Graft semitendinosus and gracilis human muscle tendons elongation. A study carried out on young adult human cadavers

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SUMMARY

In the anterior cruciate ligament knee surgery reconstruction, autologous tendons graft remains as a main option as substitutive ligaments. However time effect on graft elongation is the main reason of ligament reconstruction failure.

Traction tests have been performed on eight gracilis as well as on eight semitendinosus human muscles tendons obtained from four male cadavers at an average of 24.5 years.

Each tendon specimen has been submitted to a deformation of 2.5% of its initial length for a time interval of 600 s with continuous recording of the corresponding force relaxation. The tendon specimen was then kept at rest for 300 s as soon as it returned to its initial length. The same specimen was then submitted to a similar test. Deformation rate for both tests was 10% of its initial length per second.

Initial force values were obtained for resting time interval of 300 s as well as for 600 s. Statistical analysis suggests that the semitendinosus muscle tendon exhibits a more uniform mechanical behavior, as compared to gracilis muscle.

Keywords: Anterior cruciate ligament; Knee.

INTRODUCTION

Postsurgical ligament elongation is an important complication reported in literature. Thoyama et al.[14] report that tendon graft elongation is a critical factor related to the surgical success. Boorman et al.[2] also emphasize that time effect on graft elongation is an important factor of ligament reconstruction of soft tissue failure. Tendons and ligaments exhibit viscoelastic properties having the important function of supporting traction loads.

Abrahams[1] states that viscoelastic tissues are a combination of elastic solid with a viscous fluid. Taylor et al.[13] emphasizes the time dependence of viscous properties.

Fung[3] reports that 5% of relative deformation is the the maximum allowable limit value for normal human activities. Viscoelastic behavior is studied by means of non-destructive mechanical tests i.e. under the tendon or ligament elastic limit. Woo et al.[16] explain that when a tendon is submitted to constant elongation and remains at the same length for longer periods, the corresponding force will progressively decrease. That phenomenon is known as static relaxation force. Such a phenomenon occurs during ligament surgery reconstruction when the graft is tensioned during fixation procedure. That fact contributes to a better understanding the answer of tendons and ligaments to mechanical loading. The consequences of deformation are different when elastic and viscous properties are considered separately. The viscoelastic behavior should be studied for the adequate interpretation of mechanical characteristics of tendons[6]. The phenomenon of relaxation is often used in the study of ligament failure[2], the effects of water content upon viscoelastic behavior[7], and viscoelastic properties of irradiated tendons[4]. In the present study the mechanical behavior of gracilis semitendinosus muscle tendons was analyzed through specific mechanical tests i.e. static force relaxation to evaluate "assay" and "time" parameters. .

This paper summarizes investigational results of the tests carried out in the research study of the PhD thesis of this first author. Details out of the scope of the present paper can be found in the mentioned thesis[11].

MATERIAL AND METHODS

The use of human tendons in the present research study was approved by the Medical Research Ethical Committee of the

This investigation was carried out at the Orthopedics and Traumatology Department, Medical Science School (FCM), State University of Campinas (Unicamp).

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Medical Science School of the UNICAMP, under the Project number 168/99. Tests have been performed on eight gracilis as well as eight semitendinosus muscle tendons obtained from four male cadavers agedf 24.5 years on average (age range: 18-34 years). The causes of death were firearm injury in 3 and politrauma in 1. Tendons were obtained with the help of the Human Organs Group and Death Identification Service of the Clinics Hospital of UNICAMP.

Tendons were stored because physical and mechanical properties of specimens had to be preserved and carrying out tests when specimens were obtained was not feasible.

A Prosdócimo horizontal freezer with two doors of the Pathological Anatomy Department of the Clinics Hospital of the Campinas University was used.

Specimens were adequately stored in a freezer at –20°C. The adopted storage procedures were similar to those used by Matthews and Ellis [8]; Woo et al.[15]; Hernandez et al.[4]; Salomão et al.[12]; Pfaffle et al.[9]; and Piedade[10]. Unfreezing was carried out at room temperature (27°C). Viscoelastic tests were carried out at Lloyd TA 500 press model coupled to a PC Penthium Pro®. Data analyses were processed by Nexigen 3.0 software.

Each tendon specimen was submitted to a deformation of 2.5% of its initial length for 600 s with continuous recording of the corresponding force relaxation. The tendon was then kept at rest for 300 s as soon as it returned to its initial length. The same specimen was then submitted to a similar test. Deformation rate for both tests was 10% of its initial length per second. Force values were obtained for a time interval of 300 s as well as for 600 s. Relative deformation rate value was within the tendon elastic limit to characterize a nondestructive test i.e. a viscoelastic test.

Tests were carried out at the Laboratory of Physical and Mechanical Properties of Biological Materials of the Agricultural Machines Department, Agricultural Engineering School, Campinas University.

Data have been submitted to analysis of variance with parcels subdivided in time parameter and tendons in random blocks.

	Test 1			Test 2		
Sample number	Initial Force	Force at 300s	Force at 600s	Inital Force	Force at 300s	Force at 600s
1	6.25	4.95	4.67	9.28	7.57	7.22
2	3.66	2.50	2.32	6.60	4.81	4.51
3	9.61	7.68	7.42	13.23	10.82	10.59
4	4.96	4.07	3.87	8.66	6.82	6.55
5	13.82	11.28	10.88	16.11	13.60	13.29
6	7.94	5.80	5.47	12.03	9.72	9.32
7	5.44	4.38	4.11	5.06	4.34	4.25
8	4.44	3.56	3.37	6.86	5.59	5.40

Chart 1 - *displays initial force values and those obtained at 300 s and 600 s in two consecutive tests after 300 s of rest between tests.*

Treatment	Baseline Force	Force at 300 s	Force at 600 s	Mean force value for test
Test 1	7.01500	5.52750	5.26375	5.93542 (**B**)
Test 2	9.72875	7.90875	7.64125	8.42625 (**A**)
Mean time	8.37187 (**a**)[1]	6.71812 (**b**)	6.45250 (**b**)	

Means followed by the same letter are not different for 5% of probability. Lowercase letters indicate the comparison of means in the line and capital letters indicate comparison in the column.

Table 1*- Average force values (N) for gracilis muscle tendons under static relaxation force for three different time intervals. Mean force values compared by Tukey test.*

	Test 1			Test 2		
Sample (number)	Force at baseline	Force at 300 s	Force at 600 s	Force at baseline	Force at 300 s	Force at 600 s
1	5.81	3.85	3.60	8.40	6.56	6.22
2	4.60	3.19	2.97	7.01	5.43	5.11
3	3.08	2.10	1.97	4.63	3.36	3.15
4	4.94	3.70	3.59	6.83	5.52	5.24
5	9.06	7.51	7.11	12.43	10.64	10.28
6	25.83	22.96	22.31	18.89	17.09	16.77
7	5.21	3.69	3.39	6.81	5.19	4.89
8	4.04	3.05	2.886	6.57	4.74	4.43

Chart 2 *- Force values (N) at baseline, 300 s and 600 s for semitendinosus muscle tendons under static relaxation force for two consecutive tests with a resting interval of 300 s between tests.*

DISCUSSION

Tendon graft elongation is important for clinical outcome following anterior cruciate ligament knee surgery reconstruction. Evaluation of tendon graft mechanical behavior requires specific and viscoelastic tests. Static or cyclic force relaxation tests allow a better understanding of the tendon graft elongation phenomena can be helpful for appropriate graft tensioning during fixation procedure. In the present paper the gracilis and semitendinosus muscle tendons mechanical behavior is analyzed through static force relaxation test.From Chart 1 cannotice that force values decreased from baseline on. It means that during the same test the tendon became more deformable. However, the second test carried after 300 s of rest took larger force values to keep the deformation rate at 2.5%. Final forces in tests 1 and 2 showed that the tendons became less deformable following rest, in other words, they became rigider. These observations are valid for the gracilis and semitendinosus muscle tendons as shown in Charts 1 and 2.

With the help of an analysis of variance and Tukey test, mean force values from test 1 and 2 were compared for “test” and “time” for static relaxation tests carried out on gracilis muscle tendons by using values shown in Chart 1.

Comparison of mean force values (Table 1) shows statistically significant differences for “test” and “time” factors between test 1 and 2 and between periods of observation. Time comparison showed a statistically significant difference between baseline force value as compared to others. However, for time perio-

ds corresponding to 300 s and 600 s no significant difference was found.

Results also indicate that the force values strongly decrease from baseline on and tended to stabilize after 300 s for the gracilis muscle tendons during static force relaxation tests.

Treatment	Baseline Force	Force at 300 s	Force at 600 s	Mean force value for test
Test 1	7.82125	6.25625	5.97500	6.68417
Test 2	8.94625	7.31625	7.01125	7.75792
Mean time	8.38375 (**a**)	6.78625 (**b**)	6.49312 (**b**)	

***Table 2** - Average force values (N) for semitendinosus muscle tendons under static relaxation force for three different time intervals. Mean force values compared by Tukey test.*

Statistical analysis of data shown in Chart 2 shows significant differences between the mean baseline force values and those obtained at 300 s and 600 s for the semitendinosus muscle tendons. However, no statistically significant difference was found between the two tests, thus suggesting a more uniform behavior for the semitendinosus muscle tendon (Table 2).

CONCLUSIONS

In the present research study and with the adopted methodology, statistical results allow one to conclude that for a level of 5%:

- Within the same test the tendon was shown to be more deformable over the time, as indicated by differences between the mean baseline force values and the other force values.

- For the semitendinosus muscle tendon no difference was found between the mean force values for both tests, thus suggesting a more uniform tendon behavior (mechanical behavior is a tissue specific characteristic).

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