Fractional order hereditariness of knee human ligament and tendon

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***Abstract*—Anterior Cruciate Ligament (ACL) is one of the four major ligaments in the knee, playing a critical role in stabilizing the joint. ACL is highly susceptible to injury, overall during sport activities, often precipitating catastrophic long-term joint outcomes. The ideal replacement graft for a torn ACL would restore native anatomy and function to the knee. Most commonly used autograft and allograft, including patellar tendon (P) and hamstring tendon (H) graft, or bioengineered synthetic grafts, may substantially alter the biomechanics of the knee, permitting a return to only moderate physical activities [1]. Main issues are the sub-optimal graft properties [2] and a still incomplete biomechanics characterization [1]. The goal of the present work is to fully characterize and compare the viscoelastic behavior of the ACL and natural/artificial grafts in order to highlight the differences that should be overcome to achieve a successful biomechanical performance and an ideal graft design.**

***Keywords*—Anterior Cruciate Ligaments , Viscoelastic Materials, Grafts, Mittag-Leffler.**

I. Introduction

The mechanical behavior of soft tissues is known to be viscoelastic [5]. The shape of the stress$-$ strain curves depends on the strain rate at which the traction test is performed. Few experimental studies have been conducted in this field.

From a theoretical point of view, many of the constitutive models that have been proposed to date fail to properly consider the effect of the strain rate. Extending elastic models or adding spring and dashpot elements are two popular approaches.

While, from the tests conducted and the results obtained and it clear to reproduce or to approximate the mechanical behavior of the ACL.

II. Methodology

Mechanical testing was focused on stress-relaxation and creep phenomena, particularly important in the physiological behavior of ligaments [1] and inherently related to their peculiar multi-scale structure, ultrastructure and morphology [3]. A specific protocol (thawing – preconditioning - stress-relaxation – creep, with 15 min pauses to recover) was designed to test graft characteristics. The values of deformations which were selected as an input value for the SR, in our case understood as relative displacements of the two clamps in which the sample is blocked, were values of (0.5, 1, 2, 3, 4, 5%). After a recovery period, a creep test on the same specimen should be carried out on the same specimen at the maximum force reached in the relative previous stress-relaxation, thus to relate the two phenomena. Mechanical tests were carried out with a dynamic test system in a single axis configuration (Bose 3330, TA Instruments), revealing force (max 3kN) and displacement (max 25 mm) for every testing phase. During each measurement, the specimen was continually moistened with 0.9% saline solution Figure 1. The date of the sample test were saved and rework by wintest software.

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Figure 1: Patellar tendon clamped in testing machine

III. Results

The attention was then focused on the viscoelastic behavior of the material. It is observed that the equation of linear viscoelasticity (LV) is not met since when comparing the exponential growing law, producing the increase in the deformation within experimental Creep test, is far from the same exponential law predicted starting from the Relaxation Stress.

There are two possible solutions which can be pursued at this point: to continue with an approach that is based on the theory LV, trying to re arrange it according to the characteristics of the biological material, or a new approach that is based on the theory of non-linear viscosity (QLV)

The output data have been used to compare the different grafts performances and the stress-strain estimation has been included to obtain information about the viscoelastic behavior of the grafts. In the stress-strain curve, specifically the toe and linear regions highlighting different stiffness have been highlighted in two zones [4]. Further, in order to characterize the viscoelastic behavior, a model has been used with Mittag-Leffler function relationships that describes better then exponential law the viscoelasticity. On-going testing has been performing to compare four groups of specimens: human ACL, P, H and artificial/synthetic graft (LARS) Figure 2 e 3. It seemed effective in fully characterizing ACL and grafts viscoelastic behavior, thus to correctly identify the characteristics of each graft and to guide surgical reconstruction.

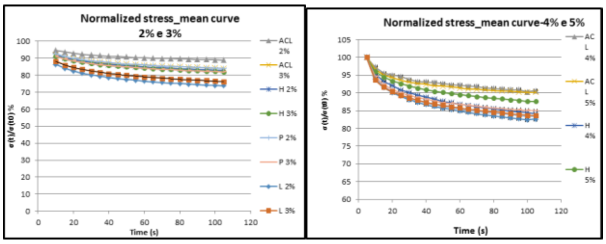

Figure 2: Stress Relaxation graphic in which it is possible to observe the curves related to the deformations of 2, 3,4,5%

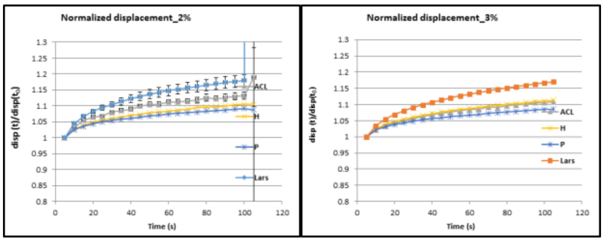

Figure 3: Curves of normalized displacement related to deformation values of 2% e 3%

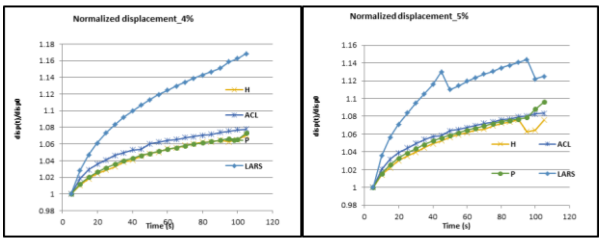

Figure 4: Curves of normalized displacement related to deformation values of 4% e 5%

IV. Conclusion

The Mittag-Leffler function class for creep and relaxation functions will be then used to achieve a constitutive, phenomenological model for the time-dependent material behavior yielding a fractional-order model for the human ligament viscoelasticity.

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