Xenograft Scaffold Full-wrap Reinforcement of Krackow Achilles Tendon Repair

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Abstract

Standard 4-strand repair of Achilles tendon tears is effective, but additional strength may be desirable in patients who are compromised or those with reruptures. Use of a xenograft scaffold has not been investigated biomechanically in Achilles tendon repair. This study compared stiffness, gap formation, and ultimate load to failure with Krackow repair vs Krackow repair augmented with xenograft scaffold in 6 matched pairs of fresh-frozen human lower extremities. The Achilles tendon was transected 4 cm above the calcaneal insertion. Specimens were randomized to receive standard Krackow repair or Krackow repair augmented with a porcine xenograft scaffold. The graft was wrapped around the repaired tendon, sutured to itself with 2-0 FiberWire (Arthrex, Naples, Florida), and attached to the tendon distally and proximally and then medially and laterally. Specimens were loaded for 200 cycles between 5 and 30 N. Load to 5-mm gapping and load to ultimate failure were measured.

Xenograft scaffold augmentation of standard Krakow Achilles tendon repair was significantly stronger and stiffer than standard Krackow repair in a biomechanical model immediately after repair (39.0±8.8 vs 24.4±4.6 N/mm; P=.01). The augmented repair group had significantly higher load to ultimate failure than did the Krackow group (862.7±174.0 vs 479.5±65.5 N; P<.01).

Biological factors remain to be investigated, but this augmentation method could provide additional strength in patients who are compromised or those with reruptures.

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Drs Wisbeck and Parks have no relevant financial relationships to disclose. Dr Schon is a consultant for Tornier.

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Achilles tendon ruptures can be treated operatively or nonoperatively. Standard 4-strand minimal incision operative repair of Achilles tendon ruptures has provided an effective lower rerupture rate and earlier return to physical activity compared with nonoperative treatment.1–3 However, successful repair may be more challenging in compromised patients with degenerative tendon tears or after rerupture. Higher rerupture rates have occurred in younger, more active individuals.4

Effective augmentation of Achilles repair has included local tendon and fascial grafts, synthetic grafts, and allografts.5–7 Recent studies have also reported significantly improved biomechanics with Achilles repair augmented with a prepared dermal allograft matrix vs unaugmented repair.8,9 Augmentation with a biological scaffold could provide an additional method of increasing functional strength of the Krackow repair in patients where the standard repair might not be adequate. Biological factors are an important part of the decision to use a biological augmentation,10 but it is also not known how much stronger a xenograft-augmented Achilles repair is than the standard repair.

We hypothesized that Krackow Achilles tendon repair augmented with a xenograft scaffold using a specific stitch technique would provide a significantly stronger repair than a standard Krackow repair. We compared stiffness and force at clinical and ultimate failure in the 2 groups.

MATERIALS AND METHODS

Power analysis determined that 6 specimens in each group would provide 80% power to detect a statistical difference at the $P=0.05$ level. Six matched pairs of fresh-frozen human lower extremities were brought to room temperature prior to testing. Four male and 2 female pairs were used, with a mean donor age of 79.3 years (range, 69–88 years). Any specimen with a diseased or injured Achilles tendon was excluded from the study. Specimens in each matched pair were randomly assigned to Krackow repair or Krackow repair with graft reinforcement. The Achilles tendon was approached through the standard midline approach. The paratenon was sharply dissected, exposing the tendon. Complete transection of the Achilles tendon was performed 4 cm above the calcaneal insertion. Krackow repair was performed using a #2 Force Fiber suture (Teleflex Medical, Triangle Park, North Carolina) with a tapered needle. A standard 4-strand Krackow stitch repair with 5 locked loops was used (Figure 1). All surgeries were performed by a single investigator (J.M.W.).

For the augmented repair group, standard Krackow repair was followed by repair augmentation with a xenograft scaffold in a full-wrap configuration (Conexa; Tornier, Minneapolis, Minnesota). Conexa is a porcine dermal matrix with a sterility assurance level of 10-6 and thickness of approximately 2 mm. The axial length of each graft was 67 mm. The graft was wrapped around the tendon to determine where it should be cut for circumferential fit. The width of the graft was such that the ends met to achieve full coverage, but not so wide as to have overlap because the goal was to keep additional bulk to a minimum. The graft was cut with a scalpel, wrapped around the tendon, and sutured to itself with 2-0 FiberWire (Arthrex, Naples, Florida). The graft was then attached to the tendon distally using #2-0 FiberWire in a figure-8 fashion. A loop of #2 Force Fiber suture (Teleflex Medical) was placed proximally, and a force of 9 N was applied via a pulley-weight system for standard tension on the graft to remove slack and avoid stretching the graft as it was sutured to the repaired tendon (Figure 2). The graft was then attached proximally with the 2-0 FiberWire in a figure-8 fashion. Grafts were attached to the tendon with 2-0 FiberWire using a lateral trap stitch (distal to proximal, then reversed) on the medial and lateral sides (Figure 3).

The specimens were prepared for loading by disarticulating the specimen at the ankle joint and stripping muscle away from the tendon. Two 5-mm centrally threaded Steinmann pins (DePuy/ACE, Warsaw, Indiana) were placed parallel
to each other medial to lateral through the calcaneus. The specimens were then secured to a Q-Test electromechanical load frame (MTS Systems, Eden Prairie, Minnesota). The Achilles tendon was secured proximally in a custom fabricated cryogenic clamp. A 9-mm differential variable reluctance transducer (MicroStrain, Williston, Vermont) was placed across the rupture site to measure gap formation. Reproducibility of differential variable reluctance transducer data has been shown in several previous studies in our lab.\textsuperscript{11-13}

In the augmented repair group, the proximal and distal pins of the differential variable reluctance transducer were placed through 1-cm vertical surgical incisions in the graft in line with the load force. The differential variable reluctance transducer was placed across the rupture site, with 1 pin proximal and 1 pin distal to the rupture site (Figure 3). Differential variable reluctance transducer mounting pins are barbed and remain secure in soft tissue under loading. All specimens were cyclically loaded for 200 cycles between 5 and 30 N, followed by static load to failure at a displacement rate of 5 mm/second. Failure was defined as repair gapping of 5 mm, and ultimate failure was defined as complete failure of the construct. Initial stiffness and stiffness at 200 cycles, load vs gap formation, and load at ultimate failure were recorded.

A paired 2-sided \textit{t} test was used to compare stiffness, load to 5-mm gapping, and ultimate load to failure between the 2 groups.

**RESULTS**

No complications or dislodging of the differential variable reluctance transducer mounting pins occurred during testing. Gapping of 5 mm occurred with suture tightening on the tendon in all 6 standard Krackow repair specimens. Ultimate failure in the Krackow group was through knot failure. All 6 specimens in the augmented repair group failed by trap suture pull-through through the graft, followed by knot failure of the Krackow repair.

The augmented repair (including graft and suture strength and method of graft application) was significantly stiffer than the Krackow repair (Table). During cyclic loading, the Krackow group gapped 2.8±0.76 mm, and the augmented repair group gapped 1.1±0.45 mm (\textit{P}=.002). The augmented repair group had significantly higher load to 5-mm gap and ultimate failure than did the Krackow group.

**DISCUSSION**

Xenograft scaffold augmentation using a specific stitch technique showed significantly higher stiffness, load to clinical failure, and load to ultimate failure compared with standard 2-strand Krackow repair of simulated Achilles tendon rupture in a biomechanical model. Augmentation of Achilles repair with a xenograft scaffold was associated with significantly less gapping during cyclic loading to 30 N compared with Krackow repair. These findings suggest a strong mechanical advantage when the Krackow repair is augmented with this biological scaffold using the stitch method described.

In the current study, a mean force of 333 N was associated with 5-mm gapping in the augmented repair group. The mean force observed at 5-mm gapping with augmentation suggests that augmented repair exceeds the forces of 289 N previously measured across an intact Achilles tendon immobilized in a 0.5-inch heel lift.\textsuperscript{14} If xenograft augmentation is proven clinically efficacious, biomechanical strength with this method could allow stronger fixation and greater potential for effective repair in compromised patients, degenerative tendons, or patients with high risk of rupture.

The current findings with augmented repair support those of a previous report that found higher strength in Krackow Achilles repair augmented with allograft dermal matrix.\textsuperscript{8} Dermal allograft augmentation had significantly higher ultimate load to failure (455.1 N±76.5 N) compared with Krackow 2-strand repair in that study (217±31 N; \textit{P}<.001). Our higher ultimate failure load with 4-strand augmented repair (678±110 N) exceeds Achilles forces estimated during normal walking (553 N) and immobilized at neutral in a boot (369 N).\textsuperscript{15}

A possible clinical consideration in the current augmentation method include longer surgical time. Augmented repair took approximately 20 minutes longer than Krackow repair in the current study, almost doubling the repair time. Considering wound complications and infection are a concern in open Achilles repair, additional operative time may affect these risks. Substantial additional cost is another consideration with augmentation using this biological graft. Use of the graft may be most appropriate for patients with complicated repair, such as patients with degenerative, frayed, and retracted tissues, and primary Achilles ruptures in young, high-demand individuals where rehabilitation, range of motion, and early

**Table**

<table>
<thead>
<tr>
<th>Krackow Group Versus Augmented Repair Group</th>
<th>Mean Stiffness (N/mm)</th>
<th>Krackow Group</th>
<th>Augmented Repair Group</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>24.4±4.6</td>
<td>39.0±8.8</td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>200 cycles</td>
<td>40.8±4.4</td>
<td>61.7±22.5</td>
<td>.10</td>
<td></td>
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<tr>
<td>Load at 5-mm gap</td>
<td>156.7±42.9</td>
<td>333.2±105.4</td>
<td>.01</td>
<td></td>
</tr>
<tr>
<td>Ultimate failure load</td>
<td>479.5±65.5</td>
<td>862.7±174.0</td>
<td>.01</td>
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</tbody>
</table>
return to strengthening are especially important.

This study was limited because it did not assess the important clinical role of biological factors inherent in the use of this graft or the potential biological role in healing. This biomechanical model does not allow evaluation of the role of the graft in clinical healing. One study found no benefit from the use of porcine small intestine submucosa xenograft in repair of massive rotator cuff repairs and recommended against xenograft use in this scenario because of potential localized reactions. Biological and healing aspects of xenograft use remain to be investigated. Our specimens were from older donors. Different results might be found with younger specimens, but considering the magnitude of the differences observed, we anticipate finding a significant difference between the constructs with younger tissue.

Our simulated rupture did not reproduce the typical clinical scenario for Achilles tendon ruptures. Achilles tendon ruptures are rarely a clean cut of a normal, healthy tendon. Transection of the tendon is a standard method for replicating ruptures in biomechanical studies, but a future study testing the strength of a repaired avulsed ruptured tendon with more typical mop ends would more specifically test the strength of xenograft augmentation. Although the current model did not allow for evaluation of the effects of the graft on skin closure and healing, we did not consider the graft repair bulky.

Xenograft scaffold augmentation of standard Krakow Achilles tendon repair was significantly stronger and stiffer than Krakow repair in a biomechanical model. The current technique for applying the scaffold may serve as a mechanically sound model for comparative studies.

REFERENCES