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Initial Pull-Out Strength of Tendon Sutures: An *In Vitro* Study in Sheep Achilles Tendon

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ABSTRACT

Forty-eight fresh frozen sheep achilles tendons were used to compare the pull-out strengths of Kessler, Bunnell and locking loop techniques which are the standard configurations described for Achilles tendon repair. A simulated Achilles tendon rupture was done with a tenotomy made 2 cm proximal to the calcaneal insertion. One of the configurations was placed at the distal end of the proximal portion of the tendon specimens using No. 5 Ticron. The distal ends of the suture materials were left free and were not used to connect the proximal and distal portions of the tendon. Using a servohydraulic materials testing machine, each tendon was tested to failure in tension at a displacement rate of 20 mm/min. All the specimens failed due to pull-out of the suture material. Since the cause of failure was suture material breakage in the previous studies reporting repair strength, they were unable to represent the effect of configuration on the strength. This study is the first to represent the effect of configuration on the initial strength since there is no failure due to suture material breakage.

Key Words: *In Vitro*; Achilles Tendon; Repair Strength.

INTRODUCTION

The treatment of Achilles tendon rupture has had operative and nonoperative proponents and even today it is still controversial. Nonoperative treatment has its supporters, but operative treatment has been the method of choice for athletes and young people.[6] The nonoperative option carries a higher rerupture rate and a lower ultimate performance and is not recommended for an active patient.[1] A primary goal of the treatment of the Achilles tendon rupture is to avoid lengthening of the tendon, and this cannot be achieved with nonoperative treatment.[10]

A review of the literature yields many operative techniques ranging from simple end-to-end suturing to more complex repairs, but only a few studies discuss the strength of repair. In 1991 Mortensen et al. reported a biomechanical study in which the Mason (a grasping type repair similar to the Kessler) and Bunnell repair methods were tested against the Savage's six strand continuous suture.[9] Watson et al. conducted a similar biomechanical study in 1995 to evaluate the initial strength of Achilles tendon repair. The Kessler, Bunnell and Krackow locking loop techniques were compared.[14] Recently in 2000 Jaakkola et al. made a biomechanical comparison of the triple bundle technique vs. the Krackow locking loop technique.[4]

The initial strength of a repair method depends on the configuration chosen and the strength of the suture material itself.[11] Since the mode of failure was suture material breakage in the previous studies, no scientific report to date has compared the pull-out strengths of commonly used repair methods in Achilles tendon. This study was designed to determine the effect of suture configurations on the force required to pull the suture material out of the tendon for Bunnell, Kessler and locking loop techniques which are current standard configurations for Achilles repair.

MATERIALS AND METHODS

Forty-eight fresh sheep Achilles tendons were prepared by cutting them 2 cm proximal to the calcaneal insertion and 1 cm distal to the musculotendinous junction. Tendons were randomly placed into three groups with 16 specimens in each. One of the following suture

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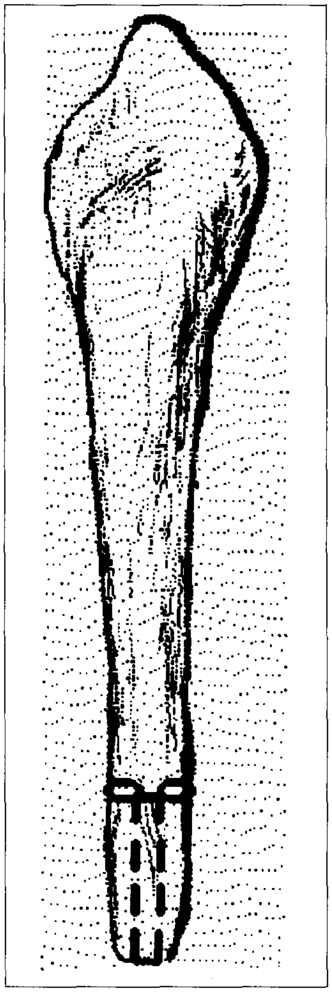

Fig. 1: A standard Kessler repair configuration.

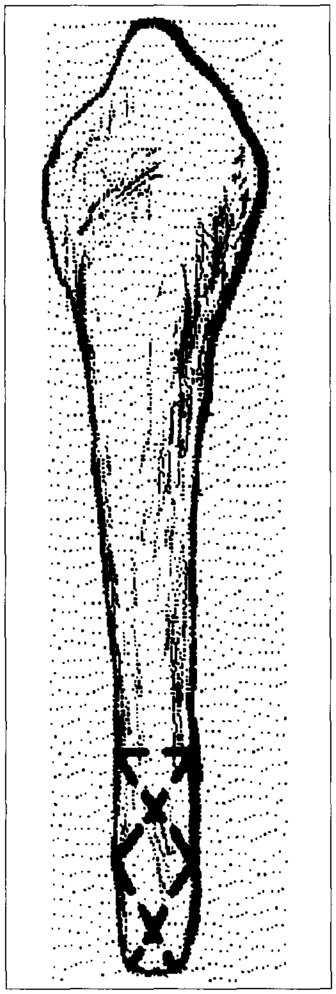

Fig. 2: A standard Bunnell repair configuration.

configurations was placed at the distal end of the specimens using No. 5 braided polyester (Ticron). These were:

1. standard Kessler suture (Fig. 1),
2. standard Bunnell suture with double criss-cross (Fig. 2) and,
3. Krackow locking loop suture with triple loop on each side (Fig. 3).

The distal ends of the suture materials were left free and were not used to connect the proximal and distal portions of the tendon. For standardization, all sutures were configured to allow two strands (minimum possible number for the Kessler and Bunnell techniques) passing the tenotomy site (Fig. 4). All tendons were stored at 23° centigrade 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, USA). Aluminum clamps were used to secure the tendon proximally and the suture material distally (Fig. 5). Tensile load was then applied at a displacement rate of 20 mm/min. Displacement rate of 20 mm/min was selected since this distraction rate was commonly used in other biomechanical tendon repair strength evaluations, especially of flexor tendons.[12,13] Different rates of load application was shown to make little difference to influence the results.[15] 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 that can be seen from the graph paper, was deemed the point of ultimate strength. The ultimate strength for each specimen as well as the location of the failure whether from the tendon or the suture material was recorded. The results were analyzed statistically using a one-way analysis of variance Tukey-Kramer test comparing the three groups of specimens.

RESULTS

The mean width of the tendons was 1.3 cm The results are presented in Table 1. All specimens from all groups failed because the suture material pulled-out of the tendon. There were no failures due to suture material breakage (Fig. 6). The mean load to failure for the Kessler, Bunnell and locking loop methods was 101.4 N (Newton), 197.4 N and 216.7 N respectively. There was no statistically significant difference between the Bunnell and locking loop, whereas the Kessler method was significantly weaker than either of the other methods. This was significant at the $p<0.001$.

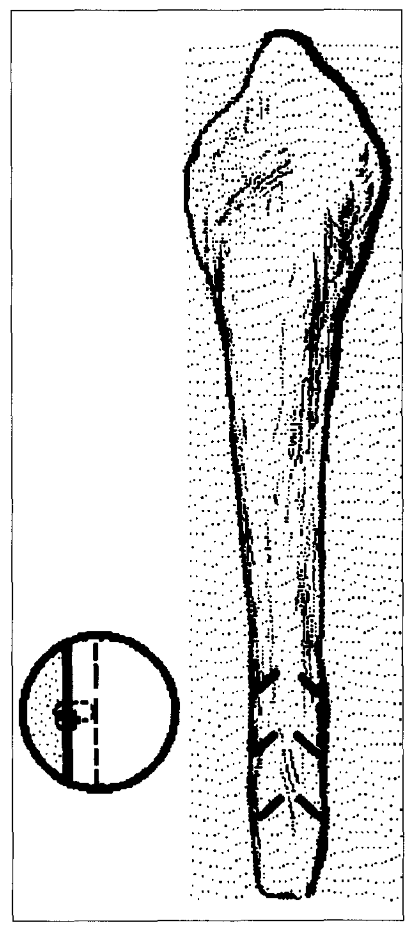

Fig. 3: A locking loop repair method with triple loops on each side. The inset shows the detail of schematic drawing.

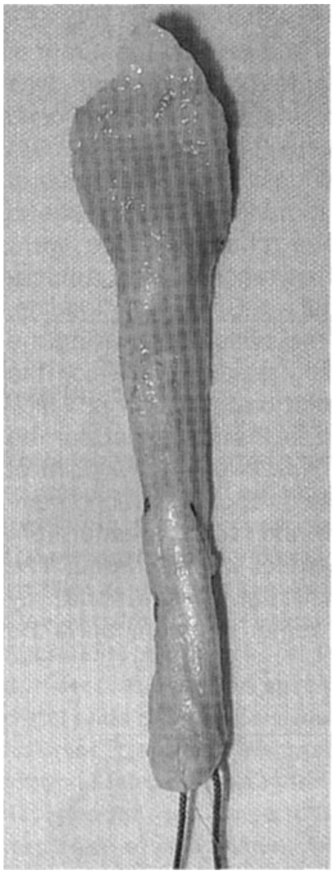

Fig. 4: A prepared and sutured sheep achilles tendon passing 2 suture strands at the tenotomy site.

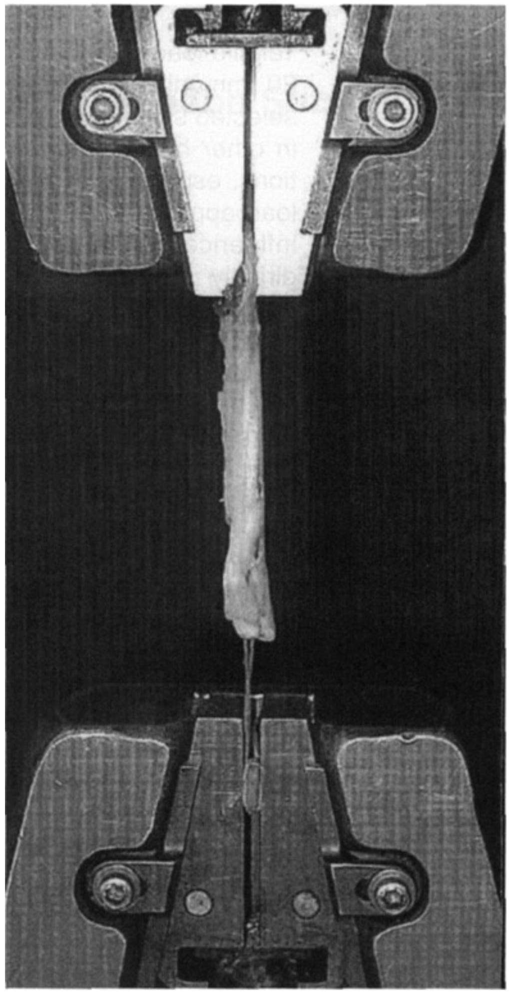

Fig. 5: Trials were done on a materials testing machine.

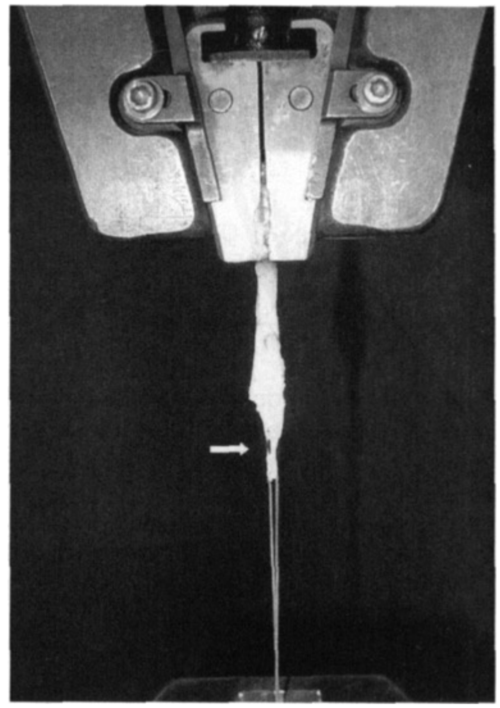

Fig. 6: All specimens failed by pulling the suture material out of the tendon.

DISCUSSION

Kessler, Bunnell and the locking loop are the standard configurations described for the repair of Achilles tendon rupture. It is of considerable clinical value and relevance to have biomechanical information on the initial strength of the repair. Repair strength of a tendon depends on the friction coefficient between the suture material and the tissue (holding capacity of the configuration on the tendon) and the tensile strength of the suture material itself.[3]

There are some reports in the literature regarding the initial strength of Achilles tendon repair. In 1991, Mortensen et al. made a biomechanical study in which the Mason (a grasping type repair similar to the Kessler) and Bunnell repair methods were tested against the Savage's six-strand continuous suture.[9] In contrast to the present study, they did not use a testing machine; instead, they applied hanging weights which they increased by 5 N every 30 seconds until failure. They reported that the mean tensile strength was 45 N, 78 N and 175 N for Mason, Bunnell and Savage's six-strand suture respectively. Since the failure site was the suture material in most of the specimens, six-strand Savage technique was found nearly three times stronger than the two strand Mason and Bunnel techniques.

In 1995, Watson et al. conducted a similar biomechanical study to evaluate the initial strength of Achilles tendon repair.[14] The Kessler, Bunnell and Krackow locking loop techniques were compared. They found the locking loop technique to be 1.58 and 1.73 times stronger than the Bunnell and Kessler techniques respectively. In that study they reported that all specimens from all groups failed at the suture, and no trial suture, regardless of the repair method, pulled-out of the tendon. Since the locking loop technique is a four strand configuration, when the failure is due to suture material breakage, it is not surprising that it is nearly two times stronger than the two

Table 1

	Kessler	Bunnell	Locking loop
Mean load (N)	101.4	197.4	216.7
SD	16.4	33.8	33.6
Maximum (N)	122.6	245.3	245.3
Minimum (N)	63.7	137.3	166.8

strand Kessler and Bunnell techniques. As Watson et al. mentioned, although their first hypothesis was to evaluate the suture tendon pull-out force, it was not confirmed due to primary failure of the suture. This study was unable to compare the effect of configuration on the strength of repair and the suture strength was measured.

Recently Jaakkola et al. made a biomechanical comparison of the triple bundle technique (TBT) vs. the Krackow locking loop technique (KLLT).[4] Six suture strands crossed the rupture site in the triple bundle technique and four strands were present in the locking loop technique. They found 453 N as the mean load to failure for TBT and 161 N for KLLT. Suture failure was reported in three cases out of eight in the TBT group and seven of eight cases in the KLLT group. Although the strand ratio is 1.5 in favor of TBT, the triple bundle technique was found to be 2.8 times stronger than the locking loop. This difference is probably related to the knot placement of the triple bundle technique which is placed away from the rupture site.

The strength of the suture strand is only one factor that influences the holding capacity of a suture; the knot and suturing techniques are two other important factors.[3] Zero Ticron and number one Ethibond suture materials were used in the previous studies, which have less tensile strengths than number five Ticron which was used in our study. This is why the suture material breakage occurred in the previous studies and did not in ours. Since the mode of failure was suture material breakage in previous studies, suture material strength was evaluated instead of the performance of suture technique,[2] so that there is no scientific report comparing the pull-out strengths of different suture configurations.

In the present study since there was no failure due to suture material breakage, the suture strand factor was eliminated. Our study is the first in measuring the pull-out strengths of common configurations used in Achilles tendon repair, hence representing the effect of configuration on the initial strength. In contrast to the findings of Watson et al., it was found that the pull-out strengths of Bunnell and locking loop techniques do not differ significantly from each other while the Kessler configuration was 50% weaker than either of the other methods. The Kessler technique involves a rectangle lying in the horizontal plane. This configuration grasps the tendon with only one suture loop on each side. The Bunnel technique generates multiple sites of transverse and oblique compression at the points where the suture crosses the tendon.[5] This difference in the configurations is probably the cause of weakness of the Kessler technique. In the study by Watson et al., the difference is not related to the holding capacity of the configuration on the tendon, but the number of strands crossing the tenotomy site. In the present study, all sutures were configured to allow two strands (minimum possible number for the Kessler and Bunnell techniques) passing the tenotomy site for standardization. Increasing the strand number will increase the suture holding capacity which is the product of the coefficient of friction between the suture strand and the tissue.[3] Alteration of the suture holding capacity eventually will effect the pull-out strength of configurations. For this reason, standardization of the strand numbers was important to equalize the suture holding capacity for each configuration. Increasing the number of strands will distribute the applied tensile force to the strands and also by effecting the holding capacity, will increase the repair strength. Although increasing the strand number is possible for each technique, it is more convenient for the locking loop configuration.

When the holding power of the configuration on the tendon fibers is stronger than the sutures, which always snap rather than pulling-out, the only remaining possibility for increasing the repair strength is to have more passes of suture and/or stronger suture material.[7] There is no reason to use complex locking features as those described by Savage, if the strength of suture strand is less than the pull-out strength of the configuration. This concept will minimize suture material on the surface of the tendon, which should reduce foreign body reaction where adhesion formation is known to occur.

The rupture model created with a scalpel in the study might be criticized because it does not reproduce the "mop end" appearance of a clinical rupture. It is important to recognize that this study on tensile strength at the repair site has been performed *in vitro* and shows "time zero" strength of the repair. Ideally it should be tested *in vivo* on experimental animals before being used clinically.

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