Acute Mechanical Evaluation of Three Shoulder Tendon Repair Suture Techniques

McGilvray, K C; Santoni, B G; Moinihan, P D; Getelman, M H; Puttlitz, C M
Colorado State University, Fort Collins, CO, Southern California Orthopedic Institute, Van Nuys, CA
Senior author puttlitz@engr.colostate.edu

INTRODUCTION:
Advances in shoulder arthroscopy, suture material, and arthroscopic anchors have allowed all-arthroscopic rotator cuff repairs to parallel the clinical outcome rates of open repairs. It is generally accepted that the weakest component in the repair remains the suture-tendon interface. There have been many complex suture configurations developed attempting to further strengthen this element of the repair. Strength increases are theorized to be directly correlated to the number of suture-tendon interfaces. From a mechanical perspective this is apparent; as the number of passes through the tendon increases the magnitude of stress applied at each interface is decreased for a given loading condition. However, current quantitative data is ambiguous, and does not address the effects of cyclic loading on rotator cuff repairs constructs in correlation with failure characteristics.

In this study we compared three suture configurations using a triple loaded Mason-Alex (D. Krueger, M. M., Inc., Raynham, MA) suture anchor system to the anchor bone interface and as such it is imperative to use an anchor of significant strength to prevent failure.

METHODS:
Twenty-four (n=24) ovine shoulders consisting of the infraspinatus tendon and corresponding humeri were harvested from skeletally mature ewes euthanized for purposes unrelated to this study. Three different suture configurations were randomized and tested. After a tear was simulated by horizontally transecting the tendon, a triply-loaded Mitek Helix suture anchor with high strength suture was placed in the supraspinatus tuberosity. Rotator cuff repairs were performed using arthroscopic piercers and one of three suture techniques: 1) 3PPCM-Simple suture pattern (n=8, 4 right and 4 left); 2) 4PPCM-Mason-Alex suture pattern (n=8, 4 right and 4 left); 3) 5PPCM-Pyramid suture pattern (n=8, 4 right and 4 left). The 5PPCM Pyramid Stitch configuration was developed for the study to create 5 passes per centimeter using a stacking of sutures to create additional strength in the construct by placing the high strength sutures on top of previously tied suture knots. A testing fixture designed to preserve the natural cross section of the infraspinatus tendon was used to apply uniaxial traction forces to the repaired construct at an angle of approximately 135º to the humerus to model the physiological force vector of the tendon. Retroradial markers were sutured on the tendon at the suture-tendon interface to allow localized calculations of gap formation across the rotator cuff repair. Each suture configuration varied with respect to the number of passes the sutures made through the rotator cuff within 1 cm of rotator cuff tissue. It was hypothesized that cyclic loading would give valuable information on tendon-bone gap formation in a clinically relevant scenario, and that quasi-static ramp to failure would demonstrate that the strength of the repairs would increase with the number of suture passes per centimeter of tendon.

The load required to generate 1, 3, 5, and 10 mm of gap at the repair site was recorded. The cyclic stiffness, defined as the slope of the load-displacement curve generated from the first cycle of loading, was quantified. Immediately following cyclic testing, those tendon specimens that survived the cyclic loading regime were loaded to failure under displacement control at a rate of 1 mm/s. Biomechanical output information on tendon-bone gap formation in a clinically relevant scenario, and that quasi-static ramp to failure would demonstrate that the strength of the repairs would increase with the number of suture passes per centimeter of tendon.

RESULTS:
Twenty-five percent (n=2/8) of the 3PPCM-Simple suture survived the initial 1000 cycle loading experiment. One hundred percent (n=8/8) of the 4PPCM and 75% (n=6/8) of the 5PPCM survived the cyclic experiment. This increase in survivability was significant relative to the baseline 3PPCM treatment (p=0.003, 4PPCM and 5PPCM respectively). The average number of cycles (mean ± SEM) to failure was significantly lower for the 3PPCM treatment (314.25 ± 153.38), relative to the 4PPCM (1000.00 ± 0.00) and 5PPCM (755.50 ± 160.09) treatment groups. For the constructs that survived the initial cyclic loading regime, there was no significant difference between treatment groups regarding the number of cycles required to generate 1 and 3 mm of gap formation. Gap formation greater than 5 mm was not noted in any of the tested constructs in any treatment group. The cyclic stiffness of the 4PPCM treatment was significantly greater than the 3PPCM (Table 1). There was no significant difference between the 5PPCM treatment and the 4PPCM treatment.

Two of the 3PPCM constructs, 8 of the 4PPCM constructs and 6 of the 5PPCM constructs were included for quasi-static ramp to failure testing. Though the 4PPCM and 5PPCM constructs demonstrated a 60.2% and 58.5% increase in ultimate force to failure, respectively, to the 3PPCM baseline group, these differences were not significant at the 0.05 level (Table 2). All tendon repairs, regardless of treatment, failed via suture pullout through the tendon (Fig. 3). No stitch tendon failures. The complexity of the repair and the three suture techniques tested was also statistically equivalent (Table 1). The load required to generate 1, 3, 5, and 10 mm of gap at the repair interface was on average greater at every measured level for the 4PPCM and 5PPCM constructs (Fig. 4). Though this difference was most notable at the 5mm level, this difference was not significant (p=0.067).

DISCUSSION:
The simulated “long-term” characteristics of rotator cuff tear repaired with either the 4PPCM Mason-Alex or the 5PPCM Pyramid stitch technique are significantly enhanced relative to the 3PPCM-Simple suture technique as demonstrated with the initial 1000 cycle testing scenario. Interestingly all of the 4PPCM survived the cyclic test, while only 6 of 8 constructs in the 5PPCM treatment group survived. Gross examination of the 5PPCM constructs that did not survive the cyclic loading regime that in both, only three of the five suture passes appeared to engage substantial tissue, with the remaining lateral passes engaging very little tendon. Thus, it was concluded that these two failed constructs were repaired in a fashion similar to the 3PPCM treatment and thus failed very early in the cyclic testing component of this research. Though the quasi-static biomechanical parameters measured here indicated no difference between the 4PPCM and 5PPCM suture techniques relative to the baseline 3PPCM treatment, our results should be interpreted cautiously due to the small remaining sample size (n=2) in the 3PPCM group used for ramp to failure testing and subsequent statistical comparison. In retrospect, a more appropriate experimental design would have been twenty-four (8/treatment group) designated solely to the cyclic loading regime, with twenty-four (8/treatment group) undergoing only ramp to failure testing.

A stitch configuration that increases the PPCM and can be easily performed arthroscopically offers greater dynamic stability for a given rotator cuff repair. The Mason-Alex and Pyramid stitch techniques displayed significantly greater cyclic longevity than the 3PPCM, Simple suture treatment. The Mason-Alex and Pyramid techniques were, on average, more resistant to 1, 3, and 5 mm of gap formation, though this difference was not significant at any measured level. It appears that a complex suture configuration with high strength suture affords significantly greater repair strength. These results indicate that the complexity of the repair may be more important than the number of passes. The complex repair may shift the load from the tendon suture interface to the anchor bone interface and as such it is imperative to use an anchor of significant strength to prevent failure.

Table 1: Stiffness Comparison Between Treatment Groups (Mean ± SE)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Cyclic Stiffness (N/mm)</th>
<th>Quasi-Static Stiffness (N/mm)</th>
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</thead>
<tbody>
<tr>
<td>3PPCM</td>
<td>43.03 ± 1.58</td>
<td>41.75 ± 0.96</td>
</tr>
<tr>
<td>4PPCM</td>
<td>51.07 ± 2.31</td>
<td>47.17 ± 2.06</td>
</tr>
<tr>
<td>5PPCM</td>
<td>49.23 ± 3.21</td>
<td>48.00 ± 2.98</td>
</tr>
</tbody>
</table>

Cyclic stiffness denotes compliance measured during first cycle of 1000 cycle loading component of testing. Quasi-static stiffness denotes using load to generate force to failure (RTF) component of testing.