PRE- AND POST OPERATIVE MUSCLE FUNCTION IN CROUCHED GAIT – A CASE STUDY USING MRI-BASED MUSCULOSKELETAL MODELS

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SUMMARY

We generated musculoskeletal models of the lower limb of a child with cerebral palsy based on MRI-data before and after surgery as well as 5 individual models of normally developing children comprising an age-matched control group. Comparison of pre- and post-operative crouch gait and normal gait show only limited improvement in gait kinematics but significant changes in the contributions of individual muscles to the acceleration of the centre of mass of the body.

INTRODUCTION

Quantification of muscle forces is needed to characterize the functional roles of individual muscles and to develop new methods for treating patients with movement disorders [9].

The contributions of individual muscles to motion of the body's centre of mass can be found by using customized musculoskeletal models [1], formulating and solving appropriate optimization problems, and performing a force decomposition analysis to calculate muscle-induced accelerations [8,9]. The aim of this study was to describe lower-limb muscle function for a child with cerebral palsy (CP) walking with a crouched gait before and after surgical treatment. The pre- and post-operative results for muscle function are also compared to those obtained for normally developing children.

METHODS

We generated subject-specific musculoskeletal models of 5 normally developing children and one child with cerebral palsy based on magnetic resonance imaging (MRI) data using methods reported previously [5]. All subjects were of the same age group (9.5 ± 1.7 years). Joint motion and ground reaction forces were recorded simultaneously as each subject walked at his or her natural cadence and speed. All data were recorded at the Orthopedic Hospital in Speising, Vienna.

Subsequent to gait data collection the child with cerebral palsy underwent surgical treatment. The semitendinosus, semimembranosus and gracilis muscle-tendon units were each lengthened, and tibial torsion was corrected (right 25°, left 40°). Joint motion and ground reaction forces were recorded again 9 months after surgery.

The musculoskeletal model of the CP child before surgery was used as a basis for developing a scaled post-operative musculoskeletal model. The model was uniformly scaled to the actual subject's size and the peak isometric forces of all muscles were estimated using a mass scaling law [1]. Changes to muscle-tendon architecture due to the surgery were simulated in the post-operative model by increasing tendon slack length of the hamstrings and gracilis muscles by 3 cm and simulating correction of the tibial torsion.

OpenSim [2,10] was used to extract the joint angle trajectories and calculate the joint moments during walking for all models. Muscle forces were calculated using static optimization and minimizing the sum of all muscle activations squared. The contributions of each lower-limb muscle to the forward and vertical accelerations of the center of mass (CoM) were calculated using the method published Lin *et. al.* [6] and the OpenSim plugin reported by Dorn *et. al*. [3,4].

RESULTS AND DISCUSSION

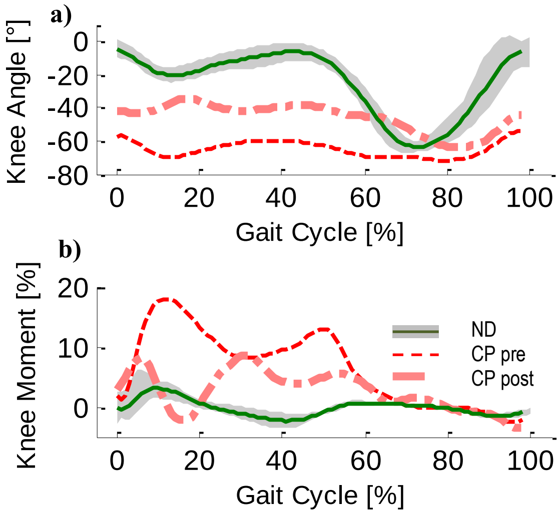

Figure 1 (a) Knee joint angle and (b) Normalized knee moment measured pre- and post-operatively in a child walking with a crouched gait (CP pre and CP post, respectively). Results for controls are represented by ND.

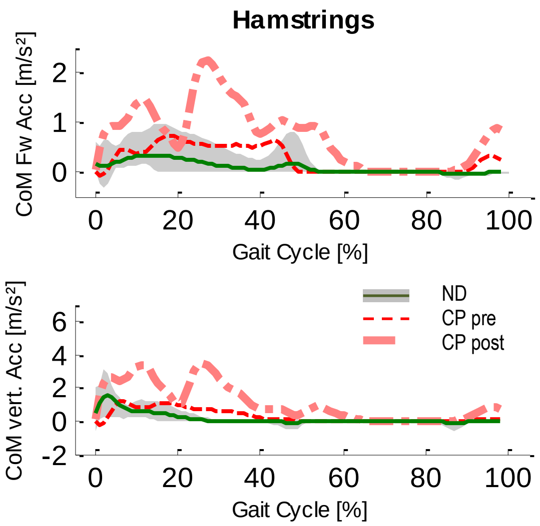

Figure 2 Hamstrings contribution to (a) forward and (b) vertical CoM acceleration in pre- and postoperative crouched gait compared to normal gait of children

Figures 1 to 3 show comparisons of the joint angle and joint moment at the knee, as well as contributions of the hamstrings and quadriceps muscles to the forward and vertical accelerations of the center of mass (CoM). We compared the child with cerebral palsy before (CP pre) and after surgery (CP post) to the control group of normally developed children (ND). The joint moments were normalized by each subject's height and weight [7].

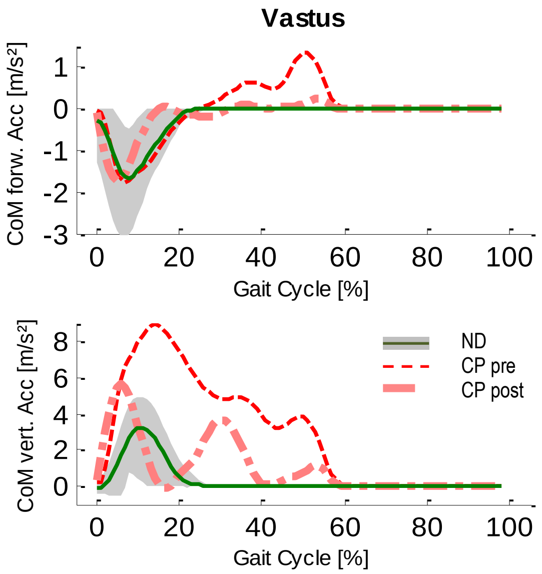

Figure 3 Vastus contribution to (a) forward and (b) vertical CoM acceleration in pre- and post-operative crouched gait (CP pre and CP post, respectively) compared to results obtained for normally developed children (ND).

The post-operative gait velocity was increased by 0,3m/s and the gait pattern was characterized by a decrease in knee flexion angle (~ 20° less), however, the knee flexion range during walking was still limited to around 30°, indicating an almost stiff knee (Figure 1a). Due to the less crouched posture, the maximum knee moment was nearly 50% lower post-operatively (Figure 1b).

The contributions of the hamstrings to the accelerations of the CoM in the forward and vertical directions were increased over the entire gait cycle (Figure 2), but they were much closer to the results obtained for the controls before surgery. In pre-operative crouched gait the quadriceps was a major contributor to the vertical acceleration of the CoM (Figure 3b). Subsequent to surgery, however, the quadriceps contributed less to vertical acceleration than that seen in the controls. The ability of the quadriceps to accelerate the body forward in terminal stance phase was drastically diminished post-operatively (Figure 3a).

CONCLUSIONS

Pre- and post-operative patient-specific models of a child with cerebral palsy as well as five subject-specific models of an age-matched control group were developed from MRI. The musculoskeletal changes due to reconstructive surgery were incorporated into the patient-specific post-operative model. The contributions of individual lower-limb muscles to the forward and vertical accelerations of the CoM were determined using optimization and a force decomposition method.

We compared the function of two of the major thigh muscles, hamstrings and quadriceps, before and after surgery to results obtained from a control group. The results 9 months after the surgery showed significant changes in muscle function. The contributions of the hamstrings to the forward and vertical accelerations were similar to normal gait of the controls before surgery; however, after surgery the contributions to both accelerations were much higher. The quadriceps contributed less to both the forward and vertical accelerations after surgery, and more closely resembled muscle function in normal gait.

These results lend insight into the biomechanics of crouched gait before and after surgical intervention. A limitation of the analysis is that muscle spasticity and co-contraction was not taken into account. Patient-specific musculoskeletal modeling combined with optimization and induced acceleration analysis are powerful tools for analyzing lower-limb muscle function pre- and post-operatively in cerebral palsy gait.

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