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Biomechanical Assessment of the Prepatellar Quadriceps Continuation

Análisis biomecánico de la continuación prepatelar del cuádriceps

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Abstract

Objective To determine the ultimate tensile strength (UTS) of the prepatellar quadriceps continuation (PQC).

Materials and Methods A human cadaveric study was performed. Ten fresh-frozen specimens were used. The proximal and medial thirds of the anterior cortex of the patella were used to assess the mechanical properties of the PQC. In each specimen, transverse section areas measuring 0.2 cm^2 (A1) and 1 cm^2 (A2) were studied. A gradual load was applied to determine the UTS.

Results The median UTS of A1 was of 232.56 N (range: 141.23 N to 295.33 N), and that of A2 was of 335.30 N (range: 216.45 N to 371.40 N). The increment in UTS was significant between the 2 areas ($p = 0.006$).

Conclusions The clinical significance of the present study lies in the fact that it shows that the PQC is a strong tissue that can be a safe anchor for reconstruction around the patella. A relatively small area supports at least 140 N, and, as the area grows, the UTS increases as well.

Level of evidence Biomechanical study.

Keywords
- knee biomechanics
- prepatellar quadriceps continuation
- ultimate tensile strength

Resumen

Objetivo Determinar la resistencia máxima a la tracción (RMT) de la continuación prepatelar del cuádriceps (CPC).

Materiales y Métodos Se realizó un estudio en cadáveres humanos. Fueron incluidos diez especímenes, en los cuales se utilizaron los tercios proximal y medial de la cortical anterior de la patela para evaluar las propiedades mecánicas de la CPC. En cada espécimen, se estudió un área de sección transversal de 0,2 cm^2 (A1) y 1 cm^2 (A2). Se aplicó una carga gradual para determinar la RMT.

Resultados La mediana de la RMT en el A1 fue de 232,56 N (rango: 141,23 N a 295,33 N) y en el A2 fue de 335,30 N (rango: 216,45 N a 371,40 N). El incremento en la TMR fue significativo entre las 2 áreas ($p = 0{,}006$).

Palabras clave
- biomecánica de la rodilla
- continuación prepatelar del cuádriceps
- resistencia máxima a la tracción

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Conclusión El significado clínico de este estudio es que la CPC es un tejido fuerte que puede servir de anclaje seguro para reconstrucciones alrededor de la patela. Un área relativamente pequeña tolera al menos 140 N y, a medida que crece el área, también aumenta la RMT.

Nivel de evidencia Estudio biomecánico.

Introduction

The extensor mechanism has a complex anatomy, and its indemnity is crucial for the activities of daily life.[1] The prepatellar quadriceps continuation (PQC) corresponds to the fibers of the rectus femoris tendon that connect the quadriceps and patellar tendon.[2] The PQC is attached to the anterior cortex of the patella by a chrondroapophyseal type of junction in which the tendon is gradually transformed into fibrocartilage.[3] During the embryonic process of formation of the patella, the quadriceps tendon superficially embeds the patella, which will subsequently give rise to the PQC.[4] In the developing patella, there is no periosteum or perichondrium; instead, a fibrocartilaginous attachment has been described. All sesamoid bones form this type of attachment in the surface that it is adjacent to a tendon.[5]

The PQC is an essential structure of the extensor mechanisms, and it must withstand friction force during flexion-extension of the knee, being in high risk of overuse injuries like prepatellar friction syndrome.[6] Moreover, PQC indemnity is crucial for active knee extension: damage to this structure, although infrequent, causes severe functional deficit.[2,7]

Macroscopic, histological and imaging descriptions of the PQC have been published.[8] Nevertheless, no biomechanical assessment of this tissue has been conducted. Surgical techniques for patellar instability have been described using the PQC as a fixation site,[9,10] so a proper understanding of its biomechanical properties is needed.

The purpose of the present study was to determine the ultimate tensile strength (UTS) of the PQC. Our hypothesis is that a small area of the PQC withstands more than 100 N, and, as the area increases, the resistance of this tissue does so as well.

Methods

Ten fresh-frozen human cadaveric knees without evidence of previous injury, abnormalities or surgery were used in the present study. The median age of the specimens was of 59 years (range: 36 to 70 years), and a total of 5 female and 5 male right knees were tested. The specimens were procured from Innoved Institute LLC (Rosemont, IL, United States) after approval from the institutional ethics in research board. Each specimen was thawed 24 hours before use.

An anterior longitudinal incision was made 10 cm above the upper edge of the patella to the tibial tubercle. The quadricipital tendon, prepatellar continuation, and patellar tendon were carefully exposed. The proximal and medial thirds of the patella were used to assess the mechanical properties of the PQC. In all ten specimens, a simple and a double stich were performed, spanning an area of 0.2 cm^2 (A1) and 1 cm^2 (A2) respectively. In five specimens, a simple stitch was placed on the proximal third, and a double stitch, on the middle third of the patella. Meanwhile, in the other five specimens, the double stitch was placed proximally, and the simple stitch, on the middle third. A non-absorbable ultra-high molecular weight polyethylene and polydioxanone suture was used (Orthocord #2, Ethicon, DePuy Synthes, Raynham, MA, United States).

The simple stitch started 5 mm laterally to the anteromedial edge of the patella. It was performed as deep as palpating the anterior cortex and advancing 1 cm toward the lateral side. A quintuple knot was made to fix the point. For the double stitch, after passing the first point 6 mm distally, a parallel 1-cm suture pass in the opposite direction was made, which was also knotted with a quintuple knot. Hence, the simple stitch suture group test was for a 0.2-cm^2 transverse section area of tissue, and the double stitch suture group test, for a 1-cm^2 transverse section area of PQC tissue. (►**Fig. 1**)

A stress-strain device was used (►**Fig. 2**), which, in one side, had a load cell with the capacity to measure up to 1,000 N (Model SSM-AJ-500; Interface, Scottsdale, AZ, United States). A sensor — a linear potentiometer for length measurement (range 300mm, reading 0.01mm) — to measure

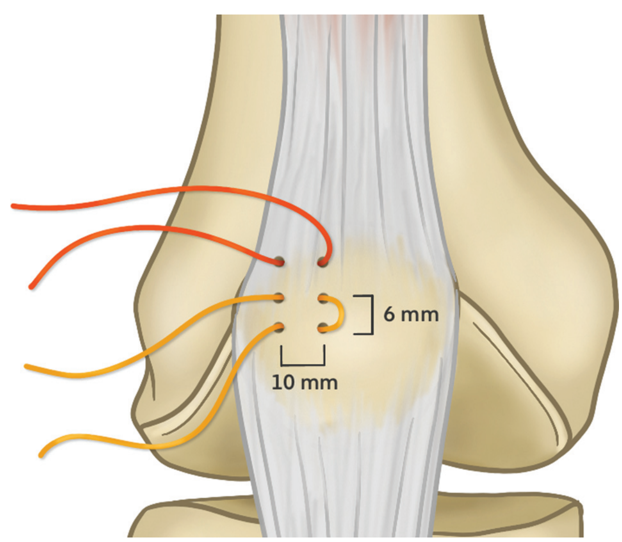

Fig. 1 Scheme of the suture distribution used in five specimens. In the other five, the double stich was placed in the proximal third of the patella, and the simple stich, in the middle third.

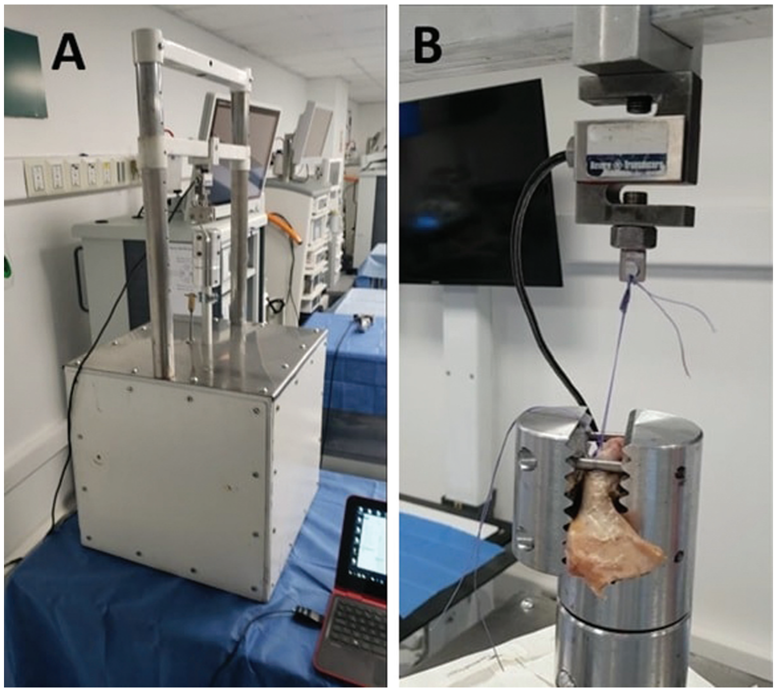

Fig. 2 A stress-strain device was used to measure the UTS (A). A cadaveric patella mounted from the suture in the device (B). A gradual load was applied to measure the PQC deformation from which the stress and strain were determined.

linear displacement was also used (Digitalanzeige Digital Linear Scale Linear Skala Externe Fernanzeige , Sauter, Basel, Switzerland). They were later exported to the Matlab (The MathWorks, Inc., Natick, MA, United States) software to build the force-displacement curve. A gradual load was applied to measure the PQC deformation from which the stress and strain were determined. The UTS was recorded. The load was applied proximally, along the longitudinal axis of the patella, emulating the tensile force of the quadricipital tendon. Failure was defined as rupture or detachment of the PQC.

The median and range of the UTS were reported. A non-parametric unpaired median test was used to compare the groups. A significance level of 5% was used, and data were processed using the Stata (StataCorp LLC, College Station, TX, United States) software, version 15.

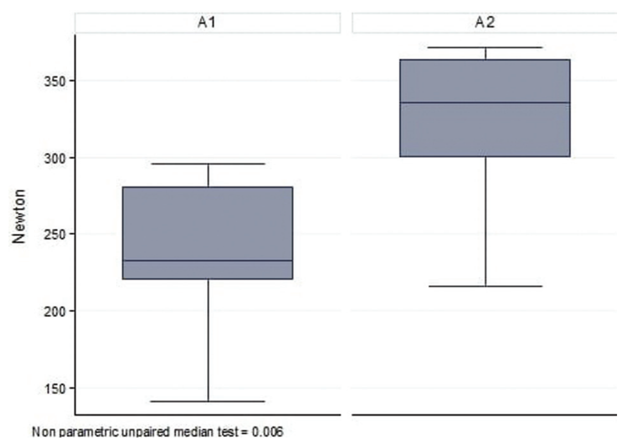

Fig. 3 Distribution of the UTS.

Results

All ten specimens were tested. The median UTS of A1 was of 232.56 N (range: 141.23 N to 295.33 N), and the median UTS of A2 was of 335.30 N (range: 216.45 N to 371.40 N). The increase in UTS was significant between the two areas ($p = 0.006$). The distribution of the UTS is shown in ►**Fig. 3**.

Discussion

The main finding of the present study is that the PQC is a resistant tissue. A small area of 0.2 mm^2 offers a resistance of 140 N, and, as the section area grows, so does the resistance of the tissue.

The mean UTS of the medial patellofemoral ligament (MPFL) complex is of 140 N,[11] so it is equivalent to the minimum UTS found for group A1 of the present study. In MPFL reconstruction, soft-tissue fixation in the femoral side has achieved good clinical results, and no significant increase in rate of rerupture.[12] Moreover, the mean ultimate load of an MPFL reconstruction using a double tunnel technique in the patella was of 213 N,[13] which is lower than a 1-cm^2 attachment in the PQC found in the present study (335 N). Given the aforementioned information, it does not seem disproportionate to use the PQC as an anchor for the reconstruction of the MPFL, which would help to reduce the costs and complications related to tunnels in the patella. However, studies designed for this purpose should be performed first.

The Green[14] and the Madigan et al.[10] quadricepsplasties are surgical procedures described for patellar instability, in which a distal and lateral transfer of the insertion the vastus medialis is performed.[10,14] This transfer depends on the fixation in the PQC. Despite the high rate of dislocation after surgery, failure has been attributed to vector forces and not PQC attachment-related failures.[15] Further, after the procedure, the patients tend to experience an increase in patellar height due to the vastus medialis pull.[16] Hence, this adds to the fact that the PQC is a strong tissue to anchor an MPFL reconstruction, which would have a more anatomic vector to stop the patella from lateral instability.

The PQC has also been used to transfer the vastus medialis in patellar instability after total knee arthroplasty. Kelly et al.[17] described a modification to the originally Insall technique, in which the vastus medialis is transferred laterally, anchoring it both in the quadriceps tendon and in the CPC.[17] It is a rescue procedure, and its main indication is when a patient with chronic patellar dislocation undergoes total knee replacement.[9]

The limitation of the present study is that only the UTS was measured, and tissue resistance to cyclic forces was not determined. Nevertheless, the PQC has been used as an attachment for decades, and no complications related to it have been reported. The present study should encourage the assessment of the resistance of an MPFL reconstruction fixed to the PQC.

Conclusion

The PQC is a strong tissue that can be a safe attachment for reconstruction around the patella. A relatively small area withstands at least 140 N, and, as the area grows, the UTS increases as well.

Availability of Data

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Author's contributions

CI: contributed with the original idea, conceived the study, drafted the paper, and performed a critical review of the final paper. RS: performed the biomechanical testing. MI: coordinated and supervised the management of the cadaver specimens. RN: performed a critical review of the final paper. MB: performed the data analysis, literature review and drafted the manuscript. All authors have read and approved the final submitted manuscript.

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Conflict of Interests

The authors have no conflict of interests to declare.

Ethical Approval

The present study was approved by the Ethics in Research Board at Clínica Las Condes, Santiago, Chile.

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