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Optimizing Achilles Tendon Repair: Effect of Epitendinous Suture Augmentation on the Strength of Achilles Tendon Repairs

Steven J. Lee, M.D.; Scott Goldsmith, M.D.; Stephen J. Nicholas, M.D.; Malachy McHugh, Ph.D.; Ian Kremenic, M.Eng; Simon Ben-Avi, Ph.D.
New York, NY

ABSTRACT

Background: **Epitendinous suture augmentation has been shown to increase gap resistance and overall strength in flexor tendon repairs of the hand. The purpose of this study was to evaluate the effect of various suture augmentation techniques in Achilles tendon repair.** ***Materials and Methods:*** **Eighteen fresh-frozen cadaveric Achilles tendons were transected and repaired with a 4-strand Krackow core stitch. Suture augmentation was performed with 3 figure-of-eight stitches in 6 specimens and a running cross-stitch weave in 6 specimens. The other 6 specimens were not augmented. Each tendon was loaded to failure on an MTS. Force to failure (defined as peak force or force at 5 mm gapping), gapping resistance, stiffness, and elongation were compared.** ***Results:*** **Force to failure ($p < 0.001$), stiffness ($p < 0.01$) and gapping resistance ($p < 0.05$) were increased by suture augmentation. Additionally failure force and gapping resistance for the cross-stitch augmentation was higher than the figure-of-eight augmentation ($p < 0.05$).** ***Conclusion:*** **Cross-stitch augmentation of Achilles tendon repair yields a stronger and stiffer repair with greater resistance to gapping.** ***Clinical Relevance:*** **Achilles tendon repairs augmented with a cross stitch weave will be able to withstand substantially higher forces than non-augmented repairs.**

Key Words: Achilles Tendon; Augmentation; Repair; Weave; Gapping

INTRODUCTION

Achilles tendon ruptures are common injuries. Surgical repair is becoming an increasingly popular method of treatment.[1,9,19,20,17,23,25,28,36,39,40] While repair techniques for flexor tendons of the hand have been extensively studied, relatively little has been reported regarding Achilles tendon repairs. Although the principles of tendon repair surgery are similar, many differences exist between Achilles tendon and flexor tendons of the hand, including the Achilles' higher forces, larger surface area to place sutures, lack of unyielding tunnels, and the tendency to rupture as opposed to a clean laceration.

The recent trend following Achilles tendon repair has been to institute accelerated rehabilitation protocols.[1,2,9,19,20,25,35,40] These include starting early range of motion and even immediate weight bearing, shorter immobilization times, earlier initiation of strengthening, and faster return to sports. These protocols, for the most part, have not been based on solid basic science.

Although re-rupture remains uncommon, excessive tendon lengthening may be a more likely occurrence with early weightbearing and aggressive rehabilitation. For example, separation of tendon ends has been clearly demonstrated after Achilles repair.[25,26,28] Furthermore, weakness in end-range plantar flexion after Achilles tendon repair has recently been attributed to excessive tendon lengthening during muscle contraction.[27] Together, these studies indicate the need for stronger Achilles tendon repairs.

The purpose of this study was to evaluate the effect of suture augmentation in Achilles tendon repair. It was hypothesized that suture augmentation of Achilles tendon repair would yield similar benefits to those found in studies of epitendinous augmentation of hand flexor tendon repairs. To our knowledge, the effect of this technique has not been previously studied in Achilles tendons.

MATERIALS AND METHODS

Eighteen fresh-frozen human cadaveric Achilles tendons with the calcaneus attached were thoroughly thawed and harvested. The average age of the specimens was 52

Corresponding Author:
Steven Lee, M.D.
Lenox Hill Hospital
Orthopedic Surgery
130 East 77th Street
5th Floor, Black Hall
New York, NY 10021
E-mail: sjleemd@aol.com
For information on prices and availability of reprints, call 410-494-4994 x226

(range, 32 to 62) years (12 male, 6 female). The ages and male/female ratios were evenly distributed between three groups. All Achilles tendons were sharply transected four centimeters proximal to the tendon insertion. The specimens were kept moist with normal saline at room temperature throughout the project.

All tendons were repaired using a 4-stranded Krackow technique[13,15] with No. 2 Ethibond sutures (Ethicon Inc., Somerville, NJ). Six repaired tendons were then augmented with 3 figure-of-eight sutures on the medial, lateral, and dorsal surfaces of the Achilles tendon. Another six were augmented with a cross stitch weave similar to that described by Silfverskiold[33,34] (Figure 1). The augmentations were performed so that the suture grabbed not only the epitenon but also the tendon tissue approximately 2.5 cm away from the rupture site. All augmentations were performed using 0 PDS sutures (Ethicon Inc., Somerville, NJ).

These techniques were chosen following a survey of 20 active orthopaedic surgeons who perform Achilles tendon repairs at our institution. The most common technique used for such repairs was a four stranded Krakow technique using No. 2 Ethibond sutures. Many surgeons reported augmenting the repairs with 3 figure-of-eight sutures placed on the medial, lateral, and dorsal surfaces of the tendon. The most common reason given for the use of figure-of-eight sutures was to help re-approximate the tendon ends, and furthermore, to possibly increase the strength of the repair. The cross-stitch weave technique was chosen as this has been shown to provide significantly increased strength in hand flexor tendons compared to the use of core suture alone.[31,32]

The specimens were secured onto a Materials Testing System by drilling a hole in the calcaneus in line with the tendon and inserting a large bolt. This was then coated with polymethylmethacrylate bone cement (Howmedica International S. de R.L., Limerick, Ireland) to eliminate any movement at the hardware-bone interface. The Achilles tendon was secured proximally onto a tendon clamp. The tendon was then rolled around the clamp several times thereby minimizing the stress on the clamp-tendon interface and eliminating slippage. The specimens were secured onto the MTS by clamping onto the head of the bolt on one side, and onto the tendon clamp on the other side (Figure 2).

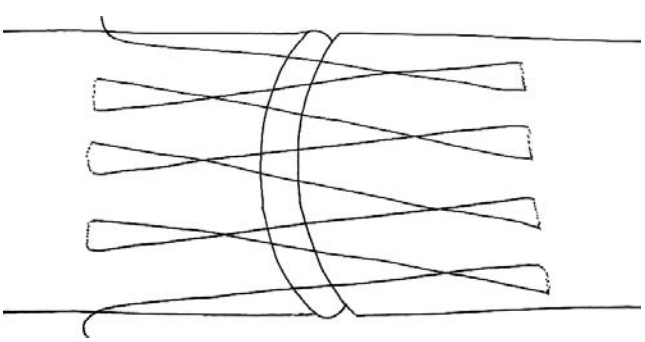

Fig. 1: Cross stitch weave augmentation.

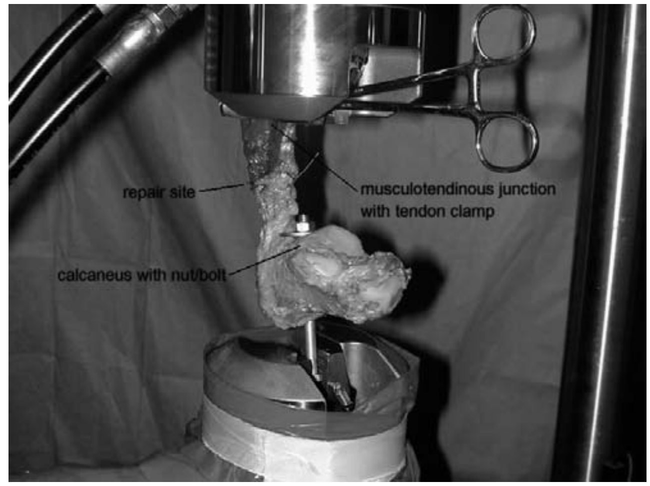

Fig. 2: MTS setup.

Unidirectional tensile loading to failure was performed on a MTS machine at 25 mm/min. Force-displacement values analyzed included peak force to failure, force at 5 mm gapping, stiffness, elongation at initial gapping, elongation at 5 mm gapping, elongation at failure, and method of failure. If failure occurred after 5 mm of gapping was apparent, force at 5 mm was recorded as failure (clinical failure). Gapping was measured using calipers.

One-way analysis of variance with Tukey's post hoc pairwise comparisons was used to compare failure force, stiffness and elongation between the different techniques (no augmentation, augmentation with figure-of-eight, and augmentation with cross-stitch weave). A p-value of less than or equal to 0.05 was denoted as significant. The results in text are given as mean $\pm$ SD. Based on previous studies,[7,26,38] it was estimated that with 6 specimens per group, a 34% increase in failure force with augmentation could be detected at $p < 0.05$ with 80% power.

RESULTS

Ultimate failure force of those Achilles tendons repaired without suture augmentation was 196 ± 33 N, with three of the 6 specimens failing after 5 mm of gapping had occurred. Tendons repaired with figure-of-eight augmentation failed at 250 ± 52 N with 1 of 6 specimens failing after 5 mm of gapping. Achilles tendons repaired with cross-stitch augmentation failed at 323 ± 47 N with all six failing prior to 5 mm gapping. Force to ultimate failure was significantly increased by suture augmentation ($p < 0.001$) (Figure 3). Figure-of-eight augmentation increased force to failure by 28% ($p = 0.06$) and cross-stitch augmentation increased force to failure by 65% ($p < 0.001$).

The force corresponding to 5 mm of gapping (clinical failure) was 169 ± 50 N in the Achilles tendon without augmentation, 248 ± 58 N in the figure-of-eight

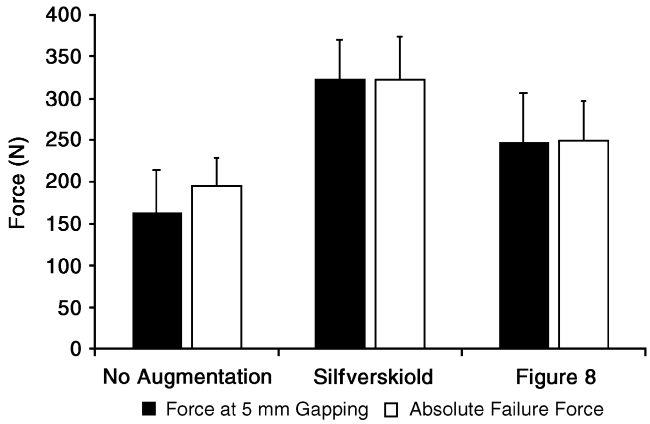

Fig. 3: Peak force at failure and force at 5-mm gapping.

augmentation, and 323 ± 47 N in the cross-stitch augmentation. Gapping resistance was significantly increased by suture augmentation ($p < 0.001$) (Figure 3). Figure-of-eight augmentation increased gapping resistance by 47% ($p < 0.05$) and cross-stitch augmentation increased gapping resistance by 91% ($p < 0.001$). Additionally, gapping resistance for the cross-stitch augmentation was higher than the figure-of-eight augmentation ($p < 0.05$).

Linear stiffness was also significantly increased by suture augmentation ($p < 0.01$) (Figure 4). Stiffness was 6.02 ± 0.99 N/mm for repairs without augmentation compared with 8.0 ± 1.1 N/mm for figure-of-eight augmentation, and 10.1 ± 2.3 N/mm for cross-stitch augmentation. Figure-of-eight augmentation increased stiffness by 33% ($p > 0.05$, not significant) and cross-stitch augmentation increased stiffness by 68% ($p > 0.05$).

More than 5 mm of gapping occurred prior to suture failure in 3 of 6 repairs without augmentation but only in one augmented repair (figure-of-eight). Gapping prior to failure was due to the suture pulling through the tendon prior to suture failure in the repairs without augmentation. Suture failure was the ultimate mode of failure for all repairs. For the augmented group, those specimens where gapping occurred prior to ultimate failure, the epitendinous sutures failed first, followed by the core sutures. For repairs where gapping was not present prior to failure, all sutures appeared to fail simultaneously.

Elongation at the point of initial gapping was significantly greater for the augmented repairs (44.7 ± 13.3 mm) versus the repairs without augmentation (28.7 ± 10.5 mm; $p < 0.05$) (Figure 5). This indicates that the suture augmentation limited suture pull-through and further supports the increased gapping resistance seen with the augmented repairs.

DISCUSSION

While some controversy exists about the best treatment for Achilles tendon ruptures, operative treatment has gained in popularity.[1,9,19,20,25,29,38,39,40] Proponents cite decreased rerupture rates, increased strength, and earlier return to function and sports.[2,19,20,30,35,38,40] The most commonly used repair

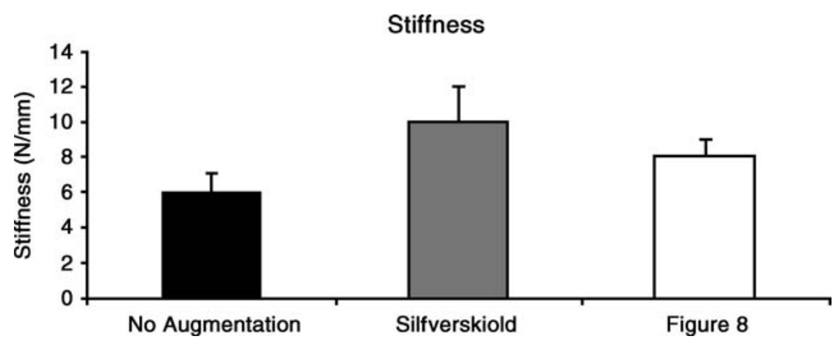

Fig. 4: Linear stiffness during elongation.

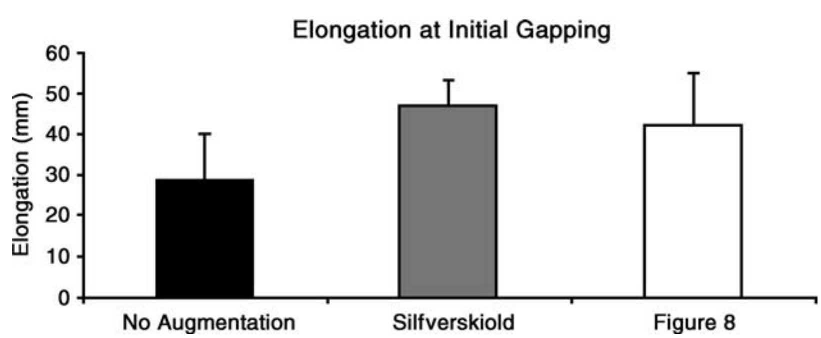

Fig. 5: Elongation at initial gapping.

techniques have reported failure forces ranging widely from less than 30 to more than 300 N.[7,26,38] However, these forces seem inadequate compared to the forces transmitted through the Achilles tendon during walking. With the ankle immobilized in neutral, the forces on the Achilles tendon has been estimated to be as high as 370 N,[1] and as high as 1500 N during normal, unrestricted walking.[10]

It would thus be surprising that the reported re-rupture rates following surgical repair would not be higher. While it is certainly important to maximize the strength of our repairs, it is probably even more clinically relevant however to create repairs that increase gapping resistance. Mullaney et al. have shown significant weakness in end-range plantar flexion following Achilles tendon repair and hypothesized that the tendon ends may have undergone excessive stretching or gapping.[27] Several authors have demonstrated separation of the tendon ends following Achilles tendon repair by placing surgical clips on the tendon ends and measuring the distance on postoperative radiographs.[16,25,26,28]

The most comprehensive research on tendon repair techniques has been on tendon repairs in the hand. The most important findings have been that: 1) increasing the number of strands that cross the repair site results in stronger repairs,[5,6,8,12,14] 2) the specific techniques of the core suture have had variable results,[3,12,21,22,24,37] and 3) the addition of epitendinous augmentation to the core sutures in flexor tendons significantly increases the repair strength and increases gap resistance.[4,13,29]

While suture augmentation is routinely performed in hand tendon repairs, many important differences exist between repairs of Achilles tendons and flexor tendons of the hand. The Achilles tendon transmits much higher forces than those seen in the flexor tendons of the hand. In fact, with weight bearing, the Achilles tendon transmits the largest force of any tendon in the body.[15,31] Most recent rehabilitation protocols increasingly advocate early mobilization and weightbearing.[1,2,9,19,20,25,35]

Therefore, there is an important need to design strong suture constructs to allow early rehabilitation and weightbearing without compromising the repair.

The Achilles tendon provides a significantly larger surface area allowing for more complex suture constructs to be performed with more technical ease than is possible in the small surface area of a flexor tendon. Furthermore, in the hand flexor tendons, placement of large sutures increases volume and friction through the confines of a tight and unyielding pulley system. The absence of rigid tunnels and the increased surface area for sutures makes these suture constructs much more feasible in the Achilles than in flexor tendons of the hand. However, as skin closure can be problematic, suture bulk should be kept to a minimum if possible. In addition, although it is possible to utilize the surrounding soft tissues for augmentation, such as the gastrocnemius-soleus fascia, the risks of nerve injury and problems with skin closure are common.[11]

The use of 0 PDS adds minimal additional bulk and is often difficult to even visualize except for the small knot.

Finally, Achilles tendons tend to rupture leaving a "mop end" appearance in contrast to a typical sharp laceration of a flexor tendon in the hand. This characteristic makes suture grasping of the Achilles tendon much more difficult. The cross-stitch weave was placed approximately 2.5 cm away from the rupture site where more normal, non-injured tendon can be found. Because of the horizontal component of the suture, the inherent nature of this cross-stitch grasps the tendon tissue much more readily than an in-line suture such as a simple running or figure-of-eight suture. This allows for a much better ability for the suture to hold tendons that typically appear like "mop ends."

Krackow et al.[18] compared the use of their fixation stitch to various other methods of attaching soft tissue to bone. Their results demonstrated relative ease of surgical technique and decreased "purse-stringing" or soft tissue constriction, compared to the Bunnell method and other similar types of fixation. In addition, they added that a second stitch can easily be used with their technique to enhance fixation.

Watson et al.[38] found their locking loop technique to be significantly stronger than a Bunnell or Kessler technique. However, failure was determined solely when there was a precipitous drop in the force. We have found a significant amount of gapping is typically present when testing these core sutures without augmentation prior to ultimate failure, and therefore, this does not accurately represent true clinical failure.

This study shows that the addition of suture augmentation significantly increased the repair strength and stiffness compared to that of a standard 4-stranded core technique. Studies of tendon repairs in the hand have shown that epitendinous augmentation can increase the repair strength by up to 50%.[16] Our study shows that failure strength can be increased by 91% and stiffness can be increased by 68%, when a cross-stitch weave technique is employed.

Increased resistance to gapping with suture augmentation is probably just as important as increased strength and stiffness. Gapping of 5 mm was chosen as a reference point as this was consistent with the literature.[26,28] It is important to note that of the specimens that were not augmented, half gapped by more than 5 mm prior to failure. Clinically this fact might be more relevant than the ultimate failure strength of the repair since many would consider gapping greater than 5 mm to be clinical failure.

The results of this study show that the addition of epitendinous augmentation significantly increases the strength, stiffness, and gapping resistance compared to that of core sutures alone. These results are even more impressive than those seen in hand flexor tendon studies. This can be explained by the fact that the cross-stitch weave is not strictly an epitendinous augmentation because the grasping loops encompass the tendon itself as well. Given the significant forces that are transmitted through the Achilles tendon and the accelerated rehabilitation programs that have been recently popularized, the need for stronger and more gap resistant repairs are obvious.

This study is inherently limited by the use of cadavers, yet they are the best known way to study this problem. An attempt was made to create a traumatic rupture in the Achilles tendon to recreate the "mop end" appearance of an acute tear in contrast to a surgical incision. This produced failure at the tendon clamp interface, not mid-substance of the tendon, at forces greater than 900 N. As far as we know, no one has recreated the traumatic rupture of the Achilles tendon in an in vitro model. Because this cross-stitch weave inherently grasps the tendon and was performed 2.5 cm away from the "mop end" site, this augmentation should not be affected by the "mop ends." In fact, the results are even more impressive since the core sutures would likely be affected by the "mop ends" and the forces seen from the core sutures alone with our in vitro model would likely be higher than the in vivo model. Future research needs to address a number of basic science issues, such as the magnitude of forces the Achilles tendon repairs are exposed to in the postoperative rehabilitation, whether there is a risk of stretching the tendon, and cyclic testing of these constructs.

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