Differential Suture Loading in an Experimental Rotator Cuff Repair

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Differential Suture Loading in an Experimental Rotator Cuff Repair

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Background: Repairs of large rotator cuff tears often fail to heal. A possible factor in these failures is excessive tension in the repair sutures, causing them to pull through the tendon.

Hypothesis: Arm positions encountered during early rehabilitation after cuff repair can dramatically increase the relative tension in the different sutures of the cuff repair.

Study Design: Controlled laboratory study.

Methods: In a cadaver model, a 4-suture supraspinatus repair was carried out with transosseous sutures. After the repair, the arm was placed in 12 different positions. The tension in each suture was monitored using individual load cells.

Results: When the arm was externally rotated relative to the plane of the scapula, the tension in the anterior suture was over 10 times that in the posterior suture ($P < .001$). When the arm was internally rotated, the tension in the posterior suture was over 10 times that in the anterior suture ($P < .0005$). When the arm was in neutral rotation, there was no significant difference in the suture tension.

Conclusions: This study is the first report of direct suture tension measurement after a model rotator cuff repair. In this model, 30° of either internal or external rotation of the arm in relation to the plane of the scapula created substantial imbalances in the tension between the most anterior and most posterior sutures of a supraspinatus repair, regardless of the position of abduction.

Clinical Relevance: Avoiding external rotation stretching during the healing of supraspinatus repairs may prevent tension overload in the critical anterior suture.

Keywords: rotator cuff repair; suture tension; repair interface motion; supraspinatus

Surgical repair of substantial rotator cuff tears frequently fail to achieve durable healing; this is at least in part because the quality of torn tendons is commonly diminished, allowing repair sutures to fail by pulling through the tendon tissue.[§] As a result, surgical techniques attempting to reapproximate deficient and degenerated tendons to bone can fail because of suture tension overload.[7,8,18] There have been many efforts to improve the surgical technique of cuff repair, but even the most modern surgical repair techniques fail to achieve durable integrity of the rotator cuff tendon in a substantial number of cases.[23,26,35] Surprisingly little attention has been directed toward methods for protecting the repair during the healing period. Specifically, the effect of arm position on the tension in individual rotator cuff repair sutures has not been previously investigated. This study tested the hypothesis that glenohumeral positions potentially encountered during rehabilitation after cuff repair can dramatically increase the relative tension in certain of the rotator cuff repair sutures.

MATERIALS AND METHODS

Setup

We used 6 fresh-frozen cadaver shoulders (age range, 71-97 years; median, 84; mean, 81.5; standard deviation, 12.2). The selected specimens had no grossly apparent rotator cuff defects or calcifications. To isolate the effects of the supraspinatus repair from the effects of other soft tissues, as in previously published cadaveric studies on cuff repair,[7-9] all soft tissues were removed from the proximal humerus except for the supraspinatus and associated capsule.

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The supraspinatus was divided from the subscapularis using the bicipital groove as its anterior border. The supraspinatus was delineated from the infraspinatus posteriorly by extending the muscular division at the scapular spine to the tendinous insertions of the muscles. The humerus was secured in a clamp fixed to the base of a material testing system (MTS) (MTS Model 858 Bionix Test System controlled by TestStar II software, MTS Systems Corporation, Eden Prairie, Minnesota) (Figure 1). The medial end of the supraspinatus tendon was secured to a clamp connected to the MTS so that the direction of pull was in a consistent horizontal direction. A plane passing through the direction of pull of the supraspinatus and through the humerus when it was vertically positioned represented the plane of the scapula. The base to which the humerus was potted had 4 locked positions of abduction: 0° (humerus vertical and at right angles to the direction of pull of the supraspinatus), 30°, 60°, and 90°. It also had 3 locked positions of rotation: 0° (flexed forearm perpendicular to the direction of pull of the supraspinatus), 30° of external rotation, and 30° of internal rotation. This system allowed the arm to be fixed in the desired degree of abduction and rotation for each test.

The supraspinatus insertion was incised from its humeral attachment. Four equally spaced and parallel 2.5-mm holes were drilled through the tuberosity in the lateral footprint of the supraspinatus insertion in a manner analogous to that used in a bone-tunnel cuff repair (Figure 2). To minimize the effect of friction in the bone tunnels on the measurement of suture tension, the holes were lubricated with PDI lubricating jelly (Healthcare Division, Nice-Pak Products, Inc, Orangeburg, New York). Four calibrated load transducers (Sensotec Load Cells Model 11, Honeywell Sensotec, Columbus, Ohio), with a full-scale range of 50 lb and 1.1% full-scale accuracy, were secured to the bone just distal to and in direct line with the lateral exit of the holes. Four equally spaced nonabsorbable braided sutures (No. 2 Ticron, Davies & Geck, Danbury, Connecticut) were passed through the tendon using a simple horizontal mattress suture 5 mm from the tendon edge. Although a number of different suture techniques could have been used, the simple horizontal mattress was selected because we have observed it to be among the more commonly used methods for tendon grasping in clinical practice.[2,18,20] Each suture was anchored to bone by passing the 2 limbs of each suture through the transosseous hole and tying them to the corresponding load transducer that was fixed to the bone. This method of fixation did not allow for movement of the sutures in the bone tunnels. The output from the load transducers was monitored in real time at 250 Hz (LabVIEW 8 Full Development System, National Instruments, Austin, Texas).

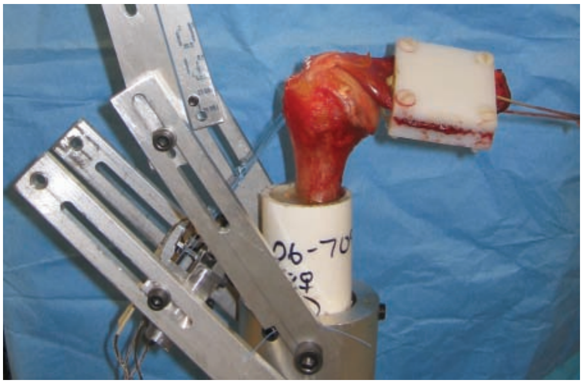

Figure 1. Experimental setup. The humerus is held in an adjustable holder permitting rotation and abduction. The supraspinatus tendon is grasped in a clamp for loading. The cuff is repaired to the humerus using transosseous sutures.

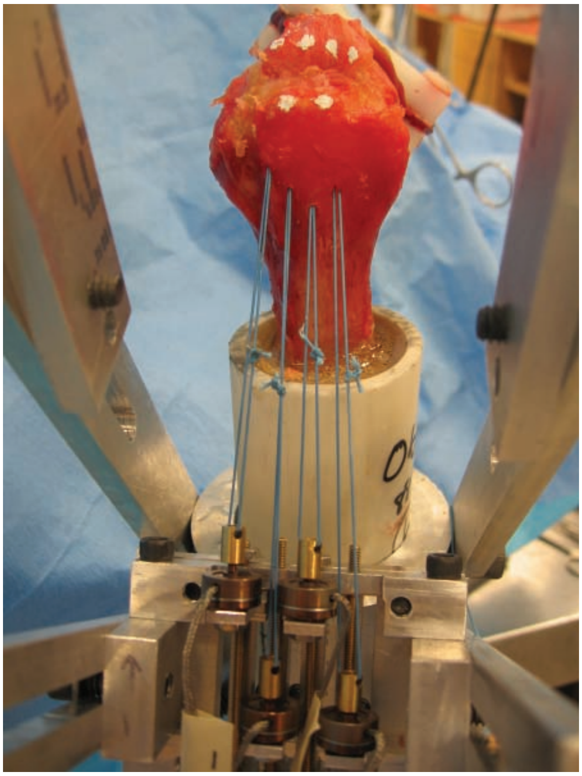

Figure 2. The repair sutures pass through lubricated holes in the tuberosity to be fixed to load cells mounted to the humerus.

Testing Protocol

All experiments were conducted at room temperature. The tendon was kept moist with saline. A wide variety of loading protocols could have been used, but we elected to emulate the situation in which the supraspinatus muscle was contracted with a moderate force with the arm in different positions. Although the in vivo loads encountered by the repaired cuff have yet to be measured, we observed that (1) supraspinatus activity during active-assisted forward elevation is approximately 13% of the maximal activity[32] and (2) supraspinatus force at maximal exertion during abduction is approximately 120 N.[22] Thus loads in the range of 20 to 40 N seemed within the limits of what would be anticipated during early postoperative rehabilitation. Before testing, all sutures were tensioned to 2 N using a custom suture-tensioning device with the humerus in 0° of abduction and 0° of rotation. The arm was then placed in the desired glenohumeral position where the tendon was preloaded to 20 N at a rate of 10 cycles/min for 10 cycles. The tendon was then loaded from 0 to 40 N while the tension in each suture was recorded with the respective load transducer. We selected the load level of 40 N to minimize the cumulative effect on the specimens. Although we cannot be sure that a minimal amount of slippage did not occur, there was no apparent movement between the sutures and the bone; none of the repairs failed with the 40-N load.

The positions selected were those likely to be included in rehabilitation after cuff repair. For example, Bigliani et al[5] recommend a program of "pendulum exercises, external rotation of the shoulder with a stick while the patient is supine, and assisted forward elevation in the scapular plane" after cuff re-repair. Cuff rehabilitation programs often include immobilization in a sling or in an abduction pillow. These programs also use various degrees of passive elevation in different planes with respect to the scapula and body.[11-13,17,20] For each of the rotational positions (0°, 30° of external rotation, and 30° of internal rotation relative to the direction of pull of the supraspinatus), this testing protocol was repeated with the arm sequentially placed in 0°, 30°, 60°, 90°, 60°, 30° and 0° of abduction in the plane of the scapula. The sequence of testing was identical for all shoulder specimens.

Data Analysis

This study tested the hypothesis that glenohumeral positions potentially encountered during rehabilitation after cuff repair can dramatically increase the relative tension in certain positions of the rotator cuff repair sutures. To simplify the analysis, we considered only the sutures at either end of the repair (ie, the anterior and posterior sutures). To analyze the interaction effects of suture position (2 levels), rotation (3 levels), and abduction (7 levels), we performed a 3-way $2 \times 3 \times 7$ repeated-measures analysis of variance followed by a series of paired multiple comparisons. Because of the number of multiple comparisons, we used Holm's sequential Bonferroni procedure[21] to maintain a $P < .05$ family-wise error rate across the 7 multiple tests (1 for each of the 7 different degrees of abduction) conducted for anterior and posterior sutures for each of the 3 rotation positions. We reported both the unadjusted P values derived from the paired comparisons and the sequential Bonferroni-adjusted P critical values in the results.[21,38] Data analysis was performed using SPSS 13.0 for Microsoft Windows (SPSS Inc, Chicago, Illinois).

Because no prior data were available on which to perform an a priori power analysis, a sample size consisting of 6 specimens was selected, with the recognition that this sample size would only adequately test for possible significant differences but not the absence of significant differences. A post hoc power analysis was performed assuming $P < .05$ and mean differences of 3 N between anterior and posterior sutures at each degree of abduction at each rotation position. This resulted in an estimated power of 0.85 for the 3-way interaction effect, while the estimated power for any 1 comparison was estimated to be only 0.10. With a sample size of 6 cadaveric shoulders, an estimated mean difference of approximately 8 N between anterior and posterior sutures would be required to reach a power of 0.80.

RESULTS

Overall Interaction of Suture Position, Abduction, and Rotation

The results of the analysis of variance for suture tension indicated that there was a statistically significant main effect for abduction ($F_{6,30} = 6.12$, $P < .001$), significant 2-way interactions for suture × rotation ($F_{2,10} = 229.50$, $P < .001$) and for suture × abduction ($F_{6,30} = 3.86$, $P = .006$), and a significant 3-way interaction for suture × rotation × abduction ($F_{12,60} = 13.75$, $P < .001$). The main effects for suture ($F_{1,5} = 2.30$, $P = .190$) and for rotation ($F_{2,10} = 2.08$, $P = .176$), and the 2-way interaction for rotation × abduction ($F_{12,60} = 0.60$, $P = .835$), were not statistically significant.

With the humerus in neutral rotation, the tensions in the anterior suture ranged from 5 N to 9 N, while the tension in the posterior suture ranged from 8 N to 13 N, in the different positions of abduction (Table 1). These tensions were not significantly different. With the humerus in 30° of external rotation, the tensions in the anterior suture ranged from 16 N to 20 N, while the tensions in the posterior suture were approximately 1 N in each of the different positions of abduction (Table 1). These differences were significant ($P < .05$). Note that the Bonferroni-adjusted significance levels are the thresholds for overall family-wise $P < .05$. For example, the first row in Table 1 for 0° of abduction at 30° of external rotation indicates that the obtained P value of .0003 is less than the Bonferroni-adjusted P value of .0100, thus exceeding the threshold to be statistically significant at $P < .05$, taking into account all 7 multiple tests. With the humerus in 30° of internal rotation with respect to the plane of the scapula, the tensions in the anterior suture ranged from 0 N to 2 N, while the tension in the posterior suture ranged from 18 N to 24 N. These differences were significant ($P < .05$), with the Bonferroni adjustment as described above. In each of the 3 rotational positions, the shoulders were tested at 0°, 30°, 60° and 90° of abduction. Then the tests at 60°, 30°, and 0° of abduction were repeated. With the number of specimens in this study, significant differences were not observed between the first and second trials at each position of abduction.

DISCUSSION

In spite of the wealth of clinical and laboratory research on rotator cuff repair, surgical repairs of substantial rotator cuff tears continue to fail to achieve durable healing.[‡] In a rotator cuff repair, the quality of the fixation of the cuff to bone is determined by the suture material,[4,36] the knot,[1,18,27,28,33,34] the quality of bone to which the suture is

[‡]References 5, 6, 11-17, 19, 20, 24, 25, 39, 40.

TABLE 1
Tension in Each Suture With Loading in Different Positions of Abduction and Rotation[a]

Position	Anterior Suture Tension (N) Mean (SD)	Posterior Suture Tension (N) Mean (SD)	Paired Comparison $P \leq$	Bonferroni-Adjusted Critical Value[b] $P \leq$
Neutral rotation with degrees of abduction below				
0	8.9 (2.1)	10.0 (5.4)	.5466	.0250
30	7.5 (2.5)	12.3 (7.0)	.1564	.0125
60	4.8 (3.5)	13.4 (7.1)	.0507	.0084
90	4.5 (4.2)	12.8 (5.6)	.0435	.0072
60 (second trial)	4.7 (3.2)	12.1 (6.4)	.0624	.0100
30 (second trial)	7.2 (2.1)	10.6 (6.3)	.2313	.0167
0 (second trial)	8.4 (1.9)	7.8 (5.4)	.7526	.0500
30° external rotation with degrees of abduction below				
0	18.1 (4.5)	1.2 (0.9)	.0003[c]	.0100
30	18.8 (4.1)	0.9 (0.6)	.0001[c]	.0072
60	19.5 (5.1)	0.9 (1.0)	.0004[c]	.0167
90	17.6 (4.6)	0.9 (1.3)	.0006[c]	.0500
60 (second trial)	17.6 (4.8)	0.7 (0.8)	.0005[c]	.025
30 (second trial)	17.0 (3.9)	1.0 (0.5)	.0003[c]	.0100
0 (second trial)	16.4 (3.6)	1.0 (0.6)	.0002[c]	.0084
30° internal rotation with degrees of abduction below				
0	1.8 (1.0)	20.5 (4.1)	.0001[c]	.0084
30	1.1 (0.9)	23.2 (5.3)	.0002[c]	.0100
60	0.5 (0.8)	23.6 (4.4)	.0000[c]	.0072
90	0.3 (0.7)	21.3 (5.4)	.0002[c]	.0100
60 (second trial)	0.5 (0.8)	22.1 (6.0)	.0003[c]	.0167
30 (second trial)	0.9 (0.7)	21.5 (6.0)	.0004[c]	.0250
0 (second trial)	1.6 (0.8)	18.2 (5.0)	.0004[c]	.0250

[a]SD, standard deviation.
[b]P value for significance of individual comparison test to maintain family-wise $P < .05$. Second trial across all 7 tests is based on Holm's sequential Bonferroni adjustment.
[c]$P < .05$, two-tailed for this paired comparison is based on Holm's sequential Bonferroni adjustment.

fixed,[9,18,37] and the quality of the tendon.[31] Although the surgeon can control the suture material, the knot, and the quality of bone (by suturing to cortical bone more distally if needed),[30] he or she cannot control the quality of the tendon. Poor-quality tendon is more prone both to tearing and to failure of repair from suture-tension overload. In spite of extensive research in tendon grasping techniques, suture purchase on the tendon remains the "weakest link" in cuff repair.[3,7] For this reason, rotator cuff repairs need protection from suture-tension overload while the bone heals to the tendon.[3,10,18] The need for protection is greater for older individuals.[7] The part of the repair most likely to fail depends on the defect in the cuff, the quality of the residual tendon, and the tension in the repair sutures.[7] The surgeon can reduce the tension in each suture by performing surgical releases of the tendon, by increasing the number of sutures, and/or by positioning the arm to distribute the tension evenly across the sutures used in the repair. The relationship between shoulder position and suture tension has not been previously investigated.

In this cadaver model of a 4-suture supraspinatus repair, positions of 30° of external rotation with respect to the scapula dramatically concentrated the load in the anterior suture, regardless of the amount of abduction. As stated in texts on shoulder radiography, the scapula usually rests in a position of 30° of internal rotation on the thorax.[29] Thus, the position referred to as "neutral" rotation of the humerus (commonly used in immobilization and passive motion of the shoulder after cuff repair) actually puts the humerus in external rotation with respect to the scapula, the position in which the anterior suture is preferentially loaded. Conversely, the "sling" position places the arm in internal rotation where the tension is concentrated in the posterior suture, again regardless of the amount of abduction.

The results of our study need to be considered in view of certain limitations. First, we investigated only 1 type of cuff repair situation: the repair to bone of an isolated supraspinatus tear; this simulates only 1 type of tendon defect. Second, it is likely that the tension in a surgically repaired tendon is not equal anteriorly and posteriorly and that the tendon's material and structural properties may not be symmetrical from front to back. Third, we studied only a repair to bone using a transosseous, simple horizontal mattress-suture repair; this simulates only 1 of many possible repair methods. Fourth, we investigated suture tension in response to a small applied load; this also simulates only 1 of many ways in which a repaired tendon might be loaded after surgery. Fifth, we only investigated suture tension in 12 different positions and thus did not explore all possible combinations of elevation and rotation. Sixth, although the specimens were from individuals advanced in age at the time of death, the tendon repaired in this study appeared grossly normal and may not represent the quality of tissue repaired in clinical cuff surgery. Seventh, we did not test the fixation to failure. Finally, we did not attempt to replicate in vitro the complex and varying patterns of loading of the individual elements of the rotator cuff mechanism that occur in vivo. Although the statistically significant differences we observed are clearly supported by the data, this sample may not have been sufficiently large to adequately rule out the possibility that some of the nonsignificant differences could be significant. In spite of these limitations, we were able to successfully test our hypothesis regarding suture tension. The data clearly show that in this model, loading the cuff in certain positions creates 10-fold differences in the tension in the anterior and posterior repair sutures. Of particular concern is the increased loading at the anterior suture when the arm is in 30° of external rotation relative to the plane of the scapula—a position equivalent to neutral rotation with respect to the thorax.[29] This position is advocated in many published recommendations regarding postoperative care of rotator cuff repairs.[§] Similarly, internal rotation in the sling position may increase the tension load in the posterior suture. This result suggests that the risk of tension overload in repair sutures may be reduced by avoiding these positions during healing of a rotator cuff repair.

CONCLUSION

Rotator cuff tears often occur in weakened tendon tissue. Repairs of torn rotator cuffs are at risk for failure due to suture tension overload at the repair site. Suture tension can be increased in certain arm positions encountered during the early healing period. This study demonstrates that positions of external rotation relative to the plane of the scapula concentrate tension in the anterior sutures, while positions of internal rotation concentrate tension in the posterior suture. Positions of neutral rotation with respect to the scapula minimized the tension at all suture locations in this cadaveric model and may be the safest positions during cuff repair healing. This was not a load-to-failure study. Our goal was to show that different positions resulted in differential loading of the repair sutures. In the clinical situation, the tension in each suture depends on the load applied by the tendon, and the "safety zone" would be determined by the quality of the tendon.

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[§]References 5, 6, 10, 12, 13, 15, 20, 30.

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