VALIDATION OF A KNEE FINITE ELEMENT MODEL FOR THE DEVELOPMENT OF SURGICAL TRAINING MODELS

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Introduction

Current knee surgical training models provide anatomically correct bony geometry but often lack functional biomechanical accuracy [1]. This inaccuracy has resulted in limited opportunities for surgeons to practice techniques like computer navigated total knee arthroplasty, which relies on measurements of joint mechanics. In this research, we aimed to develop a finite element model (FEM) which reproduces the mechanics of a healthy knee for developing biomechanically fidelic surgical training models, with validation through experimental assessment in a six degree-of-freedom (6DOF) hexapod robot.

Methods

A knee FEM was developed with a reduced ligament set. Bones were modelled as rigid bodies, with deformable articular surfaces used for contact modelling. Kinematic axes were defined as open-chain cylindrical axes. Five ligaments – the lateral collateral ligament (LCL), the anterolateral ligament (ALL), the medial collateral ligament (MCL), the anterior cruciate ligament (ACL) and the posterior cruciate ligament (PCL) – were modelled as point-to-point linear springs. Latin hypercube sampling was used to adjust the reference strain (slack length) of each ligament to explore the range of manufacturing tolerances which may be produced.

Three knee models were manufactured, containing the distal femur, proximal tibia and fibula, and ligaments with different reference strains. The proximal femur and distal tibia were embedded into aluminum potting cups to match the orientation and alignment of the FEM. The potted knee models were mounted in a custom-built 6DOF hexapod robot with kinematic axes aligned with the robot's axes.

In both the FEM and hexapod experiments, knee kinematics were measured at extension (15°), mid-flexion (45°), and full-flexion (90°). At each flexion angle: 1) all off-axis shear forces and moments were minimized using an adaptive load control algorithm. 2) 20 N of superoinferior (SI) tensile force was applied to ensure the ligaments were taught. 3) (a) ±10 Nm VV moment was applied with all other rotation and translation axes (except SI translation) constrained; (b) ±100 N AP load was applied with all three rotations axes, and mediolateral displacement constrained.

Results

The VV mechanics calculated using the FEM at extension were similar to the range of cadaveric knees (Figure 1). The VV mechanics of the manufactured knee models were similar to both the solution space of the FEM and the cadaveric results.

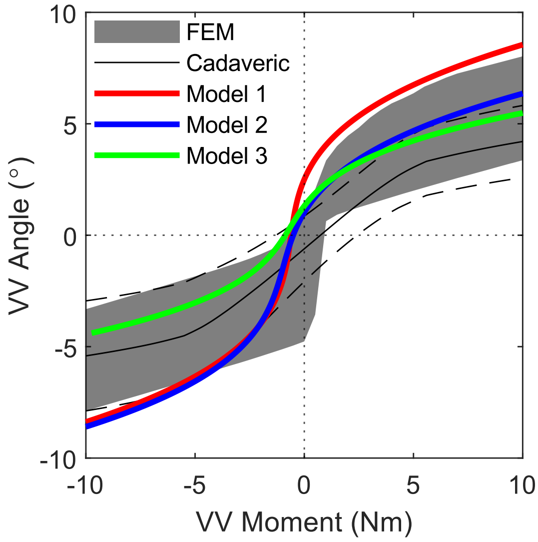

Figure 1: Measured VV angle due to applied moment at extension for the three knee models overlaid onto the 5-95% solution space of the FEM, and the mean (solid line) and standard deviation (dashed lines) of 21 cadaveric knees (unpublished data).

Discussion

The FEM reproduced the mechanics of healthy cadaveric knees. Experimental measurements of the knee models manufactured based on the FEM allowed for validation. Using knee models manufactured based on the FEM, surgeons can learn and practice surgical techniques which rely on measurements of joint mechanics in a low-risk environment.

References

1. Clifton W et al, Clin Anat, 33:428-430, 2020

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