Predictive Simulations of Assisted Gait Can Distinguish Important Gait Features Among Spinal Cord Injury Patients

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Summary

This study aimed to determine if predictive simulations can identify subject-specific gait features of spinal cord injury patients. Optimal control techniques were used to personalize the musculoskeletal models of three patients and generate predictive simulations of walker-assisted gait. Four simulated and experimental gait parameters were compared. The simulations successfully captured key gait deviations, such as excessive trunk inclination. Future work is required to include more subjects and analyze additional gait parameters.

Introduction

Predictive simulations of human motion have the potential to aid the design of assistive devices, foresee rehabilitation outcomes, and analyze isolated muscular features of spinal cord injury (SCI) patients. Various calibration tools have been developed to personalize the Hill-type muscle-tendon parameters of the musculoskeletal models used in these simulations (e.g., [1]). However, it remains uncertain whether models with this level of personalization can accurately predict pathological gait. This study aims to determine if, using optimal control techniques and a calibrated musculoskeletal model, we are able to accurately predict the patient-specific gait features of SCI subjects, including their individual compensatory movements and stabilization strategies.

Methods

Experimental data were gathered for 3 SCI subjects. Maximum isometric tests for the ankle, knee and hip joints were performed with a handheld dynamometer. Subsequently, static trials, gait and sit-to-stand-to-sit motions were recorded using an optical system and two force plates. The electrical activity of 8 muscles per leg was measured for all static and dynamic trials with an electromyography (EMG) device.

The subject-specific optimal fiber length and tendon slack length parameters of the recorded muscles of the 3 subjects were estimated on GPOPS-II [2], using the direct collocation method in a multiphase optimal control problem (OCP). Three gait and sit-to-stand-to-sit trials were used in the parameters' optimization. The cost function tracked the inverse dynamics joint torques calculated with OpenSim and the EMG signals.

An additional OCP was developed to generate fully-predictive simulations of assisted gait, using an implicit formulation of the musculoskeletal dynamics [3]. The multi-term cost function minimized metabolic energy rate, muscle activity, joint accelerations and passive torques [4]. The walker used by the patients was implemented in the model through kinematic constraints. Four gait parameters were compared between the experiments and the simulated walk of the patients: the range of motion (ROM) of the right knee and right ankle, the mean trunk inclination, and the circuity index.

Results and Discussion

The simulations correctly predicted which subjects had the highest ankle ROM and lowest knee ROM (Figure 1). In the case of subject 2, the predicted ROMs were within the standard deviations of the experimental values. However, these results might have been affected by the rather strict bounds given to the joint angles in the OCP. Moreover, the gait predictions identified that subject 3 walked with the highest mean trunk inclination. This parameter provides important insight into the stability of the patient. In fact, subject 3 was over-reliant on the walker, indicating poor confidence in his lower limb stability. In addition, all subjects had an almost-optimal circuity index (i.e., close to 1). The predictive simulations accurately identified which subjects had the highest, lowest, and middle circuity index values.

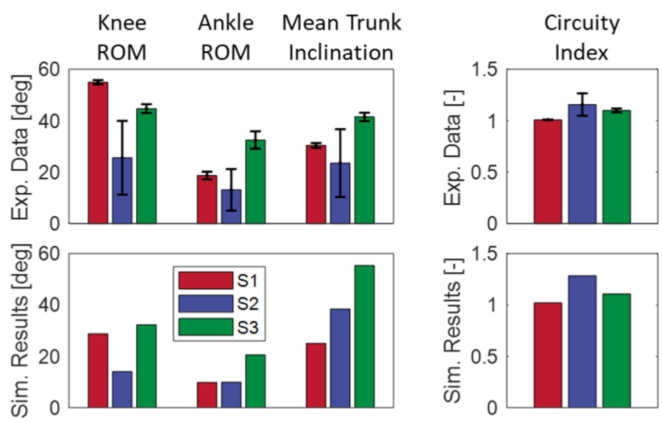

Figure 1: Four gait parameters calculated from the experimental (exp.) data and simulation (sim.) results of 3 SCI subjects (S1-S3).

Conclusions

This study achieved promising results regarding the prediction of subject-specific gait features of SCI patients. Ongoing work is being performed to include more subjects and analyze parameters related to kinetics and muscle activity.

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