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Comparative determination of the mechanical strength of the grafts models of the half of the peroneus longus tendon and the semitendinosus tendon (experimental study)

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Abetuae

Purpose To perform the comparative assessment of the mechanical strength of models of semitendinosus and peroneus longus tendon grafts prepared using the GraftLink technique. Materials and methods Tendon material was collected on the base of the Irkutsk Regional Bureau of Forensic Medicine. The main stage of the mechanical strength study of graft models was carried out at the National Research Irkutsk State Technical University, the Department of Strength of Materials, using universal tension testing desk-standing machine Shimadzu AGS-10kNXD. The mechanical strength of graft models of tendon of the semitendinosus and peroneal longus muscles, prepared by a known method (GraftLink technique) was defined. Statistical data processing was carried out using the statistical software Statistica for Windows 10.0 (StatSoft Inc., USA; license holder is the Irkutsk Scientific Center of Surgery and Traumatology). We used a nonparametric method for defining the statistical significance of differences, i.e. the Mann-Whitney test. Differences in the compared groups were considered statistically significant in p < 0.01. Results The mechanical strength of the graft harvested from the semitendinosus muscle tendon according to the known technique averaged out at 351.8 ± 133.0 N, and the mechanical strength of the graft from the half of the peroneus longus tendon, prepared in a known manner, averaged out at 632.4 ± 193.7 N. Statistically significant differences were revealed (p < 0.01). Discussion Our study is the only one that shows the results of studying the mechanical strength of allografts prepared by two different techniques. In addition, we identified two phases of the graft rupture, when the free end of the graft being the weakest site of the graft ruptures during the first phase Conclusion The rupture of the graft from the half tendon of the peroneus longus muscle, prepared using the GraftLink technique, occurred at a force of 632.4 ± 193.7 N, which is 1.8 times more than the graft from the semitendinosus muscle prepared using the GraftLink technique.

Keywords: graft, plastic surgery, anterior cruciate ligament, peroneus longus tendon, semitendinosus tendon, GraftLink technique

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INTRODUCTION

The choice of graft for anterior cruciate ligament (ACL) plasty is still controversial. Despite numerous studies, there is currently no consensus on the choice of the optimal graft, the method of its formation and fixation [1–6]. In recent decades, the tendon from the patellar ligament with two bone blocks (BTB, bone-tendon-bone) has been the most commonly used material for ACL repair, but over time, trends have changed towards the use of semitendinosus and gracilis tendons (ST-G, semitendinosus – gracilis) [7, 8–10].

Significant disadvantage of taking the above tendon materials for the subsequent formation of grafts is that each of them is an integral part of the para-articular complex responsible for both passive and active stabilization of the joint, and removal of any part of it inevitably leads to partial loss of the biomechanical unity of a complex anatomical formation. [11].

An alternative when choosing a tendon material for subsequent formation of an ACL graft can be use of the tendon of the long peroneal muscle. When it is taken, the biomechanics of the knee joint is not affected, since the tendon of the long peroneal muscle is anatomically located in the lower leg, which is extremely important in the rehabilitation period. Two studies confirm the effectiveness of using this tendon.

Kozhevnikov E.V. et al., harvested the tendon was from the long peroneal muscle, then the graft was formed from it and implanted using endoscopic technique, while replacing the defect not only in the anterior cruciate ligament, but also in the internal lateral ligament (ILL). Patent No. 2430696 dated October 10, 2011 was obtained for this technique [12].

The disadvantage of the described method is the need to harvest the whole tendon, similar to the technique of harvesting tendons from the pes anserinus area, with an additional risk of damage to the branches of the peroneal nerve and the formation of subcutaneous and intermuscular hematomas. In addition, the negative effect of the complete removal of this tendon on the biomechanics of the ankle joint and foot becomes obvious, since the most massive tendon of the two pronators is taken [12, 13].

Thus, optimization of the tendon material sampling for the formation of a graft with optimal strength

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properties is one of the main stages in both primary and revision ACL plasty.

The purpose of the work is to conduct a comparative assessment of the mechanical

strength of graft models from the semitendinosus and long peroneal muscles prepared by a known method (GraftLink technique) under experimental conditions.

MATERIAL AND METHODS

Material for the study was harvested at the premises of Irkutsk Regional Bureau of Forensic Medicine according to RF Government Regulation of July 21, 2012 N 750 "On approval of the Rules for the transfer of the unclaimed body, organs and tissues of a deceased person for use in medical, scientific and educational purposes, as well as the use of the unclaimed body, organs and tissues of a deceased person for these purposes" (according to Federal law of 21.11.2011 N 323-FZ).

The object of the study were 30 cadaveric tendons of the semitendinosus muscle (mean length 26 ± 1.7 cm) and 15 tendons of the peroneus longus muscle (mean length 27 ± 2.1 cm) taken from 30 male donors aged 32 to 76 years. (mean age was 51.7 ± 14.5 years), who died from injuries and somatic pathology not associated with connective tissue pathology. The material was taken no later than 12 hours after the onset of death.

Semitendinosus tendon graft formation

At the first stage, the tendon was harvested as follows: a linear skin incision 4.5-5 cm long was made 2.3–2.5 cm vertically medial to the tibial tuberosity. Using a Mosquito-type clamp, soft tissues were pushed back to the tendons of the pes anserinus, which is formed by the tendon of the semitendinosus and gracilis muscles, and a horizontal incision of 2.0-2.5 cm was made. Under the tendon of the sartorius muscle, the distal part of the tendon of the semitendinosus muscle was isolated and taken on a holder. The distal end of the tendon of the semitendinosus muscle was sutured with Lavsan threads No. 4 with a twisting suture and cut off. The stripper was embedded according to the method (Moore et al. Method for using a tendon stripper and leader set. US Patent 4.773.417 09.29.1988) to a depth of no more than 26 cm. A free fragment of the tendon of the semitendinosus muscle was put into the wound. After harvesting the tendon, the surgical wound was sutured with lavsan threads No. 4.

At the second stage, a semitendinosus graft was formed from the harvested tendon as follows: the ends of the tendon were sutured end-to-end (GraftLink technique) with lavsan threads No. 4, then the tendon was bent so that a four-bundle graft model was obtained, the ends of which were sheathed with a twisting suture with Vicryl 2-0 threads 1.5 cm on each side.

Peroneus longus tendon graft formation

At the first stage, the tendon of the long peroneal muscle was harvested as follows: the tendon of the long peroneal muscle was palpated proximal to the ankle joint by 2.5–3.0 cm, and 1.0 cm away from the fibula, a linear direct incision was made with a scalpel 3.5–5.0 cm long. Using a "Mosquito" clamp, the soft tissues

were moved apart until the required tendon of the long peroneal muscle was found, it was exposed and sutured with polypropylene No. 4 threads with a twisting suture, and the distal end of the tendon was cut off. The tendon of the long peroneal muscle was cut off and brought into the wound with a stripper in the proximal direction. After harvesting the tendon, the surgical wound was sutured with lavsan threads No. 4.

At the second stage, the graft model was formed from the harvested tendon of the peroneus longus muscle as follows: the tendon was divided into 2 equal halves, the free ends of the resulting half tendons were sutured end-to-end (GraftLink technique) with lavsan threads No. 4, then the tendon was bent so that a four-bundle transplant model was obtained, the ends of which were sheathed with a twisting suture with Vicryl 2-0 threads, 1.5 cm on each side.

The graft models were immersed in Belyakov's solution, prepared according to the generally accepted method (patent No. 2235462), and stored in a refrigerator at a temperature of -20° to -25°.

The main part of the experiment was conducted on the premises of Irkutsk National Research Technical University; the study of the mechanical properties of the graft models was carried out on a Shimadzu AGS-10kNXD universal benchtop tensile testing machine with a maximum load of 10 kN. Determination method: direct high-precision constant-speed deformation control method by ball screw drive without backlash. This machine allows you to test samples for tension and compression in one direction (Fig. 1).



Fig. 1 Testing machine Shimadzu

The force measurement was carried out with an accuracy within $\pm\,0.5\%$ of the specified value in the range from 1/1 to 1/500 of the rated power of the load element, which complies with JIS B7721 Class 0.5, EN 10002*2 Grade 0.5, ISO 7500*1 Class 0.5, BS 1610 Class 0.5 and ASTM E4, test force calibration is automatic.

Immediately before the study of mechanical properties, the graft models were thawed at room temperature for 2–2.5 hours.

Both ends of the graft model were fixed in improvised clamps. For stable fixation of the tendon, the surface of the metal half-rings was wrapped with a medical adhesive tape. Medical adhesive tape refers to tape (layered) materials, its friction coefficient is 0.15 N (Fig. 2).



Fig. 2 Varian of graft model fixation using metal hooks in the improvised clamps

Each clamp was attached to the tensile testing machine.

The mechanical properties of the samples were determined as follows: the opposite ends of the sample were placed between the clamps of the testing machine, then the dimensions (length and diameter) were taken and the speed of the traverse transport was set. After the start of the test, the traverse with the upper clamp moved at the given speed, stretching the sample. On the monitor screen of the machine, a graph of polycyclic loads was

displayed – the "load-tension" curve. The stretching rate was 20 mm/min with an accuracy of \pm 0.1%. As a result of the experiment, the values of the applied load at sample rupture were recorded. The stretching parameters were set using the TRAPEZIUMX computer program.

The experimental stress values in the loading direction were calculated using the formula (ultimate tensile force) [6]:

$$\sigma = P/S$$

where P is the load at break, N; S is the cross-sectional area of the sample, mm².

In automatic mode, the experimental data were processed. Figure 3 is a screen printout of the user interface of the TRAPEZIUMX software (Fig. 3) in a typical case.

The assessment of the normality of distribution was carried out using the Shapiro-Wilk test. In the first group (Peroneus longus tendon graft), the force values were 0.99 N, in the second group (Semitendinosus tendon graft) -0.94 N.

These data allows us to conclude that the nature of the distribution differs from normal (p < 0.05-0.001).

Also, the assessment of normality and homogeneity of distribution of the sample was carried out through the indicators of asymmetry and kurtosis (Table 1).

Table 1 Indicators of asymmetry and kurtosis

Sample	Asymmetry	Kurtosis
1 group	2.914	10.856
2 group	0.054	-1.288

In 3 out of 4 cases, the asymmetry and kurtosis indicator was non-zero, which indicates a possible abnormal distribution, in addition, a number of samples turned out to be heterogeneous in terms of kurtosis.

The preliminary analysis does not allow the full use of parametric statistical tests (requiring normality and homogeneity of distribution), and the nonparametric Mann-Whitney U-test was used to further test the research hypothesis.

As a result of the analysis, it was found that there were significant differences between the comparison groups in terms of the studied indicator "force" (N) (p > 0.05, p > 0.01, p > 0.001).

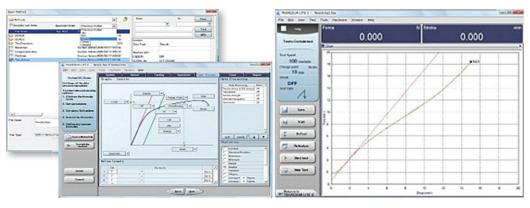


Fig. 3 Screen printout of the user interface of the TRAPEZIUMX software

RESULTS

Determination of mechanical strength of a semitendinosus tendon graft model prepared in a known way (GraftLink technique)

During the first stage of the experiment, two phases of rupture were revealed. In the 1st phase, the rupture of the free end of the graft model occurs. In the 2nd phase, the remaining portions of the graft withstood the load, and they were stretched, and then completely ruptured.

As a result, the following values were obtained: the average value of the force at which rupture occurs was 351.8 ± 133.0 N, and the average elongation at which rupture occurs was 8.2 ± 2.8 mm (Fig. 4).

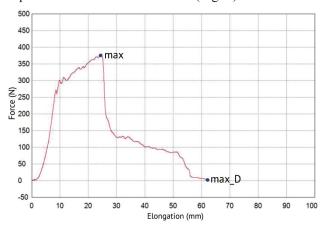


Fig. 4 Diagram of mechanic strength of the semitendinosus tendon graft model (technique GraftLink)

Determination of mechanical strength of a half peroneus longus tendon graft model prepared in a known way (GraftLink technique)

During this stage of the study, the following values were obtained: the average value of the force at which rupture occurs was $607.8 \pm 101.2 \text{ N}$, and the average elongation at which rupture occurs was $8.4 \pm 8.5 \text{ mm}$ (Fig. 5).

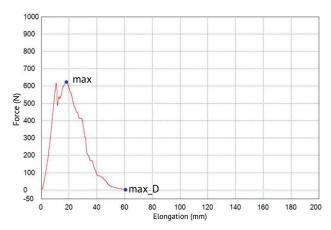


Fig. 5 Diagram of mechanical strength of the ½ part peroneus longus tendon graft model (technique GraftLink)

For a comparative analysis of the study result, the nonparametric Mann-Whitney test was used (Fig. 6). As a result of the comparative analysis using this criterion, significant differences between the groups were obtained (p > 0.05).

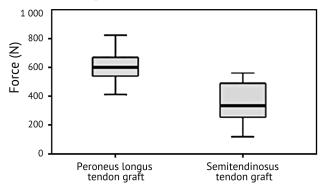


Fig. 6 Comparing graft models from $\frac{1}{2}$ part of the tendon of peroneus longus and tendon of the semitendinosus muscle using Mann-Whitney test

DISCUSSION

Our study is the only one that shows the results of studying the mechanical strength of allografts prepared by two different techniques. We have demonstrated that a graft model prepared from half of the tendon of the long peroneal muscle can achieve loads sufficient to withstand the forces that arise in everyday life after ACL reconstruction, which reaches 570 N [15]. But the force required for loads on the knee joint during rehabilitation reaches 700-750 N [16].

Mayer et al. [17] in their study talk about formation of a three-bundle graft. However, the free ends of the threebeam graft are located on different sides, and the free ends of the four-beam graft are sutured together. As a result, in a three-beam graft, sutures must be performed on each side, which makes this method inefficient and laborious.

Fabbri et al. [18] suggest that the strength of the graft depends on the viscoelastic properties of the tendon itself, and not on the method of preparation, since, in his opinion, there are no differences between the threebundle, four-bundle, or two-bundle methods of graft formation

It can be assumed that the signs of instability of the knee joint during the early rehabilitation of patients after ACL reconstruction are associated with the system of suspension fixators. But Johnson et al. showed that modern systems of suspension clamps are able to withstand loads up to 2230 N [19]. In our study, the tendons had different lengths and diameters, so it can be assumed that the rupture depends on these parameters, but we found that the rupture of all graft models occurs at the suture of the free end of the graft, at the suture-tendon interface. This leads to conclusion that the weakest link in the "graft-suspension fixator system" is the suture at the free end of the graft, which in our study, on average, withstands a load of $607.8 \pm 101.2 \text{ N}$.

Therefore, for aggressive early rehabilitation of patients, it is necessary to strengthen the free end of the graft so that it can withstand a load of at least

750 N. Understanding the mechanism of graft rupture is important to avoid undesirable outcomes during early

rehabilitation of patients, as well as to find ways to strengthen the free end of the graft.

CONCLUSION

Based on the results of the experimental study, it can be concluded that the use of a graft model from half of the tendon of the peroneus longus muscle provides greater (1.8 times) mechanical strength compared to the graft model from the tendon of the semitendinosus muscle.

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