AN IN VITRO BIOMECHANICAL COMPARISON OF ACHILLES TENDON REPAIR: Modified Triple Kessler Versus Krackow Suture Technique

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INTRODUCTION

Achilles ruptures are familiar to the trauma aspect of orthopedic surgery. There have been many studies designed comparing one technique to another as well as some discussion as to whether repair techniques are strong enough to withstand early range of motion in the postoperative days following the procedure (1-4). In 1983, in an attempt to find the simplest, strongest, and most efficient suture method to repair tendon end-to-end and tendon-to-bone, Kenneth A. Krackow, originated a technique that now, 25 years later, has been the most widely used technique to repair Achilles tendon ruptures (5, 6). There are many methods to Achilles tendon rupture repair that are not only limited to open procedures but also percutaneous and endoscopic type tendon repairs. However, open repairs remain the mainstay treatment of choice for both acute and chronic ruptures (7). Brief overviews from other studies have indicated the success with endoscopic repair, however, there are associated complications with endoscopy in sural nerve damage and/or neuritis (8).

There are reports in the literature that argue for approaching the repair with minimal incision placement in an attempt to reduce the chances of postoperative wound complications (9-11), which leads us to discuss the aim for percutaneous techniques, also a minimal incision placement method. This mini-open technique, with a specialized device, has the benefits of reducing the size of the incision in an attempt to minimize postoperative wound management; however, the function of the device is limited to a specific area and acuity of the tendo-achilles rupture, specifically: acute rupture (<10 days), and rupture located between 2 and 8 cm above the tendon insertion site (12).

There would not be an argument except for the fact that there are many methods of open repair discussed in the literature. The aim/objective of this study would not be to displace all other methods but to demonstrate two different methods of repair with a modification of a classic method that in the past has been shown to be weaker in strength than the more commonly used Krackow method. We hypothesize that the modified triple Kessler technique will have higher force to failure due to an increased number of strands and knots crossing the repair site, and multiple level passage of the suture material through the Achilles tendon length. We speculate that the modified triple Kessler may be a biomechanically stronger method of fixation not due to the increased number of locking loops within the tendon (like the Krackow) but due to the increased number of knots across the repair site; this is believed to be the key to increasing the amount of axial force the repair can withstand. The purpose of the study is to biomechanically compare the 2 strand, 2 knot method of the 5 locking loop Krackow with the modified 6 strand, single locking loop, triple Kessler in vitro. It is through this in vitro study that we may prove the hypothesis that the triple, 6 knot, single locking loop Kessler will withstand a greater force of axial load than the standardized 2 knot, 5 locking loop Krackow. We believe that it is the greater number of suture wires and knots at the repair junction used, such as with the modified Kessler, that will withstand a greater force in comparison to having more locking loops within the tendon.

MATERIALS AND METHODS

Twelve fresh frozen human cadaveric foot and ankle specimens (both females and males from Shiley Center of Orthopedic Research and Education) were obtained for use in this study to compare the strengths of the two methods of tendon repair. The twelve specimens were divided evenly into 2 groups with the Krackow suture method as the control group. Each gastrocnemius-soleus muscle-Achilles tendon-calcaneus was dissected free from the rest of the limb with preservation of the entire calcaneus disarticulated from its anatomical joint articulations. This allows for the passing of a Steinmann pin through the bone to maintain the bone to tendon attachment for testing. The repairs were standardized across all 12 specimens to allow for unbiased loading conditions. A rupture was simulated in the tendon with a scalpel approximately 4 cm from the calcaneal insertion; a standard 5-cm labeled bard-parker was used for all specimens to ensure equitable measurement. The tendons were repaired per the 2 methods with 6 specimens in each group (Figure 1); 6 specimens were repaired using the standardized 5-locking loop Krackow repair method and labeled as control group A (Figure 2), and the other 6 specimens were repaired using the adapted 6-knot, 6-suture strand single locking loop modified triple Kessler labeled as tested group B.

The suture material used for all specimens in the study was No. 2 Fiberwire (braided polyblend polyethylene suture, Arthrex Inc, Naples Florida). The locking loops method standardized as the Krackow method as depicted in Figure 1 used one suture strand for each side of the tendon stump. This is the same method as described by Watson et al (3) with five locked loops created on the outside edges (medial and lateral) of the tendon in a repetitive fashion; both the proximal and distal stump where repaired in the exact same fashion. This remained our standardized repair for all 6 specimens.

For consistency in the tested group, the primary author was the primary surgeon who repaired the modified triple Kessler suture technique. The modified Kessler as depicted in Figure 2, shows a Kessler suture single locked-loop in a staggered fashion using 3 suture strands for each tendon end, with the first suture strand started on the most peripheral edge of the tendon and looped-locked approximated 1 cm from the rupture site. The needle is passed through the tendon end and out the tendon end closest to the marginal edge in acceptable tissue. This is repeated in the second suture strand where it is started slightly central to the first suture and advanced and locked further proximal along the tendon.

The third suture strand needle is inserted from the most central aspect of the tendon stump and advanced proximal and singly looped-locked proximal to the second suture strand along the proximal tendon exiting along the marginal edge going across the tendon at the same level, locked-looped, and exiting the central and lateral to the entering suture. All sutures ends from the proximal and distal tendon stumps were coapted and tied in a square knot fashion from

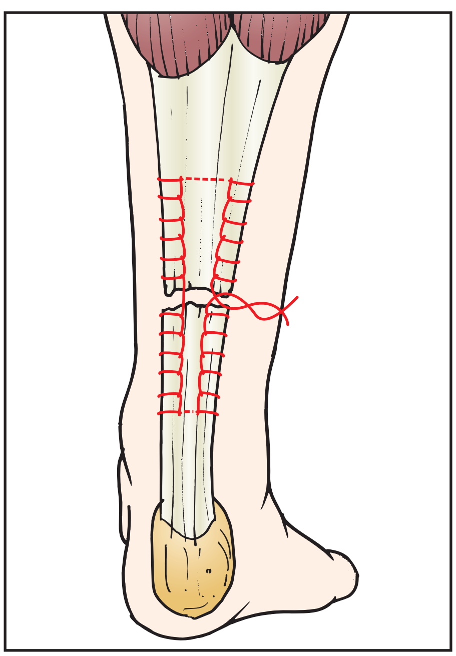


Figure 1. The tendons were repaired using the two methods.

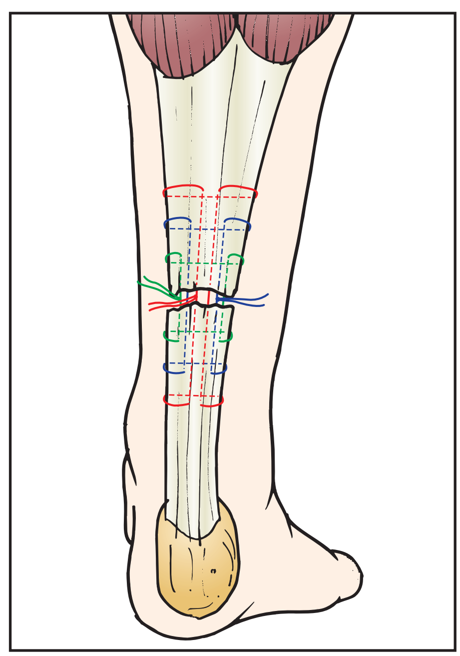


Figure 2. Six specimens were repaired using the standardized 5-locking loop Krackow repair method and labeled as control group A.

the most outer set of sutures inward centrally. In both groups, an additional continuous running suture with Vicryl 3-0 (Ethicon, Sommerville, NJ) was made enforcing the ends of the tear.

All specimens were frozen at -20°C and left to gradually thaw the day before surgical repair and dissection. Once dissected and surgically repaired, the specimens were refrozen for 3 weeks and gradually thawed overnight to be tested. Each specimen was mounted onto a servo-hydraulic testing device (Instron model 8511) with a loading cell capacity of 1,000 lbs (Figure 3). A soft tissue clamp was secured to the soft tissue of the gastrocnemius-soleus muscle proximally. A Steinmann pin was placed transversely through the calcaneus and secured to an adapted load cell portion of the Instron machine (Figure 4).

Once loaded, all specimens were tested on a standard load to failure at a tension rate of 35 mm/minute. Once complete slack had been removed, the machine was calibrated and zeroed. Loading began at 35 mm/minute and these data created a force versus displacement curve. The point on the curve where there is an observed precipitous drop indicated the point of ultimate loss of pull. The ultimate strength and loss of the specimens tested were recorded. The results were then analyzed to include length, thickness, and width of the tendons tested along with the load to failure for the 2 groups. Failure was complete disruption of the repaired ends with a 1-cm gap. The results were statistically analyzed using a paired t-test to compare the two groups of specimens ($P = 0.0004$).

RESULTS

Table 1 depicts the results of the failure to load resistance of the two groups tested, group A represents the control group and group B represents the tested group. Table 2 illustrates the differences between the average value of the length, width, and thickness of the tendons in the specimens from group. All data were statistically measured using the paired t-test. There was no notable statistical *P* value difference in the thickness and width of the tendons from the two groups tested A and B. There, however, was a significant difference between repair methods in the load resistance between group A and B, based on the *P* values ($P < 0.004$). The calculated difference in average length of the tendons showed a close statistical significance from each group, which could be a factor that may affect the outcome between groups A and B. Still, it is likely that the magnitude of response relative to this difference is not sufficient to be solely due to length differences since the measured value did not achieve a *P*-value of less than 0.004. Failure was complete disruption of the repaired ends with a 1 cm gap. The mean ± SD load to failure of group A (single Krackow) was 112.6 ± 33.8; for group B (Modified triple Kessler), 378.6 ± 76.2. Using the paired t-test, the results favored group B (Modified triple Kessler) findings ($P < 0.0004$). All of the ruptures failed at the knots at the level of the repair without any sutures pulled through the substance of the tendon.

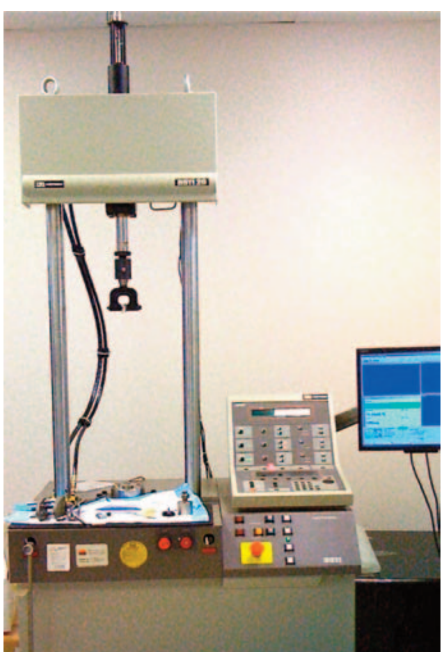


Figure 3. The servo-hydraulic testing device (Instron model 8511).

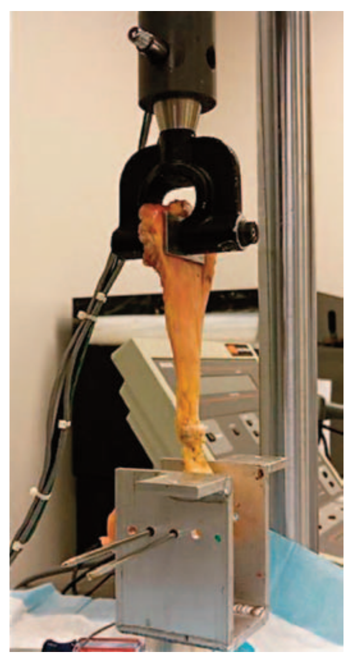


Figure 4. A Steinmann pin was placed transversely through the calcaneus and secured to an adapted load cell portion of the Instron machine.

Table 1

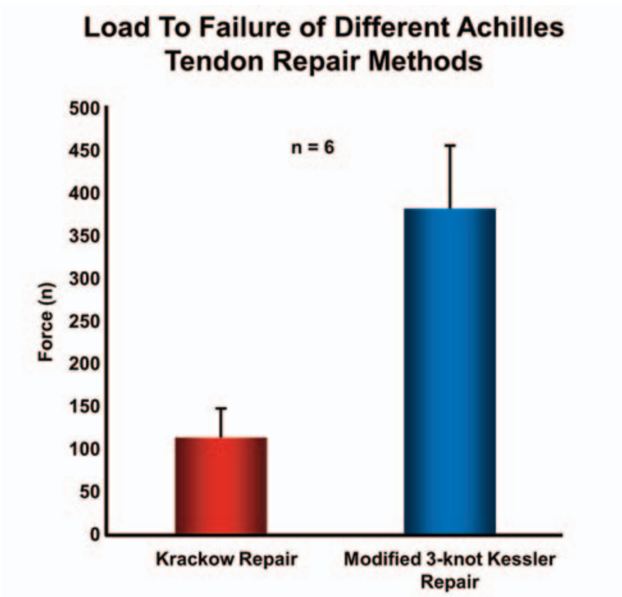
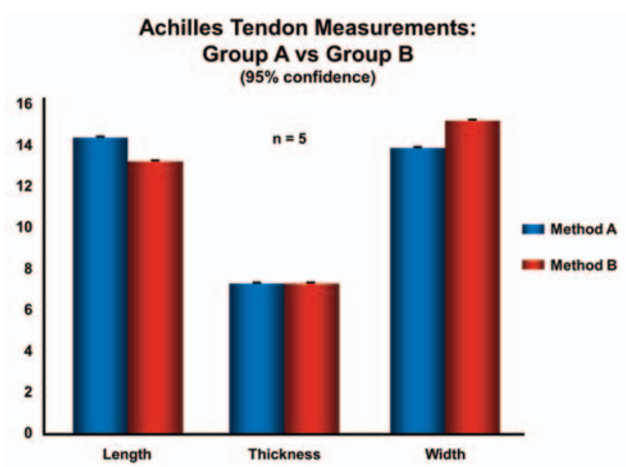


Table 2



DISCUSSION

There was a notably significant difference between the two groups tested. There have been many modifications or adaptations from the method first described in 1986 by Krackow (6). The original Krackow suture method is better described as a double locking loop method using two sutures for each tendon end creating two sets of 2-3 locking loops for a total of five to six locking loops within the tendon end (5, 6). Since then, it has been observed that most surgeons have modified the originally described technique to using one suture to create five to six interlocking loops within the tendon bulk for each tendon end. Since 1986, there has been a production of many different types of suture material that have stronger, and better pullout strength than the older generation of sutures. In a study by Cook et al, the strength of braided polyblend polyethylene suture (Fiberwire) was tested against the braided polyester suture (Ethibond) for Achilles tendon repairs and the fiber wire material was proven to be significantly stronger than the traditional larger suture material commonly used for the Achilles tendon repairs (13). Other studies also demonstrate the superiority of the braided polyblend polyethylene suture (Fiberwire) to its competitors for tendon repair in regard to diameter and strength (13-15). Presently, more surgeons prefer the braided polyblend Fiberwire as suture of choice in repairing Achilles tendon; the suture used in our study for both group A and B was the No. 2 Fiberwire.

We compared our results to both Watson et al and McCoy and Haddad (3, 16) and found that in terms of our tested group B, our triple Kessler suture weave was 4.4 times stronger than Watson's single Kessler and 2.26 times stronger than the McCoy and Haddad double Kessler weave. McCoy and Haddad simulated their double Krackow to match Watson's simulated Krackow and found that theirs was 1.35 times stronger. Our study employed the single suture 5-locking loops to equate with Watson's double strand 5 locked loops in proximal tendon. We however, employed a total of 5 locked loops in both proximal and distal stumps. McCoy (16) stated they were emulating Watson's double Krackow but did not specify the number of locking loops in the proximal and distal ends. Watson et al used No. 1 Ethibond suture and McCoy used No. 2 polyester Mersilene; whereas, we used No. 2 Fiberwire in our study. In comparison to their double 5-locking loop krackow versus our single 5-locking loop Krackow, Watson's was 1.3 times stronger and McCoy's was 1.7 times stronger than our suture method (3,16). This supports our findings that the number of locking loops within the tendon may not be the contributing factor for better load to failure but the number of square knots at the level of the repair.

Watson et al (3) did indicate in their study that although the Kessler had better gap resistance than the Bunnell, the locking loop remained significantly superior to the 2 other standard methods. Watson et al did not regard the considerable differences between the locking loop repair with the 2 other counterparts, Kessler and Bunnell, in that the locking loop repair had 4 to 5 locking loops within the tendon versus the 2 in the Kessler and zero in the Bunnell. In addition, there were 4 knots made at the ruptured site versus the 2 knots for the Kessler and Bunnell. We felt that this was pertinent to our study because it supported our prediction that the number of knots at the repair site may be the contributing factor for increased failure to load across the repair site. An overview of the literature demonstrates a segregation of thought among studies that argue for the number of sutures versus the number of loops within the tendon construct with others that compare multi-strand repairs using methods such as the Krackow or Kessler to report a stronger failure to load at the knot and reduction of gap formation at the repair site all with modifying the repair of having the knot tied away from the rupture site (4, 17-21).

Achilles tendon rupture is a familiar traumatic orthopedic injury, which occurs commonly in active individuals from 30-60 years of age (22) or as commonly called "weekend warriors." There are various studies performed that evaluate which types of sutures are the strongest to be used for repair, which incisional approaches, either mini-incision versus open, would result in lesser degree of complications, and which suture technique methods result in the best tension to load with highest load to failure rates. There are many suture techniques ranging from the Krackow, Bunnell, Kessler, triple bundle, Achillon (Integra) percutaneous method device, that are repeatedly studied (2-10, 12, 16, 18, 20, 21, 23, 24). Knot strength and number of knots at the ruptured site and knot placement have also been widely studied (20). Additionally, local grafts, such as peroneus and plantaris tendons or allografts have been used as reinforcements (23). However, simulated Achilles tendon repairs mask the variability of each live tendon rupture, which can differ from site of ruptures, to quality of the ruptured tendon, acute versus chronic, and availability of local grafts to use for reinforcement.

We are aware of the weaknesses to a cadaveric study in terms of the inaccuracy of truly replicating an in vivo event in an in vitro setting. Cadaveric studies do have their limitations in that aspect but care was taken to ensure that each simulation was closely replicated in all 6 pairs of cadaveric Achilles tendon ruptures from type of suture used to location of transected tendon. The authors are also aware that another limitation to cadaveric studies is the lack of variability that is presented in the real-life setting as well as replicating the true physiologic conditions of tendon quality under acute or chronic inflammatory conditions following injury. Another limitation that was not considered in this study was a time allotted comparison to perform the two types of techniques calculating which method was more or less time efficient. The small number of cadaveric specimens used in this study was also a limitation along with the simplicity in using the paired t-test for the statistical analysis.

Our senior author, MB, originally adapted this triple Kessler technique from the repair of hand flexor tendons. The modification for the triple was primarily due to the bulk of the Achilles tendon compared to the smaller sized flexor tendon. Our senior attending has been using this method for 10 plus years as his primary method of Achilles tendon repair. A retrospective study for postoperative success would be ideal to assess for rerupture rate, wound formation, and or early rehabilitation. This would provide a more accurate assessment for the comparison of the two methods tested in our study as to which technique is physiologically and clinically the more efficacious repair.

CONCLUSION

Our results show that the modified triple Kessler repair was stronger in this cadaveric biomechanical study compared with the traditionally used single Krackow technique. These results may be important in determining the choice of repair for a surgically open-technique of Achilles tendon rupture repair.

REFERENCES

1. Jaakkola JI, Beskin JL, Griffith LH, Cernansky G. Early ankle motion after triple bundle technique repair vs. casting for acute Achilles tendon rupture. Foot Ankle Int 2001;22:979-84.
2. Mandelbaum BR, Myerson MS, Forster R. Achilles tendon ruptures. A new method of repair, early range of motion, and functional rehabilitation. Am J Sports Med 1995;23:392-5.
3. Watson TW, Jursit 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 1995;16:191-5.
4. Yostumoto T, Miyamoto W, Uchio Y. Novel approach to repair of acute Achilles tendon rupture; early recovery without postoperative fixation or orthosis. Am J Sports Med 2010;38:287-92.
5. Krackow KA. The Krackow suture: how, when, and why. Orthopedics 2008;31:931-3.
6. Krackow KA, Thomas SC, Jones LC. A new stitch for ligament-tendon fixation. Brief note. J Bone Joint Surg Am 1986;68:764-6.
7. Rosenzweig S, Azar FM. Open repair of acute Achilles tendon ruptures. Foot Ankle Clin 2009;14:699-709.
8. Chan KB, Lui TH, Chan LK. Endoscopic-assisted repair of acute Achilles tendon rupture with Krackow suture: an anatomic study. Foot Ankle Surg 2009;15:183-6.
9. Davies MS, Solan M. Minimal incision techniques for acute Achilles repair. Foot Ankle Clin 2009;14:685-97.
10. De Carli A, Vadalà A, Ciardini R, Iorio R, Ferretti A. Spontaneous Achilles tendon ruptures treated with a mini-open technique: clinical and functional evaluation. J Sports Med Phys Fitness 2009;49:292-6.
11. Lui TH. Surgical tip: Repair of acute Achilles rupture with Krackow suture through a 1.5 cm medial wound. Foot Ankle Surg 2010;16:28-31.
12. Huffard B, O'Loughlin PF, Wright T, Deland J, Kennedy JG. Achilles tendon repair: Achillon system vs. Krackow suture: an anatomic in vitro biomechanical study. Clin Biomech (Bristol, Avon) 2008;23:1158-64.
13. Cook KD, Clark G, Lui E, Vajaria G, Wallace GF. Strength of braided polyblend polyethylene sutures versus braided polyester sutures in Achilles tendon repair: a cadaveric study. J Am Podiatr Med Assoc 2010;100:185-8.

14. Benthien RA, Aronow MS, Doran-Diaz V, Sullivan RJ, Naujoks R, Adams DJ. Cyclic loading of Achilles tendon repairs: a comparison of polyester and polyblend suture. Foot Ankle Int 2006;27:512-8.
15. Wust DM, Meyer D, Favre P, et al. Mechanical and handling properties of braided polyblend polyethylene sutures in comparison to braided polyester and monofilament plydioxanone sutures. Arthroscopy 2006; 22:1146.
16. McCoy BW, Haddad SL. The strength of Achilles tendon repair: a comparison of three suture techniques in human cadaver tendons. Foot Ankle Int 2010;31:701-5.
17. Dogramaci Y, Kalaci A, Sevinc T, et al. Single Side locking on the opposite of the modified Kessler tendon repair prevens gap formation and suture pull-out: a biomechanical evaluation in sheep tendons. Eklem Hastaliklari ve Cerrahisis. Joint Diseases and Related Surgery 2009;20:102-6.
18. Labib SA, Rolf R, Dacus R, Hutton WC. The "Giftbox" repair of the Achilles tendon: a modification of the Krackow technique. Foot Ankle Int 2009;30:410-4.
19. Lee SJ, Goldsmith S, Nicholas SJ, McHugh M, Kremenic I, Ben-Avi S. Optimizing Achilles tendon repair: effect of epitendinous suture augmentation on the strength of Achilles tendon repairs. Foot Ankle Int 2008;29:427-32.
20. McKeon BP, Heming JF, Fulkerson J, Langeland R. The Krackow stitch: a biomechanical evaluation of changing the number of loops versus the number of sutures. Arthroscopy. 2006;22:33-7.
21. Turker M, Cetik O, Kilicoglu O, et al. Over-the-knot placement technique enhances tensile stability of tendon repairs. Foot Ankle Int 2010;31:1006-13.
22. Maffulli N. Rupture of the Achille tendon. J Bone Joint Surg Am 1999;817:1019-36.
23. Akgün U, Erol B, Karahan M. (Primary surgical repair with the Krackow technique combined with plantaris tendon augmentation in the treatment of acute Achilles tendon ruptures). Acta Orthop Traumatol Turc 2006;40:228-33.
24. 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 Int 2000;21:14-7.