CHARACTERISTICS OF THE PATELLAR TENDONS IN ANTERIOR CRUCIATE LIGAMENT INJURED ATHLETES

Carla S Pereira[1,2], Jasenko Klauznicer [1], Dustin Maree[1], Rodney Whiteley[1] and Taija Finni[2]

ASPETAR Orthopedic and Sports hospital, Doha, Qatar[1]
Neuromuscular Research Center, University of Jyväskylä, Jyväskylä, Finland [2]

The purpose of this study was to demonstrate the characteristics of patellar tendons and the quadriceps strength of athletes with anterior cruciate ligament reconstruction (ACLR) throughout rehabilitation. Athletes of different sports (n=27) had both patellar tendons (PT) assessed with ultrasound tissue characterization (UTC) method, and bilateral isokinetic quadriceps strength quantified in intervals of 1.5 months over their rehabilitation period. Reduction in the quality of the involved PT was observed after ACLR surgery, with these values returning to baseline at approximately 7.5 months post surgery. The uninvolved PT displayed no significant differences. Despite the increase in quadriceps strength, no statistical relevance was observed. ACLR caused reduction in the quality of the involved PT which might be correlated with tendon symptoms during the rehabilitation.

KEYWORDS: UTC imaging, ultrasound tissue characterization, ACL, ACL reconstruction, isokinetic.

INTRODUCTION: Anterior cruciate ligament (ACL) injury is one of the most debilitating injuries in sports. During the rehabilitation post-ACL reconstruction (ACLR), some complications, i.e. a persistent deficit of strength and anterior knee pain (AKP), may occur (Kartus, Magnusson, et al., 1999; Xiaobo et al., 2015).

AKP is the generic term used to classify any pain that occurs in the anterior part of the knee. Pain on palpation, pain in deep squat, magnetic resonance imaging (MRI) and ultrasound (US) are among the tests to assess AKP. The most common sources of AKP after ACLR include patellar tendinopathy, and the harvesting site of the patellar tendon (Xiaobo et al., 2015). MRI studies demonstrated that even two years after the ACLR with bone patellar tendon bone graft (BTB), the gap caused by harvesting the tendon displayed a different signal to regular tendons (Kartus, Lindahl, Stener, Eriksson, & Karlsson, 1999). However, it has been noted that the size of the donor site gap gradually decreases over the years (Svensson, Kartus, & Ejerhed, 2004). To the best of our knowledge there are presently no validated approaches which document the quality of the healing patellar tendon after ACLR.

Ultrasound tissue characterization (UTC) has been used to assess the integrity of tendons. It utilizes an US transducer (SmartProbe 10L5, Terason 2000, Teratech, USA) fixed in a transverse position allowing to capture 598 sequential transverse images of the tendon at regular distances of 0.02 cm. The UTC algorithm compares and correlates successive transverse images of the tendon to quantify the stability of the echo-patterns. The validation of this method is based on the histopathologic study of the superficial digital flexor tendons of horses (van Schie, Bakker, Jonker, & van Weeren, 2003), and the use of UTC has expanded to human tendons (de Vos, Heijboer, Weinans, Verhaar, & van Schie, 2012; van Schie et al., 2013) with high intra- and inter-observer reproducibility for both, acquisition and analysis (van Schie et al., 2010). Thus, the main goal of this study was to demonstrate the quality of the involved and uninvolved patellar tendons and the quadriceps strength of athletes with ACLR throughout the period of rehabilitation. We hypothesizedthat the patellar tendon of the involved leg would show a lower quality on the UTC scan in comparison to the uninvolved patellar tendon due to the altered pattern of activation and deficit of strength of the quadriceps muscle observed in ACL injured patients.

METHODS: A total of twenty-seven male professional athletes registered in different sports clubs in Qatar (10- football, 2- handball, 2- basketball, 2- volleyball, 1- table tennis, 2- field hockey, 1- horse-riding, 1- swimming, 1- rugby, and 5- futsal) who underwent the surgery for the ACL reconstruction and completed their rehabilitation at Aspetar participated in this longitudinal study. Assessments (Ax) were conducted 1.5 months (M) apart during their rehabilitation period, from pre-operatory (time 0) to 12 months. Participants included in this study had completed at least 3 Ax each. Quadriceps strength was tested by an isokinetic concentric evaluation, performed on both, uninvolved and involved legs, in this order. Exception for the 1.5 M Ax, when the test was performed in the uninvolved leg exclusively. The athletes were asked to perform five repetitions of knee extension and flexion for each leg at 60 degrees/s. A Biodex dynamometer (System 4, Biodex Medical Systems, Shirley, New York, USA) was used. The quality of the patellar tendons was assessed by using the UTC imaging system. A single experienced examiner (CSP) acquired and analyzed all images. Several contours were manually drawn around the patellar tendon circumference approximately 0.5 cm apart. Based on the continuity, integrity, and alignment of the tendon bundles that are reflected on the stability and on the homogeneity of the echo pattern, the UTC algorithm distinguishes four color coded echo-types. Echo-type I – generated by intact and aligned bundles; Echo-type II – generated by discontinuous, swollen and wavy secondary collagen bundles; Echo-type III – generated by a loose matrix consisting of smaller fibrils; Echo-type IV - generated by predominantly amorphous matrix with cells and fluid (van Schie et al., 2003). The sum of echo-types I + II was adopted to describe healthy tissue (better tendon quality) and the sum of echo-types III + IV was adopted to describe disorganized tissue (worse tendon quality) (van Schie et al., 2010). The variables considered in this study were: (1) percentage of echo-types I + II, (2) percentage of echo-types III + IV, and (3) Peak torque of Quadriceps divided by the participant's body weight (PT/ BW). For the statistical analysis a linear mixed model was used considering time of the assessment and involved and uninvolved legs. Level of significance of $p<0.05$ (*) was set. The program IBM SPSS v.21 was used for all statistical analyses (SPSS Inc, Chicago, Illinois, USA).

RESULTS: The mean age of the participants at the time of data acquisition was 25.2 years (range, 16 to 37 years), body mass was 73.9 ± 15.9 kg, and height was 1.75 ± 0.1 m. Sixteen participants had ACLR with bone patellar tendon bone graft, and the remaining 11 participants had undergone ACLR with hamstrings graft. Since some participants missed a few Ax and may have completed their rehabilitation program at different time points, the number of participants in each Ax time has varied (Table 1).
Figure 1 illustrates the absence of statistical differences in percentage of echo-type I + II, and percentage of echo-type III + IV on the uninvolved patellar tendons despite time (p>0.05), and the differences between involved and uninvolved tendons throughout the rehabilitation period. Additionally, Figure 1 demonstrates the significant decrease of echo-types I + II along with a significant increase of echo-types III + IV that persisted up to 7.5 months post ACLR in comparison to pre-surgery. Despite some significant differences observed between certain time points, the increase in quadriceps peak torque in the involved leg throughout the rehabilitation process displayed no statistical significance in comparison to prior- ACLR (Table 2). Moreover, the uninvolved leg displayed significant greater quadriceps peak torque in comparison to the involved leg from 3M to 6M and then again at 10.5M (Table 2).

Table 1: Number of participants with different harvesting sites in each assessment time.

Graft/ Ax	0 M	1.5 M	3 M	4.5 M	6 M	7.5 M	9 M	10.5 M	12 M
BTB (n)	11	11	13	9	10	5	1	4	2
Hst (n)	3	7	8	8	7	5	1	2	3

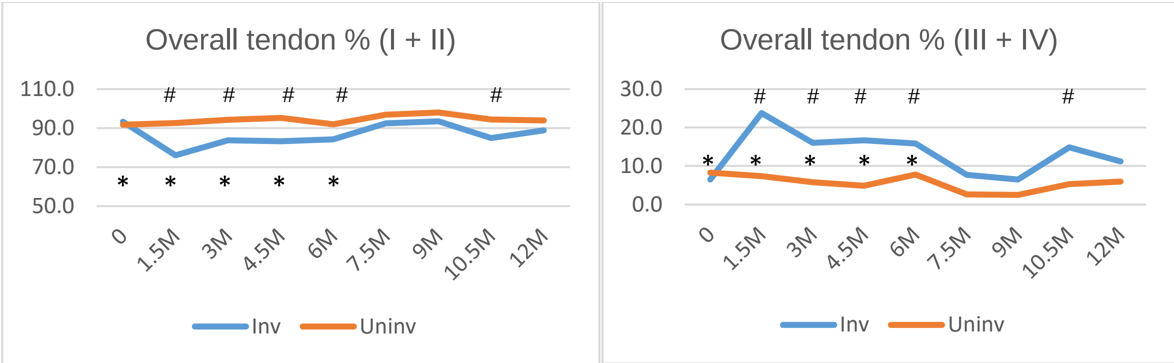

Figure 1: Percentage of echo-types (I+II) and (III+IV) in each assessment for involved and uninvolved patellar tendons.

* statistical difference in comparison to baseline for the involved leg
# statistical difference between involved and uninvolved legs

Table 2: Means and standard deviations of the Quadriceps peak torque/ BW for the 12 months.

Ax time	0 M	1.5 M	3 M [#]	4.5 M [#]	6 M [#]	7.5 M	9 M	10.5 M [#]	12 M
PT/BW Inv	232±21	NA	217±17[a]	225±19[a]	259±19	264±25	244±56	279±32	311±35[a]
PT/BW Uninv	235±21[b]	209±19[c]	264±17[c]	297±19[b,c]	288±19[c]	306±25[b,c]	255±56	292±32[c]	304±35[c]

[a] statistical difference in comparison to 12M for the involved leg
[b] statistical difference in comparison to 0M for the uninvolved leg
[c] statistical difference in comparison to 1.5M for the uninvolved leg
[#] statistical difference between involved and uninvolved legs

DISCUSSION: The main purpose of this study was to explore the quadriceps strength and the quality of the involved and uninvolved patellar tendons througout the rehabilitation period of athletes post- ACLR.

Despite the expected drop in quadriceps strength on the involved leg at 1.5 M post-ACLR, we observed a progressive improvement of quadriceps peak torque/BW in the involved and uninvolved legs throughout the rehabilitation period. The involved leg displayed significant smaller quadriceps peak torque in comparison to the uninvolved leg from 1.5 to 6 months, and at 10.5M. Interestingly, at 7.5M, 9M and 12M no significant differences in peak torque were noted. Conversely, a systematic review that assessed the quadriceps muscle activation by using superimposed burst or interposed twitch technique have shown that the deficit of quadriceps activation occurred bilaterally in ACLR and AKP patients (Hart, Pietrosimone, Hertel, & Ingersoll, 2010).

A reduction in quality of the involved tendon was observed at 1.5 months post-ACLR, as demonstrated by a decrease in the proportion of intact aligned collagen bundles (echo-types I + II – better tendon quality) with concomitant increase in the proportion of loose matrix (echo-types III + IV – worse tendon quality). The reduced quality of the involved patellar tendon in comparison to the uninvolved one was noted during almost the whole rehabilitation process. Previous studies have observed similar findings in symptomatic tendons (Docking, Rosengarten, Daffy, & Cook, 2015; van Schie et al., 2010). Even though AKP is very common in ACLR subjects (Xiaobo et al., 2015), this parameter was not considered at this stage. Additionally, harvested and unharvested patellar tendons were included together in the analysis. Based on these results we expect that by separating harvested from unharvested patellar tendons, and taking AKP into account could potentially highlight more differences within the patellar tendon.

CONCLUSION: This study identified a reduction in the quality of the involved patellar tendon during the rehabilitation period post-ACLR, regardless of the progressive improvement in quadriceps peak torque. Since quadriceps strength alone appeared not to ensure the maintanance of the quality of the patellar tendon, we propose further investigation taking into consideration the graft used for the ACLR and the presence of AKP to justify the changes observed in the involved patellar tendons of ACLR participants during rehabilitation.

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ACKNOWLEDGEMENTS: We would like to thank Abdulaziz Farooq for the statistics advice, and our colleagues from the ACL Ax center and rehabilitation department Argyro Kotsifaki, Bart Sas, Carla de Paula, Jaleleddine Belhaj, Kosntantinos Defteraios, Martina Jakob Emeršič, Mansour Otayek, Mayolo Camacho, Mirna Anadani, Paul Read, Riadh Miladi, Sean McAuliffe, Theodosia Palli, and Vasileios Sideris for all the contribution and support.