Validation of a Person-Specific Knee Model to Accurately Predict Patellofemoral Kinematics for a Variety of Dynamic Tasks Using Biplanar Videoradiography

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Summary

Measuring patellofemoral (PF) joint kinematics in vivo is challenging, and this has limited PF injury and pathology research. Musculoskeletal modelling may address these limitations, but the accuracy of available models is still unclear. Therefore, this study seeks to use biplanar videoradiography (BVR) to determine the accuracy of person-specific multibody knee model predictions of six degree of freedom (DOF) tibiofemoral (TF) and PF kinematics for several dynamic movements. Preliminary results showed that while these models were able to accurately simulate some of the joint kinematics with high levels of accuracy, further improvements are needed to increase the overall accuracy of this model.

Introduction

In the knee, geometric features have been associated with an increased risk of PF injury or pathology; however, the ability to measure PF joint function in vivo is challenging. Optical motion capture is frequently used to measure joint kinematics; however, the large amount of patella motion underneath the skin limits the accuracy of this method in measuring PF kinematics. Calculating PF kinematics using person-specific musculoskeletal modelling offers a means to address these limitations, but the accuracy of these models is still unclear. Therefore, this study seeks to use BVR to quantify the accuracy with which a person-specific multibody knee model can predict six DOF TF and PF kinematics for a series of dynamic tasks.

Methods

CT scans and MRIs of the right knee of one participant (male, 21yrs) as well as time synchronized BVR, optical motion capture and force plate data of a lunge ascent and walk task were used in this study. The CT scans were segmented and converted to 3D meshes of the femur, tibia and patella. These meshes were superimposed onto the BVR capture using 3D Slicer AutoScoper which provided relative bone pose at each time frame [1]. The MRIs were segmented to produce a person-specific model of the bone and cartilage of the femur, tibia and patella as well as the menisci. These models were then integrated into two separate generic musculoskeletal models [2,3], with attachments sites, wrapping surfaces, and slack lengths updated based on the person-specific knee geometry. The participant's trials were then simulated by each model in OpenSim with six DOF TF and PF kinematics calculated using the Concurrent Optimization of Muscle Activations and Kinematics (COMAK) routine [4]. The kinematics from the BVR data were compared to the simulated kinematics of the models for all six DOF at both the TF and PF joints.

Results and Discussion

Preliminary results of this study showed that both models were successful in accurately predicting PF mediolateral translation (RMSE 0.5 to 1.3mm), PF tilt (RMSE 2.1° to 4.6°), as well as TF adduction (RMSE 1.2° to 2.9°) (**Table 1**). However, errors were larger for TF flexion, PF flexion, PF rotation, and PF anterior-posterior translation during the lunge ascent task, and TF rotation, PF flexion, and PF superior-inferior translation during the walk task. The Rajagopal model performed the best for simulating the lunge task in all movements other than PF flexion and PF anterior-posterior translation, and for all PF motions other than PF flexion for the walking simulation. However, the Arnold model better simulated all TF rotations during walking.

Table 1: RMSE of simulated compared to BVR kinematics for both models during lunge ascent and walking task.

	Lunge Ascent		**Gait**	
	Arnold	Rajagopal	Arnold	Rajagopal
Knee Flex (°)	14.7	**11.3**	**1.9**	2.0
Knee Add (°)	2.9	**1.9**	1.3	1.3
Knee Rot (°)	7.7	**3.0**	**8.4**	8.7
PF Flex (°)	**12.2**	16.4	**15.8**	16.5
PF Rot (°)	10.5	**9.1**	6.7	**3.9**
PF Tilt (°)	4.8	**3.2**	4.5	**2.2**
PF AP (mm)	**10.3**	12.1	8.1	**7.2**
PF SI (mm)	2.5	2.5	19.3	**17.3**
PF ML (mm)	1.3	**0.6**	0.5	0.5

Conclusions

While these models were able to accurately simulate some of the joint kinematics with high levels of accuracy, the results varied between both model types as well as task. Overall, implementing the knee model into the Rajagopal model had better results. However, further improvements are needed to increase the overall accuracy of this model for predicting TF and PF kinematics. This study is ongoing and will consist of 10 participants with simulated dynamic tasks of lunge descent and a single leg hop also being analyzed.

References

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