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ANALYSIS OF THE MECHANICAL BEHAVIOR OF THE POSTERIOR CRUCIATE LIGAMENT IN A PORCINE MODEL

ANÁLISE DO COMPORTAMENTO MECÂNICO DO LIGAMENTO CRUZADO POSTERIOR EM MODELO SUÍNO

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ABSTRACT

Introduction: The knee has shown a significant increase in the frequency of injury due to sports practice. This increase and the improvement of surgical techniques of ligament reconstruction have led to a greater indication of this treatment to achieve a function close to normal. Objective: To conduct a preliminary analysis of the ligament behavior. Methods: The study consisted of the validation of an anatomical model of the pig, in which five models were subjected to mechanical tests. The data on the loads of the in situ model and the strains of the posterior cruciate ligament were collected. Results: The analysis of the tensile load showed, at first, a nonlinear increase in stresses. Subsequently, the pig's knee showed a relatively linear intermediate response until failure around 1,200 N. Strain × time showed a response of the posterior cruciate ligament, which also has a relatively linear response. Conclusion: We observed a linear behavior in the range of 1,000 to 5,000 microstrains in the strain of the posterior cruciate ligament. We suggest further studies to understand knee ligaments regarding their behavior in their function. ***Level of Evidence IV, Biomechanical Study.***

Keywords: Ligaments. Tensile Strength. Mechanical Stress.

RESUMO

Introdução: O joelho tem demonstrado um aumento significativo de frequência de lesão devido à prática esportiva. Esse aumento e a melhoria das técnicas cirúrgicas de reconstrução ligamentar têm levado a maior indicação desse tratamento com o objetivo de se atingir uma função próxima do normal. Objetivo: Realizar uma análise preliminar do comportamento ligamentar. Métodos: O estudo consistiu na validação de um modelo anatômico do porco, em que cinco modelos foram submetidos a ensaios mecânicos. Foram coletados os dados das cargas do modelo in situ e das deformações do ligamento cruzado posterior. Resultados: Na análise da carga trativa, foi observado que em um primeiro momento existe um aumento não linear das tensões. Em sequência, há uma resposta intermediária relativamente linear do joelho suíno até a falha em torno de 1.200 N. A deformação versus tempo mostrou uma resposta do ligamento cruzado posterior, que também possui uma resposta relativamente linear. Conclusão: Observou-se um comportamento linear na faixa de 1.000 até 5.000 microstrains na deformação do ligamento cruzado posterior. Sugerem-se novos estudos para a compreensão dos ligamentos do joelho quanto ao comportamento deles na sua função. ***Nível de Evidência IV, Estudo Mecânico.***

Descritores: *Ligamentos. Resistência à Tração. Estresse Mecânico.*

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INTRODUCTION

The knee is one of the body joints most vulnerable to trauma, which has been occurring more frequently in recent years due to sports practice.[1-3] This increase and improvement of surgical ligament reconstruction techniques have led to a greater indication of this treatment to achieve a function close to normal.[4]

The understanding of the behavior of knee structures regarding the tensile loads can allow to understand its physiological behavior to create new strategies to improve the result and choose the best graft for ligament reconstruction. The costs of ligament revision surgery and the scarcity of options as revisions are conducted may be factors that worry knee surgeons and managers.[5]

The concern with the quality of the reconstruction has made the researchers analyze the different points that can influence the result, such as new fixation devices, types of graft and other techniques that improve the result.[6]

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The study was conducted at Centro Federal de Educação Tecnológica Celso Suckow da Fonseca and Instituto Nacional de Traumatologia e Ortopedia.
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The knee is a synovial diartrodial joint and some animals are used to simulate and reproduce surgical techniques, such as cattle and pigs, which can be widely used for training of surgeries and techniques.[7-10]
Mechanical tests to understand the behavior of materials can be performed as tensile and compression tests. We used tensile loads to evaluate the ligament structures to observe the stress in the specimens and the strain over time.[11]
The lack of information in the tested ligament structures and in the behaviors of the *in situ* ligament, the performance of destructive and *in vitro* tests, allow a distributed analysis of the load of ligament failure as well as the strain behavior over time.
For studies to develop new techniques, the National Health Council established in Resolution 1 of 07/15/1988, Decree 93,933 of 01/1987, Chapter II, Article 5, Item II, that: “Research in human beings must be based on previous experimental research conducted in animals”.
Our study aimed to perform a preliminary analysis of the ligament behavior (posterior cruciate ligament) regarding the imposed tensile loads and their behavior by measuring their strains.

MATERIALS AND METHODS

The study consisted of the validation of an anatomical model of the pig’s knee, in which five knee models of young pigs without reconstruction were subjected to mechanical tests on the Instron device, with the extended knee being subjected to increasing tensile stress forces until the final failure of these models *in vitro*.
The study was conducted in partnership with the Instituto Nacional de Traumatologia e Ortopedia, Universidade de Valença and Centro Federal de Educação Tecnológica Celso Suckow da Fonseca (CEFET/RJ) and the samples were provided by the animal room of the Universidade de Valença, respecting ethical standards to use the animals.
The anatomy of the pig’s knee is essential because it is one of the joints significantly similar to the human being’s, being a synovial diartrodial joint used as an anatomical model for experimental studies and surgical training.[7]
The models were dissected keeping the four main knee ligaments 13.5 cm away from the articular surface of the femoral and tibial knee. A 6-mm cross-sectional hole was performed in the proximal (femur) and distal (tibia) segment and were kept in a refrigerator of −80°C after removal. On the day of the experiment, they were removed from the refrigerator five hours before the test and wrapped in gauze with 0.9% physiological saline. They were subjected to destructive tests, until the failure of the specimens, at room temperature in an air-conditioned room (22°C).
The anatomical models were thawed according to what was planned, keeping the four main knee ligaments to subject them to mechanical testing.
Five young pigs were evaluated to observe the ligament behavior and regarding the tensile load of the knees. A displacement of 3 mm/minute was imposed.
Strain gages were placed, which are transducers capable of measuring mechanical strains in specimens, in posterior cruciate ligaments due to possible access to the extended knee. Then the data on the loads of the *in situ* model and the strains of the posterior cruciate ligament were collected from the information of the strain gages.
The strain of the posterior cruciate ligament was observed during the failure test of the specimens (Figure 1).

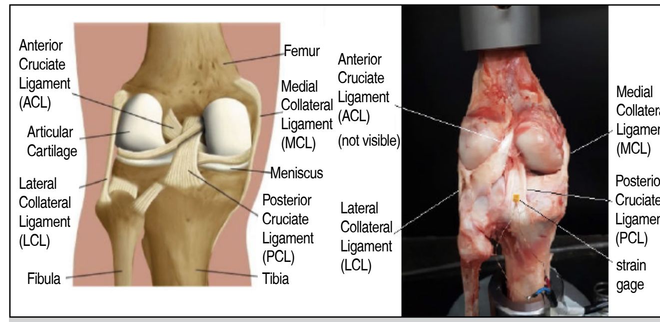

Figure 1. Image with posterior view of the knee structures (left) and of the anatomical model attached to the Instron with strain gage glued to the posterior cruciate ligament (right).

The results were obtained and tables were generated with descriptive numerical values and load × displacement and strain × time graphs.

RESULTS

We observed the posterior cruciate ligament by analyzing the knee behavior and the tensile loads, and we found a linear behavior when measuring the strain with the strain gage.
In the analysis of the tensile load, the load × extension graph showed, at first, an accommodation and a nonlinear increase in stresses. Subsequently, it showed a mean relatively linear intermediate response of the pig’s knee until failure around 1,200 N (Figure 2).

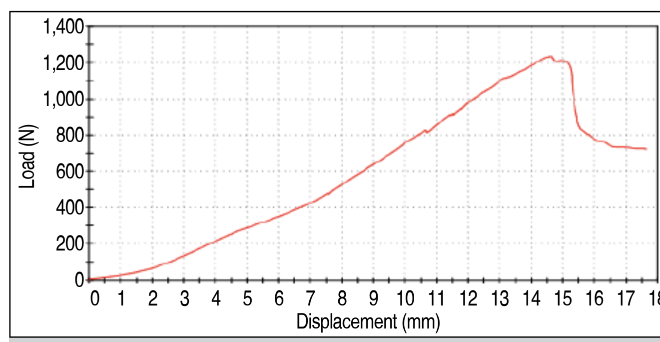

Figure 2. Load × displacement.

The load was apparently redistributed by other structures after failure, leaving some remaining residual strength. A relatively large displacement was imposed before the failure was noticed. The strain × time graph shows the response of the posterior cruciate ligament, which also has a relatively linear response between 1,000 and 5,000 microstrains (Figure 3).

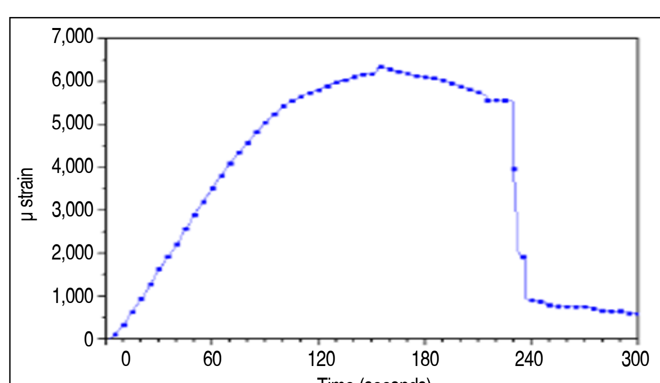

Figure 3. Strain × time Graph.

DISCUSSION

The stability of the knee and its function depends on the perfect ligament action, and the reconstruction requires that the ligaments behave appropriately due to the loads imposed on it.

The knee is a joint that is subjected to compressive and tensile forces. The tensile forces request the ligament structures, which show complex behavior, different from the elastic, viscous or rigid behavior, and may show different behaviors depending on the applied load and time.

The reconstructions of ligament structures are frequently analyzed to understand the behavior of fixations and what would be the best fixation material. However, ligament behavior is essential to propose the best techniques, types of graft and fixation materials. The reconstruction seeks more rigid systems[12] to reduce eventual translations that may arise in the postoperative period, but accommodations may arise over time.

Some studies analyze in 3D models as if they had an elastic or rigid behavior[13] in studies of graft extraction analysis, disregarding a viscoelastic behavior either of the tendon used as a graft or of the remaining ligaments.[14] Galbusera et al.[15] affirms the importance of researchers who perform 3D simulations to consider the anisotropic and nonlinear behavior of ligament and tendon structures.

In our study, the posterior cruciate ligament showed a relatively linear behavior in the intermediate loads during the imposed load. The use of strain gages allowed to understand the strain behavior of the analyzed material, and in the case of musculoskeletal tissues they allow to understand this behavior and the choice of graft to better replace the injured structure.

The limitation of our study is that the analyzed structure is an *in situ* structure and the complexity of the redistribution of forces and stresses must be considered in the evaluation, thus, *in vitro* studies with isolated biomechanical tests of ligaments are necessary.

The strength of this study is the extraction of numerical values and data using strain gages to obtain new information, which might be the vanguard for use in musculoskeletal tissue tests.

CONCLUSION

Our study observed the linear behavior from 1,000 to 5,000 microstrains in the strain of the posterior cruciate ligament during the *in situ* displacement of the knee joint. We suggest further studies to understand knee ligaments regarding their behavior in knee function.

AUTHORS' CONTRIBUTION: Each author contributed individually and significantly to the development of this article. RRPR: writing, idealization and performance of sample dissections and mechanical tests; PPK: idealization, intellectual concept, testing and data analysis; BTD: testing and data collection; JAMG: article review and intellectual concept of the article; WRP: responsible for the samples and dissection of the samples.

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