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Estimation of Subject-specific Knee Ligament Properties

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1. Introduction

Ligaments play an important role in sustaining sufficient knee joint stability. Ligament properties are, however, subject-specific with high interpersonal variance [1]. Unfortunately, ligament properties are immeasurable in vivo, causing a common absence of subject-specific ligament properties in current musculoskeletal models, making them unsuitable for preoperative planning. We present a method for estimating subject-specific ligament properties based on a novel non-invasive six degree-of-freedom (DOF) arthrometer.

2. Materials and Methods

A novel arthrometer, previously presented in [2], were used to acquire a six DOF knee laxity profile on a cadaveric specimen. Twelve monoplanar and four multiplanar load cases were applied to the cadaveric knee in 30 degrees of flexion. Position and orientation of femur and tibia were recorded using motion capture and bone pin markers. A musculoskeletal (MS) model of the cadaveric knee was formulated in the AnyBody Modeling System (AnyBody Technology, Denmark), encompassing subject-specific bone geometry, cartilage, ligament insertion and origin points gathered from segmented MRI and CT scans in Mimics (Materialise, Belgium) (Fig. 1). Anterior cruciate ligament, posterior cruciate ligament, medial collateral ligament and lateral collateral ligament were modelled as double bundle springs. Force-dependant kinematics [3] were applied in the model to solve the position and orientation of the knee joint during each laxity measurement. Complex optimisation [4] was performed in MATLAB (MathWorks, USA) by wrapping the MS model, allowing optimisation of ligament stiffness and slack length to match experimental data. For evaluation, the optimised ligament parameters were applied in the MS model to predict the experimental measurements. The results from the optimised model were compared to predictions from a MS model with generic ligament parameters obtained from the literature [5].

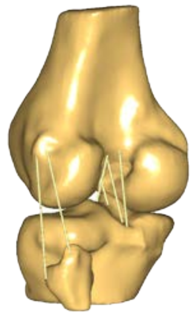

Figure 1: Graphical representation of the MS model

3. Results

The optimised model predicted the position and orientation of the knee joint in all sixteen measurements with an average error of 2.26±1.71 mm and 1.67±1.63°. The generic model had a prediction error of 2.76±2.47 mm and 2.92±4.50°.

4. Discussion and Conclusions

The presented method proved capable of improving the predictions compared to a MS model based on generic ligament properties.
However, the evaluation was based on experimental data that was also used to optimise the ligament properties. Future evaluations of the method should be performed on external data to identify its applicability.
Furthermore, the number of required laxity measurements and model complexity require further investigations in order to improve the methods predictability and robustness.

5. References

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