Comparing in vitro and in silico human knee kinematics and posterior cruciate ligament forces during knee flexion and extension

James Cowburn[1], David Williams[1], Petra Bonacic-Bartolin[2], Katie Powell[1], Janine Flohr[1], Jenny Williams[1], Bryce Killen[3], Ilse Jonkers[3], Andrew Amis[2], Richard van Arkel[2], Cathy Holt[1]

[1]Musculoskeletal Biomechanics Research Facility, School of Engineering, Cardiff University, Cardiff, UK

[2] Biomechanics Group, Department of Mechanical Engineering, Imperial College London, London

[3]Human Movement Biomechanics Research Group, Department of Movement Science, KU Leuven, Belgium

Email: cowburnj1@cardiff.ac.uk

Summary

Musculoskeletal modelling (MSM) can provide detailed information about knee motion and loading to inform surgical interventions. In an initial study comparing knee translations and posterior cruciate ligament (PCL) forces generated by a current MSM with a human cadaveric specimen, the generic MSM performed best when simulating low knee flexion, deviating substantially beyond ~45° flexion. This suggests generic MSM are not suitable for high flexion movements.

Introduction

In vitro and *in silico* studies provide valuable information to understand knee motion and loading. A key aim is to develop an integrated framework to understand knee kinematics and loading, pre- and post-surgical interventions. *In vitro* analysis can provide detailed loading information for soft tissues, e.g., ligaments, that can be used to validate MSMs. An initial analysis of a generic MSM is presented by comparing the tibiofemoral kinematics and dynamic behaviour of a single ligament, PCL, with a cadaveric knee specimen.

Methods

Cadaveric knee specimens were tested in a KUKA-KR-160-R150 robotic actuator (KUKA) with 6 degree-of-freedom (DOF) load cell (Delta, ATI) controlled by SimVitro software. Specimens were flexed to 90 at $10°\cdot s^{-1}$ and extended back to neutral. Ligamentous tissues were excised sequentially and re-testing performed using displacement-control replicating the measured intact specimen kinematics. The change in recorded forces and moments following excisions were attributed as the kinetic contribution of the tissue under the assumption of superposition (*in vitro*). Data for the PCL excision under 50 N compressive loads were used for further analysis. A forward dynamic simulation was performed using a generic, unscaled MSM [1]. Muscles were removed and gravity set to $0\ m\cdot s^{-2}$. All non-tibiofemoral DOF were locked, with knee flexion prescribed as the experimental data. The total ligament forces and the five simulated knee DOF kinematics were extracted for analysis (*in silico*). Ligaments were modelled as non-linear and linear spring-dampers at low and high strains, respectively [2]. The translational kinematics and PCL forces were compared between *in vitro* and *in silico* during analysis.

Results and Discussion

The model performed best at predicting knee translations and PCL forces for knee flexion below ~45° (Fig.1). RMSE anteroposterior (AP), compression/distraction (DC), and mediolateral (ML) forces were 13.68 N, 40.96 N, and 7.43 N, respectively but decreased when focusing between 0-45° flexion (AP = 5.41 N, CD = 10.36 N, ML = 2.45 N). This was reflected in the kinematics, which deviated in AP and Vert directions after ~45°. Although it should be noted that it could not be determined from this preliminary work that the PCL is the sole contributor to the erroneous kinematics, it highlights the performance of the generic model at lower flexion. This is likely due to the original model validation using dynamic MRI limited to 36 - 45° [1], which may lead to incorrect outputs for studies involving high flexion activities, such as sit-to-stand. Future work will integrate subject-specific elements informed by cadaveric specimens to allow better prediction of knee biomechanics.

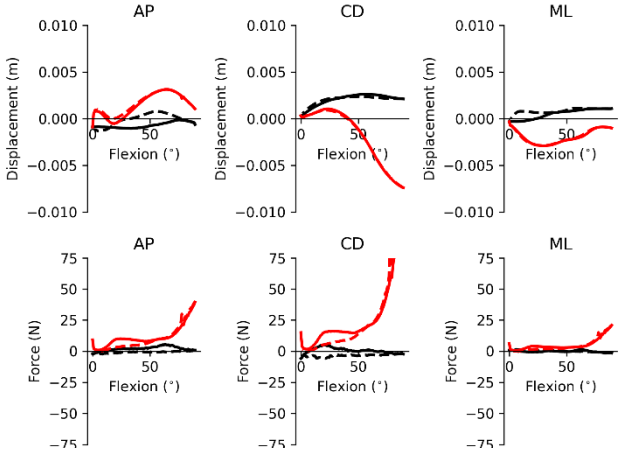

Fig. 1: *In vitro* (black) and *in silico* (red) knee kinematics (top) and PCL forces (bottom) in flexion (solid) and extension (dashed) phases.

Conclusions

Generic MSM could not reproduce the knee translational motion and PCL forces seen with the cadaveric specimen, particularly when the knee was highly flexed. This highlights the benefit of informing MSM with *in vitro* data to improve analysis of knee motion and loading from *in vivo* experiments, especially during high knee flexion activities.

Acknowledgments

This research was funded by the Engineering and Physical Sciences Research Council [grant numbers EP/X039870/1 and EP/X04002X/1].

References

[1] Lenhart et al. (2015) *Annals Biomed Eng*, 43, 2675–2685

[2] Blankevoort & Huiskes (1991) . *J Biomech Eng*, 113, 263-9