Impact of mesh refinement on knee contact pressure estimations and musculoskeletal simulation accuracy

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Summary

Accurate modeling of knee contact forces and pressures is important for musculoskeletal simulations. However, the resolution of femur and tiba meshes can significantly impact efficiency and predictions. This study evaluates the influence of various femur mesh resolutions on knee contact force estimations in musculoskeletal simulations. Different mesh configurations are analyzed to assess their impact on simulation accuracy and computational cost.

Introduction

Musculoskeletal simulations typically depend on a rigid multibody kinematic chain driven by muscles [1]. The joint contact information is simplified to a contact wrench (three forces and three moments). To enable the computation of detailed contact pressures, we have developed a smoothed contact pressure model based on an elastic foundation contact model [2]. These simulations involve solving an optimal control problem (OCP) using gradient-based optimization algorithms and automatic differentiation tools [2]. A key factor impacting accuracy and computational efficiency is the geometric resolution of the tibia and femur meshes used in contact modeling. This study aims to evaluate the effect of varying femur and tibia mesh resolutions on knee contact force and pressure estimations and kinematics. By comparing simulations using different mesh configurations, we assess the trade-offs between computational cost and accuracy of tracking simulation.

Methods

A full body tracking simulation was formulated as an optimal control problem (OCP) using a gradient-based optimization approach. The experimental data used are from an over-ground walking trail (a forefoot strike gait cycle) from the Grand challenge competition to predict in vivo knee loads [3]. The skeletal model has 34 DoFs including 20 lower-limb DoFs actuated by 94 muscles, and the 8 upper-limb DOFs were torque-driven. The hip was modeled with three rotational DoFs, the right knee with six DoFs (three translational and three rotational), and the ankle with two rotational DoFs. The muscle-tendon lengths and moment arms were parameterized using a reduced polynomial approach to improve computational efficiency.

To investigate the effect of femur mesh refinement on knee contact force and pressure estimations and joint kinematics, the femur geometry was tested with two different levels of refinement, low-resolution mesh with 171 face meshes, and a medium-resolution mesh with 258 face meshes.

The tibia geometry mesh was kept constant with 50 faces across all simulations. The knee contact forces and joint kinematics obtained from different mesh resolutions were compared in terms of RMSE relative to experimental data. Additionally, computational efficiency was assessed by comparing simulation times across the different mesh configurations.

Results and Discussion

The results showed that higher-resolution meshes lead to kinematics closer to experimental values. The 258-face femur refinement improved the tracking of experimental data, particularly in hip DoFs (see Fig 1). The mean RMSE across all joint angles was 2.14° (SD: 2.63°) for the 258-face refinement, compared to 2.62° (SD: 3.08°) for 171-face refinement, indicating a slight overall improvement in kinematic accuracy with finer mesh resolution.

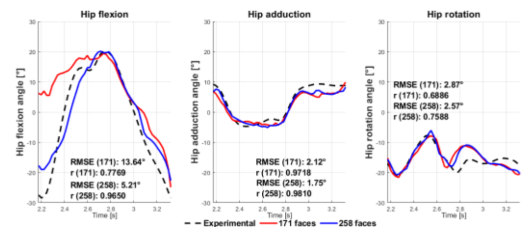

Figure 1: Comparison of hip Joint kinematics across Femur mesh refinements

In terms of knee contact forces tracking, the RMSE value of medial KCFs was 75.13 N (r = 0.98) for the 258-face meshes, slightly higher than the 69.26 N (r = 0.98) for 171-face meshes. However, the RMSE of lateral KCF was 84.84 N (r = 0.88) for the 258-face meshes, lower than the 102.61 N (r = 0.81) for 171-face meshes. Despite improving accuracy, the computational time increased, the 171-face refinement required 2.62 h with 1334 iterations, whereas the 258-face refinement required 3.63 h with 1891 iterations reflecting 39% increase in computation time.

Conclusions

The results show that increasing the femur mesh resolution enhances joint kinematic accuracy and KCFs estimations, the 258-face refinement demonstrated superior tracking of hip joint angles and better tracking of lateral KCF, as well as increasing the computational time cost. This analysis will be increased with more mesh resolutions.

Acknowledgments

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