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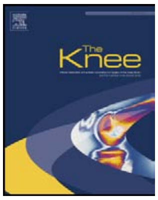

Effect of tendon tensioning: An in vitro study in porcine extensor tendons

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ABSTRACT

Graft tensioning is a controversial issue in anterior cruciate ligament reconstruction (ACLR) that has not achieved consensus between peers. The purpose of this study is to determine if after tensioning tendon length and resistance to maximal load changes. We performed an in vitro study with 50 porcine extensors tendons. The first group (P = 25) was tensioned with 80 N (19.97 lb) for 10 min, using an ACL graft preparation board. The second group (C = 25) was used as control and was not tensioned. The average initial (groups P and C) and post tensioning tendon length (group C) were measured; the average initial and post tensioning tendon diameter were measured as well. All samples were fixated in a tube–clamp system connected to a tension sensor. The samples were stressed with continuous and progressive tension until ultimate failure at maximum load (UFML) occurs. The initial mean length was: P before tensioning = 13.4 mm ± 1.4 mm (range 10.5–16.5); P after tensioning = 13.8 mm ± 1.4 mm (range 11.5–16.5); C = 13 mm ± 1.35 mm ($p = 0.005$). The mean diameter was: P = 5.6 mm (4.5–6); C = 5.5 mm (range 4.5–6) ($p > 0.05$). The UFML was: P = 189.7 N (114–336); C = 229.9 N (143–365) ($p = 0.029$). Tendon tensioning with 80 N for 10 min produced 3% average elongation. These could be beneficial in ACLR since tendon tensioning decreases elongation of the graft after fixation. Regardless, tendon tensioning is not innocuous since it diminishes their resistance when continuously stressed until complete failure occurs.

1. Introduction

Anterior cruciate ligament (ACL) reconstruction with semitendinosus–gracilis (STG) tendons is a frequent procedure performed currently. In the past few years this technique has been developing with newer and improved surgical options, based on the enhanced knowledge that has been achieved secondary to experimental studies and patient's clinical follow-up [1–9].

Trying to optimize clinical results after ACL reconstruction, different studies have analyzed different aspects of the surgical technique used during the procedure. Graft tensioning is one important point to consider for this purpose. It has been reported in the literature that after ACL reconstruction, anterior–posterior knee laxity decreased with an increase of initial graft tension before final fixation. Considering factors such as stress relaxation and the remodeling process of the graft after its fixation, it could be reasonably assumed indispensable to apply greater initial tension than the laxity–match pretension for restoration of adequate stability after the graft remodeling [10].

It is necessary to consider that under tensioning the graft must be balanced with the risk of over constraining the knee, which may lead to pathologic stresses on the joint cartilage, graft failure, or infra patellar contracture syndrome [13].

Graft tensioning, is a point of controversy in ACL reconstruction that has not achieved consensus between peers so far, observing their biomechanical properties and clinical results [11–13].

There are studies that support tensioning, with variable amounts of tension described as appropriate. Howard et al. [14] describes that soft tissue grafts elongate when tensile loads are applied, secondary to their viscoelastic properties. According to Howard, this effect alters knee stability after ACL reconstruction with soft tissue grafts without tensioning. In their experimental study with bone–patellar tendon–bone grafts, with a control group and another group tensioned with 89 N for 4 min, measuring graft length before and after tensioning; they found that tendon length increases 14% after tensioning, improving knee stability after ACL reconstruction.

Consequently different authors agree that in ACL reconstruction, tensioning prior fixation reduces graft tension loss secondary to their viscoelastic properties [15,16].

Finally, there is no consensus on the amount of graft tension (measured in Newtons) appropriate to achieve optimum results without altering graft biomechanics properties, finding in the literature different studies that present variable results [14,17–19]. The purpose of this study was to determine if tensioning affects tensile properties of the graft, by measuring ultimate failure at maximum load (UFML) in pre tensioned and non tensioned tendons

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and tendon length after tensioning. We hypothesized that graft tensioning decreases tendon tensile resistance, altering their biomechanics properties, elongating the tendon as an additional effect.

2. Methods

Local legislations do not allow us to perform clinical or biomechanical experimental studies in human tissues; therefore we use diverse animal models. It has been published previously that porcine tendons, regarding their mechanical behavior, present similar characteristics to human tendons [20,21]. An in vitro experimental study was performed using fifty porcine extensor tendons of twenty-five domestic pigs (*Sus scrofa domestica*) with similar weight and age at time of harvest; two extensor tendons were harvested from each pig (Fig. 1).

Before sample testing, tendons were sutured with a whip stitch technique in both ends using Fiber Wire suture (Arthrex ®, Naples, Florida, USA).

Samples were separated in two groups, no randomization was applied. In the first group P ($N = 25$), samples were tensioned in a commercially available ACL graft preparation table (Arthrex ®, Naples, Florida, USA) (Fig. 2) using 80 Newtons (N) (19.97 lb) for 10 min. This tension value was applied based on Numazaki et al. [18] and Edwards et al. [23] findings; they reported that graft tensioning above 80 N has no biomechanical advantages before ACL reconstruction.

In this study grafts were tensioned for 10 min based in Lee et al. [11] conclusions; in their study they documented that tendon tensioning with 89 N for 5 min lengthen 87.7% of the final graft elongation obtained at 30 min of tensioning. The second group C ($N = 25$) samples were used as control without tensioning.

Initial graft length and diameter were measured in all cases. In group P length was measured before and after tensioning with the milimetric ruler of the graft preparation table, documenting length in millimeters. Samples diameters were measured with a commercially available ACL reconstruction graft calibrator (Arthrex ®, Naples, Florida, USA).

After graft measurement (groups P and C) and tensioning of group P, samples were placed with two clamps into a pulley machine designed for this study, connected with a PASCO ® tension sensor (Fig. 3), with 9 cm of distance between proximal and distal fixation, trying to simulate the regular graft length used in ACL reconstruction. Progressive and continuous tension was applied until ultimate failure at maximum load (UFML) was obtained, registered in graphic curves using the PASCO ® software (Fig. 4).

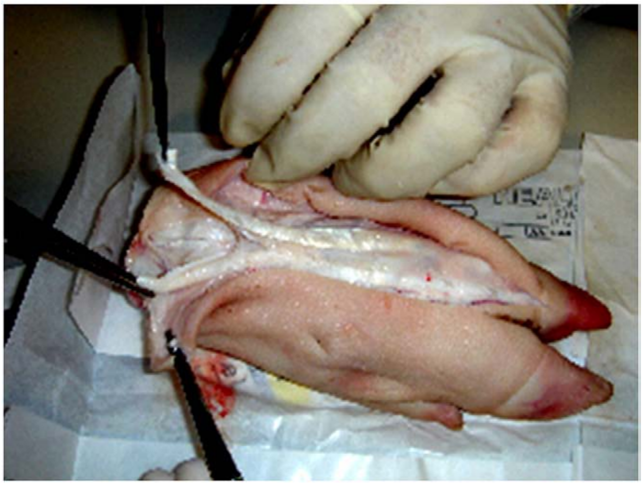

Fig. 1. Extensor tendons harvested from porcine samples. Two tendons were harvested from each sample.

Fig. 2. Tendon tensioning was applied to all samples in group P with a commercially available graft workstation. Insert: Constant tension values applied to all grafts in group P (80 N for 10 min).

2.1. Statistical analysis

Results were analyzed using ANOVA and samples *T*-tests with SPSS software (Windows, Microsoft, Redmond, WA). Statistical power was set in 90 (10% Beta error) with 95% confidence interval and significance of $p < 0.05$. We used parametric tests for 2 independent samples (*T* test studies) given the normal distribution of continuous data of our results [22].

3. Results

In group P (tensioned samples) the average initial length before tensioning was 13.4 ± 1.36 mm (range 10.5–16.5) and average length after tensioning 13.8 ± 1.35 mm (range 11.5–16.5) ($p = 0.005$). This resulted in a 3% final graft elongation after tensioning. In group C (control grafts) the average initial length was 13 ± 1.4 cm (range 11.5–16).

In group P, the average initial diameter was 5.6 mm (range 4.5–5); for group C the average initial diameter was 5.5 mm (range 4.5–6) ($p > 0.05$). Samples length and diameter following continuous tension were not measured given that 50% of them were partially ruptured after UFML; this situation produced difficulties for samples measurement.

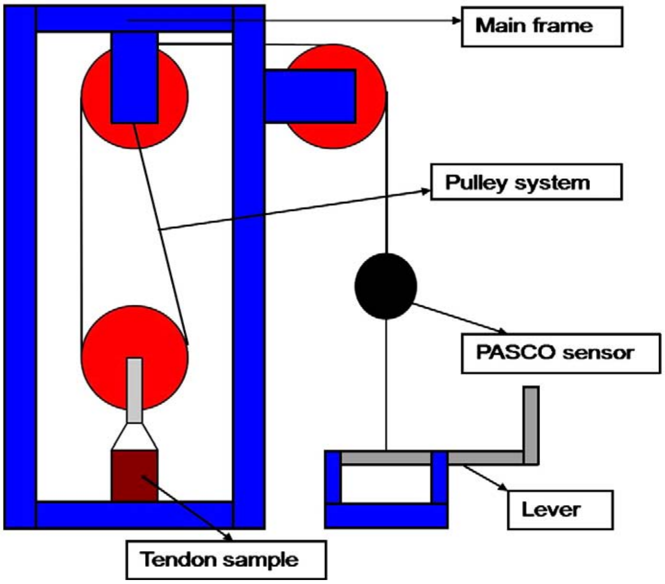

Fig. 3. Schematic drawing of the pulley machine connected to PASCO tension sensor used to produce samples UFML.

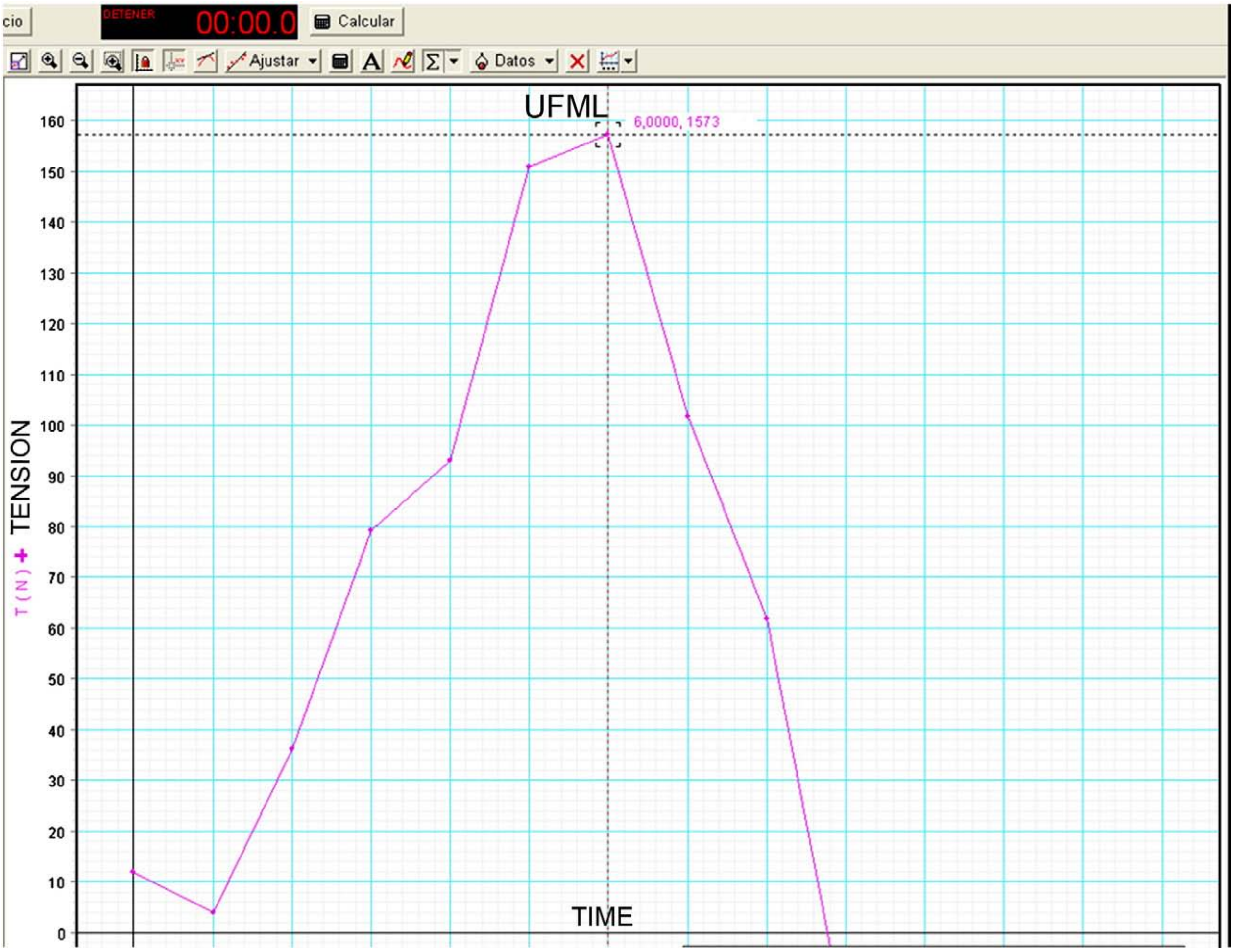

Fig. 4. Graphic curve of constant and continuous tension applied to samples until UFML, documented as abrupt curve inflexion.

The average UFML values for group P was 189.7 N ± 60.73 (range 114–336) and for group C 229.9 N ± 65.26 (range 143–365) ($p = 0.029$). Mean UFML values were higher for the control grafts, documenting this way a significant difference among groups.

4. Discussion

In this study we found that tendon tensioning with 80 N for 10 min produced a final 3% average elongation (P before tensioning = 13.4 mm ± 1.4 mm; P after tensioning = 13.8 mm ± 1.4 mm vs. C = 13 mm ± 1.35 mm; $p = 0.005$), without altering average diameter before and after tensioning. These findings are similar to those described in different studies published in the literature [12,14,16].

We documented as well that the final resistance to continuous tension until tendon failure occurred was minor in tensioned tendons (P = 189.7 N vs. C = 229.9 N; $p = 0.029$). At maximum admitted tensioning values for a reasonable period of time, tendons changed their mechanic properties with substantial decrease of UFML values. To our knowledge, in current literature there are few reports of possible graft loss of mechanical properties after tensioning [19].

Despite the efforts of orthopedic surgeons to control graft tension at the time of ACL reconstruction, numerous authors have demonstrated that tension decreases in the post operative period, presumably from creep and graft remodeling. Up to date there is no consensus regarding tendon tensioning prior final fixation or on the subject of the optimal tension to be used.

When tensioning tendon grafts, the knowledge of their biomechanical properties before and after fixation, are fundamental in order to maintain knee stability following reconstruction. This subject could be achieved subsequent an appropriate understanding of the biological, biomechanical and technical concepts of the different grafts used for this surgical procedure [1–6]. Currently there is no consensus regarding this topic.

Different authors described in the literature tendon graft mechanical effects after tensioning with different values using different time intervals [12,13]. Lee et al. [12] in an experimental study performed in deep flexor porcine tendons, tensioned the grafts in their group 1 with maximum manual tension, in group 2 tension was applied with a commercial graft tensiometer with 89 N for 15 min before fixation and in group 3 the graft was fixated to the femur and then tensioned with 89 N for 15 min before final tibial fixation. In all of the samples after final fixation of the graft, they applied cyclic load (1000 cycles at 1 Hz frequency); then tension of the graft was performed until UFML was achieved, measuring graft elongation. They conclude that intrarticular tensioning before final tibial fixation significantly minimizes graft elongation in time 0 compared with the other groups. They did not found differences among groups in UFML results.

Heis et al. [13] published an exhaustive revision of graft tensioning in ACL reconstruction. They emphasize that graft intrarticular excessive tensioning increase femoral–tibial load; affecting the posterior cruciate ligament. In that study, they performed ACL reconstructions in cadaver specimens analyzing final anterior–posterior knee laxity and knee flexion, separating two groups where grafts are tensioned at 68 N and 88 N. They conclude that excessive tensioning of grafts can cause slight posterior tibial subluxation, causing loss of knee extension.

In another study, Howard et al. [14] gave explanation that soft tissue grafts elongate after tensile loads are applied, secondary to their viscoelastic properties. In their study they used bone–patellar tendon–bone grafts, tensioned with 89 N for 4 min, measuring graft length before and after tensioning; their results show 14% increase in graft length after tensioning.

Graf et al. [15] in an experimental study in primates using bone–patellar tendon–bone grafts, concluded that tensioning reduces final tension loss secondary to viscoelastic relaxation.

Regarding different tensioning values, Yasuda et al. [16] used 20, 40 and 80 N grafts tensioning for 3 min, applied with a commercial available tensiometer in three groups of ACL reconstruction patient groups. At two year follow-up, anterior–posterior knee laxity was 2.1, 1.4 and 0.6 mm respectively. They conclude that 80 N graft tensioning before final fixation offers better stability after ACL reconstruction.

On the other hand Ejerhed et al. [17] in a study of 53 cases of ACL reconstruction with bone–patellar tendon–bone grafts with tensioning of 39 N for 10 min in one group using a control group without tensioning, found no differences in knee laxity evaluated with KT 1000 or in functional results evaluated with Lysholm, Tegner and International Knee Documentation Committee (IKDC) results.

Numazaki et al. [19] in an experimental study in porcine tendons applied 20, 80 and 140 N for graft tensioning. They concluded that tensioning above 80 N does not offer biomechanical advantages and that low values of graft tensioning can cause loss of grafts mechanical properties, resulting in greater elongation when compared with the groups where higher tensioning values was applied.

In the present study 3% graft elongation was found after 80 N for 10 min tensioning ($p=0.005$); consequently, graft tensioning before final fixation could decrease final graft elongation after ACL reconstruction, avoiding progression to an increase of anterior–posterior knee laxity.

The weaknesses of this study are that we only tensioned the grafts for a given period of time (10 min) at a constant load (80 N) and that we are not aware if a different graft would have the exact same mechanic characteristics of the tendons we used. These variables could affect the presented results. Another weakness is that for technical difficulties we did not measure grafts length and diameter after UFML was achieved.

This study addressed the importance of tendon tensioning. We found that tendon tensioning with 80 N for 10 min produced a 3% average graft elongation. This information could be beneficial in ACL reconstruction since tendon tensioning decreases post final fixation elongation of the graft. Nevertheless, tendon tensioning is not innocuous since it diminishes the UFML.

5. Conclusion

Tendon tensioning with 80 N for 10 min produces 3% graft elongation. This could be beneficial in ACL reconstruction, given that tensioning could decrease graft elongation after final fixation. Regardless, tendon tensioning is not innocuous since it diminishes their resistance when continuously stressed until complete failure occurs.

6. Conflict of interest statement

The authors did not receive any outside funding or grants for this work. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity.

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