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Biomechanical Analysis of Krackow Suture Fixation Strength of Cadaver Achilles Tendon with Loop Distance Variance of 5 mm, 7.5 mm, and 10 mm

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SUMMARY

Background. The incidence of Achilles tendon rupture continues to increase significantly from year to year. The Krackow technique for Achilles tendon repair has proven to be stronger than two clinical standards, Kessler modification technique, and Bunnel technique. However, the incidence of re-rupture and complications in the Krackow technique is still high if an earlier mobilization is carried out. From several studies, it appears that the distance between knots can affect the strength of suture fixation. The purpose of this study is to analyze: How does the difference in loop distance in Krackow suture affect the strength of suture fixation.

Methods. This is a comparative analytic study with an experimental design. Cadaveric Achilles tendon was made rupture by 4 cm incision above its insertion. Then, it was repaired using Krackow suture with a loop distance of 5 mm (group 1), 7.5 mm (group 2), and 10 mm (group 3). Suture fixation strength was assessed with a standard load to failure test. The results were analyzed statistically using a one-way analysis of variance and post hoc test.

Results and Discussion. The mean value of Krackow suture fixation strength in group 1 was 81.2±18.9 N, group 2 was 106.8±16.5 N, and group 3 was 132.3±28.6 N. There was statistically significant mean difference between the strength of tendon fixation in the loop distance of 5 mm, 7.5 mm and 10 mm (p-value=0.002). The most effective group was group 3 (10 mm) because it had the highest mean difference (51.10000, p = 0.000). Possible mechanisms that can increase the strength of tendon fixation in greater loop distance (10 mm) are a greater suture–tendon interaction, a more secure grip power of the sutures on the tendon surface, expanding stress concentration to the tendon surface area, and increased stiffness to counteract tensile forces.

Conclusions. The 10 mm loop distance from the Krackow suture results in a significantly stronger suture fixation than the 7.5 mm and 5 mm loop distance for Achilles tendon rupture in cadaver.

KEY WORDS

Biomechanical testing; cadaveric Achilles tendon; Krackow suture; loop distance.

BACKGROUND

The incidence of Achilles tendon rupture continues to increase significantly from year to year, mostly due to sports injuries (1-4). In Finland, the incidence of rupture increased from 2.1/100,000 in 1979 to 21.5/100,000 in 2011(1). Meanwhile in Canada, the incidence of rupture was 18.0/100,000 in 2003, rising to 29.3/100,000 in 2013(3). Likewise in the United States, the incidence of rupture also increased from 1.8/100,000 in 2012 to 2.5/100,000 in 2016(4). The increased incidence of rupture is due to the growth and rising interest in sports activities, especially in young men (1-4) Most of Achilles tendon rupture (75%) is related to recreational activities in particular in soccer, basketball, tennis, and squash, but 25 % of ruptures may occur in sedentary patients(2). Badminton is the leading cause of the rupture in Finland.1 Meanwhile, basketball is most often involved in the United States(4). Patients aged 40-59 years had the most considerable rise (78%) in the incidence of ruptures(4). Possibly predisposing factor was passive mechanical properties change of the tendon in older patients (5).

Treatment of Achilles tendon rupture can be non-operative or operative. Non-operative treatment is generally through immobilization by casting and functional bracing (6,7). As for operative treatment, three main suture techniques have shown excellent results, namely the Bunnell, Kessler, and Krackow techniques(6,7). Operative treatment (open surgery or percutaneous repair) showed significantly improved clinical and functional outcomes than non-operative treatment (8). In 1940, Sterling Bunnel introduced a suture technique that permits cross-penetration between tendon fibers (9). Then, the grasping suture technique was described by Isidor Kessler and Fuad Nissim in 1969, which later became a popular method for repairing flexor tendons (10,11) In 1986, Kenneth A. Krackow introduced a unique tendon suture technique using locking loops (12,13). The Krackow technique for Achilles tendon repair has proven to be superior from two clinical standards, Kessler modification technique, and Bunnel technique (14,15). The average strength of tendon fixation from the Krackow technique (147 newtons) proved significantly stronger than the Kessler modification technique (85 newtons) and the Bunnel technique (93 newtons)(15). However, there was no significant difference in suture strength between the Krackow, Bunnell, and Kessler techniques that were performed with a double suture weave (16). The Krackow technique also stronger compared to the percutaneous method (17). Some research on the Krackow technique is also widely done, including those that modify the number of loops (2, 4, 6 loops) where the results were no statistical differences in peak load to failure (18). Research by McKeon et al. showed that the addition of second interlocking suture placed at 90° to the first proved to be stronger (18). Other research by Hapa et al. showed that the number of locking loops might have an influence on the Krackow suture strength using the larger diameter, high-strength sutures (14). But, it did not examine whether loop distance variance of the Krackow suture can influence the suture fixation strength. A study from Ortiz et al. showed the triple-strand Dresden technique significantly stronger than the Dresden technique, a modified oblique Dresden technique, and a Krackow technique (19).

Several meta-analysis studies showed that the incidence of re-rupture in operative treatment varies from 3.1% - 5.0% compared to 8.8% - 13% in conservative treatment (20-23). A meta-analysis from Soroceanu et al., and Van der Eng et al., showed that operative management of Achilles tendon rupture did not show better results than conservative treatment. It was because of the same re-rupture rate and higher complications if earlier weight-bearing was carried out after four weeks (24,25). Meanwhile, operative treatment using the Krackow technique showed a low re-rupture rate of 2.5% (26). However, a prospective study from Twaddle et al. showed an increased re-rupture rate by 10% in operative treatment with the Krackow technique if an early motion was carried out after ten days, and 4.5% in conservative management (27). In fact, an early motion has proven beneficial for healing and tendon function, both in animal and human studies (26).

The occurrence of high re-rupture rates can be caused by the weakness of the suture due to differences in the loop distance of the Krackow technique. Also, suture materials can influence tendon repair on the biological level (28). Good suture techniques for Achilles tendon repair are needed because strong suture fixation can facilitate an early rehabilitation program to prevent joint stiffness. Strong suture fixation and good suture technique are associated with a lower re-rupture rate (7,18, 29-31). According to Y.F. Wu and J.B. Tang, a factor that can influence suture fixation strength, is the distance between core suture placement and the cut end of the tendon. Lengthening the distance can effectively increase the suture fixation strength, with the optimal length between 0.7 - 1.0 cm (32). Also, N. Kozono et al., examined the Kessler core suture with 6 Pennington locking loop at the edges made asymmetrically at distances of 1 mm, 2 mm, 3 mm, 4 mm, and 5 mm. It showed that the distance 3 mm or more had significantly stronger suture fixation than 1 mm (33).

From these studies, it appears that the loop distance of the suture can influence the suture fixation strength. However, in the Krackow technique, there was no standardization of optimal loop distance to provide high suture fixation strength. Moreover, no biomechanical studies were examining whether the loop distance variance of the Krackow suture can influence the suture fixation strength. The purpose of this study was to analyze: biomechanical of the Krackow suture fixation strength of cadaver Achilles tendon with loop distance variance of 5 mm, 7.5 mm, and 10 mm.

MATERIALS AND METHODS

This is a comparative analytic study with an experimental design. Eleven human cadavers (21 Achilles tendons, age range between 40 to 60 years old, six males and five females) were obtained from the Department of Forensic and Legal Medicine, Faculty of Medicine Universitas Padjadjaran/Dr. Hasan Sadikin General Hospital Bandung, Indonesia. The cadaver was embalmed with a formalin-containing solution (34). This study was performed after receiving ethical clearance from the Health Research Ethics Committee of our

institution and followed the international ethical principles as well as the ethical standards of the Muscle, Ligaments and Tendons Journal (35).
Cadavers were positioned prone, and gastrocnemius muscle-Achilles tendon complex was dissected. Achilles tendons were made rupture with a scalpel 4 cm proximal to the calcaneal insertion (avascular zone 2-6 cm from its insertion)(22-24). Then, the tendon was repaired with Ethibond No. 5 (Braided, nonabsorbable, polyester fiber; Ethicon, USA) in one of three ways with seven specimens in each group. The Krackow technique was used starting 7 mm from the cut end of the tendon with a configuration of 3 locking loops and 2 strands (12,13,32,36). The locking loop distance was performed 5 mm in group 1, 7.5 mm in group 2, and 10 mm in group 3. For accurate range, measurements were made with a ruler and marked with markers on the tendon (see **figures 1** and **figures 2**).
The specimens were secured onto a tensile testing machine (CV. Abdi Tunggal Perkasa – Fanatron Indonesia, West Java, Indonesia) with a maximum tensile load of 100 pounds (444.8 N), and a maximum traction length of 12 inches (30.48 cm). The tensile testing machine was calibrated by the National Accreditation Committee (Indonesia) following the Japanese Industrial Standards (JIS Z 2241: Tensile Testing). A Steinmann pin was drilled transversely through the calcaneus and affixed to the machine. The soft tissue of the gastrocnemius muscle was secured proximally onto a custom made nylon clamp (**figure 4**). The clamp was made asymmetrical teeth jaw shape to prevent tendon slippage (37,38). The Steinmann pin and the clamp were not found to be weak points in the machine construct. Because the calcaneus bone was not dissected free from the cadaveric body, the Achilles tendon is rotated 90 degrees on its insertion. However, the direction of pull was still parallel with the longitudinal axis of the Achilles tendon. After that, the specimens were loaded in tension until failure of the Achilles tendon (see **figure 3** and **figure 4**). The ultimate strength was considered the peak force recorded by the machine.
Before the statistical test is performed, the numerical data is assessed by the normality test using the Shapiro Wilks test to examine whether the data is normally distributed. Then, the results were analyzed statistically using a one-way analysis

Figure 1. A. Cadaveric Position, B. Marking of the incision and suture area of the Achilles tendon, C. The sharp incision of the Achilles tendon, D. Tendon repair with the Krackow Technique.

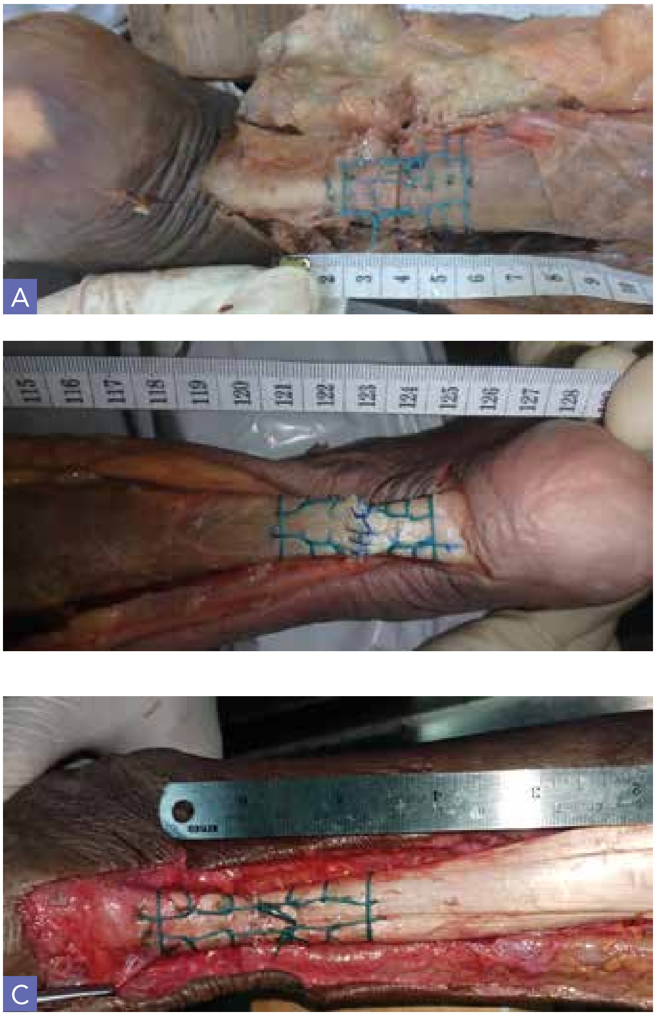

Figure 2. The Krackow Technique with locking loop distances of 5 mm (A), 7.5 mm (B) and 10 mm (C).

Figure 3. Tensile testing machine

Figure 4. Achilles tendon secured onto a tensile testing machine (A, B). The monitor showed the ultimate strength (C).

of variance (ANOVA) comparing the three groups of specimens to assess if there was an effect of loop distance variance of 5 mm, 7.5 mm, and 10 mm to the Krackow suture fixation strength. If there was an effect, post hoc tests using Fisher's least significant difference (LSD) were performed to assess differences between the loop distance variance. An α level of 0.05 was assumed to be statistically significant.

RESULTS

The results are summarized in **table I**. From all groups, the Krackow suture fixation strength had a minimum value of 53.9 N, a maximum value of 170.9 N, and a mean value of 106.8 N with a standard deviation of 29.9 N.

In group 1 (loop distance 5 mm), a minimum value of suture fixation strength was 53.9 N, a maximum value was 109.7 N, and a mean value was 81.2 N with a standard deviation of 18.9 N. Whereas in group 2 (loop distance 7.5 mm), a minimum value of suture fixation strength was 95.3 N, a maximum value was 142.9 N, and a mean value was 106.8 N with a standard deviation of 16.5 N. Finally, in group 3 (loop distance 10 mm), a minimum value of suture fixation strength was 103.4 N, a maximum value of 170.9 N, and mean value of 132.3 N with a standard deviation of 28.6 N. Shapiro Wilks test showed that the data are normally distributed (p-value = 0.177, >0.05), so a parametric test was used. The mean value of the Krackow suture fixation strength in group 1 was 81.2 N, group 2 was 106.8 N, and group 3 was 132.3 N (**figure 5**). From the one-way analysis of variance test results, the p-value was 0.002 ($p < 0.05$), which means there was a statistically significant difference between Krackow suture fixation strength with a loop distance variance of 5 mm, 7.5 mm, and 10 mm. Fisher's least significant difference testing revealed that for all three groups, group 3 were stronger than both group 1 and group 2 because group 3 had the highest mean difference of 51.1 compared to group 1 with p-value = 0.000 ($p < 0.05$) and mean difference of 25.5 compared to group 2 with p-value = 0.043 ($p < 0.05$) (**table II**).

Table I. Characteristics of the Krackow suture fixation strength based on loop distance.

Variable	Loop distance			Σ N=21
	Group 1 5 mm	Group 2 7.5 mm	Group 3 10 mm	
	N=7	N=7	N=7	
The Krackow Suture Fixation Strength (N)				
Mean ± SD	81.2±18.9	106.8±16.5	132.3±28.6	106.8 ± 29.9
Median	79.8	100.0	130.4	103.4
Range (minimum-maximum)	53.9-109.7	95.3-142.9	103.4-170.9	53.9-170.9

Table II. Post Hoc Test of Krackow suture fixation strength based on loop distance.

Loop Distance		Mean Difference Krackow suture fixation strength (I-J)	p
(I) Group	(J) Group		
5 mm	7.5 mm	-25.6*	0.043
	10 mm	-51.1*	0.000
7.5 mm	5 mm	25.6*	0.043
10 mm	10 mm	-25.5*	0.043
	5 mm	51.1*	0.000
	7.5 mm	25.5*	0.043

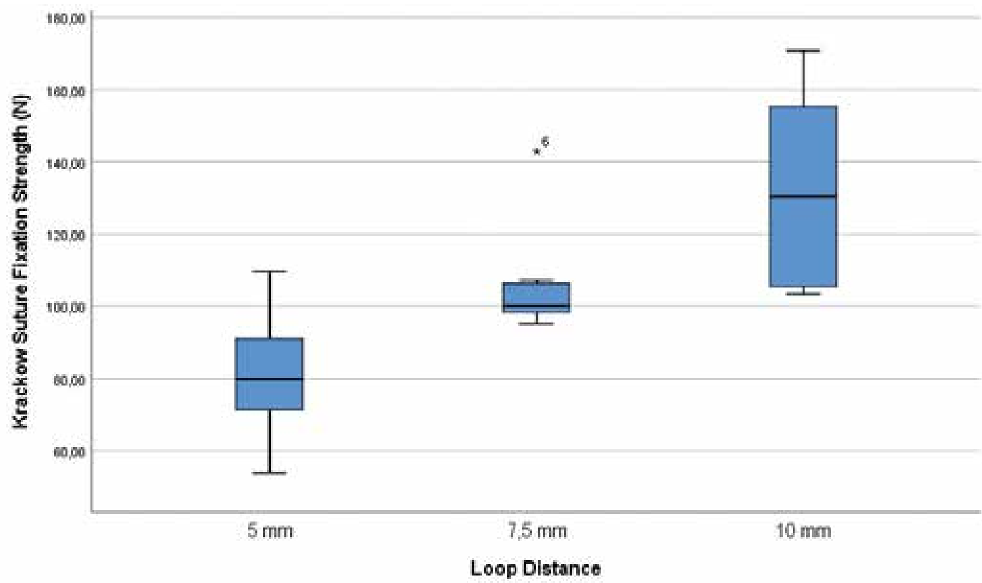

Figure 5. Krackow suture fixation strength based on loop distance.

DISCUSSION

The results showed that there was a statistically significant mean difference between the Krackow suture fixation strength in all groups with a loop distance variance of 5 mm, 7.5 mm, and 10 mm. From all groups, the most effective was group 3 (loop distance 10 mm) because it had the highest mean value of tendon fixation strength compared to group 1 (5 mm) and group 2 (7.5 mm). Kenneth A. Krackow first introduced this unique tendon suture technique using locking loops in 1986 (12,13). The average strength of tendon fixation from the Krackow technique (147 newtons) proved significantly stronger than the Kessler modification technique (85 newtons) and the Bunnel technique (93 newtons) (15,39). But, there was no significant difference in strength between the Krackow, Bunnell, and Kessler suture techniques, when each was performed with a double suture weave (16). The Krackow technique also stronger compared to the percutaneous method (17). Some research on the Krackow technique is also widely done, including research by McKeon et al. showed that the addition of second interlocking suture placed at 90° to the first proved to be stronger (18).

An early motion has proven beneficial for healing and tendon function, both in animal and human studies (26). However, an early motion could increase the re-rupture rate by 10% in operative treatment with the Krackow technique (27). The occurrence of high re-rupture rates can be caused by the weakness of the suture due to differences in the loop distance of the Krackow technique. Strong suture fixation and good suture technique are associated with a lower re-rupture rate (7,18, 29-31). Several factors that can influence the suture fixation strength include the number of suture strands, suture materials, locking or grasping loop configuration, suture knots, knots or loop distance, and core suture tension (32). Several meta-analysis studies showed that the incidence of re-rupture in operative treatment varies from 3.1% - 5.0% compared to 8.8% - 13% in conservative treatment (20-23). A meta-analysis from Soroceanu et al., and Van der Eng et al., showed that operative management of Achilles tendon rupture did not show better results than conservative treatment. It was because of the same re-rupture rate and higher complications if earlier weight-bearing was carried out after four weeks (24,25) Meanwhile, operative treatment using the Krackow technique showed a low re-rupture rate of 2.5% (26).

According to Y.F. Wu and J.B. Tang, a factor that can influence suture fixation strength, is the distance between core suture placement and the cut end of the tendon. Lengthening the distance can effectively increase the suture fixation strength, with the optimal length between 0.7 - 1.0 cm (32). Also, N. Kozono et al., examined the Kessler core suture with 6 Pennington locking loop at the edges made asymmetrically at distances of 1 mm, 2 mm, 3 mm, 4 mm, and 5 mm. It showed that the distance 3 mm or more had significantly stronger suture fixation than 1 mm (33). Also, N. Kozono et al., examined the Kessler core suture with 6 Pennington locking loop at the edges made asymmetrically at distances of 1 mm, 2 mm, 3 mm, 4 mm, and 5 mm. It showed that the distance 3 mm or more had significantly stronger suture fixation than 1 mm (33). From these studies, it appears that the loop distance of the suture can influence the suture fixation strength.

However, in the Krackow technique, there was no standardization of optimal loop distance to provide high suture fixation strength. In this study, the loop distance variance of the Krackow technique proved to influence the suture fixation strength significantly. From the biomechanical studies that have been conducted, the loop distance of 10 mm in the Krackow technique has the highest mean value of suture fixation strength (132.3 N) compared to the loop distance of 5 mm and 7.5 mm. The mechanism that can increase the suture fixation strength is the longer the suture distance, the higher the interaction between tendons and sutures (32). Also, greater loop distance can increase the strength of the suture grip on the tendon surface and further strengthen the suture fixation (32). A long loop distance can also divide the stress concentration to a greater surface area, thereby increasing the suture fixation strength (33,40) In addition, the greater loop distance can increase stiffness to neutralize the tensile forces so that the suture fixation strength is stronger (32,40,41) Tendon stiffness indicates the magnitude of the force required to produce elongation from a tendon segment. The suture tendon stiffness suggests the ability of the suture to resist tendon deformation to the stress force (32,41). Therefore, in this study, the suture fixation strength was highest at the 10 mm loop distance because it had high stiffness to resist tendon elongation from the tensile force.

The results of this study are supported by research from Yi Cao et al., who examined locking cruciate sutures on the flexor tendon with the core purchase distance 10 mm and 4 mm. Sutures purchase of 4 mm have suture fixation strength 20-45% lower than suture purchase of 10 mm (41). Other studies from Kim et al., and Lee et al., also supported this research. It showed that the tendons with a core suture purchase of 10 mm had a high suture fixation strength (42,43). The distance of the core suture to the cut end of the tendon determines the number of tendon segments that interact with the suture. Extending the length can increase the suture fixation strength due to the more significant interaction between the suture and tendons (32,41). Likewise, with the locking loop suture in the Krackow technique, the longer the loop distance, the more Achilles tendon segments interact with the Krackow suture, thereby increasing the suture fixation strength. It was proven in this study, the loop distance of 10 mm showed a mean value of suture fixation strength that was significantly stronger than the loop distance of 7.5 mm and 5 mm.

Although the results showed that the mean value of suture fixation strength is significantly higher in the Krackow technique with a loop distance of 10 mm in this study, some weaknesses cannot be avoided. First, the researcher could have subjectivity in conducting this research. It can be minimized by performing according to standards and using a ruler and marker so that the measurements were correct. Second, differences in the size of the cadaveric tendon can also cause bias in this study. Therefore, this study used adult cadavers, age 40-60 years old, so that the size of the tendon is not too varied. Third, the elasticity of tendons can be different due to differences in gender and age, so that it can affect the ultimate failure of the tendon (44,45,46). Fourth, Achilles tendon was not placed along with its physiological boundary condition (aligned with the tibia). The calcaneus bone was not dissected free from the cadaveric body because of an ethical issue in our institution. So, the Achilles tendon is rotated 90 degrees on its insertion. However, the direction of pull was still parallel with the longitudinal axis of the Achilles tendon. It had no impact on the results because all the specimens were aligned with the same technique. Fifth, in this study, the length of the loop distance of the Krackow suture has proven to be stronger, but the optimal loop distance has not yet been determined for a range of more than 10 mm. So, further research is needed to asses biomechanical strength for loop distances more than 10 mm. Sixth, the cadaver Achilles tendon certainly does not have the biochemical healing ability, as occurs in living human tendon. Intrinsic factors and extrinsic factors can influence the tendon healing process. Too much tendon suture can also cause fibrotic tissue to form, thereby increasing stiffness in the ankle joint. Therefore, further research is needed to asses biomechanical of the Krackow suture fixation strength of living human tendon with loop distance variance of 5 mm, 7.5 mm, and 10 mm to strengthen the results of this study.

CONCLUSIONS

Based on the results, this research concludes that the 10 mm loop distance of the Krackow suture results in a significantly stronger suture fixation than the 7.5 mm and 5 mm loop distance for Achilles tendon rupture in cadaver.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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