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Experimental validation for the Achilles tendon reinforced with new techniques

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Abstract

An Achilles tendon injury is most common among subcutaneous tendon ruptures and accounts for 47 %. **The purpose** was to experimentally evaluate the effectiveness of new methods of the Achilles tendon reinforcement. **Material and methods** The experimental part of the work was performed in 3 stages using 60 biomannikins with intact Achilles tendon. A Krakow suture was used at stage 1 for a group of 20 tendons and a force that would result in rupture of the tendon was measured. Reinforcement was performed using the plantaris tendon (technical innovation offered at the Samara State Medical University) at the 2nd stage and the force required for the appearance of signs of rupture was subsequently measured. A portion of the peroneus longus tendon (RF patent No. 2616767) was used for reinforcement at the 3rd stage and the force measurement produced. **Results** The mean force required to rupture the Krakow suture applied to the tendon at the first stage was 11.5 kg., The force required to rupture the suture reinforced with the plantaris tendon at the second stage measured 33.4 kg. The force required to rupture the suture reinforced with a portion of the peroneus longus tendon at the third stage was 37.3 kg. **Conclusion** The new techniques offered to reinforce the Achilles tendon with the plantaris tendon and a portion of the peroneus longus tendon at the distal base facilitated increase in the strength of the injury site by 195.6 % and 214.4 %, respectively.

Keywords: Achilles tendon, experiment, reinforcement

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INTRODUCTION

Achilles tendon injuries are the most frequent and account for up to 47 % among subcutaneous ruptures [1–3]. Rerupture is one of common complications of Achilles tendon surgery along with infection and requires repeated interventions [4, 5]. There is controversy on prevention strategy [6–9]. Consequences of prolonged ankle immobilization leading to severe hypotrophy of the triceps are reported with a long rehabilitation period [10, 11]. Early activation of the ankle joint is important avoiding elongation of the Achilles tendon that would result in decreased plantar flexion of the foot. The strength of the Achilles tendon suture can be increased with modern suture material minimizing the risks of infectious complications due to the subcutaneous location of the tendon avoiding ligature fistulas, deep and superficial necrosis and preserving the sliding apparatus at the site. Reinforcement of the rupture site according to indications allows increase of the strength of the Achilles tendon suture. Some authors suggest strengthening the rupture zone with synthetic materials increasing the risk of infectious complications [12], others do not find primary reinforcement of the Achilles tendon necessary with the established methods.

The purpose was to experimentally evaluate the effectiveness of new methods of the Achilles tendon reinforcement.

Research objectives:

1) evaluate the strength of the Achilles tendon using the Krakow whipstitches, new reinforcement methods for the Achilles tendon in the experiment and compare the results obtained;

2) identify indications for primary reinforcement of the Achilles tendon in clinical practice using new techniques.

MATERIAL AND METHODS

The experimental part of the work was performed using 60 tendons of biomanequins with intact Achilles tendon. Three experimental groups were identified. A linear or Z-shaped access on the posterior aspect of the tibia was produced in the 3 groups and the Achilles tendon was intersected in the "classical" rupture zone (20–50 mm from the enthesis) and the Krakow suture applied. The strength of the experimental Achilles tendon repaired with the Krakow suture was measured in the first group (20 tendons). Reinforcement was performed using the plantaris tendon (technical innovation offered at the Samara State Medical University) in addition to the Krakow suture in the second group and the force required for the appearance of signs of rupture was subsequently measured. A portion of the peroneus longus tendon (RF patent No. 2616767) [13] was used for reinforcement in addition to the Krakow suture in the 3rd group and the force required for the appearance of signs of rupture was measured. The weight required for the appearance of signs of rupture was measured in all study groups (60 tendons) using the Garin electronic weighbeam (measuring accuracy of 10 grams).

The article was reviewed by the SamSMU Bioethics Committee for compliance with ethical standards. Based on evidence-based medicine statistical processing of the results was produced using the Statistica 6.0 program. Testing of the null hypothesis about the absence of the reinforcement effect was performed in three ways. The confidence intervals of the means calculated for the samples at each stage of the study did not overlap with each other and were arranged in a strict sequence from the third stage to the first.

The first group included 20 experiments of the Achilles tendon stitched with the Krakow suture using VICRIL 1 thread. Then the Krakow suture was applied to the distal and proximal ends of the Achilles tendon. The threads were connected with each other followed by adaptive sutures applied at the gap (Fig. 1a). Then the distal end of the Achilles tendon was cut off with a portion of the calcaneus fixed with a 5 mm thread. The weight required for the appearance of signs of rupture of the Krakow suture was measured using the Garin electronic weighbeam (measurement accuracy 0.1 g) (Fig. 1b). The mean strength value in 20 experiments was 11.5 kg (112.78 N).

The second group (20 experiments) included the Achilles tendon reinforced with the plantaris tendon. The reinforcement technique was patented as a technical innovation at the SamSMU. A VICRIL 1 thread was used for the suture. Then the Krakow suture was applied to the distal and proximal ends of the Achilles tendon. The threads were connected with each other, and adaptive sutures used for the rupture. Then the plantaris tendon was distally exposed to preserve the nutrition of the latter. The average length of the plantaris tendon was 340 mm and thickness measured 2 mm. The length was sufficient to reinforce the rupture site. The plantaris tendon was U-shaped and X-shaped in the Achilles tendon with 5 cm off the rupture site and additionally fixed in the Achilles tendon with nonskid sutures (Fig. 2a). Then the distal end of the Achilles tendon was cut off with a portion of the calcaneus fixed with a 5 mm thread. The weight required for the appearance of signs of rupture of the Krakow suture was measured using the Garin electronic weighbeam (measurement accuracy of 10 g) (Fig. 2b). The mean strength value in 20 experiments was 33.4 kg (327.54 N).

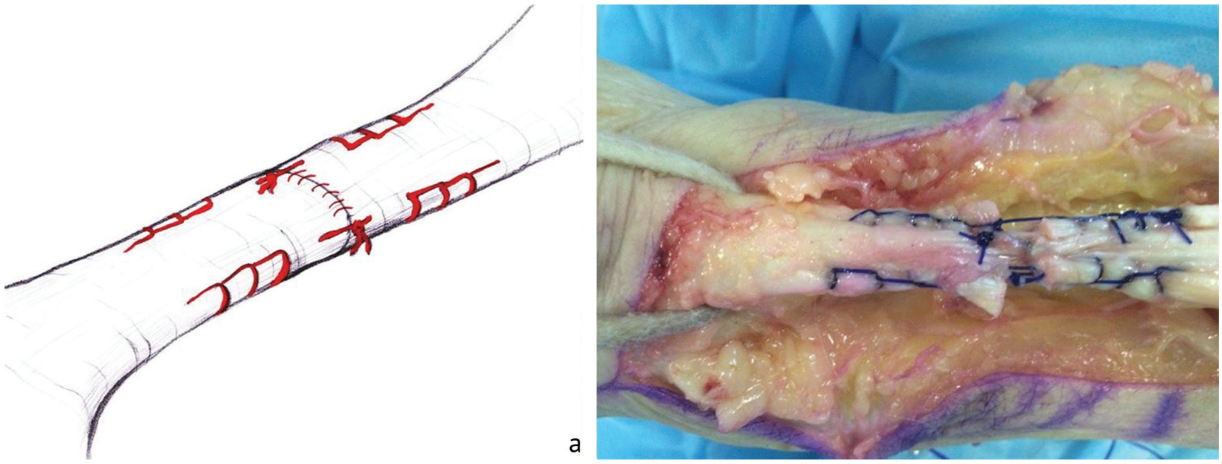
a b

Fig. 1 The diagram showing the Krakow suture of a tendon (a) and signs of rupture of the tendon suture in the experiment (b)

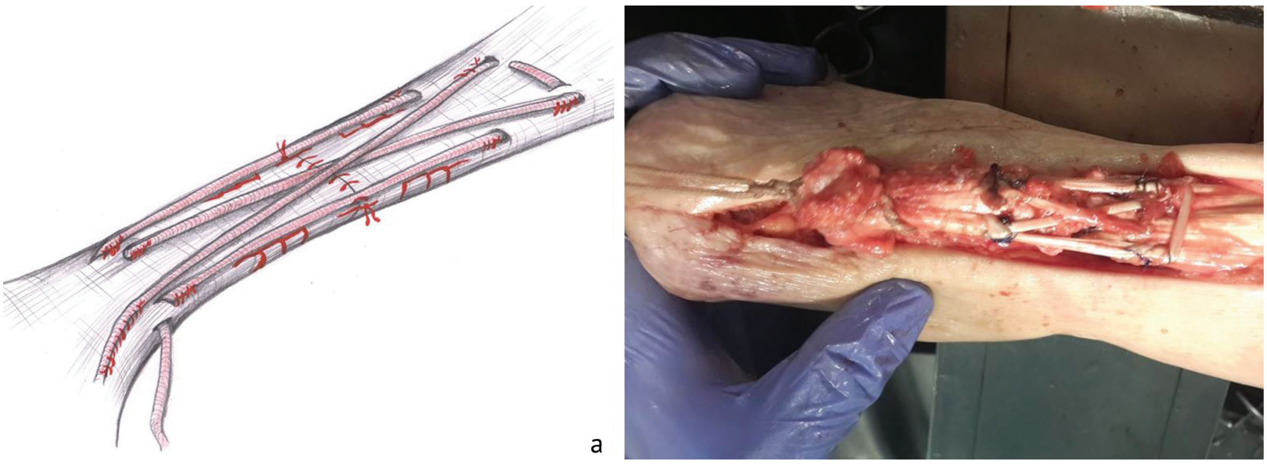
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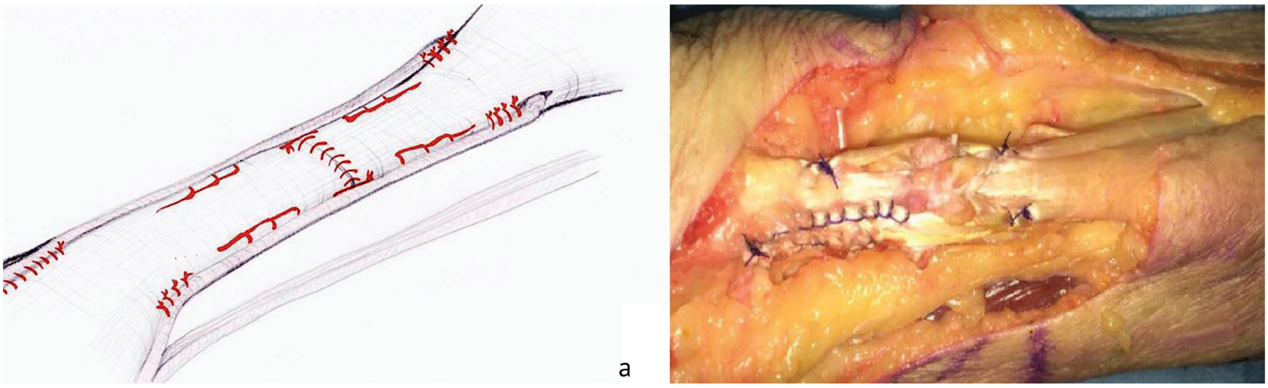
Fig. 2 Diagram showing the suture reinforced with the plantaris tendon (a) and appearance of rupture signs (b)

The third group included 20 experiments of the Achilles tendon reinforced with a portion of the peroneus longus tendon. The technique of the Achilles tendon reinforcement was patented with invention No. 2616767 [13]. A VICRIL 1 thread was used for the suture. Then the Krakow suture was applied to the distal and proximal ends of the Achilles tendon. The threads were connected with each other, and adaptive sutures were used for the rupture site. A portion of the peroneus longus tendon was distally exposed to preserve nutrition. On average, the portion of the peroneus longus tendon used was 190 mm long and 5 mm thick. The length was suffecient to reinforce the rupture site. The portion of the peroneus longus tendon was U-shaped in the Achilles tendon with 5 cm off the rupture site, stitched at the medial side and additionally fixed in the Achilles tendon with nonskid sutures (Fig. 3a). Then the distal end of the Achilles tendon was cut off with a portion of the calcaneus fixed with a 5 mm thread. The weight required for the appearance of signs of rupture of the Krakow suture was measured using the Garin electronic weighbeam (measurement accuracy of 10 g) (Fig. 3b).

Null hypothesis testing of the reinforcement effect was performed in three stages. Initial data and descriptive statistics were collected at the first stage. The second stage aimed at checking homogeneity of standard deviations. The third stage was meant to verify the homogeneity of math expectations. The linear model constructed for correlations between the tensile force and the reinforcement method had a high level of significance (coefficient of determination R2 = 0.99, Fisher criterion F = 3079, p » 0). Multiple comparisons of the means in the groups performed by randomization and using Bonferroni correction showed a high significance of the reinforcement effect of the plantar tendon (Student's criterion t =19.5, p » 0) and the peroneus longus tendon (t = 23, p » 0).



a b

Fig. 3 Diagram showing the suture reinforced with the portion of the peroneus longus tendon (a) and appearance of rupture signs (b)

RESULTS

The average strength value in 20 experiments of the first group was 11.5 kg (112.78 N) (Table 1). The average operation time was 45 min.

The average strength value in 20 experiments of the second group was 33.4 kg (327.54 N) (Table 2). The average operation time was 55 min.

The average strength value in 20 experiments of the third group was 37.3 kg (365.79 N) (Table 3). The average operation time was 60 minutes.

Table 1

Comparison of the forces required for the rupture of the Krakow suture

Experiment No.	Result, kg	Force (N)
1	12.36	121.21
2	11.58	113.56
3	9.74	95.52
4	11.87	116.40
5	10.42	102.19
6	13.06	128.07

Table 1 (continued)

Comparison of the forces required for the rupture of the Krakow suture

Experiment No.	Result, kg	Force (N)
7	12.50	122.58
8	12.16	119.25
9	11.79	115.62
10	10.88	106.70
11	12.24	120.03
12	10.73	105.23
13	11.62	113.95
14	12.07	118.37
15	9.85	96.60
16	11.71	114.84
17	10.56	103.56
18	13.02	127.68
19	9.91	97.18
20	12.47	122.29

Table 2

Comparison of the forces required for the rupture of the Achilles tendon suture reinforced with the plantaris tendon

Experiment No.	Result, kg	Force (N)
1	30.41	298.22
2	32.76	321.27
3	33.58	329.31
4	33.91	332.54
5	35.01	343.33
6	34.89	342.15
7	34.82	341.47
8	34.61	339.41
9	34.75	340.78
10	35.00	343.23
11	32.84	322.05
12	30.67	300.77
13	33.21	325.68
14	34.14	334.79
15	33.78	331.27
16	30.93	303.32
17	31.97	313.52
18	32.69	320.58
19	33.82	331.66
20	34.96	342.84

Таблица 3

Comparison of the forces required for the rupture of the Achilles tendon suture reinforced with a portion of the peroneus longus tendon

Experiment No.	Result, kg	Force (N)
1	37.53	368.04
2	38.30	375.59
3	35.89	351.96
4	36.90	361.86
5	37.61	368.83
6	38.02	372.85
7	36.85	361.37
8	37.22	365.00
9	3827	375.30
10	37.12 к	364.02
11	35.92	352.25
12	36.78	360.69
13	38.19	374.52
14	37.36	366.38
15	37.41	366.87
16	36.89	361.77
17	37.57	368.44
18	38.17	374.32
19	36.93	362.16
20	37.65	369.22

With numerical values received statistical data processing was produced in 3 stages.

1. Baseline data and descriptive statistics

Dependent variable: pull test, N

Independent factor: reinforcement techniques

Total number of measurements: 60

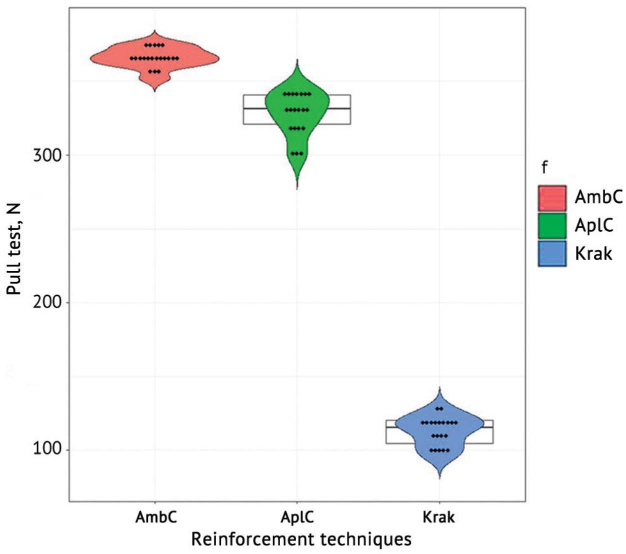
Number of factor ranking: 3

Equal group proportions: there are

1.1 Statistics for different factor ranking

	Factor		
	AmbC	**AplC**	**Krak**
Mean	366.1	327.9	113.0
Median	366.625	331.465	115.230
Standard deviation	6.833	14.590	10.150
Ni	20	20	20
Standard error	1.528	3.262	2.271
Min	351.96	298.22	95.52
Max	375.59	343.33	128.07

1.2 Diagram of observations distributed by groups



This "violin diagram" shows a smoothed density function of the data distribution in each group. The borders of the boxes are the first and third quartiles (25th and 75th percentiles, respectively), the line in the middle of the box is the median (50th percentile). Bonferroni correction was applied for multiple comparisons. The significance level of 0.05 was adopted for the null hypothesis when all pairs of treatment methods did not differ from each other. The significance level of 0.017 was used for comparisons of each particular pair of methods.

1.3 Values of critical and confidence probabilities

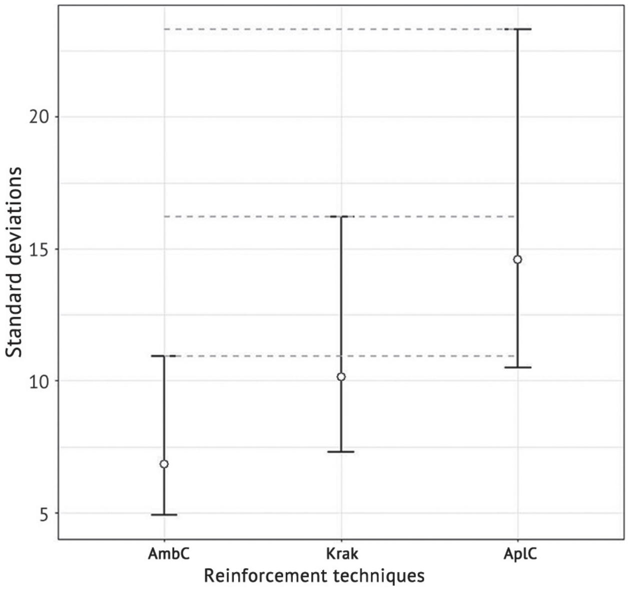
alpha	alphaM
0.05	0.017

2. Checking uniformity of standard deviations

2.1 Confidence intervals of standard deviations at alpha = 0.017

	Factor		
	AmbC	**AplC**	**Krak**
Standard deviation	6.833	14.590	10.150
Ni	20	20	20
CI_low	4.912	10.490	7.297
CI_upper	10.92	23.32	16.22

2.2 Diagram of confidence intervals of standard deviations



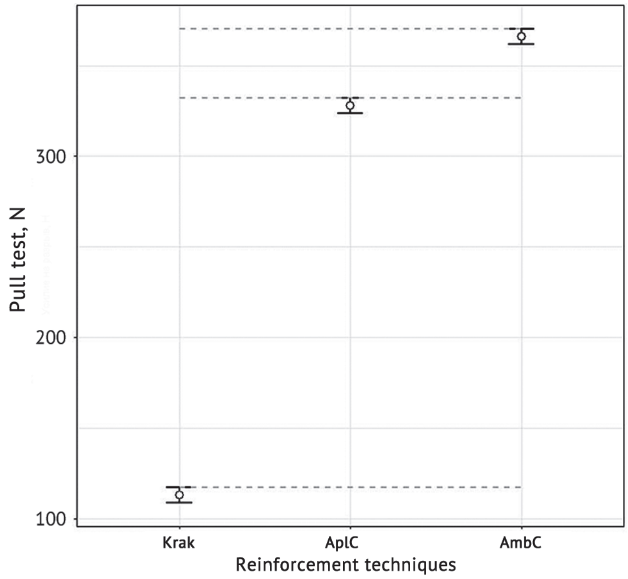
To compare different methods with t-test you need to first make sure that the spread (variance) in each group is approximately the same. Confidence intervals were employed to verify the assumption. The diagram above showed the confidence intervals for standard deviations overlapping each other and one can assume that the variances were homogeneous. The Bonferroni adjusted p-value was used. The hypothesis of equal population means could be tested.

3. Checking the uniformity of mathematical expectations

3.1 Confidence intervals of group means at alpha = 0.017

	Factor		
	AmbC	**AplC**	**Krak**
Mean	366.1	327.9	113.0
Ni	20	20	20
CI_low	361.8	323.6	108.7
CI_upper	370.4	332.2	117.3

3.2 Diagram of confidence intervals of mathematical expectations



3.3 Tests of paired comparisons of group means

3.3.1 Parametric Student's t-test

Factor	**AmbC**	**AplC**	**Krak**
	Student's t-test		
AmbC		3.4700	23.0000
AplC	**0.0076**		19.5000
Krak	**< 0.001**	**< 0.001**	
	Parametric p-value		

Note: the Bonferroni adjusted p-value was used

3.3.2 Permutation test Student's t-test

	AmbC	**AplC**
AplC	**0.006**	
Krak	**0.006**	**0.006**

Note: the Bonferroni adjusted p-value was used

The test of paired comparisons was produced using the usual parametric method and the permutation algorithm unrelated to the nature of the data distribution. Both tests showed that the null hypothesis of the hypothesis of equal population means should be rejected for all pairs of methods.

DISCUSSION

Repair of the torn Achilles tendon using the plantaris tendon as a reinforcing membrane was first described by T.A. Lynn in 1966. In 2004, E.M. Bluman offered to reinforce the injury site with the plantaris tendon in Z-shaped manner. Randomized trials comparing primary reinforcement (Lindholm method employed lateral flaps for the Achilles reconstruction; Lynn performed reinforcement with a flattened plantar tendon) included those performed by S. Aktas and T. Nyyssonen who used end-to-end suture. The cohorts of patients described did not differ in rerupture rate and functional results. N. Maffulli and co-authors recommended primary reinforcement for long-term neglected and repeat ruptures [14, 15]. Among Russian authors A.A. Panov et al. offered to use a titanium nickelide mesh implant for the Achilles tendon reinforcement and reported a significant reduction in the recovery time of working capacity in comparison with primary end-to-end tendon suture [16].

Publications reporting comparison of the strength of tendon sutures are difficult to summarize. The same suture in the hands of different users can show different results and would be dependent more on the condition of the tendon tissue and the strength of the thread. We chose to use the VICRIL 1 thread due to its technical characteristics (a half-life period of 30 days and complete resorption after 56–70 days) that was optimal for a tendon suture. Our suture application relied on the findings rerported by Russian researchers A.A. Gritsyuk and A.P. Sereda who experimentally established the maximum strength of the Krakow suture [14]. We analyzed the literature on Achilles tendon reinforcement and made efforts to understand the effectiveness of reinforcement of the site using autologous tissues through the experiments.

Reinforcement of the Achilles tendon with autologous tissues including the plantaris tendon and a portion of the peroneus longus tendon on the distal base allowed for a 3-fold increase in the strength of the suture. The use of autologous tissues on a distal feeding base was expected to reduce the rate of infectious complications in comparison with synthetic materials. The disadvantage of the plantaris tendon reinforcement is the variable distal location of the plantararis tendon [17], and harvesting the autograft for reinforcement can be difficult. The new method of Achilles tendon reinforcement aimed at increased strength of the Achilles tendon reinforcement with predictable harvesting of the autotendon on the distal base.

We intended to identify accurate indications for the Achilles tendon reinforcement. For example, no reinforcement procedure would be practical for open traumatic injury to the severed Achilles tendon due to the normal morphological structure of the tendon at the injury site [18–21]. And a pronounced dystrophy of the Achilles tendon in association with corticosteroid use in the treatment of achillobursitis with dissociated ends of more than 3 cm can be addressed with reinforcement of the Achilles tendon suture. Another indication for reinforcement is long-term Achilles tendinitis that is unresponsive to conservative treatment. Patients are concerned with Achilles tendon pain that increases after physical activity [22–25]. Examination reveals a thickening in the middle third of the Achilles tendon and soreness during palpation in this area. The purpose of surgical treatment of the pathology is the removal of the involved parathenone and resection of involved tendon at the site of aseptic inflammation. Reinforcement at the site can be considered according to indications preventing a rupture at the site of Achilles excision. Clinical details of the reinforcement procedure will be presented in the next article.

CONCLUSION

1. Methods offered to reinforce the Achilles tendon with the plantaris tendon and a portion of the peroneus longus tendon on the distal base facilitated the strength increased at the injury site by 195.6 and 214.4 %, respectively, in comparison with Krakow whipstitches.

2. There is a greater risk of rerupture with pronounced dissociated fibers at the ends of the rupture site and Achilles tendinitis as evidenced by the literature. Reinforcement of the Achilles tendon using techniques offered can help to minimize the risks of rerupture that will be explored in the clinical chapter of the work.

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