An in vivo comparison of the modified Mason-Allen suture technique versus an inclined horizontal mattress suture technique with regard to tendon-to-bone healing: A biomechanical and histologic study in sheep

Theodore F. Schlegel, MD, a Richard J. Hawkins, MD, b Chad W. Lewis, PhD, c and A. Simon Turner, BVSc, MS, Dipl ACVS, c Denver, Vail, and Fort Collins, CO

The purpose of this study is to examine long-term tendon-to-bone healing, by use of a sheep animal model, after rotator cuff repairs performed with 2 different suture techniques: an inclined horizontal mattress suture pattern placed with special arthroscopic instrumentation (HMS) and the modified Mason-Allen pattern (MMA). After a pre hoc power analysis, 18 skeletally mature sheep were randomly assigned to either the HMS or MMA repair technique, with contralateral limbs used for the control group. At 26 weeks, the animals were euthanized. Six sheep from each group underwent biomechanical testing. Load-to-failure and stiffness results indicated no statistically significant difference between the 2 groups. Avulsion of the tuberosity was the primary mode of failure for both groups. In the remaining 6 sheep, histologic evaluation demonstrated that, regardless of treatment, the tendon appeared completely healed in the bony trough. Because the long-term biomechanical and histologic properties of healed tendons repaired with an HMA technique are equal to those obtained with an MMA technique, the inclined horizontal mattress suture may be appropriate for arthroscopic rotator cuff repair. Short-term studies are necessary to determine whether these findings are true early after tendon repair, when failure may be most common. (J Shoulder Elbow Surg 2007;16:115-121.)

A major concern in rotator cuff repair surgery is failure, particularly in large and massive tears. 3,6 Traditionally, rotator cuff repairs have been performed by reapproximating the torn tendon to a bony trough created in the greater tuberosity. 7 It is critical to have sufficient strength at the time of the initial repair to permit early rehabilitation and to improve the likelihood of a successful repair. The modified Mason-Allen suture has been popular for open rotator cuff repairs because of its superior holding power in soft tissue. 4,5 At this time, the majority of all rotator cuff repairs are performed via a classic open or miniopen technique. These approaches make it relatively easy to place the modified Mason-Allen suture pattern.

Recently, there has been a growing trend toward all-arthroscopic rotator cuff repair. When this technique is being used, it is extremely difficult to place a modified Mason-Allen suture because of the constraints of the current arthroscopic instrumentation. The simple and horizontal suture patterns are technically more feasible in all-arthroscopic repairs. The strongest possible construct should be created because the initial strength of the tendon attachment to bone is an important factor in the final success of the repair and will ultimately permit more aggressive initial rehabilitation programs.

The purpose of this study was to determine whether the long-term results after repair of a horizontal suture technique with special instrumentation is as secure as the modified Mason-Allen technique when reattaching tendon to a bony trough in an animal model.

MATERIALS AND METHODS

After performance of a pre hoc power analysis (power = 80%; α = .05), the right infraspinatus tendon in 18 skeletally mature sheep was reattached into a bony trough. Half of the sheep were randomly assigned to a group in which tendon fixation was performed via the modified Mason-Allen suture (MMA), and the other half underwent fixation by use of an automated suturing device to place a horizontal mattress suture (HMS) (Figure 1). This animal
model was chosen because the infraspinatus tendon in the sheep is similar to the human supraspinatus in width and thickness. The investigation was approved by the Colorado State University Animal Care and Use Committee (protocol No. 98-064A-01) (Fort Collins, CO).

Operative technique

Preoperative analgesics and antibiotics were administered to all animals. General anesthesia was induced with ketamine (4 mg/kg) and diazepam (7.5 mg) and was maintained with halothane (1.5%-3%) in 100% oxygen (2 L/min). After aseptic preparation, a 12-cm incision was made over the right shoulder. The infraspinatus muscle and tendon were isolated. The tendon was then sharply detached from the greater tuberosity of the humerus.

A bony trough, 2.0 cm in length and 0.5 cm in depth, was prepared in the proximal humerus with an osteotome and bur. The infraspinatus muscle and tendon were isolated. The tendon was then sharply detached from the greater tuberosity of the humerus.

A bony trough, 2.0 cm in length and 0.5 cm in depth, was prepared in the proximal humerus with an osteotome and bur. The infraspinatus tendon was sutured into the trough by use of three No. 2 Ethibond nonabsorbable sutures (Ethicon, Somerville, NJ) via either a modified Mason-Allen technique or a horizontal mattress technique. In both groups, 3 suture anchors were used to secure the tendon to the bony trough. Once reattachment was accomplished, standard closure of soft tissues was performed.

Postoperative protocol

After surgery, assessment of pain was recorded daily in each sheep. All animals received pain management for 3 days. The sheep were temporarily restricted by the attachment of a 6-inch softball under the foot of the operative limb in an attempt to reduce weight-bearing forces. The softball remained in place for 6 weeks, during which the sheep were confined to a small pen. After 6 weeks, the ball was removed, and the animals were allowed unrestricted activities in a larger pen.

Sample preparation

At 26 weeks after surgery, the sheep were euthanized in a humane manner with an intravenous overdose of barbiturate. At necropsy, each infraspinatus muscle-tendon complex and its corresponding humerus were dissected from both the operative and contralateral control limbs. After harvest, each sample was frozen at −30°C and stored at this temperature until biomechanical testing was performed.

Biomechanical testing

Six of the infraspinatus muscle-tendon complexes and humeri from each treatment group were used for biomechanical testing. Each sample was thawed in normal saline solution at 37°C, and nonessential tissue was resected. The humeral end of each sample was potted in anatomic alignment with Dyna-Cast (low-temperature thermostat resin; Kindt Collins, Cleveland, OH). The sample was attached to a servohydraulic testing machine (model 809; MTS, Eden Prairie, MN) by use of specialized grips. The lower grip, made from aluminum, held the potted end of the sample. The upper grip was clamped to the infraspinatus tendon in anatomic alignment with the Cryo-Jaw (custom made at CSU) design by use of carbon dioxide, frozen to −25°C ± 5°C. Similar to other tendon-healing studies, sutures were not cut before testing.

After each sample was prepared and attached to the testing apparatus, a 5-N cyclic preload was applied. Each sample was then loaded to failure by use of the MTS machine, with a rate of distraction of 500 mm/min, as has been done in previous work. The site of failure was
Table I Load to Failure and Stiffness

<table>
<thead>
<tr>
<th>Group</th>
<th>Load to failure (N) (mean ± SD)</th>
<th>Stiffness (N/mm) (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MMA</td>
<td>3223 ± 1077*</td>
<td>324 ± 82†</td>
</tr>
<tr>
<td>HMS</td>
<td>3853 ± 486*</td>
<td>354 ± 41†</td>
</tr>
<tr>
<td>Control</td>
<td>5007 ± 623</td>
<td>564 ± 91</td>
</tr>
</tbody>
</table>

*Significant difference between control group and both treatment groups (P < .05).
†Significant difference between control group and both treatment groups (P < .05).

noted for all specimens. Force and displacement data were collected at 100 Hz to calculate load to failure, and the slope of the linear portion of the force-displacement curve was measured to determine the stiffness of the bone-tendon interface.

Statistical analysis

The mean, SE, and SD of load to failure and stiffness were determined. By use of analysis of variance and Tukey post hoc analysis for equal variances (α = .05), the differences between the HMS group, MMA group, and control group were determined for the responses with regard to load to failure and stiffness.

Histologic evaluation

Three specimens from each group were evaluated by a single pathologist blinded to treatment for assessment of the integrity of the tendon insertion site, the degree of collagen ingrowth, and the contribution of periosteal fibers to the organization of the tendon attachment. The specimens were fixed in 10% neutral buffered formalin and then decalcified with formic acid and resin ion exchange. Sequential 7-μm sections were obtained from the insertion (repair) site of the decalcified specimen and stained with hematoxylin-eosin. The area of interest was the gap between the stump of the infraspinatus and the bony trough. There are no specific criteria for scoring soft-tissue repairs to bone, but the histologic evaluation consisted of qualitative assessment of the integrity of the tendon insertion site.

RESULTS

The load to failure (in newtons) and stiffness (in newtons per milliliter) were determined for both treatment groups and the control group, and the results are summarized in Table I.

At 26 weeks, the mean load to failure was 3223 ± 1077 N in the MMA group and 3853 ± 486 N in the HMS group. The mean stiffness was 324 ± 82 N/mm in the MMA group and 354 ± 41 N/mm in the HMS group. The site of failure for the entire HMS group occurred as a partial or complete avulsion of the greater tuberosity with the attached healed tendon, as did all but 1 specimen in the MMA group. The remaining MMA specimen failed at the tendon-grip interface.

No significant difference was found between the treatment groups with regard to load to failure (P = .359) or stiffness (P = .769). When the treatment limbs were compared with the contralateral normal control limbs, there was a statistically significant difference between load to failure in the control group and both treatment groups (P < .05); however, the HMS and MMA groups were not significantly different.

Similarly, there were statistically significant differences in stiffness when treatment limbs were compared with control limbs (P < .001 for MMA group and P = .001 for HMS group). These results are summarized in Figure 2.

The histologic findings were similar between the 2 treatment groups. In all sections, regardless of the treatment group, the infraspinatus tendon healed into the bone medial to the original repair site (Figure 3, A). The repaired construct revealed that a gap formed at the bone-tendon interface, where tendons had partially pulled away from the repair site. This defect was filled with disorganized fibrous scar tissue (Figure 3, B). At the site of tendon reattachment, the junction between the tendon and bone showed a zone of fibrocartilage consistent with normal tendon (Figure 3, C). In each specimen, there was a mild increase in remodeling of the bone with some narrow fibrosis, especially around the sutures.

DISCUSSION

The purpose of this study was to compare 2 widely used suture patterns, the modified Mason-Allen suture and an inclined horizontal mattress suture, with regard to the long-term outcome of tendon-to-bone healing by use of a sheep model. This model has been used, as well as validated, as a method by which to examine in vivo influences of tendon-to-bone healing. This study has shown that the inclined horizontal mattress suture, placed with a specially designed instrument intended for arthroscopic rotator cuff repairs, is as secure as the modified Mason-Allen suture when repairing tendon to a bony trough in the long term. The biomechanical properties, as reported in the load-to-failure and stiffness values for the healed tendon, showed no statistically significant difference between the 2 groups.

The inclined horizontal mattress pattern is believed to have improved tendon-holding power compared with that of a traditional horizontal mattress suture. This difference may be explained by the fact that, when a traditional horizontal mattress suture is created, the suture is placed through the superior surface of the tendon at a desired distance from the free edge and at a 90° angle to the tendon, exiting on the
inferior aspect, once again at a 90° angle (Figure 1, B). The suture is then passed parallel to the free edge along the inferior aspect of the tendon at a set distance and then through the tendon at a 90° angle to both the inferior and superior surfaces. This traditional horizontal mattress suture differs from the in-

Figure 2 Load to failure (A) and stiffness (B) in control group versus MMA and HMS groups.
clined horizontal mattress suture created with the automated suturing device used in this study. With this instrumentation, the suture enters the superior surface and then travels obliquely away from the edge of the tendon, ultimately exiting on the undersurface of the tendon at a greater distance away from where it started on the superior surface. Thus, an inclined horizontal mattress suture is created (Figure 1, C). By the nature of this inclined suture pattern, the holding power is increased because the suture travels for a longer distance in the tendon when compared with the traditional horizontal mattress suture. The resultant vector of the inclined horizontal mattress suture creates a compressive force at the bone-tendon interface.

Another unique finding in this study was the consistency (SD) that was seen in the load-to-failure and stiffness results for the horizontal mattress group when compared with the MMA group. The SD in the HMS group was nearly half that in the MMA group. This may be explained by the fact that the suturing device allows for a very reproducible method of applying the suture. The automated suturing device creates a sewing-machine consistency. This reproducibility is not generally created when the suture is placed by hand, as is the modified Mason-Allen suture.

Another possible explanation for the lower SD with the HMS technique has to do with the ability of the suture to slide once placed within the tendon. This provides the advantage of having equal tension on both limbs of the suture once it is secured to bone. This may not always occur when the MMA suture is used, because the upper limb of the suture often locks onto the horizontal limb, creating an opportunity for unequal tension in the sutures as they are secured to bone.
bone. The consistency in the limbs of the suture may provide a more reproducible repair.

When the biomechanical results in the control group were compared with those in both study groups, there were statistically significant differences in both load to failure and stiffness. These results are consistent with other studies, which have shown that the intermediate biomechanical results after tendon healing are inferior to normal tendons. The decreased strength of the healed construct is believed to be a result of early cyclic loading. These low-level loads create an early gap formation at the tendon-bone interface in animal models. Histologic evaluation from this study, along with others, confirms this biologic process, which occurs during early healing. Eventually the tendon heals medially into the bone. The consistency in the limbs of the suture may provide a more reproducible repair.

An all-arthroscopic technique for rotator cuff repairs can be technically challenging. The theoretic advantages of this technique compared with the open or miniopen procedure are decreased postoperative pain and decreased postoperative morbidity. The success of tendon-to-bone healing relies on many factors, one of which is believed to be the initial security of the repair. It should be noted that our study did not evaluate initial security but only addressed long-term repair. In the long term, any initial differences in suture method could be masked, as significant scar tissue fills the gap in all cases in this animal model. Further study evaluating these approaches at earlier time points, between 1 and 8 weeks, may provide further important information on the comparison of these approaches. Nevertheless, for an all-arthroscopic repair, the ability to reattach the torn tendon to bone and create a secure construct has been limited by the current techniques. At this time, it can be quite difficult to perform an all-arthroscopic technique because of challenges related to creating appropriate suture pattern placement in tendon. In fact, the ability to use a modified Mason-Allen suture in an arthroscopic repair is considered significantly challenging by even the best arthroscopists. With the development of new instrumentation, the surgeon may be able to place a suture easily arthroscopically, which provides fixation that is as secure as that achieved with the present open treatment methods. Since the completion of this study, we have now started to use this suture device in our arthroscopic rotator cuff repairs. This instrumentation has allowed us to place a desired suture pattern easily and quickly in our early human clinical protocols. Armed with the basic science results, we have now become more confident in our all-arthroscopic repairs and have started a prospective study to evaluate our clinical outcomes.

Future research is necessary to develop anchoring systems that will allow secure fixation via a knotless technique. We are presently using an anchoring system that has been developed to allow for a knotless technique. This anchor allows us to create ideal tension with our repair and secure fixation. This knotless anchor is compatible with our current automated suture device, creating an increased sense of confidence in our arthroscopic rotator cuff repairs.

We gratefully acknowledge Tyler Richardson and Jenna Godfrey for their technical assistance.

REFERENCES