Suture Anchor Biomechanics After Rotator Cuff Footprint Decortication

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Purpose: To identify the biomechanical consequences of violating the cortical shelf when preparing the greater tuberosity for suture anchor repair. Methods: Demographic information and bone mineral density were obtained for 20 fresh-frozen human humeri (10 matched pairs). Suture anchors were placed at a predetermined location in decorticated and non-decorticated settings after randomization. Anchors were tested under cyclic loads followed by load-to-failure testing. The number of cycles, failure mode, stiffness, and final pullout strength were recorded. Results: Nineteen specimens met the inclusion criteria for final testing. A significant difference in mean ultimate load to failure was seen between the non-decorticated specimens (244.04 ± 89.06 N/mm) and the decorticated humeri (62.84 ± 38.04 N/mm, \( P < .0001 \)). Regression analysis showed positive correlations with female gender and decreased bone mineral density (\( P = .008 \) and \( P = .0005 \), respectively). Conclusions: Decortication of the rotator cuff footprint significantly decreases the pullout strength of the suture anchor. Gender and bone mineral density also play a significant role in bone-anchor biomechanics and should be considered during repair. Clinical Relevance: Caution should be exercised when preparing the rotator cuff footprint before suture anchor placement because of the significant risk of early repair failure at the bone-anchor interface.

Arthroscopic rotator cuff repair plays an integral role in the surgical treatment of shoulder pain related to pathology of the degenerative rotator cuff.\(^1\)\(^-\)\(^3\) Arthroscopic techniques for rotator cuff repair are becoming increasingly used in part because of the ease of use and success of screw-in-type suture anchors.\(^3\)

Failure of the repair can be attributed to a multitude of factors, both patient and technique related. The tissue itself, both bone and tendon, often dictates the healing potential and durability of the repair. The rate of rotator cuff pathology increases with age.\(^1\)\(^,\)\(^4\) The quality of the patient’s bone also has an age-dependent relation, and the bed for tendon repair may be of compromised bone quality.\(^5\)\(^,\)\(^6\) In addition, many authors have shown osteopenic changes to the greater tuberosity in the presence of a rotator cuff tear, independent of age.\(^7\)\(^-\)\(^11\) Reported failures of fixation have been linked to suture anchor loosening, migration, and pullout.\(^12\)\(^-\)\(^16\) Initial failure can lead to intra-articular damage, pain, and reoperation.\(^17\)\(^-\)\(^19\)

Greater tuberosity decortication is commonly performed because of the perceived biological benefit; however, the ideal method of preparation remains unclear. Decortication of the rotator cuff footprint may influence suture anchor biomechanics. The holding strength of screw-type implants is compromised in an osteoporotic setting, often seen accompanying rotator cuff tears.\(^20\) Removing the stronger cortical bone may further place the anchor at risk of pullout and failure.\(^21\) Studies have shown that suture anchors have improved pullout characteristics when placed in areas of increased bone mineral density (BMD).\(^22\)\(^-\)\(^25\) The purpose of this study was to identify the biomechanical consequences of violating the cortical shelf when preparing the greater tuberosity for suture anchor repair. We hypothesized that decortication of the rotator cuff footprint would decrease the pullout force of a suture anchor compared with non-decorticated controls to below a safe minimum value.

Methods

Twenty fresh-frozen human cadaveric humeri (10 matched pairs; Rutgers Robert Wood Johnson Medical
School Anatomical Association, Piscataway, NJ) were harvested and stored at −20°C. Specimens were thawed at 4°C for 36 hours before testing. Once fully thawed, all soft tissue was removed and the specimens were visually inspected for osseous defects about the greater tuberosity. The distal end of the humerus was potted approximately 10 mm below the distal border of the humeral head in a 2-part epoxy resin. A Lunar dual-energy x-ray absorptiometry machine (GE Medical Systems, Waukesha, WI) was used to measure the bone density of each specimen. The proximal aspect of the greater tuberosity was divided into 3 separate regions of equal size (anterior, middle, and posterior regions) using a flexible ruler and in accordance with previous studies. The proximal anterior and proximal middle regions of the greater tuberosity of each specimen were selected for testing because these areas have been previously shown to have similar and consistent bone quality and suture anchor pullout characteristics; in addition, they are clinically relevant areas for placement of suture anchors in rotator cuff repair. Titanium 5.5-mm all-metal suture anchors (Ti Twinfix Ultra; Smith & Nephew, Andover, MA) were used. As has been performed in previous studies evaluating suture anchor biomechanics, the original suture was replaced by a 0.6858-mm-diameter stainless steel wire rope (McMaster Carr Supply, Chicago, IL) before insertion to increase stiffness and eliminate suture breakage as a mode of failure. In accordance with the manufacturer’s recommendations, the center of the region of interest was identified and tapped before insertion of the suture anchors. The anchors were then inserted at a 45° angle to the bone surface. The proximal humeral shaft that had been previously potted in epoxy was fixed to a custom-built variable-angle jig. The jig was rotated on the Instron machine (MTS Systems, Eden Prairie, MN) to create a vector of pull directly in line with the suture anchor. This angle was chosen based on previously established studies by Barber et al. and simulates a worse-case scenario for suture anchor pullout and failure. The steel wire that replaced the original suture was then fixed to the Instron mechanical testing crosshead (model 5569, 10-kN load cell; MTS Systems).

Each specimen was cyclically tested with an extension rate of 1 mm/s, similar to previously published data. Cyclic testing consisted of 4 different testing conditions (cycle 1: 0 to 50 N for 10 cycles; cycle 2: 0 to 100 N for 10 cycles; cycle 3: 0 to 150 N for 10 cycles; and cycle 4: 0 to 200 N for 10 cycles). If the anchor remained intact after cyclic loading, the specimen was then pulled to failure. The number of completed cycles, mode of failure, and ultimate load were recorded for each pullout test. The load-elongation curve for each specimen was also recorded and used to calculate the stiffness of anchor fixation. The average stiffness of...
fixation for each cycle was calculated by examining the load-elongation curve between the 10% and 90% points of the maximum load using a custom-written analysis program (Bluehill Software, Norwood, MA).23

All statistical analysis was performed using R software (version 3.0.3; R Foundation, Auckland, New Zealand) including standard t tests, linear models, and Spearman correlation coefficients. We applied t tests to compare the mean final pullout loads for the decorticated and non-decorticated groups. Linear models were used to analyze the combined effect of age, gender, and BMD on final pullout strength. Spearman correlation was calculated to analyze the relation between gender and BMD. An a priori power analysis using previous load-to-failure data showed that a sample size of 18 specimens would provide statistical power of 80% to detect mean differences in load to failure of 1 SD between the 2 regions of interest in the greater tuberosity (β = .1, α = .05).23

Results

One complete specimen was excluded because of a visual defect noted before testing. Another specimen testing site was eliminated because of the occurrence of a visible fracture during anchor placement (Fig 4). Thus there were 19 total specimens (10 male and 9 female specimens) with a mean age of 74.4 years (range, 64 to 89 years and 42 to 93 years, respectively). The mean final decortication depth was 5.6 mm (range, 4.1 to 7.2 mm). The average dual-energy x-ray absorptiometry result was 0.628 g/cm² for the male cohort and 0.552 g/cm² for the female cohort (SD, 0.11 g/cm²).

All suture anchor pullout failures occurred at the bone-anchor interface. The non-decorticated group showed statistically significantly higher load-to-failure values and numbers of cycles than the decorticated group, with mean load-to-failure values of 244.04 ± 89.06 N/mm versus 62.84 ± 38.04 N/mm (P < .0001) (Fig 5). For each load interval, there was no significant difference in stiffness between the groups at 50 N (P = .287) and 100 N (P = .1031). However, none of the anchors placed into decorticated areas reached 150-N or 200-N loads during the cyclic loading testing.
The non-decorticated group achieved significantly more cycles under the loading conditions ($P < .001$) (Table 1).

Regression analysis including decortication group and specimen age, gender, and BMD was performed. The presence of decortication ($P < .0001$), gender ($P = .008$), and BMD ($P = .0005$) were significant regarding decreased final pullout strength of anchors.

**Discussion**

The results of this study showed that decortication of the rotator cuff footprint significantly decreases the pullout strength of the suture anchor. Investigations looking at this primary parameter are limited. As part of their most recent biomechanical updates, Barber et al. tested cyclically loaded anchors in a cortical and cancellous environment. For this secondary outcome measure, they found no difference in the final pullout strength between each group. However, they used a small sample of porcine femurs. Animal models, particularly porcine models, may overestimate the biomechanical properties compared with human models and may not show differences between groups that would be apparent in human models. In addition, there were no BMD data to quantify the quality of each specimen’s bone-anchor interface. This limits the conclusions that can be drawn related to anchor performance.

The minimum pullout strength needed per anchor is approximated at 200 to 300 N. Estimates vary, in part because the minimum pullout strength depends on how the author has measured the vector and which muscle of the rotator cuff is being evaluated. There is no consensus regarding the "minimum" pullout strength of an anchor. Our data would indicate that the differences in ultimate load to failure between non-decorticated and decorticated specimens seen in this study are not only statistically significant but also clinically significant because the decorticated anchors pulled out at a mean of $62.84 \pm 38.04$ N/mm, well below the aforementioned threshold for estimated minimum pullout strength.

Several studies have looked into the effect of bone quality on anchor performance. Rossouw et al. showed that suture anchors placed in the lateral proximal humerus, using a transosseous technique to achieve placement of a lateral anchor, had better pullout biomechanics than anchors placed in decorticated bone in the greater tuberosity proper. Mahar et al. investigated insertion depth as a means to improve bony purchase. They found that deeper placement of suture anchors at 6 mm below the eyelet compared with the standard insertion depth at 3 mm resulted in greater displacement during cyclic loading. Another study by Mahar et al. found that a suture anchor designed to undergo intracortical placement had greater failure loads. They postulated that this may be due to decreased migration within the humeral head. However, this suture anchor design used a stronger suture,
which may have accounted for the increased performance of this specific anchor. Snyder and Burns have identified the "crimson duvet" as a means to deliver a biologic clot to the repair site in an effort to improve the healing environment. Many surgeons perform the routine practice of decorticating the rotator cuff footprint before repair to expose it to bone marrow elements. Kida et al. established that drilling the proximal humerus released marrow elements, which were isolated in the repaired tendons of chimeric rats. The drilled cohort had improved load-to-failure results after rotator cuff repair. Levy et al. recently tested a cannulated implant in a rat model and did not find histologic or mechanical benefit to the repaired tendon. Jo et al. have investigated the use of channeling during rotator cuff repair. In their latest clinical study, they were not able to show clinical superiority; however, they were able to show a significant decrease in retear rate. Similarly, a prospective Level I study by Milano et al. was not able to show that microfracture of the greater tuberosity during rotator cuff repair had a beneficial effect on clinical outcomes. Further subgroup analysis on postoperative magnetic resonance imaging to assess the structural integrity of the rotator cuff showed better healing in patients with large rotator cuff tears.

The principal goal of rotator cuff repair surgery is durable tendon-to-bone healing. Unfortunately, this outcome is often elusive because of both intrinsic and extrinsic factors related to anatomy, biomechanics, biology, and rehabilitation. The lack of strong consensus guidelines for arthroscopic rotator cuff repair means that the surgeon should use prudent judgment. Ideally, the surgeon should consider the principles of native footprint restoration: minimizing interface motion and gap formation, achieving optimal compression, and promoting local permeation and vascularity. Future investigations stemming from this study could include biomechanical testing of other techniques such as light cortical abrasion and microfracture and subject these techniques to an in vivo setting. Combined biomechanical and biologic investigative results should bring us closer to identifying the most beneficial environment. Ideally, this will be a cost-effective measure that ensures a mechanically strong repair and drives gene expression toward a more native tendon insertion.

### Limitations

One of the limitations of this study is the depth of decortication. Although deep channeling was been suggested to allow mesenchymal stem cells to extravasate, the full decortication of the anchor bed performed in this study is deeper than what most surgeons perform clinically. We sought to confirm cortical bone removal through visible cancellous bone exposure and wanted to ensure that we were indeed comparing a fully decorticated state with a non-decorticated anatomic state. The pullout characteristics of suture anchors after removal of only 1 mm of cortical bone (cortical scuffing) comprise an area for future study. Another weakness is that the direction of pull in this study design was in line with the suture anchor, which

### Table 1. Suture Anchor Cyclic Data

<table>
<thead>
<tr>
<th></th>
<th>Final Pullout Strength, N</th>
<th>Difference in Final Pullout Strength, N</th>
<th>No. of Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Mean</td>
<td>SE</td>
</tr>
<tr>
<td>Non-decorticated</td>
<td>19</td>
<td>244.035</td>
<td>20.431</td>
</tr>
<tr>
<td>Decorticated</td>
<td>18</td>
<td>62.834</td>
<td>8.966</td>
</tr>
</tbody>
</table>

CI, confidence interval; SD, standard deviation; SE, standard error.
is different from how these anchors are loaded clinically. We sought to test the worst-case scenario for anchor pullout, and our findings were consistent and comparable to previously published cadaveric biomechanical studies. We also only placed anchors in the anterior and middle proximal greater tuberosity because of the similar BMD and anchor pullout characteristics in this study, although anchor placement in vivo is often dictated by tear pattern and may include placement in the posterior greater tuberosity. Another limitation of the study is the type of anchor used and insertion technique. Nonmetallic anchors that are not tapped represent a reasonable clinical scenario and are a possible subject of future investigation.

Conclusions

Decortication of the rotator cuff footprint significantly decreases the pullout strength of the suture anchor. Gender and BMD also play a significant role in bone-anchor biomechanics and should be considered during repair.

References
