Increased Mediolateral Contact Element Density in Foot-Ground Contact Models Improves Estimation of Frontal Plane Ground Reaction Moments

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Summary

This study analyzes the effect of mediolateral (ML) foot-ground contact (FGC) model contact element density on the estimation frontal plane ground reaction moments using direct collocation optimal control. The results show higher ML density more accurately produces frontal plane moments.

Introduction

Creating clinically useful predictive musculoskeletal simulations of individuals with movement impairments such as knee osteoarthritis or stroke requires accurate estimations of joint loads [1]. Predicting joint loads for a new motion is commonly done with FGC models that estimate ground reactions [2], for which one of the primary design decisions is contact element density [3]. Although important, many existing FGC models do not accurately produce ground reaction moments [2], causing center of pressure (COP) errors which have been shown to negatively affect joint load calculations [4]. A COP error of just 1 cm has been shown to cause up to 14% error in joint load calculations [4]. To better estimate ground reaction moments and therefore joint loads, this study analyzes the effect of ML contact element grid stiffness on frontal plane ground reaction moments using walking predictions generated using direct collocation optimal control [2].

Methods

A personalized full body OpenSim [1] skeletal model was created for a high functioning stroke patient using experimental marker data with the Neuromusculoskeletal Modeling (NMSM) Pipeline’s model personalization toolset [5]. Four FGC models were calibrated using kinematic and 6-DOF force plate data with the NMSM Pipeline’s GCP tool. The FGCs had viscoelastic contact elements uniformly arranged in a foot-shaped grid with widths (ML) ranging from 2-5 elements, and a height (anteroposterior) of 5 elements for all models. Each contact element applied stiffness, damping, and horizontal friction forces to the foot using calibrated parameters. Optimal control problems were then run using the NMSM Pipeline’s Treatment Optimization toolset with the full-body OpenSim model and each of the four calibrated FGC models to create dynamic walking simulations. Tracked quantities included joint positions and velocities, controls included joint accelerations and torques, and ground-pelvis residual loads were constrained to be within 0.1 N and 1 Nm to achieve dynamic consistency. Ground reactions and inverse dynamics (ID) joint loads were not tracked, to simulate a predictive simulation in which they are unknown. Ground reaction loads in the solutions were evaluated by comparing them to experimental ground reactions.

Results and Discussion

Percent RMS errors are presented for frontal plane ground reaction and ID moments produced from the walking simulations (Table 1). All FGC models produced similarly accurate vertical GRFs, but higher ML densities produced more accurate frontal ground reaction moments (Figure 1). Higher errors in frontal ground reaction moments resulted in higher errors in the subtalar joint moment, but did not significantly affect frontal knee or hip moments.

Table 1: Percent RMS errors of lower limb frontal ground reaction and ID moments for each ML density, averaged between sides.

Moment [Nm]	5	4	3	2
Ground	12.9	15.6	26.2	25.0
Subtalar	17.1	21.0	31.8	22.6
Knee	11.0	10.7	12.9	11.6
Hip	13.5	12.9	14.1	12.9

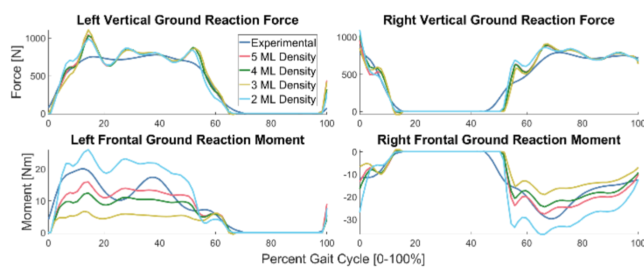

Figure 1: Vertical ground reaction forces and frontal plane ground reaction moments for each ML density.

Conclusions

This study analyzed the effect of ML contact element density on frontal plane moments during dynamically consistent gait simulations. Walking simulations revealed that ML grid density has a significant effect on calculating frontal plane ground reaction moments and subtalar joint moments. These results indicate that choosing a denser grid is important to produce accurate frontal ground reaction moments.

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