Comparison of Ultrasonic Suture Welding and Traditional Knot Tying in a Rabbit Rotator Cuff Repair Model

Shane J. Nho, MD; Brian J. Cole, MD, MBA; Augustus D. Mazzocca, MD; James M. Williams, PhD; Anthony A. Romeo, MD; Charles A. Bush-Joseph, MD; Bernard R. Bach, Jr., MD; Nadin J. Hallab, PhD

Section of Sports Medicine, Department of Orthopedic Surgery, Rush Medical College, Rush University Medical Center, 1725 West Harrison Street, Suite 1063, Chicago, IL 60612

nhos@rshs.edu

INTRODUCTION

Ultrasonic suture welding has emerged as a new technology that will enable the orthopedic surgeon to weld suture loops rather than the more difficult procedure of arthroscopically tying knots. However, suture welding has not been examined in an in vivo model of rotator cuff repair. The aim of the present study is to evaluate ultrasonic suture welding of monofilament suture in an animal model of rotator cuff repair with biomechanical and histological analyses.

METHODS

46 Shoulders of 23 NZW rabbits were randomly assigned to one of three treatment groups: SHAM (N=15), KNOT (N=15), WELD (N=16). Supraspinatus defects were surgically created and acutely repaired with suture anchors loaded with either No.2 Ethibond for KNOT shoulders or No.2-0 nylon for WELD shoulders. 18 Weeks post-operatively, all animals were sacrificed, and the shoulders underwent either biomechanical testing or histological analysis. The maximum load to failure, stress, strain, and modulus were determined. Histologic specimens were stained with hematoxylin and eosin with safranin-O staining and picrosirius red staining for analysis.

RESULTS

Macroscopic Analysis

Upon macroscopic analysis, the SHAM shoulders demonstrated minimal scarring of the deltoit muscle. The supraspinatus tendon was intact without any gross abnormalities. The repaired shoulders revealed an extensive degree of scar tissue from the supraspinatus insertion to the undersurface of the deltoit. Although quantitative measurements were not made, the welded loops were less bulky and lower in profile compared to the knotted loops. In the KNOT shoulders, the Ethibond knot was encapsulated in a scar tissue mass. One of the KNOT shoulders appeared to be a healed, mildly displaced humeral head fracture which was most likely secondary to the insertion of the suture anchor. Loose bodies of small suture fragments were observed in two WELD shoulders, but the welded loop in each case was intact. Another WELD shoulder contained a calcified mass just superior to the sutured tendon. There were no specimens with gap formation between the tendon and humeral head. There was no evidence of suture elongation, suture slippage, or suture breakage for any repaired supraspinatus tendons.

Biomechanical Analysis

The surface area was significantly greater in the KNOT (17.5mm², P=0.001) and WELD (21.0mm², P=0.008) groups than the SHAM (10.5mm²) group. Although the maximum load to failure of the KNOT (161.9N) and WELD (161.6N) groups was less than the SHAM (206.4N) group, only the stress of the experimental groups (10.2N/mm², 8.3N/mm²) was statistically inferior to the control (20.6N/mm²) group (P=0.002, P=0.0001). The repaired supraspinatus tendons of both experimental groups were approximately 80% (KNOT 78.42%, WELD 78.27%) of the tensile strength of the intact supraspinatus tendons.

There were no detectable statistical differences between the KNOT and WELD groups. All specimens failed at the tendon-to-bone junction, and the suture anchor was intact in all 30 specimens. Additionally, there were no apparent differences observed between any group for tissue strain, specimen strain, tissue modulus, and specimen modulus (Table I).

Microscopic Analysis

In all specimens, there was good integration of tendon-to-bone healing without any evidence of the surgically created defect. Apart from the thickening of the subdeltoid bursa, there were no histologic signs of acute inflammatory changes in any specimen. Additionally, there were no abnormalities in any specimen in terms of the articular cartilage of the humeral head, vascularity, and cellularity. In all SHAM treated specimens, the transition zone architecture was regular with clearly demarcated zones of tendon, unmineralized fibrocartilage, mineralized fibrocartilage, and bone. Also, an intervening subdeltoid bursa is apparent between the supraspinatus tendon and the overlying deltoit muscle fibers in all specimens. Dense regular collagen fibers can be seen in all samples. In two of five specimens, a random arrangement of collagen fibers could be seen in the articular side of the tendon in the picrosirius red stained section and an increased proteoglycan staining was also observed in the same area in the Safranin-O stained sections. The herring-bone appearance is consistent with a fibrocartilage differentiation within the substance of these two tendons. The four of five KNOT specimens demonstrated regular transition zone architecture with tendon fibers interdigitating with trabecular bone. In four of five KNOT specimens, mild subdeltoid bursa thickening with loosely arranged connective tissue was noted. Dense, longitudinally oriented collagen fibers are visible in all samples. One specimen was noted to have irregular transition zone architecture with poor collagen fiber arrangement of the tendon zone. Ethibond suture fragments surrounded by moderately irregular collagen orientation in the immediate area can be demonstrated in one supraspinatus tendon. Proteoglycan staining was absent in all KNOT specimens. In four of five WELD specimens, regular transition zone architecture was observed. Moderate or marked subdeltoid bursal thickening was also observed in all WELD samples. Dense longitudinal collagen fibers were observed in two of five WELD specimens. Three of five WELD specimens had irregular collagen fiber orientation with a corresponding increased proteoglycan staining consistent with herring-bone pattern. In one of the specimens, a widened fibrocartilage zone of the articular side was seen, and evidence of early bone formation of the bursal side could be demonstrated.

CONCLUSIONS

The stress of the KNOT and WELD groups were significantly lower than the SHAM group, but no differences were observed between KNOT and WELD groups. Both KNOT and WELD shoulders demonstrated increased bursa thickness compared to control specimens. Ultrasonic suture welding is a reasonable alternative to arthroscopically tied knots with the additional benefits of ease of use, rapid application, and low profile suture loops, and therefore, may permit a greater number of surgeons to perform an all-arthroscopic rotator cuff repair.

Table I. Biomechanical characteristics of experimental groups.

<table>
<thead>
<tr>
<th>GROUP</th>
<th>MAXIMUM LOAD (N) ± SD</th>
<th>STRESS (N/mm²) ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHAM (n=10)</td>
<td>206.41±47.45</td>
<td>20.63±7.46</td>
</tr>
<tr>
<td>KNOT (n=10)</td>
<td>161.86±63.28</td>
<td>10.24±5.10††</td>
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<tr>
<td>WELD (n=10)</td>
<td>161.55±85.36</td>
<td>8.32±3.84†††</td>
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<tr>
<td>ANOVA</td>
<td>0.279</td>
<td>0.0001</td>
</tr>
</tbody>
</table>

††† Denotes statistical significance from SHAM at P<0.001.

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