Predictive Simulations of Musculoskeletal Model to Study Biomechanics in Walking with Weak Hip Abductors

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Summary

A predictive simulation framework was used to study biomechanics of altered walking patterns with weak hip abductors. The prediction outcome showed key gait features that aign with clinically observed gait.

Introduction

Predictive simulation generates movement by applying a control policy and meeting dynamic and geometric constraints, revealing the link between muscle properties and movement [1]. There is however still a need to evaluate the simulation's generalizability and performance. This study aims to analyze how gait patterns might change with weak hip abductors, using a predictive simulation framework and a musculoskeletal model scaled to one nondisabled subject.

Methods

The framework developed by D'Hondt et al. was used [2], which frames walking prediction as a model-based optimal control problem with multi-objective cost functions. The 3D musculoskeletal model includes the head, arms, trunk, and lower limbs, featuring 33 skeletal degrees of freedom, 94 Hill-type musculotendon units, and four foot segments. It was scaled to the anthropometry of a nondisabled female subject (35 years old, 62 kg, 1.70 m). Cost function weights were optimized by bilevel optimization, with the inner loop running predictive simulation and the outer loop minimizing average root mean square error (RMSE) weighted by joint kinematics variability [2]. Bayesian Optimizer was used to search for optimal weights based on RMSE in the outer loop.

Hip abductor weakness was modeled by reducing gluteus medius and minimus strength from 5% to 100% of their original strength. Half of the gait cycle was simulated and recriprocated, assuming symmetry, for computational efficiency. To avoid local minima, multiple initial guesses were used, including data from Falisse et al. [1], quasi-random, optimal, and suboptimal solutions at the closest strength level. Results that minimized the cost function were analyzed, including kinematics, kinetics, and metabolic cost, estimated using Bhargava model [3]. Due to the lack of ground truth, previous datasets were used for qualitative validation.

Results and Discussion

The optimized weights in the cost function predicted a lower RMSE (3.0 deg) compared to the manually tuned weights (5.8 deg) reported previously [2]. In the predicted gait patterns, as hip abductor strength decreases, lateral trunk sway and frontal plane pelvis obliquity modify drastically; the model predicts a pattern with excessive pelvis elevation and trunk lean towards the stance leg in midstance, and lower hip abduction moment, qualitatively similar to patterns observed in persons with hip abductor weakness resulting from myelomeningocele (estimated strength level: 0-10% [4]). There are also some similarities with observed gait in persons with cerebral palsy (estimated strength level: 50% [5] and 20-30% [6]), mostly in trunk movement (Figure 1). The estimated metabolic cost increased consistently with increasing weakness.

The 100% strength simulation results do not, and cannot be expected to, fully agree with experimental data, due to the model assumption and simplifications, including imposed movement symmetry. Achieving more realistic predictions also requires accurate expression of cost function; as it, it may neglect or not explicitly define some aspects, such as balance and/or altered motor control. Still, the results indicate that the model has promising predictive ability.

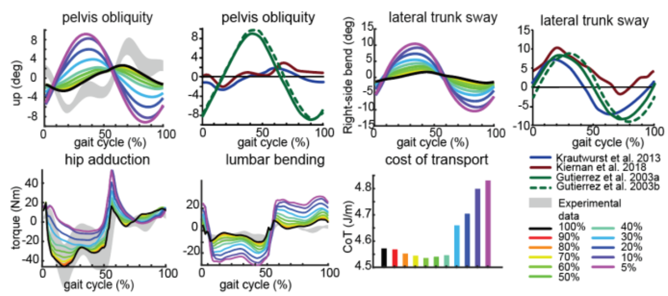

Figure 1: Observed (gray) and predicted kinematics, kinetics, and metabolic cost with increasing amount of hip abductor weakness (5-100% reduction). Observed kinematics in persons with weak abductors are also shown.

Conclusions

The framework captures key gait features and shows promise in understanding the relationship between muscle weakness and walking pattern. It can be useful in future work to design optimal exoskeleton assistance with simulation.

Acknowledgments

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