BIOMECHANICAL ANALYSIS OF KNEE JOINT FLEXION IN HEALTHY, CRUCIATE DEFICIENT AND CRUCIATE SUBSTITUTE CONDITIONS

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Introduction

Cruciate ligament rupture is one of the most common knee injuries in sports, with 64% of athletic knee injuries in pivoting sports being due to ACL tears [1].

As cruciate ligaments cover an important role in joint kinematics and proprioception, injuries lead to functional alterations in joint stability and, in long term, to damages to adjacent structures.

Reconstructive surgeries allow to restore functional stability to the deficient knee.

This work aims to understand how much the knee joint function is influenced by the cruciate ligament damages and verify how the replacement strategies allow to restore the proper joint stability.

Computational Models can predict the effects of traumatic events and surgical repair and replacement strategies. They provide information that would otherwise be difficult or impossible to obtain from experiments.

Materials and Methods

A 3D model of a knee was created to simulate knee movement and the impact of ACL and PCL injuries. The model was made using information from literature and CT images, and the materials were considered homogeneous and linear elastic isotropic [2]. The cruciate and collateral ligaments were modeled as different bundles and represented as one-dimensional elements: linear elastic isotropic beam elements for the collateral and non-linear springs for the cruciate [3]. The patellar tendon was divided into three bundles and represented as beam elements. The model was used to simulate the knee's passive motion from 0° to 90° with a healthy knee, a knee with ACL injury, a knee with PCL injury and a knee with both ACL and PCL injury (injuries were represented by decreasing the ligament stiffness by 25% and 50%). Finally, the model was used to simulate cruciate replacement firstly using the patellar tendon as a graft and then using a synthetic graft called LARS.

Results

The values of intra-extra rotation and the antero-posterior translation of the lateral and medial tibia were investigated.

All cases examined follow the same trend, but the magnitude changed compared to the intact knee. After an initial extra-rotation between 0° and 10°, the tibia rotated internally and translated anteriorly with flexion. In amplitude, intra-rotation is larger as ACL stiffness decreases, as well as the anterior translation of the lateral compartment of the tibia. On the other hand, PCL-deficient reduced the anterior tibial translation both laterally and medially.

When both the cruciate are injured, a significant increase in the internal tibial rotation and in the anterior translation occur (lower than the ACL deficient case).

In case of cruciate reconstruction, the behavior is similar to the native. There are no significant differences in terms of antero-posterior translation and axial rotation of the tibia, both in the case of reconstruction with the patellar tend and with the synthetic graft.

Discussions & Conclusions

The results were consistent with experimental and literature data. The ACL and PCL play important roles in anterior-posterior constraint and joint stability, and injury to the ligaments affects joint kinematics. Cruciate reconstruction can effectively restore joint stability. The model developed in this study can be used for subject-specific predictions of joint kinematics and provide a basis for joint disease treatment.

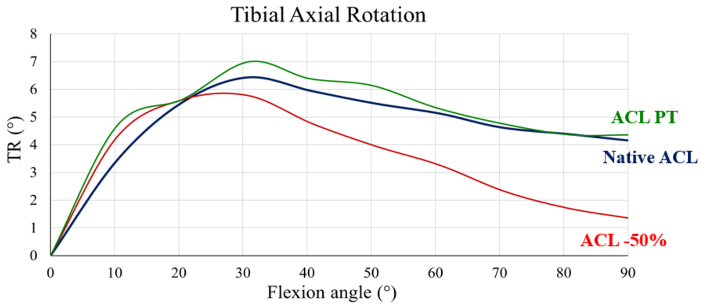

Figure 1: A graph of the Tibial Rotation in case of Native Knee, ACL-deficient Knee and ACL-reconstructed Knee (with Patellar Tendon grafting). It is possible to see how the reconstructed knee behavior is closer to the native one, if compared to the ACL-deficient knee

References

1. Kim et al, Journal of Bone and Joint Surgery, 2011
2. Pianigiani, S. et al., Muscles, ligaments and tendons journal, 2018
3. Blankevoort, L., & Huiskes, R., Journal of biomechanical engineering, 1991