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PII: S1751-6161(16)00047-3
DOI: http://dx.doi.org/10.1016/j.jmbbm.2016.02.009
Reference: JMBBM1805

To appear in: *Journal of the Mechanical Behavior of Biomedical Materials*

Received date: 23 October 2015
Revised date: 1 February 2016
Accepted date: 4 February 2016

Cite this article as: G. Criscenti, C. De Maria, E. Sebastiani, M. Tei, G. Placella A. Speziali, G. Vozzi and G. Cerulli, Reconstruction of Medial Patello-femora Ligament: Comparison of two surgical techniques, *Journal of the Mechanica Behavior of Biomedical Materials* http://dx.doi.org/10.1016/j.jmbbm.2016.02.009

Reconstruction of Medial Patello-femoral Ligament: Comparison of two surgical techniques

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Keywords: Medial patello-femoral ligament (MPFL), ligament biomechanics, structural properties, Ligament reconstruction, surgical techniques

Abstract

The medial patello-femoral ligament is considered the most important passive patellar stabilizer and its proper functionality is essential for the patello-femoral joint stability. In this work, 18 human knees were randomly divided into two groups and reconstructed through two different surgical techniques: the “Through tunnel tendon” and the “Double converging tunnel” reconstructions. Subsequently, the samples were mechanically tested to evaluate the structural properties of reconstructed femur-MPFL-Patella complex (rFMPC). Particular attention was given to maintain the anatomical orientation between the patella and the graft. Both procedures showed lower stiffness and higher ultimate strain and absorbed energy compared to the native MPFL, but the advantages of the double converging tunnel technique are related to the restoration of the native MPFL sail-shape, to a better stress distribution on the patella, to the use of a single interference screw as fixation device and to the simplicity, rapidity and cost-effectivity of the surgical procedure. The evaluation of the structural properties of rMPFL is fundamental to evaluate the adequacy of the different techniques to restore the physiological structural properties of the native MPFL.

1. Introduction

Recurrent patellar dislocations and instability are common diseases with an incidence of 5.8 per 100.000 (Colvin et al., 2008) and with a recurrent rate of 44% after non-operative treatment of an acute injury (Hawkins et al., 1986). The causes of patellar dislocations can be genu valgum, patella alta (Insall et al., 1972; Kannus et al., 1992), ligament laxity (Mountney et al., 2005), contracture of lateral patellar soft tissues, hypoplasia of the lateral femoral condyle, a laterally located tibial tubercle, vastus medialis insufficiency and abnormal attachment of the iliotibial tract (Deie et al., 2005). The lateral patellar dislocation depends on different factors. The joint geometry plays an important role on patello-femoral joint stability and is influenced by the depth, the steepness and the groove of the trochlea (Colvin et al., 2008). The effect of the Vastus medialis obliquus and vastus lateralis obliquus can influence the stability of the patella pulling it medially and laterally (Colvin et al., 2008). The femur and tibial alignment is fundamental for patellar stability (Colvin et al., 2008) and is expressed by the Q-angle defined as the “acute angle formed by the vector for the combined pull of the quadriceps femoris muscle and the patellar tendon” (Horton et al., 1989). The highest risk of dislocation is when the knee is in full extension (highest Q-angle) because the patella is not constrained in the trochlea (Colvin et al., 2008). Another important effect is played by the Retinacula and in particular by the MPFL. It seems to be the most important passive patellar stabilizer and it acts 50-60% of the force of the medial soft-tissue which restrains the lateralization of the patella between 0° and 30° of flexion (Bicos et al., 2007; Cash et al., 1988; Cofield et al., 1977; Conlan et al., 1993; Desio et al., 1998; Hautamaa et al., 1998; Hawkins et al., 1986; Larsen et al., 1982; Mäenpää et al, 1997; Mountney et al., 2005;). Previous studies demonstrated that the MPFL is always injured after lateral patellar dislocation (Nomura et al., 2003; Nomura et al., 2005) and in most cases a surgical reconstruction is suggested to restore patello-femoral stability and MPFL functionality.

In order to stabilize the patello-femoral joint, different surgical approaches such as lateral release, medial repair, distal realignment and antero-medialization of the tibial tubercle were described in literature but a gold-standard procedure for the treatment of patellar stability is not defined yet (Colvin et al., 2008). Lateral release seemed to be the only uneffective procedure, while trochleoplasty was used with controversial results because of the high risk of irreversible articular and subchondral injuries (Colvin et al., 2008). The Medial patello-femoral reconstruction and several types of distal realignments were the two approaches that showed the best results in the treatment of patellar stability (Koëter et al, 2007; Mountney et al., 2005; Palmer et al., 2004; Pidoriano et al., 1997) and, from a biomechanical point of view, MPFL reconstruction provided more stability than a medial tibial tubercle transfer (Colvin et al., 2008).

Different points of view regarding the graft choice and tension, knee flexion angle and fixation methods were presented in literature for MPFL reconstruction (Colvin et al., 2008). In particular, adductor magnus autograft, tibialis anterior allograft, semitendinosus tendon (Colvin et al., 2008), bone-quadriceps tendons autograft of bone-patellar tendon allograft (Steiner et al., 2006), double hamstring tendon (Beck et al., 2007) were proposed as graft. The optimal knee flexion angle to tension the graft was ranged between 30°- 90° (Colvin et al., 2008; Nomura et al., 2006; Ostermeier et al., 2007; Panagopoulos et al., 2008; Steiner et al., 2006) but these values are controversial. Different fixation methods for the femoral region were compared by Mountney et al. such as suture repair, suture anchor repair, blind-tunnel and through tunnel reconstruction (Mountney et al., 2005) performing the ultimate load analysis while Lenschow et al. compared the structural properties of five different graft fixation at the patella focusing on the stiffness of the reconstructed ligament and on the elongation of the graft after cyclic tests (Lenschow et al., 2013).

However, from a biomechanical point of view, the most important goal of a surgical reconstruction is to restore the structural properties of the MPFL in physiological conditions. For this reason, the objective of this study was to compare the mechanical/structural properties of Through tunnel tendon and Double converging tunnel MPFL’s reconstruction techniques using semitendinosus tendon as graft in order to identify the best one to restore the mechanical properties of the MPFL in physiological conditions and anatomical position.

2 Materials and Methods

2.1 Preparation of specimens

A total of 18 human cadaveric knees from 6 women and 8 men with a mean age of 75 ± 9 years were used in this experiment. None of these showed patellar instability, knee injuries, surgical procedures or arthritic deformations. The Nicola's Foundation Onlus Ethics Committee has given its approval for this study. The cadavers were dissected following the procedure presented by Placella et al. (Placella et al., 2014).

The specimens were randomly assigned to two groups (N = 9). In the first group (Group A) the reconstruction was performed using a through tunnel tendon technique while in the second group (Group B) a double converging tunnel technique was used.

2.2 Methods of repair and reconstruction

Two different MPFL reconstruction techniques were tested: the through tunnel tendon and double converging tunnel techniques. The reconstructions were performed by a team of orthopaedic surgeons specialized on knee surgery at Nicola's Foundation Onlus Research and Teaching Centre under the approval of ethics committee. The through tunnel tendon technique was chosen because it was the one that showed better structural properties in literature (Mountney et al., 2005). The double converging tunnel technique was chosen because it allowed to restore the native MPFL sail-shape, to use a single interference screw and to improve the stress distribution on the patella. The grafts, represented by the semitendinosus tendons were harvested from each knee and wrapped in saline-soaked gauze to prevent dehydration.

2.2.1 Through tunnel tendon reconstruction

The reconstruction was performed using the semitendinosus tendon as graft (average diameter 5.5 ± 1.3 mm) and drilling a 7 mm femoral tunnel slightly distal to the adductor tubercle and a 7 mm patellar tunnel along the middle third of the medial side of the patella (Fig. 1). Bioresorbable interference screws (8 x 20 mm, Biorci, Smith & Nephew) were used as fixation devices for the patella and the femur. During this procedure the knee was flexed at 60° in order to check the optimal maximal graft length (Smirk et al., 2003).

2.2.2 Double converging tunnel reconstruction

The reconstruction was performed using the semitendinosus tendons as graft (average diameter 5.7 ± 0.9 mm) for the repair of the MPFL.

In order to avoid tendon creep, the final parts of graft were sutured with No.2 Ethicon sutures (Krackow suture) and preloaded with a 40 N force for 10 minutes using a tensioner. Two Kirschner wires were drilled at the proximal one third and at the center of the medial edge of the patella with an angle of 90°.

The femoral tunnel was anatomically placed distally to the adductor tubercle, at the insertion of the native ligament (Nomura et al., 2005). The graft was passed through the patellar converging tunnels forming a loop (Fig. 2) and its free final parts were inserted in the femoral tunnel.

The graft pretensioning was manually performed pulling the suture on the lateral side of the femur avoiding over tensioning.

Finally, a bioresorbable interference screw (8 x 20 mm, Biorci, Smith & Nephew) was used for the fixation of the graft at the femoral insertion. During this procedure the knee was flexed at 60° in order to check the optimal maximal graft length (Smirk et al., 2003).

2.3 Uniaxial tensile tests

Eighteen reconstructed femur-MPFL-patella complex (rFMPC) were tested. A custom designed mechanical frame was used to align the rFMPC specimen with the 5 kN load cell in order to obtain a correct uniaxial tensile test in anatomical position. The femur was fixed using bone cement and four screws. It was mounted horizontally on the base frame of an Instron 5965 materials-testing machine and it was 37±2° externally rotated. In this configuration, the graft was tangential to medial femoral condyle during the tensile test and simulated the physiological function in its femoral insertion (Burks et al., 1998).

Kim et al. demonstrated that the orientation of the specimen during tensile testing has a significant effect on stiffness and failure modes of the FMPC (Kim et al., 2014). In particular, with an anatomical orientation the angle between MPFL and patella (~90°) was preserved, stiffness and ultimate load of the native FMPC were increased due to more uniform loading of the collagen fibers of the native MPFL (Quapp et al., 1998). For this reason, in this study, the patella was fixed in a custom clamp in anatomical orientation using bone cement, attached directly to the load cell on the moving crosshead (Fig. 3).

All the specimens were left in 37 °C saline bath for 30 minutes before the uniaxial tensile test. A preload of 1N was applied and the tissue was subjected to a 10 cycle preconditioning between 0 mm and 2 mm of extension. It was then extended at 10 mm/min to failure. From the resulting load-elongation curves, stiffness (defined as the slope of the linear region of the load–elongation curve), ultimate load, ultimate elongation and absorbed energy were determined. The failure mode was also noted.

2.4 Statistical Analysis

A one-way statistic analysis of variance (ANOVA) was used with a significant level p of 0.05 to determine differences between the structural properties of the reconstructed FMPCs and the natural ones. Tukey's multiple comparisons test was used to perform post hoc analysis. Statistical significance between the control group and the experimental ones is indicated with (*) which represents a p-value < 0.05, (**) which represents a p-value < 0.01, and (***) which represents a p-value < 0.001.

3 Results

The parameters describing the mechanical behaviour of the FMPC reconstructions included stiffness, ultimate load, ultimate elongation and absorbed energy. They were obtained from a uniaxial tensile test and are listed in table 1. The obtained results were compared with the structural properties of the native MPFL in physiological condition tested with the same experimental protocol (Criscenti et al. 2015).

In the through tunnel tendon reconstruction, eight rFMPC (88.9%) failed at the femoral attachment and only one (11.1%) at patellar side and, in both cases, because of tendon slippage over the interference screws. In the double converging tunnel reconstruction, seven rFMPC (77.8%) failed at the femoral attachment because of tendon slippage over the interference screw and two (22.2%) at patellar side because of patellar fracture.

No statistical differences were found in the ultimate load analysis comparing the native MPFL and the surgical reconstructions (Fig. 4).

The native MPFL and both surgical reconstructions showed a significantly different stiffness while no differences were found between the two techniques (Fig. 5). In particular, in both reconstructions, the stiffness was significantly lower than the one of the native MPFL.

Opposite trends were found considering the ultimate elongation (Fig. 6) and the absorbed energy (Fig. 7). In both cases, the results are similar for the two techniques and significantly higher than the one of the native MPFL.

4 Discussion

In this study, the structural properties of the human MPFL reconstructed with two different techniques were compared to the structural ones of the native human MPFL in anatomical orientation using the semitendinous tendon, from the same samples, as graft.

Kim et al., in a porcine study, demonstrated that the orientation of the specimen during tensile testing had a significant effect on stiffness and failure modes of the FMPC (Kim et al., 2014). In particular, in case of anatomical orientation, the angle between MPFL and patella (~90°) is preserved; stiffness and ultimate load of the FMPC are higher, due to more uniform loading of the collagen fibers of the MPFL (Quapp et al., 1998).

In literature, there are different studies that compared different patellar fixation techniques and MPFL reconstructions (Hapa et al., 2012; He et al., 2013; Lenschow et al., 2013; Mountey et al., 2005).

Mountney et al. compared the ultimate strength of four different methods of MPFL repair and reconstruction demonstrating that the through tunnel tendon technique was the only one with a behavior similar to the native MPFL (Mountey et al., 2005).

Hapa et al. tested four different fixation techniques using bovine tendons as graft with artificial patella (Hapa et al., 2012).

Leschow et al. compared five different fixation strategies for a free tendon graft at the porcine patella in MPFL reconstruction under cyclic loading and load to failure testing showing that “fixation by transosseous sutures provided similar load to failure and elongations but less stiffness compared with fixation by anchors, interference screws or transverse tunnels" (Lenschow et al., 2013).

He et al. evaluated the biomechanical behavior of different fixation methods of the hamstring tendon graft on the patella demonstrating that the four suture fixation method was the best one (He et al., 2013).

In all these studies, the specimens were tested in non anatomical orientation estimating the structural properties in the case non physiological stresses.

The similar values found in the ultimate load analysis comparing the native MPFL and both surgical reconstructions suggested that the physiological ultimate load of the native MPFL was reproduced.

Observing the stiffness analysis, the native MPFL was stiffer than both reconstructions. In particular the stiffness of the reconstruction, when the through tunnel tendon technique was used, was 32% of the native MPFL, while for the double converging tunnel techniques it was the 40%. These values are considerably lower than the native MPFL and the failure modes suggested that to use interference screws as fixation methods is not the optimal solution due to the graft slippage on the screw. In view of this consideration, the double converging tunnel technique shows an average increase of stiffness equal to 8% respect to the through tunnel tendon technique.

Both the surgical reconstruction showed a considerably higher ultimate elongation compared to our tests with the native MPFL but similar to the results present in literature. In particular Mountney et al. showed that the MPFL rupture occurred at 26 ± 7 mm (Mountney et al., 2005) while Burks et al. noted that the mean ultimate elongation was 25 mm (Burks et al., 1998). These results suggested that the ultimate elongation of both reconstructions were acceptable and the discrepancy with the native MPFL depends on the quality of the original samples.

Considering the Absorbed Energy, significantly higher values were found for both reconstructions. In both cases, the absorbed energy was two times higher than the native MPFL due to the shape of the graft and to the reconstruction techniques. In particular, the tubular shape of the semitendinosus tendon permitted to absorb more energy than the native MPFL that was flat and sail-shaped. The through tunnel tendon reconstruction is characterized by a constant cross sectional area (CSA) that was higher than the native MPFL, whose CSA is function of its length. Considering the double converging tunnel technique, the sail-shape structure of the native MPFL was reproduced but the empty space in the central region causes a different stress distribution and higher energy absorption.

The advantages of the double converging tunnel technique are related to the restoration of the native MPFL sail-shape, to a better stress distribution on the patella, to the use of a single interference screw as fixation device and to the simplicity, rapidity and cost-effectivity of the surgical procedure. These results were confirmed by the clinical outcomes published by Nelitz et al. who proposed a converging V-shaped tunnels techninque showing a significant improvement of knee function and patient satisfaction without any episode of redislocations (Nelitz et al., 2012). In another clinical study, Wang et al. confirmed that a double bundle reconstruction achieved better clinical outcomes than a single bundle technique (Wang et al., 2013).

A limitation of this study was related to the age of the human cadaveric knees. Specimens with a mean age of 75 years were used and the decrease with age of the mechanical properties of cancellous bone could be the cause of graft slippage and tunnel breakage (Mountney et al., 2005). Another limitation was related with the selected strain rate that is correct in physiological conditions and for the comparison with the native MPFL but is not adequate to simulate an impulsive traumatic event. To perform this kind of experiments, higher strain rates with a magnitude of hundreds of mm/min and cyclic tests are suggested.

Moreover, the biomechanical analysis of the reconstructions is a good starting point but should be considered as a simplified model of the real problem. Further investigation as kinematics analysis and finite elemets (FEM) modelling are required to analyse the effect of the other tissues present in the patello-femoral joint, of the knee flexion and of impulsive loads to simulate traumatic events.

Although the results demonstrated the partial inadequacy of both techniques to restore the mechanical and structural properties of the native MPFL, these surgical treatments are currently used in clinical practice. However, ambiguous long-term results with postsurgical complications including wear and degradation of the reconstruction represent high risk factors for the treatment success.

Conflict of interest statement

All authors confirm they have no financial of other conflict of interest relevant to this study

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FIGURE LEGEND

Fig. 1 - Through tunnel tendon reconstruction
Fig. 2 – Double converging tunnel reconstruction
Fig. 3 – Experimental setup: Through tunnel tendon reconstruction (a) vs. Double converging tunnel reconstruction (b)
Fig. 4 – Ultimate load analysis: comparison between the native MPFL and the two different reconstructions
Fig. 5 – Stiffness analysis: comparison between the native MPFL and the two different reconstructions
Fig. 6 – Ultimate elongation analysis: comparison between the native MPFL and the two different reconstructions
Fig. 7 – Absorbed energy analysis: comparison between the native MPFL and the two different reconstructions


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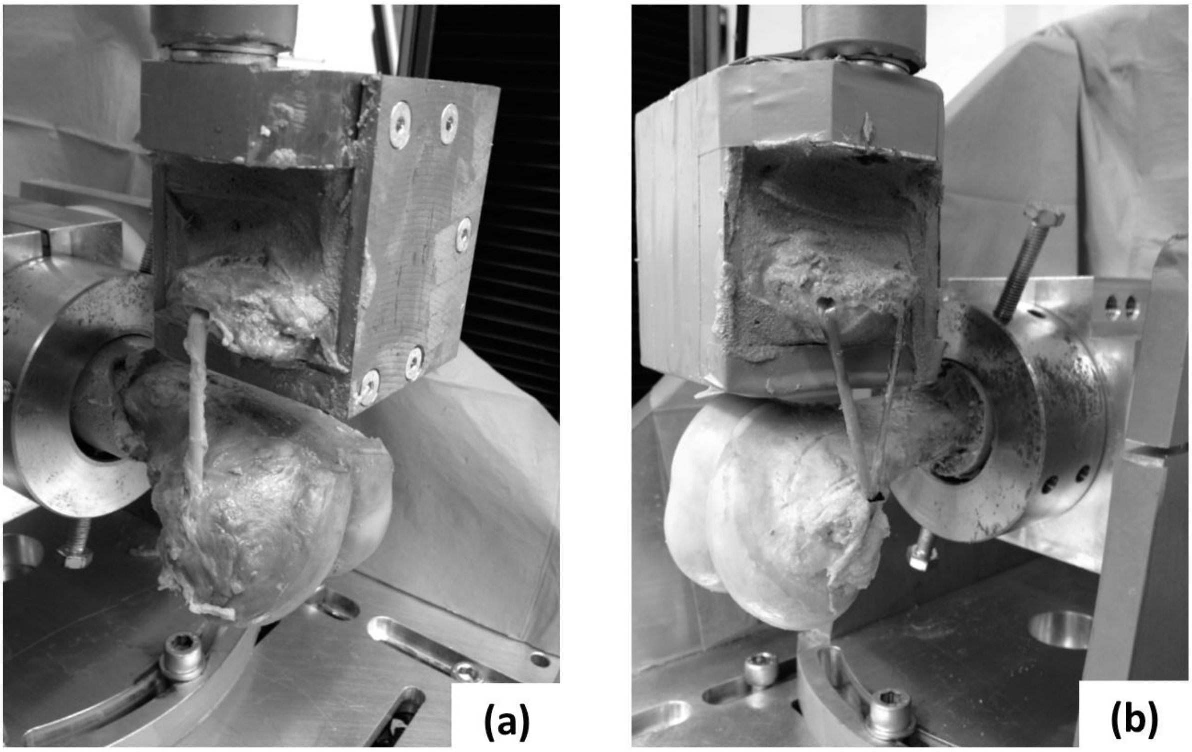
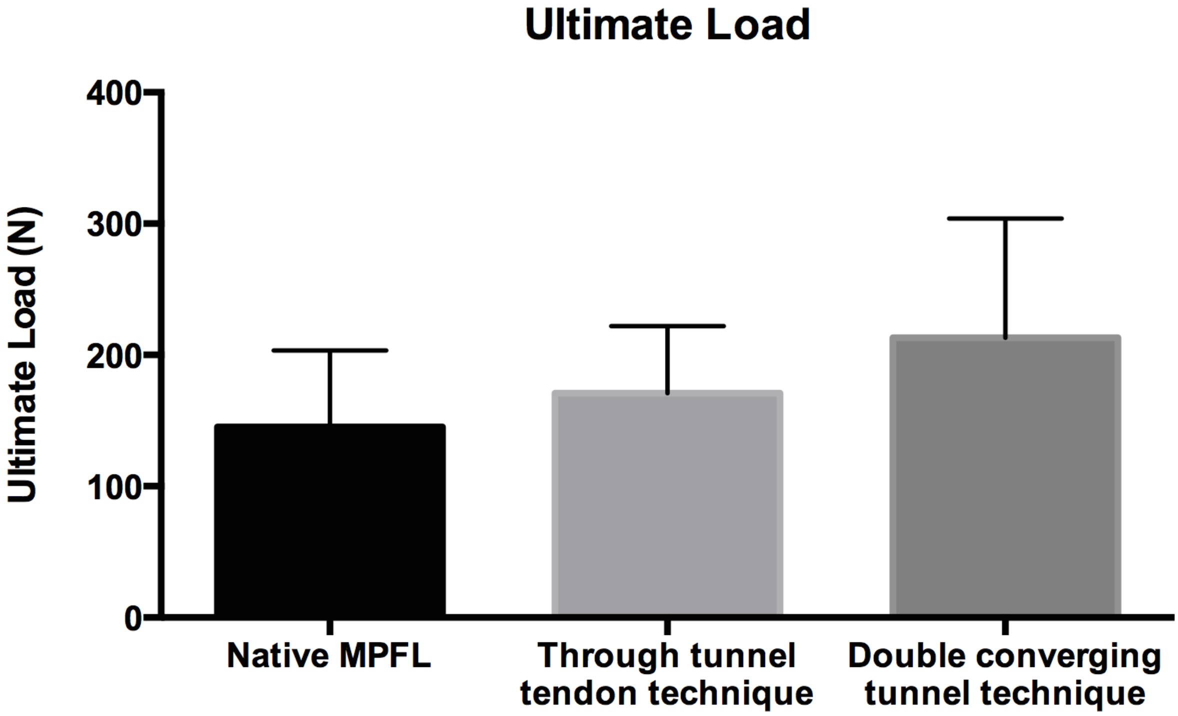

(a)
(b)


Ultimate Load
Ultimate Load (N)
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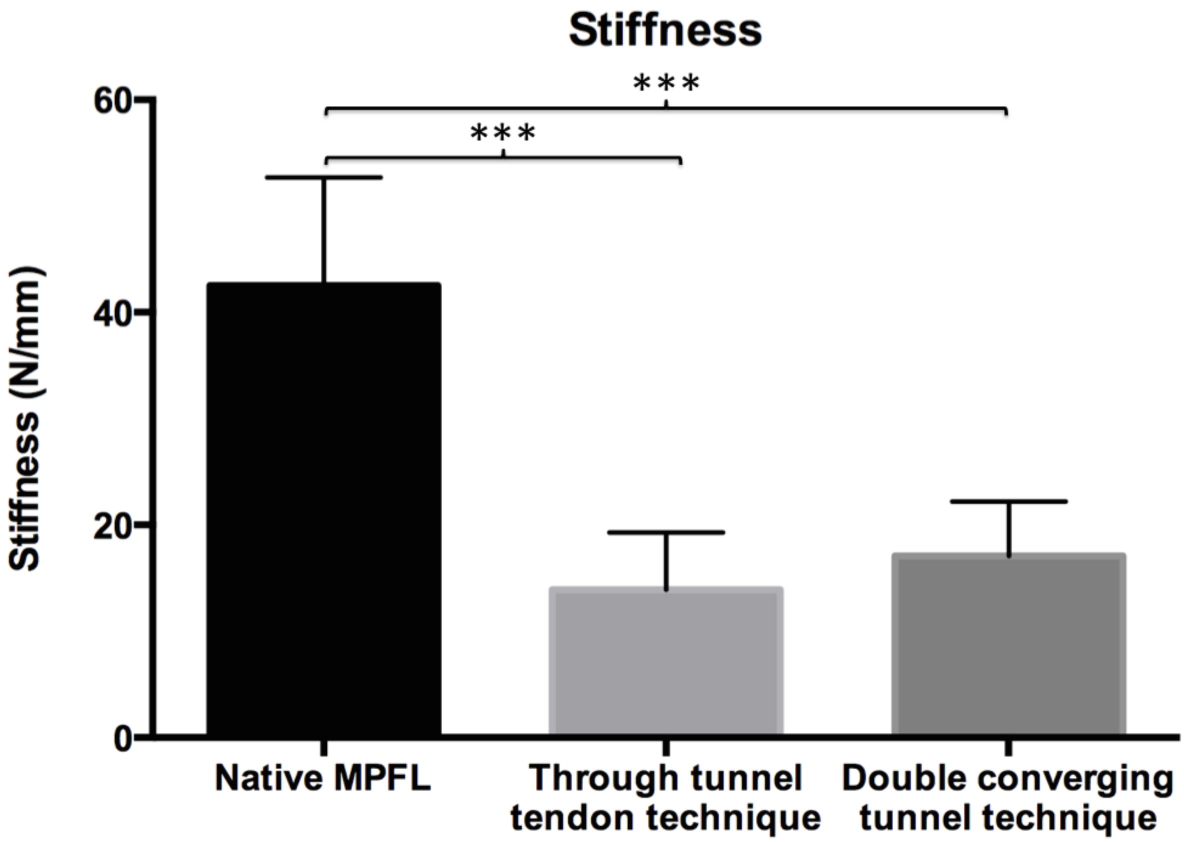
300
200
100
0
Native MPFL
Through tunnel tendon technique
Double converging tunnel technique


Stiffness
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Stiffness (N/mm)
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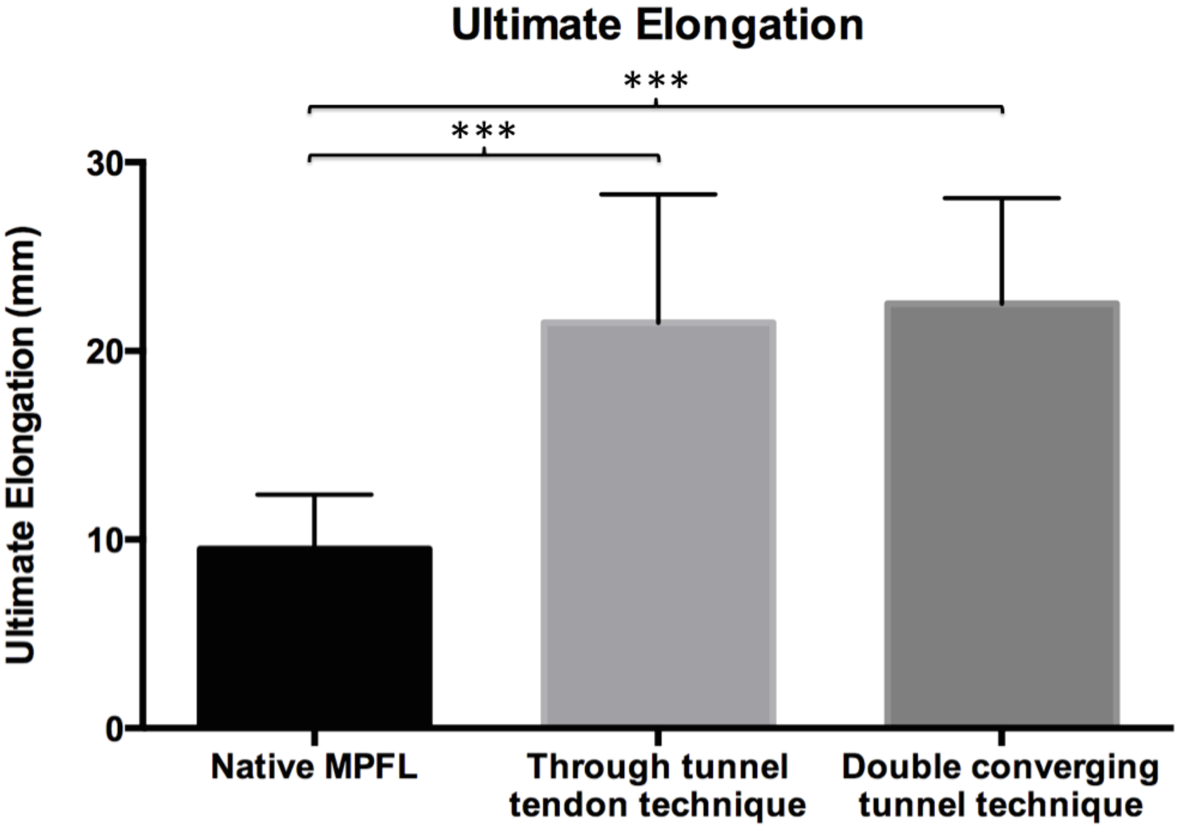
40
20
0
Native MPFL
Through tunnel tendon technique
Double converging tunnel technique


Ultimate Elongation
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Ultimate Elongation (mm)
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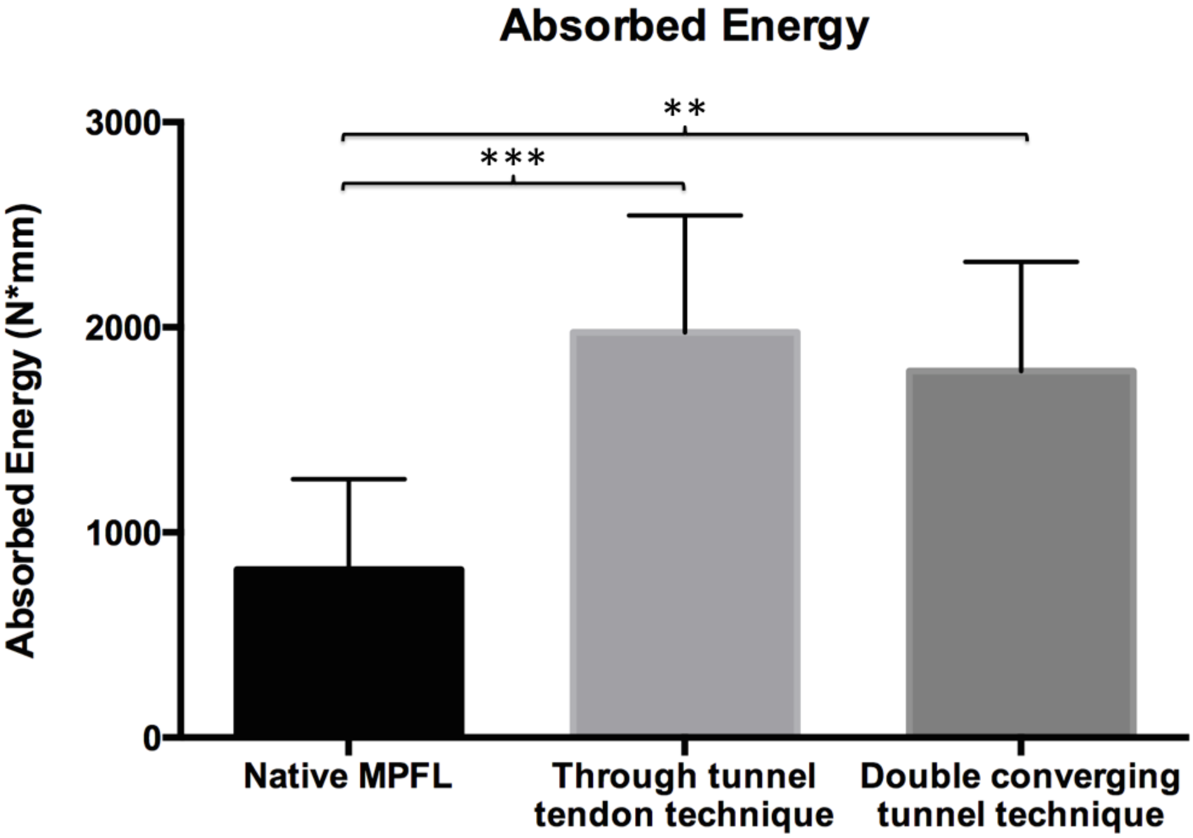
20
10
0
Native MPFL
Through tunnel tendon technique
Double converging tunnel technique



Structural properties	Native MPFL	Through tunnel tendon reconstruction	Double converging tunnel reconstruction
Ultimate load (N)	145 ± 58	171 ± 51	213 ± 91
Ultimate Elongation (mm)	9.5 ± 2.9	21.5 ± 6.8	22.5 ± 5.6
Linear stiffness (N/mm)	42.5 ± 10.2	13.9 ± 5.4	17.1 ± 5.1
Absorbed Energy (N-mm)	819 ± 441	1795 ± 570	1786 ± 534

Tab.1 – Mechanical behaviour of the femur-MPFL-patella complex reconstructions