approximately 3,000 cycles (Fig 6).

Qualitative analysis of repair gapping revealed 2 distinct patterns during the initial 4,000 cycles at low loading levels. All transosseous tunnel repair constructs (n = 6) failed by suture cutting through the tunnels with no evidence of suture pulling through tendon. All suture anchor repair constructs (n = 6) failed through both partial suture pulling through tendon and partial pullout of suture anchors. No suture anchors completely pulled out or bone bridges completely failed before completing the initial 4,000 cycles.

For the load cycles performed at a high level (high loading levels), 2 of 6 open construct specimens failed before completing 2,000 high load cycles. In one of these specimens 2 of 6 sutures broke (the 2 sutures in the posterior tunnel) after 10 cycles. In the other specimen the posterior transosseous tunnel fractured during the eighth cycle. After failure in each specimen, more than 1.5 cm of gapping was observed at the repair site.

Only 2 of 6 suture anchor construct specimens tolerated all 2,000 cycles at high loading levels. Of 6 suture anchor constructs, 2 failed early, at 60 cycles and 144 cycles, with a completely displaced fracture of the proximal humerus occurring at all suture anchor insertion sites. Both fractures occurred at the level of the greater tuberosity insertion site for the suture anchors, with the anchor holes appearing to act as a stress riser. Finally, the remaining 2 suture anchor constructs failed with breakage of 4 suture strands (both sutures in the middle and posterior anchors) at 51 and 724 cycles. More than 1.5 cm of gapping was observed at the failed repair sites.

**DISCUSSION**

We found no significant difference between the initial biomechanical fixation strength of a transosseous tunnel construct compared with a single–lateral row suture anchor repair construct. However, the suture anchor construct consistently had lower gapping values at each cycle interval, as depicted in Fig 6, although these differences were not found to be sig-
nificant. It should be noted that because our study was 80% powered to detect an effect size of 5 mm, we would be unable to detect a significant difference between treatments that was less than that value. Our results also indicate that the posterior aspect of a massive rotator cuff repair is more likely to fail than the anterior part of the repair under low loading conditions (low loading levels). This finding was independent of the fixation construct. Finally, we also found that a significant amount of gapping occurred during the initial 25 cycles during testing of both constructs (Fig 6). These data suggest that loading the repair with loads representing active motion may significantly compromise repair integrity. Immediate active motion after repair may lead to early repair failure and is not recommended.

Numerous authors have evaluated the initial biomechanical strength of rotator cuff tears in cadaveric models. We recognized several limitations with these models, which we attempted to improve upon to evaluate the fixation strength of massive rotator cuff repairs. First, all prior studies evaluated small- or medium-sized tears (1 to 3 cm long). Burkhart et al.6,7 created a 2 × 1–cm tear as a standard tear size to be evaluated. Other authors have replicated this same tear size in subsequent evaluations.8,14 To our knowledge, no studies have evaluated the cyclic response of the fixation techniques used for massive rotator cuff tears (≥5 cm). Second, only the supraspinatus tendon was loaded to 180 N in the previous studies.6–9,14 Burkhart et al.7 originally chose 180 N to load the supraspinatus based on force estimation models using the cross-sectional area of the supraspinatus. The model estimates maximal supraspinatus forces by use of a conversion factor (force per cross-sectional muscle area) derived from forearm muscles. Two thirds of the maximal supraspinatus force was arbitrarily chosen as the loading condition “so the load was considered to be well within the physiologic range.”7

Although we recognize that it is not possible to directly measure in vivo rotator cuff tendon forces, we believe that there are other studies that better represent the estimation of forces than those used to derive the value of 180 N of Burkhart et al.7 In our study we used data on actual force estimation of the rotator cuff muscles at our position of interest and loaded all tendons in their respective directions of pull with the humerus in this position.10,12 These forces are representative of those clinically encountered during postoperative rehabilitation after rotator cuff repair when patients are allowed active forward elevation to 90°. Active elevation is routinely allowed after the first 6 weeks postoperatively when sling use is discontinued. Force estimation of the rotator cuff required for elevation of the arm was determined by use of rotator cuff cross-sectional areas and measured muscle moments of arms.12 Maximal force estimation was based on isometric Cybex values.12 Consequently, we believe that our model better replicates the forces encountered by all rotator cuff muscles at our position of interest.

We found significantly greater gapping in the posterior aspect of the repair. Ma et al.13 also noted significantly greater posterior repair gapping in single-tendon tears repaired with single- and double-row techniques. Greater posterior repair site failure may be a result of several factors. First, the larger infraspinatus loading in our study may increase the likelihood of posterior repair failure. Our study independently loaded both the supraspinatus and infraspinatus, unlike the study by Ma et al. They also found increased posterior repair gapping with only single-tendon loading, therefore it is unlikely to be completely a result of higher infraspinatus loading. The quality of the bone in the proximal humerus, specifically the greater tuberosity, is another factor that likely affects the initial fixation strength of the posterior aspect of a repair of a large rotator cuff tear. The bone density of the posterior greater tuberosity has been identified as inferior to the anterior greater tuberosity.15 Consequently, inferior posterior bone quality will likely lead to increased bone tunnel failure and suture anchor pullout. Both partial anchor pullout and bone tunnel failure occurred as primary modes of repair failure in our study, suggesting that bone quality plays a significant role in repair failure.

The limitations of our study include the small number of cadaveric specimens that were tested. Although we found no significant difference between the transosseous tunnel and single–lateral row suture anchor repair constructs, the effect size at which the study was sufficiently powered may be larger than a clinically significant difference. Nevertheless, effect size is subjective because there are no available data to determine how a gap distance at a repair site relates to rotator cuff repair healing. A second limitation is that we only evaluated one position with one set of loading parameters. Because of the limited number of specimens, we selected a position and load pattern that replicated the position at which maximal forces would be encountered by the repair if the arm were raised actively. Third, all repairs were performed by the lead author of the report, who was not blinded to the study; therefore bias may have been introduced into the methodology. Fourth, the repair constructs were cho-
sen to simulate traditional open and arthroscopic repair constructs. All repairs were performed in an open fashion after the shoulder had been disarticulated without the use of arthroscopic equipment. Therefore both constructs “simulated” open and arthroscopic repairs but were not technically performed as if a patient was undergoing the surgical procedure. Fifth, most shoulder surgeons performing arthroscopic repairs do not actively “load” the repair initially as in this study; therefore it may have been more appropriate to test repairs with loads observed during passive motion. Therefore significant loading of the cuff immediately after repair may not be clinically relevant, rather a “worse-case scenario.” Finally, chronic rotator cuff tears were replicated with tendon excision in normal rotator cuffs, although this method of tear creation does not duplicate the attritional, degenerative nature of chronic tears in vivo.

CONCLUSIONS

We found no significant differences in gapping of in vitro massive rotator cuff tears repaired with transosseous tunnel and single-row suture anchor constructs. However, a trend indicated an improvement with the suture anchor technique. Gapping was found to significantly increase from anterior to posterior along the repair line in both repair constructs. Immediate active motion protocols produced gapping irrespective of repair technique, and neither repair performed optimally even under low loading conditions.

REFERENCES


