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Suture Holding Capacity of the Achilles Tendon during the Healing Period: An In Vivo Experimental Study in Rabbits

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ABSTRACT

Background: **Early motion and weightbearing is known to promote the healing of Achilles tendon repair. It is important to be informed about the repair strength for a secure rehabilitation. There are reports about the initial repair strength of Achilles tendons; however, they are mainly in vitro studies that represent the time zero strength of the repair. Softening of the tendon observed during the biological process of the tendon healing, which may effect the suture holding capacity and in turn the repair strength of the tendon has not been evaluated before.** ***Methods:*** **In the current study, the suture holding capacity of rabbit Achilles tendon was observed at various times during the healing period.** ***Results:*** **The suture holding capacity of the tendon at the end of the first and third weeks after surgery was found to be similar within 30% of the control tendon. However, at the end of the fourth week it was doubled reaching 65% of the control tendon.** ***Conclusions:*** **Intrinsic tendon insufficiency which causes a decrease in the suture holding capacity of the tendon may lead to pull-out of the suture material during the postoperative third week. This period is precarious for early motion and weightbearing since the suture holding capacity of the tendon doubled relative to the previous three weeks.**

Key Words: Achilles; Experimental; Suture Holding Capacity

INTRODUCTION

The treatment of choice for Achilles tendon ruptures is operative repair especially for active people.[6] Although early motion and weightbearing promote the healing of the Achilles tendon, high loading forces may result in failure of the suture repair. To minimize these risks of rerupture and damage to the healing tendon, it may be important to recognize the tensile strength and limitations of the repair.

A number of biomechanical studies have been done to determine the initial strength of Achilles rupture repair;[5,8,16,17] however, the biological processes that modulate the physical properties of the tendon result in an alternating tensile strength during the healing period.[7,9,10,11,12] Softening of the tendon ends with ensuing decrease of the suture holding capacity has been proposed as a mechanism for this alteration.[7,12] However, scientific data regarding the suture holding capacity of the tendon during the healing period is lacking. Thus, the aim of this study was to document the suture holding capacity of the rabbit Achilles tendon at various times during the healing period.

MATERIALS AND METHODS

Thirty rabbits of both sexes, weighing 2.8 to 3.4 kg, were divided into three groups. The animals were housed in individual cages at the University of Marmara Animal Facility in Istanbul. All protocols were approved by the University of Marmara Animal Care and Use Committee. After anesthesia with a mixture of xylazine (80 mg/kg) and ketamine (50 mg/kg) intramuscularly, the skin over and around the right Achilles tendon was shaved and thoroughly scrubbed. The tendon was approached through a medial skin incision and freed from the surrounding tissue. The tendon was cut 1.5 cm from its insertion on the calcaneus. The severed ends of the tendon were approximated with No. 2 Ethibond suture (Ethicon, Somerville, NJ) with a Kessler technique. In all of the repairs, the knot was left on the lateral side of the distal tendon away from the tenotomy site. The skin incision was closed by single stitches of 3-0 silk. The limb was immobilized in a light plaster-fiberglass cast that kept the ankle fully plantarflexed and the knee flexed to approximately 45 degrees. No procedure was done on the

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left legs of the animals that were used as controls to measure the time zero suture holding capacity of the tendon.

At the end of postoperative weeks 1 (group I), 3 (group II) and 4 (group III) animals were sacrificed with an overdose of pentobarbital sodium. Immobilization casts were removed and the skin incisions were reopened. The Achilles tendon was freed from the surrounding tissue and excised 2 cm proximal to the musculotendinous junction proximally and the calcaneus distally. The Achilles tendon was approached on the left side (control) and prepared by cutting it 1.5 cm proximal to the calcaneal insertion and 2 cm proximal to the musculotendinous junction. The Kessler configuration was placed at the distal end of the tendon with No. 2 Ethibond. The distal ends of the suture materials were left free and were not used to connect the proximal and distal portions of the tendon.

All tendons were stored at −23 degrees C until the time of testing. On the day of the testing, tendons were thawed at room temperature and kept moist with lactated Ringer solution to prevent drying. Each specimen was placed into a materials testing machine (model 1321B, Instron, Canton, MA, U.S.A). Aluminum clamps were used to secure the tendon proximally. In the experimental group, a steel n-shaped wire was passed through the tenotomy site and put within the jaws of the testing machine distally (Figure 1). The suture material was distally loaded through this wire (Figure 2). In the control group, the tendon proximally and the suture material distally were put in the testing machine (Figure 3). Tensile load was then applied at a displacement rate of 20 mm/min. Load characteristics were directly plotted on an X-Y chart recorder, and a force-displacement graph was obtained. Before any loading, the 'slack' was taken out of the system by placing the specimen at a uniform starting position, at which the machine was zeroed. The point on the curve at which there was a precipitous drop in the force was deemed the point of ultimate strength. The results were analyzed statistically using a one-way analysis of variance Tukey-Kramer test comparing the three groups of specimens to each other and also to control groups.

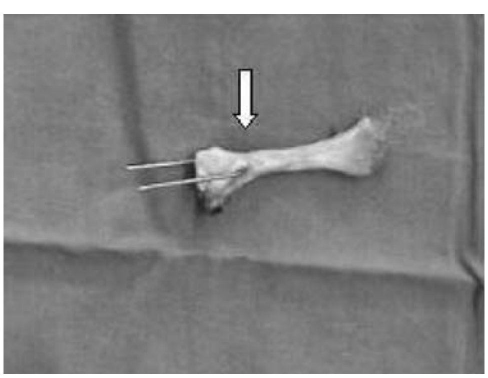

Fig. 1: A wire was passed through the tenotomy site.

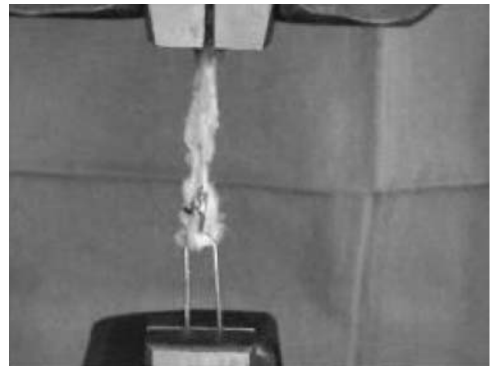

Fig. 2: Tendons were loaded through a wire in the experimental group.

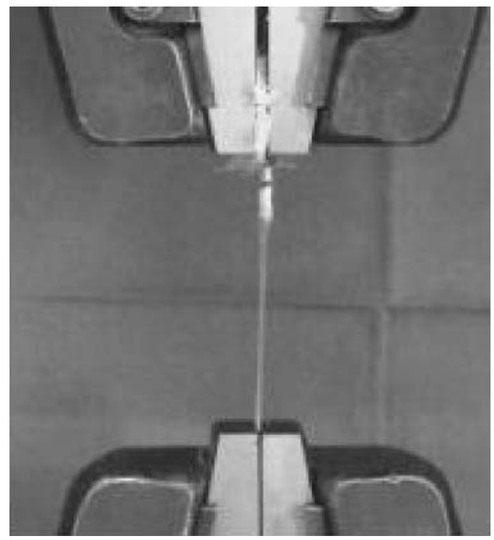

Fig. 3: Tendons were loaded through the suture material in the control group.

RESULTS

All specimens from all groups failed because the suture material pulled out of the tendon (Figure 4). There were no failures from suture material breakage or untying of the knot. At the end of the first week after surgery, the mean load to failure of the experimental and control tendons were 19.6 N and 68.1 N, respectively. At the end of third week, the mean of the suture holding capacities of the experimental and control tendons were 21.0 N and 67.5 N, respectively. The mean load to failure was 44.1 N in the experimental group and 68.5 N in the control group at the end of the fourth week (Table 1).

There was no statistically significant difference between the control groups at 1, 3, and 4 weeks. The comparison of the suture holding capacities of the tendons at the end of the first and third weeks were statistically nonsignificant. However, both were statistically different when compared to the suture holding capacity of the postoperative fourth week ($p < 0.001$). The comparison of the fourth week and

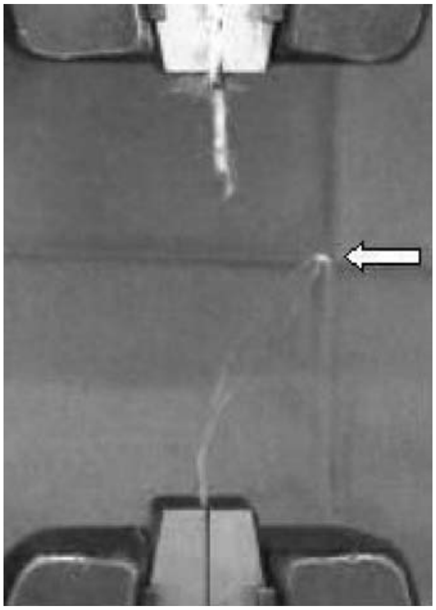

Fig. 4: In all the groups the suture material pulled-out of the tendon.

Table 1: Suture holding capacities of the tendons according to postoperative days

	7 day	21 day	28 day
Mean Load (N)	19.6	21	44.1
SD	8.6	2.3	15.3
Maximum (N)	29.6	24.5	68.8
Minimum (N)	9.7	19.8	24.6

N; Newton, SD; Standard Deviation

its control group was not statistically significant with regard to the suture holding capacity.

DISCUSSION

Suture holding capacity of the tendon is an important factor that determines the strength of the tendon repair construct. Other factors are the suturing technique and the strength of the suture strand. Suture holding capacity of the tendon depends on the friction coefficient between the suture material and the quality of the tendon tissue itself.[4] During the healing period of an Achilles tendon, formation of new collagen fibrils around the tenotomy site add some strength to the repair. However, evidence in rabbit Achilles tendon indicates that, after repair of the tenotomy, 20 weeks are required to reach 65% strength of the normal tendon.[1,14] Certainly, this period is longer in human Achilles tendon where regeneration potential is lower than in rabbits. Therefore, the strength of the primary repair has definite significance until the newly formed tendon tissue matures.

Previous studies reporting the tensile strength of the healing Achilles tendon investigated the whole strength without quantifying the suture holding capacities separately.[12,13,14,15] In the current study, suture holding capacity of the tendons were quantitatively measured at different times in the healing period with a standard suture configuration (Kessler). The suture holding capacity of the rabbit Achilles tendon was found to be similar at the end of the first and third weeks: 30% of normal tendon. At the end of the fourth week, the suture holding capacity doubled relative to the first and third weeks, reaching 65% of normal tendon.

Mason and Allen have reported an initial drop in the tensile strength of the tendon within 5 days after the repair.[7] Nyström and Holmlund[9,10,11] described a biphasic separation of the tendon ends after suture of Achilles tendon where the first separation took place during the first 5 days while the second one began at about 20 days.[9,10,11] In the study of Mason and Allen,[7] the suture-holding capacity of the tendon could not be evaluated because the sutures began to break 14 days after the repair. This handicap was mentioned in the study, indicating that heavier suture materials should be used to determine the ultimate suture-holding capacity of the tendon. In the current study, a heavy suture material (2 Ethibond) was used, which pulled out through the tendon instead of breaking, enabling us to measure the suture holding capacity of the tendon.

The drop of the tensile strength at the first week after repair was attributed to edematous softening of the tendon ends during the inflammatory phase of healing.[7,9,10,11,12] In the present study, the suture holding capacity of the tendon was only 30% of the normal tendon at 7 days after repair. This may represent softening of the injured tendon. This finding was in accordance with previous studies that showed that in healing rabbit calcaneal tendons, inflammation continues until about 7 days after tenotomy and fibroplasia begins thereafter.[2,13]

Involuntary contraction, reinnervation of the muscle fibers, and plastic deformation of the neocollagen were hypothesized to be the cause of separation of the tendon ends at the end of the third week in the former studies.[11,12] However, in the current study, the suture holding capacities at the end of the first and third weeks of the repair were similar. This confirms that separation of the tendon ends at the third week may be caused by a second decrease in the suture holding capacity of the tendon similar to that in the first week after repair. Electron microscopy findings of healing rabbit Achilles tendons may offer an explanation for the low suture holding capacity of the tendon at the end of the third week.[2] Enwemeka[2] described three different stages during the healing period. In the third period, which began 12 days after surgery, there was a progressive alignment and organization of the collagen fibrils into bundles that were oriented in the longitudinal axis of the tendon. The Kessler suture configuration, which has a more longitudinal component than oblique and transverse passages, may slide through these newly formed longitudinally oriented, weak collagen fibril bundles, leading to a decrease in the suture-holding capacity of the tendon at the end of the third week. The findings also were in accordance with the study of Pneumaticos et al.,[12] who found the mechanical properties of the tendons were found to be closely related to the quality and the orientation of the collagen fibers.

The results of the current study do not allow for determination of the effect of biological healing on the total strength of the repair. However, comparative data are available from the study of Enwemeka,[3] who investigated the tensile strength of healing rabbit Achilles tendons. The mean tensile strength of the tendons was approximately 95 N at the end of the third postoperative week. Although different suture materials were used, in our study the suture holding capacity of the tendon accounted for only 20% of the total tensile strength at the end of the third week. In the study of Thermann et al.,[15] the tensile strength of the repair was doubled between the second and fourth weeks in rabbit Achilles tendons. In the current study, the suture holding capacity was doubled within 1 week between the third and fourth weeks. This indicates a later but faster intracompartmental recovery (improvement in the tendon tissue matrix) with respect to extracompartmental (formation of new collagen fibrils) healing.

The incompetent suture holding capacity in the early periods of the repair indicates an intrinsic tendon insufficiency. This period is precarious for early motion and weightbearing. In the literature, the strongest in vitro repair of the Achilles tendon was reported by Jaakkola et.al.[5] They measured 453 N as the time zero strength (in vitro just after suturing) for triple bundle technique. Although the repair method was different from that of Kessler, it can be estimated from the current study that the strength of the repair might decrease up to 135 N (30% of time zero strength) at the end of the third week. Softening of the tendon observed within this period may result in suture pull-out through the tendon, and the strength of the tendon may not be sufficient for weightbearing and early motion. However, at the fourth week of the repair the increase in the suture holding capacity of the tendon appeared to be sufficient to allow weightbearing and early motion.

A limitation of this study was that the rupture model created with a scalpel does not reproduce the “mop end” appearance of a clinical rupture. However, a severe strain would be required to rupture healthy tendon, and this was impractical under experimental conditions. Another limitation of the study is that the suture holding capacity of the tendon was measured proximal to the tenotomy site. Nevertheless in our opinion, the suture holding capacities of the distal and proximal parts of the tendon are little, if any, different. Finally, the data obtained from the study represented findings in rabbit Achilles tendons and may not be completely applicable to clinical practice.

In summary, the suture holding capacity of the rabbit Achilles tendon was similar at the end of the first and third weeks after repair (30% of the control tendon’s strength). This period is risky for early motion and weightbearing because the suture material may pullout of the tendon. At the end of the fourth week, the suture holding capacity of the tendon doubled approaching 65% of the control tendon, which would allow safer motion and protected weightbearing.

REFERENCES

1. **Aoki, M; Ogiwara, N; Ohta, T; Nabeta, Y.:** Early active motion and weightbearing after cross-stitch Achilles tendon repair. Am. J. Sports Med. **26(6)**:794–800, 1998.
2. **Enwemeka, CS:** Inflammation, cellularity and fibrillogenesis in regenerating tendon: implications for tendon rehabilitation. Phys. Ther. **69**:816–825, 1989.
3. **Enwemeka, CS:** Functional loading augments the initial tensile strength and energy absorption capacity of regenerating Achilles tendons. Am. J. Phys. Med. Rehabil. **71**:31–38, 1992.
4. **Holmlund, DE:** Suture technic and suture-holding capacity: a model study and a theoretical analysis. Am. J. Surgery. **134**:616–621,1977.
5. **Jaakkola, JI; Hutton, WC; Beskin, JL; Lee, GP:** Achilles tendon rupture repair: biomechanical comparison of the triple bundle technique versus the Krakow locking loop technique. Foot Ankle **21**:14–17, 2000.
6. **Maffulli, N:** Current concepts review. Rupture of the Achilles tendon. J. Bone Joint Surg. **81-A**:1019–1036, 1999.
7. **Mason, ML; Allen, HS:** The rate of healing of tendons. An experimental study of tensile strength. Ann. Surg. **113**:424–459, 1941.
8. **Mortensen, NH; Saether, J:** Achilles tendon repair: a new method of Achilles tendon repair tested on cadaverous materials. J. Trauma. **31**:381–384, 1991.
9. **Nyström, B; Holmlund, D:** Separation of sutured tendon ends when different suture techniques and different suture materials are used. An experimental study in rabbits. Scand. J. Plast. Reconst. Surg. **17**:19–23, 1983.
10. **Nyström, B; Holmlund, D:** Separation of tendon ends after suture of Achilles tendon. Acta. Orthop. Scand. **54**:620–621, 1983.
11. **Nyström, B; Holmlund, D:** Experimental evaluation of immobilization in operative and non-operative treatment of Achilles tendon rupture. A radiographic study in the rabbit. Acta Chir. Scand. **149**:669–673, 1983.
12. **Pneumaticos, SG; Noble, PC; McGarvey, WC; Mody, DR; Trevino SG:** The effects of early mobilization in the healing of Achilles tendon repair. Foot Ankle **21**:551–557, 2000.
13. **Postacchini, F; DeMartino, C:** Regeneration of rabbit calcaneal tendon: maturation of collagen and elastic fibers following partial tenotomy. Connect. Tissue Res. **8**:41–47, 1980.
14. **Roberts, JM; Goldstrohm, GL; Brown TD; Mears DC:** Comparison of unrepaired, primarily repaired and polyglactin mesh-reinforced Achilles tendon lacerations in rabbits. Clin. Orthop. **181**:244–249, 1983.
15. **Thermann, H; Frerichs, O; Biewener, A; Krettek, C:** Healing of the Achilles tendon: an experimental study. Foot Ankle **22**:478–483, 2001.
16. **Watson, TW; Jurist, KA; Yang, KH; Shen, K:** The strength of Achilles tendon repair: an in vitro study of the biomechanical behavior in human cadaver tendons. Foot Ankle. **16**:191–195, 1995.
17. **Yildirim, Y; Esemenli, T:** Initial pull-out strength of tendon sutures: an in vitro study in sheep Achilles tendon. Foot Ankle. **23**:1126–1130, 2002.