INTRODUCTION

Full thickness rotator cuff tears are a common injury which usually results in crescent shaped tears and are thought to be caused by mechanical forces of the muscle retracting. Treatment of the full thickness tears, until recent advancements in arthroscopy, has had unsuccessful results. Failure of rotator cuff fixation has been reportedly caused by cyclic loading of the tendon in vivo [1]. Also, researchers have quantified that current repairs only restore a maximum of 85% of the original footprint of the rotator cuff [2]. Recently, a new double row arthroscopic technique has been reported that re-establishes the footprint of the rotator cuff; however, no quantification of the footprint or biomechanical testing of the double row repair has been performed [3]. Therefore, the objective of our study was to investigate the response of the intact, torn and arthroscopically repaired rotator cuff tendon to both cyclic loading and load-to-failure along with quantifying the restoration of the original rotator cuff footprint.

MATERIALS AND METHODS

Five fresh frozen human cadaveric shoulders (mean age=48±9 years) were dissected to reveal the rotator cuff interval. 3 cm of the rotator cuff interval was then isolated starting at the most anterior point of the supraspinatus footprint and proceeding posterior toward the infraspinatus tendon. The tendon was then clamped in a custom sinusoidal clamp and attached to the crosshead of a materials testing machine (Adelaide Testing Machines, Model TT5-25 Series, Toronto, Canada). The humerus was potted in a cylindrical mold of epoxy putty (Immersion, San Jose, CA) and then used to record the footprint of the isolated tendon’s attachment site and custom software was then used to calculate the area of the footprint. The intact tendon was subjected to 100 cycles of cyclic loading from 20N to 100N at a constant speed of 2.5 mm/sec. After one half hour of recovery, a 3 cm tear was created starting along the greater tuberosity and including all the attachment area to simulate a massive rotator cuff tear. After a preload of 5N, the torn tendon was subjected to the same cyclic loading protocol performed on the intact tendon (Figure 1A). After another recovery period, the full thickness rotator cuff tear was then repaired using an arthroscopic double row technique (Figure 1C). Four 3 mm holes were drilled 7 mm apart along the greater tuberosity and along the margin of the cartilage of the humeral head for a total of eight holes. Eight suture anchors (AnchorSew, USS Sports Medicine, North Haven, CT) were then implanted into the eight drill holes. Both ends of each suture of the top row of four anchors were then passed through the rotator cuff using a suture passer (ArthroSew, USS Sports Medicine, North Haven, CT). The suture passer grasped approximately 8 mm of tendon, and each end of the one suture strand was placed 3 mm from the subsequent end. One end of the suture from the top row was then tied to corresponding suture from bottom row using a Reef knot. This knot was pulled into the bottom anchor and the remaining suture was drawn taught. The remaining two ends were then tied into the top anchor using a Revo knot. After each pair of anchors were secured, the new footprint of the repaired rotator cuff was digitized as previously described and the area was calculated. Another round of cyclic loading was then performed. Elongation (mm) at 100N (1st cycle), cyclic creep (mm), and permanent elongation (mm) of the intact, torn and repaired tendon were calculated using the load-displacement curve.

After another recovery period a load-to-failure protocol was then performed at a speed of 1.25 mm/sec. The structural properties of the repaired tendon including ultimate load (N) and stiffness (N/mm) were derived from the load-elongation curve and the mode of failure was recorded. A one-way repeated measures ANOVA was used to statistically compare the elongation and cyclic creep of the intact, torn and repaired rotator cuff tendon with a significance set at p<0.05.

RESULTS

Cyclic loading caused a characteristic crescent shaped deformity in the tendon after 100 cycles (Figure 1B). The restoration of the original footprint after repair ranged from 70 to 150%. There were no significant differences in the elongation of the intact (2.1±0.4 and 2.6±0.4mm) and repaired (2.0±0.6 and 2.5±0.6mm) tendons at either cycle; however, both were significantly smaller than the 3cm tear (3.4±0.7 and 4.0±1.1mm) tendon (p<0.05,Table 1). The intact, 3cm tear, and repaired tendon were found to have no significant differences in cyclic creep (0.5±0.2mm, 0.5±0.3mm, 0.4±0.1mm), respectively. The permanent elongation of the repair after completing cyclic loading was 0.6±0.4mm. During failure of the repaired tendon, the ultimate load was found to be greater than 500 N with failure at the tendon-suture interface (4 of 5) and one tendon slipping out of the tendon clamp during failure. The average stiffness of the repaired tendon was also found to be 97.6±21.2N/mm.

DISCUSSION

The footprint and biomechanical properties of the intact, torn and repaired rotator cuff were characterized utilizing cyclic and failure loading protocols. Cyclic loading of the 3cm tear tendon appeared to cause a crescent shape (Figure 1B) after only 100 cycles which suggests that overuse without treatment could explain the characteristic shape of tears seen in vivo. Although the range of footot revision varied, they were greater than or equal to previously reported procedures [2]. In response to cyclic loading, the amount of cyclic creep was similar for all three states; however, the differences in elongation at the 100th cycle showed the Double Row repair to restore the elongation caused by a full thickness tear. Consequently, the repair also exhibited low levels of permanent elongation and had comparable structural properties to the intact rotator cuff [4] which suggests that early rehabilitative loading could be allowed without compromising the initial stability of the repair. Although these repairs are performed on healthy tendons and the state of the torn rotator cuff in vivo could be compromised, we feel that our testing setup provides a more realistic tear than previous studies. The Arthroscopic Double Row repair also provides a larger tendon-to-bone interface which after healing could increase the properties of tendon and compensate for possible degeneration of the tendon seen in full thickness rotator cuff tears.

REFERENCES


ACKNOWLEDGEMENTS

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Table 1.  Cyclic Properties of the Intact, 3cm Tear and Repaired Rotator Cuff

<table>
<thead>
<tr>
<th>ROTATOR CUFF STATE</th>
<th>Intact</th>
<th>Torn</th>
<th>Repaired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elongation at 100N (1st cycle)</td>
<td>2.1±0.4</td>
<td>3.4±0.7*</td>
<td>2.0±0.6†</td>
</tr>
<tr>
<td>Elongation at 100N (100th cycle)</td>
<td>2.6±0.4</td>
<td>4.0±1.1*</td>
<td>2.5±0.6†</td>
</tr>
<tr>
<td>Cyclic Creep</td>
<td>0.5±0.2</td>
<td>0.5±0.3</td>
<td>0.4±0.1</td>
</tr>
<tr>
<td>Permanent Elongation</td>
<td>-</td>
<td>-</td>
<td>0.6±0.4</td>
</tr>
</tbody>
</table>

*compared to intact, †compared to 3cm tear, p<0.05.