A Novel Method to Determine Suture Anchor Loading After Rotator Cuff Repair: A Study of Two Double-Row Techniques

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Abstract

Background: The addition of a lateral suture anchor fixation row to rotator cuff repairs has been shown to improve initial cuff reattachment strength and footprint area. This study evaluated the mechanical function of this lateral row by measuring suture tensions at the individual anchor sites.

Materials and Methods: Eight cadaveric shoulders underwent simulated rotator cuff repairs, using either double-row or suture-bridge repair techniques. Suture tensions at each anchor were measured for several static, simulated shoulder positions relevant to postoperative patient management by specially designed instrumented anchors.

Results: Significantly greater suture tensions were measured at the medial anchor sites than at the lateral sites for the double-row (p < 0.001), as well as the suture-bridge constructs (p < 0.016). In the double-row technique, the lateral row sustained 21% (range, 6 to 31) of the total anchor load; whereas, in the suture-bridge technique, the lateral row sustained 33% (range, 8 to 42). Shoulder abduction from 45° to 60° had little effect on anchor tensions; 20° internal and external rotation significantly (p = 0.032) increased loads on the anterior and posterior anchors.

Conclusions: Forces are transmitted through the entire body of the tendon at its humeral fixation, loading the lateral anchors, as well as the medial row, for the two fixation techniques studied. These findings explain the higher laboratory-obtained fixation strengths of double-row techniques. The magnitude and distribution of anchor suture tensions could have important implications for postoperative positioning and activity.

Rotator cuff tendon repairs using arthroscopic techniques have become increasingly common. Surgeons have a wide array of instrumentation, implants, and techniques that make more complex tears amenable to arthroscopic repair. However, in spite of these advances, the failure rate of arthroscopic rotator cuff repair for massive cuff tears remains high, with reported re-tear rates between 41% and 94%. The need to improve these clinical results has led to the development of techniques and associated devices to improve the strength of the repair and the contact area and pressure of the tendon on the cuff footprint to increase its healing ability.

One such innovation is the use of a “double-row” rotator cuff repair. In this repair method, two rows of anchors are used to fix the cuff; one along the articular cartilage margin and the second at the lateral ridge of the greater tuberosity. This technique allows the surgeon to increase the strength of repair by increasing the number of sutures passed through the tendon and by increasing the area of contact between the tendon and bone. The “transosseous equivalent,” or suture-bridge technique, involves using a medial row of anchors, with sutures passed and tied through the tendon medially, after which the suture tails are draped over the remaining lateral cuff tendon and fixed laterally. This repair configuration has been shown to increase not only the contact area, but also the mean contact pressure over the footprint.

The addition of lateral row fixation, either by a double-row or suture-bridge technique, has been shown to increase the strength of cuff fixation in biomechanical studies.
However, we know of no studies that document the relative tensions carried by the lateral and medial rows. The purpose of this study was to develop a method in which the loads borne by individual anchors in a simulated rotator cuff repair could be assessed. Using this novel experimental model, we sought to determine the relative anchor tensions experienced by the medial and lateral rows in double-row and suture-bridge rotator cuff repair constructs for several, clinically relevant shoulder positions. Our initial hypothesis was that the medial rows would bear most of the load.

Materials and Methods
A cadaveric study was performed using eight fresh-frozen shoulders. The shoulders were stored at -20°C and were thawed to room temperature before testing. The humeri were disarticulated, and all muscle and soft tissue attachments, except for rotator cuff tendons, were detached; the cuff tendons being detached at their scapular origins. The distal portion of each humerus was potted with polymethylmethacrylate into a square aluminum tube. Rotator cuff tears were created by visualizing the anterior and posterior extents of the supraspinatus tendon, followed by sharp detachment of the tendon in its entirety from the greater tuberosity. Specimens were randomized into two groups of four, and tendons reattached to the tuberosity by either a double-row or suture-bridge technique.

The instrumented anchors created for this study consisted of a loop of 0.45 mm nylon-coated, stainless steel cable, contained within a 1.6 mm diameter stainless steel tube (Fig. 1). The free ends of the cable were attached to a brass coupon, to which a linear strain gauge (KFG-3-120-C1-11; Omega Engineering, Stamford, Connecticut) was affixed by epoxy and coated with a thin silicone layer for protection. The other end of the coupon had an 18-gauge stainless wire “tail” attached for anchor fixation. Each anchor was calibrated by holding the wire tail in a vise, applying 1 kg, 2 kg, and 5 kg to the loop and measuring the resulting strain output, using a digital strain meter (P-1500; Measurements Group, Raleigh, North Carolina). For experimental use, these anchors were inserted retrograde into the transhumeral tunnels until the tube was just below the bone surface, and the loop exposed (Fig. 1). The tube was then affixed to the medial humerus with a drop of cyanoacrylic adhesive.

In the double-row group constructs, six transhumeral tunnels (1.7 mm diameter) were created with a long drill, exiting on the medial side of the humerus. They were evenly spaced over the greater tuberosity, with three tunnels at the articular margin spaced 10 mm apart from anterior to posterior and three created directly 10 mm lateral to the initial set. In the suture-bridge group, six transhumeral tunnels were also created; the medial tunnels were in the same positions but the three lateral transhumeral tunnels were created 15 mm lateral to the medial row. A No. 2 Ethibond (Ethicon, New Brunswick, New Jersey) suture was passed through each cable loop of our anchors and then used to repair the tendon to the greater tuberosity.

For the medial row in both techniques, horizontal mattress sutures were created, with both suture limbs passed through the tendon, 15 mm from its lateral edge. Corresponding limbs from each suture were spaced 5 mm apart. Knots were tied simulating an arthroscopic technique, with an initial...
Weston followed by three alternating half-hitches.

In the double-row group, simple vertical stitches were placed in the lateral margin of the tendon, with only one suture limb passing through the tissue 10 mm from the edge of the tendon. The knots were tied in an identical fashion, with the limb through the tendon acting as the post.

In the suture-bridge group, the limbs of the three medial row knots were passed through the lateral anchor loops. The sutures were crossed such that the limbs of the middle knot were passed through the anterior and posterior loop, and a limb from the anterior and posterior knots was tied to each respectively. Finally, the second limb from the anterior knot was passed through the middle loop of the lateral row and tied to the second limb from the posterior knot (a schematic of this configuration shown in Fig. 3).

The free end of the supraspinatus was wrapped over the straight side of a steel D-ring and fixed to itself by sutures. The mounting tube of the specimen construct was then fixed in a vise. The loops of the anchors were subsequently individually tensioned by applying a spring gauge of 10 Newtons to their medial wire extension “tails” and securing the tails, under tension, to a rigid frame attached to the medial side of each humeral construct.

The individual gages were then multiplexed to the digital strain meter and “zeroed.” The cuff repair had a 50-Newton force applied by tensioning the supraspinatus using a fixed weight. This load was applied to the supraspinatus D-ring by a nylon cord that passed over a pulley held on an adjustable (for angle and direction of “pull”) ring stand. This experimental set-up is shown in Figure 2. Loads at the six anchor sites were measured with the supraspinatus held at 45° and 60° to the superior margin of the greater tuberosity, in a direction directly over the humeral head to simulate arm positions in a standard and abduction sling. At the 45° position, loads were also applied at 20° anteriorly and posteriorly to the initial position to simulate rotation.

The load borne at each anchor was recorded for each loading condition after 2 minutes for equilibration, and at the end of testing, with the load removed to check gauge and anchor stability. Strain data from individual anchors were collected and converted to loads using the calibration curves (all linear). Unpaired Students t-tests were used for statistical comparisons.

**Results**

Significantly greater total loads were measured for the medial anchor rows than the lateral rows for the double-row (p < 0.001) and suture-bridge (p = 0.016) constructs. A typical result is shown in Figure 3. With the double-row technique, the lateral row sustained 21% (range, 6 to 31) of the total tension on all anchors. For the suture-bridge technique, the lateral row sustained 33% (range, 8 to 42) of the total tension. This difference between the two techniques was not significant (p = 0.330). Shoulder abduction from 45° to 60° had little obvious effect on anchor tensions; 20° simulated internal, and external rotation significantly (p = 0.032) increased loads (from 65% to 110%) on the two anterior or posterior anchors of both rows.

**Discussion**

Our findings demonstrate that a significantly greater load is borne by the medial row of anchors, compared to the lateral row in both the double-row and suture-bridge repairs. However, it is apparent that forces are transmitted through the entire body of the tendon at the fixation and not interrupted at the medial anchors. Somewhat surprising was the amount of load that is borne by lateral row anchors. Initially, we hypothesized that an intact medial row of anchors would preclude loads being transferred to the lateral row, and lateral fixation only became a factor once the medial row had failed. It is also interesting that the amount of the total load, approximately 25% to 35%, borne by the lateral row is similar to the increase in rotator cuff fixation strength found in laboratory studies.3,5,11,12

These loads on the lateral anchors at the time of rotator cuff repair may impact on the type of fixation best suited for this location. Studies have demonstrated decreased bone mineral density in the trabecular bone of the distal greater tuberosity when compared with the proximal bone.13 Additionally, the bone mineral density of cancellous bone in the greater tuberosity has been shown to be further reduced in patients with full-thickness rotator cuff tears.14 Taking these factors into account, lateral row anchors may need to be capable of withstanding higher tensions and pull-out load than previously thought.

In our study, no significant differences were observed in the medial-lateral tension distributions when the cuff was positioned 45° or 60° to the footprint. This would suggest that the type of sling, with or without an abduction pillow, would not impact the tension distributions. However, further investigation of static and dynamic shoulder positioning may clarify the best position of immobilization and mode of early therapy. The increased anchor loading seen with
rotation raises concerns and merits further study.

The limitations of this study include the relatively small sample size, and that anchor loads were only determined in a few static positions. In this model, the anchors all started with the same suture-cuff tension, which is clinically unlikely. In fact, when the tension was partially released in the medial row during specimen disassembly, the lateral row was visually seen to bear most of the load. Also the two rows were quite linear and placed with the anchors in both rows in line with each other and, generally, with the applied load, which is probably not achieved in an actual patient. This pattern is also only one possible anchor positioning. The stability of this method was not tested in fatigue, so its ability and stability to measure loads in cyclic tests is unknown. This was the initial concept for this study to measure how loads were transferred between the anchors as tendon cut-through occurs. Lastly, the total anchor loading was 40% to 70% of the applied 50 N. It was determined that the angle of pull on the anchor loop affected friction of the cable against the anchor body. Although this would be consistent for all anchors for a particular test, the anchors should have been calibrated for different load application angles. This would be critical for dynamic range of motion testing and could have affected the load measurement comparison between 45° and 60°.

In conclusion, we were able to develop an experimental model where the loads experienced by the individual suture anchors in a simulated rotator cuff repair could be quantified. Only one applied load was used, but it seems likely that the results would be similar for other loads that were less than those causing failure of the tendon or sutures. While we expected the medial row to bear the majority of the load in double and suture-bridge constructs, a surprising finding was the amount of load borne by the lateral row for both techniques. This may have implications for the type of cuff fixation device used, as well as for rehabilitation after fixation of tears using either of these techniques. In future studies, determination of tension distributions with other anchor arrangements, measurements in positions of static forward flexion and extension, and analysis of tension throughout dynamic shoulder motion could help optimize repair strength and direct early therapeutic methodology.

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