27/28th International Conference
ENGINEERING MECHANICS 2022
Milovy, Czech Republic, May 9 –12, 2022
Paper **#90**, pp. 169–172, doi: 10.21495/51-2-169

STRENGTH TESTS OF HUMAN TENDONS FOLLOWING PROLONGED STORAGE

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Abstract: *This work presents investigations into tendons of human origin used for the reconstruction of ligaments in the knee joint. The scope of tests included a static tensile test using strength testing machine MTS Criterion Model 43 (MTS Systems, Eden Prairie, MN, USA). Samples of long peroneal muscle (peroneus longus) tendons and short peroneal muscle (peroneus brevis) tendons were subjected to testing. The main objective of the research was to determine mechanical properties of tendons after a prolonged period of storage, which lasted 9 years. The following mechanical properties of tendons were obtained: maximum breaking force Fmax , maximum stress σmax [MPa] and Young's modulus E [MPa].*

Keywords: Uniaxial tension test, Human tendons, Young's modulus, Ligament reconstruction, Tissue bank.

1. Introduction

Tendons are prone to rupture due to their structure and function they play in the motor organ. That is why they often require reconstruction. Tendon injuries may be treated, however, that does not guarantee full recovery of the biomechanical properties tendons had before the injury. Understanding of the biomechanics of tendons is necessary for the improvement of their treatment. One of the methods of tendon injury treatment is their reconstruction in the surgical procedure using tendons obtained from donors (Abraham et al. 1998; Leite, CBG, Demange, MK. 2019). In this procedure, an important role is played by tissue banks, which specialize in sampling, preparation and storage of reconstructive materials. In compliance with the current regulations and procedures in tissue banks, the prepared samples which are stored longer than 5 years may not be used in the surgical procedures of tendon reconstruction. The available literature includes information on experimental tests which aimed to determine mechanical properties of tendons and other biological structures (Kamiński et al. 2009; Jones et al. 2007; Joszko et al. 2019; Joszko et al. 2018; Gzik-Zroska et al. 2016; Gzik-Zroska et al. 2021). However, no results were found in the scope of the studies which would evaluate the impact of prolonged storage on the alteration of mechanical properties of tendons. Therefore, the objective of this work was to determine the mechanical properties of tendons following a nine-year period of storage.

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2. Materials and Methods

The investigations involved 8 human tendons of long and short peroneal muscle (peroneus longus and peroneus brevis), which were obtained from deceased donors (3 men at the age of 25 ± 4). Each tendon was divided into 2-3 smaller samples, depending on their original length. In total, 20 samples of peroneus longus and peroneus brevis were used in the investigations. All the tendons were deep frozen in liquid nitrogen vapour (-130°C) and sterilized by a radioactive dose of 25kGy. The storage time of the tendons in the tissue bank lasted 9 years. Such a long period of storage resulted from the lack of demand for this type of tendon in reconstructive surgical procedures. On the day of the performance of strength tests, the tendons were defrosted for 30 minutes at a room temperature (Fig. 1a). Next, the samples were rinsed in a solution of saline solution. The above-described procedure of preparation of the samples prior to strength testing complies with the procedure applied during the reconstruction of tendons in the knee joint. To determine mechanical properties, a uniaxial elongation test was applied using strength testing machine MTS Criterion Model 43 (MTS Systems, Eden Prairie, MN, USA (Fig. 1c). Tendon samples were fixed in the strength testing machine in specially designed grips eliminating the slide and concentration of stresses at the point of the sample fixation (Fig.1b). Prior to testing, an initial force of 10 N was applied to the samples. Then, a tensile test was performed at a velocity of 50 mm/min. The testing continued till the moment of the sample's breaking. During the test, the samples were moistened with the solution of saline solution in the form of an aerosol to prevent their drying. The tests were carried out at a temperature of 25°C. On the basis of the conducted investigations the following parameters were determined: maximum breaking force F_{max} , maximum stress σ_{max} [MPa] and Young's modulus E [MPa].

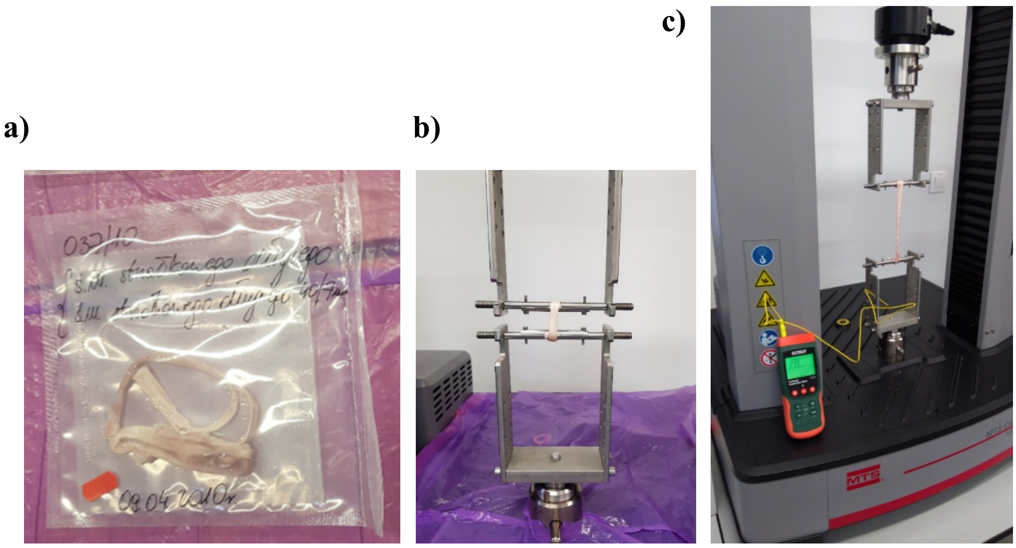

Fig. 1: Testing station: a) samples prepared for testing, b) fixation grips, c) strength testing machine.

Table 1 presents types of tendon samples which were subjected to tests as well as their designation and dimensions.

3. Results

On the basis of the performed tests, it was observed that tendons of the long peroneal muscle (peroneus longus) showed higher values than the mechanical properties of tendons of the short peroneal muscle (peroneus brevis). In the case of maximum breaking force F_{max} (Fig.2a), the difference in the obtained mean values amounted to 175.6 N, whereas the difference obtained for maximum stress σ_{max} (Fig.2b) equalled 7.4 MPa. A significant difference was observed also in the case of Young's modulus E (Fig.2c), which equalled 25.5 MPa.

Table 1. Type and designation of tendons subject to testing

Tendon Type	Sample No	Dimensions after Division	
		Cross-sectional Area [mm^2]	Length [cm]
Peroneus longus tendon, left leg	(PL)	49.02	10
		38.48	25
Peroneus brevis tendon, left leg	(PB)	60.82	12.5
		40.72	12.5
Peroneus longus tendon, right leg	(PL)	33.18	12.6
		39.59	12.6
		37.39	12.6
Peroneus brevis tendon, right leg	(PB)	23.76	12.3
		25.52	12.3
Peroneus longus tendon	(PL)	33.18	12.6
		30.19	12.6
		34.21	12.6
Peroneus longus tendon	(PL)	37.39	13.3
		41.85	13.3
		38.48	13.3
Peroneus longus tendon	(PL)	35.26	11.5
		36.32	11.7
		38.48	11.2
Peroneus longus tendon	(PL)	32.17	18.5
		33.18	18.4

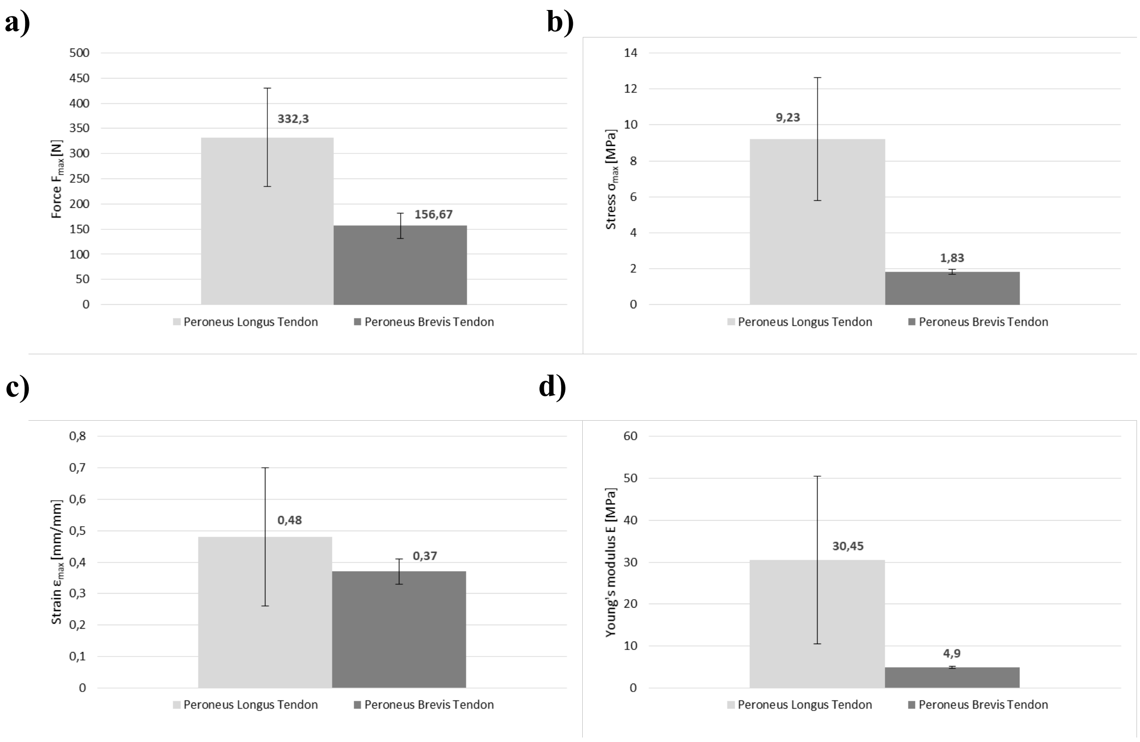

Fig. 2: Mechanical properties: a) maximum breaking force F_{max}, b) maximum stress σ_{max} c) maximum strain ε_{max} d)Young's modulus E.

4. Discussion and Conclusions

Within the framework of this work, a review of the subject literature was conducted and on the basis of thereof the methodology of biomechanical tests was prepared. The main objective was the determination of the mechanical properties of donors' tendons after a long period of storage. The tested samples were going to be disposed of due to the fact that their expiry date had passed, and so had their usability as grafts. Anatomical length of the tendons prepared for testing enabled their division into smaller sections, which were later subjected to tensile tests in the following strength testing machine: MTS Criterion Model 43. The obtained results were analyzed with a view to maximum breaking force, maximum stress and strain as well as Young's modulus. On the grounds of the results analysis, it can be stated that the tendon of the long peroneal muscle (peroneus longus) shows considerably better strength properties. On the other hand, comparing the obtained mechanical properties of tendons with the literature data provided by Morales-Orcajo et al. (2016), there were differences in the obtained values. The smallest differences were noted for F_{max}. The difference for the tendon (PL) was 13.7 [N] and for the tendon (PB) the difference was 82.3 [N]. In the case of maximum stress σ_{max}, differences were noted for the tendon (PL) at the level of 10.77 [MPa] and for the tendon (PB) 18.17 [MPa]. The greatest differences were noted for Young's modulus for the tendon (PL), the difference was 196.5 [MPa] for the tendon (PB), the difference was 198.1 [MPa]. The next step of the test is to do fatigue tests on a larger number of samples. Such testing would make it possible to assess if a long period of storage and cyclic loading affect each type of tendon and its mechanical properties in the same way. The presented studies may contribute to further research whose results may influence the alteration of currently valid regulations and procedures of tissue storage.

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