ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

Compensation by Residual Muscles During Walking in a Patient After Medioposterior Thigh Muscle Resection for Soft Tissue Sarcoma

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INTRODUCTION

Soft tissue sarcoma (STS) is a relatively rare type of cancer and often occurs in the lower limb, which causes movement disorders due to wide resection involving adjacent muscles. The rare and heterogeneous aspects of STS and the paucity of knowledge of movement strategies in these patients hinder the development of effective exercise prescription for recovering movement after resection of STS in the lower limb.

We report on a patient after thigh muscle resection for STS and describe how he compensated for the loss of muscles during walking. We estimated forces generated by each residual muscle by using musculoskeletal simulation to determine the relationship between muscle function and movement.

METHODS

The patient was a 62-year-old man (height: 1.68 m, body mass: 73.4 kg) diagnosed with leiomyosarcoma. The adductor magnus and longus, gracilis, semitendinosus, semimembranosus, long head of the biceps femoris, sartorius, and posterior part of the vastus medialis on the left (ipsilateral) leg had been resected, and the measurement was performed 9 years after surgery. The study protocol was approved by the Ethical Review Board of the Graduate School of Medicine, Kyoto University. Written informed consent was obtained from the patient prior to data collection.

Experimental data were collected using a 7-camera motion capture system (VICON MX, Vicon, Oxford, UK) with 2 Kistler force plates. Recordings of the standing position and 5 repetitions of level walking at a self-selected speed were collected with 35 retroreflective markers attached to the patient according to the Plug-in Gait protocol (Vicon). Electromyographic (EMG) signals of the gluteus maximus, gluteus medius, vastus lateralis, tibialis anterior, gastrocnemius, and soleus of the ipsilateral side were recorded in each walking trial and used to verify that the estimated muscle forces were consistent with the measured muscle activity. Strength of muscles around the hip (flexors, extensors, adductors, and abductors), knee (flexors and extensors), and ankle (plantar flexors, dorsiflexors) was obtained using a hand-held dynamometer (μ-Tas F-1, ANIMA Corp., Tokyo, Japan).

We generated simulations of the patient's walk by using OpenSim [1]. The marker trajectory and ground reaction force data were processed using C3DToolBox [2] for MATLAB (2012a, MathWorks, Massachusetts, USA) for the analysis in OpenSim.

To create a patient-specific model, we scaled a generic model with 23 degrees of freedom and 92 musculotendon actuators [3-6] by using the marker positions in the upright posture, and resected muscles were deleted from the scaled model (Figure 1). The maximal isometric forces of the muscles on the ipsilateral leg were scaled by the ratio of muscle strength of the ipsilateral leg to that of the contralateral leg to reflect the general weakness of the ipsilateral leg muscles. Specifically, maximal isometric forces of the ipsilateral muscles were multiplied by the ratio derived from corresponding muscle strength (e.g., gluteus medius for the ratio of hip adduction strength).

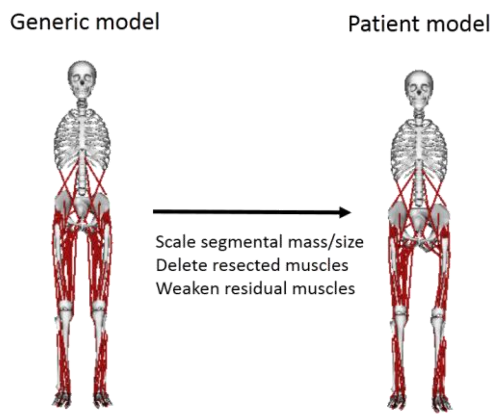

Figure 1: The musculoskeletal model of the patient. Segmental mass and size were scaled, and muscles on the left leg were modified from a generic model.

A least-square algorithm was used in inverse kinematics analysis to predict the joint motions from marker trajectories. After reducing dynamic inconsistency between model kinematics and ground reaction force by using the residual reduction algorithm [1], we estimated muscle forces during walking by the computed muscle control [7]. Muscle excitation was constrained using EMG data as necessary. Because a single trial with 2 force plates was not sufficient to generate a simulation of one complete stride, we connected the results of 2 simulations derived from 2 of 5 trials to obtain the change in muscle forces during one complete stride. We qualitatively compared the estimated muscle forces of each muscle group (hip flexors, hip extensors, hip abductors, knee extensors, and ankle plantar flexors) on the ipsilateral side with those on the contralateral side.

RESULTS AND DISCUSSION

The patient model adequately tracked the original kinematic and kinetic data calculated according to the Plug-in Gait protocol. The average differences of pelvis/lower-limb joint angles and lower-limb joint moments were 4.3° and 1.9% BW, respectively. The patterns of estimated muscle forces agreed qualitatively with the EMG data (Figure 2).

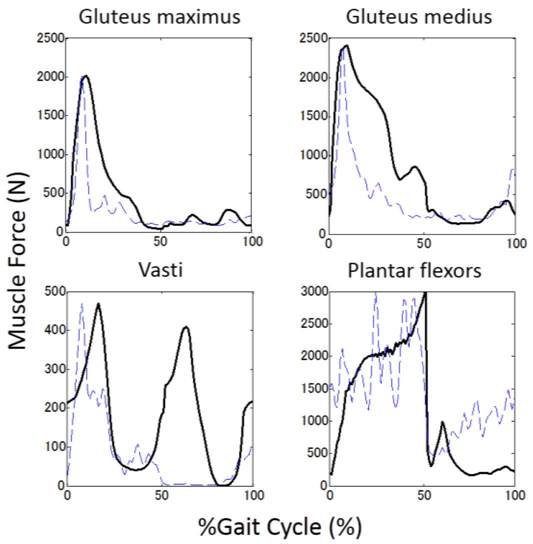

Figure 2: Muscle forces (solid line) and experimental EMG signals (dashed line) of the ipsilateral side. The EMG signals from 5 gait cycles were averaged and normalized for maximal force exerted by corresponding muscle(s). Note that each line of muscle forces has a discontinuous point due to the connection of 2 simulations. The EMG of the vastus lateralis was compared with the summed muscle forces of the vasti (vastus medialis, lateralis, and intermedius). The EMG of the soleus was compared with the summed muscle forces of the plantar flexors (soleus and gastrocnemius).

The muscle forces of interest are shown in Figure 3. The gluteus maximus on the ipsilateral side exerted about 4 times as much force as that on the contralateral side, which might compensate for the loss of bilateral hamstrings that work as hip extensors. The muscle forces of the plantar flexors were larger on the ipsilateral side than on the contralateral side during early stance. Increased muscle forces of the gluteus maximus and plantar flexors might contribute not only to body support as indicated in normal gait [8] but also to reducing the load on the vasti via dynamic coupling. Increased muscle force of the ipsilateral iliopsoas might help stabilize the hip after initial contact by co-contraction with the gluteus maximus, but would pose the risk of excessive stress on the hip. Because hip adductors can extend the hip when the hip is flexed [9], as in the first half of the stance phase during gait, the removal of the adductor muscles might be associated with these increased muscle forces around the hip.

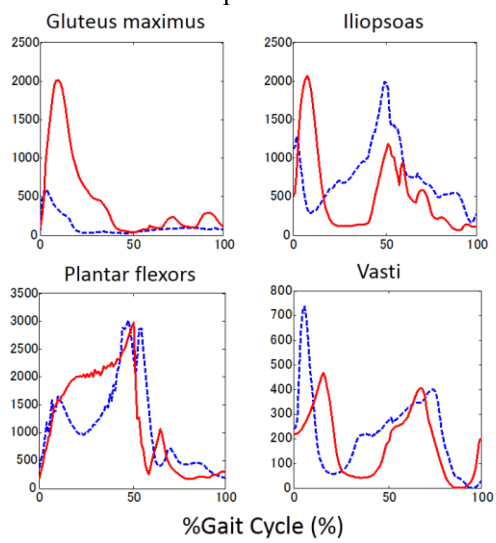

Figure 3: Muscle forces during gait (solid line: ipsilateral side, dashed line: contralateral side)

CONCLUSIONS

In the patient's gait model, the muscle forces of the ipsilateral gluteus maximus, iliopsoas, and plantar flexors were increased during the first half of the stance phase, which would stabilize the supporting leg. Strengthening specific muscles on the ipsilateral leg (e.g., gluteus maximus and plantar flexors in the presented patient) would be helpful for patients after lower-leg muscle resection because compensatory increased muscle forces might cause excessive stress on the residual muscles, which lack force capacity comparable to those on the contralateral side. Further study including induced acceleration analysis will be needed to reveal how these changes in muscle forces influence body support and propulsion, which would help us understand how patients cope with loss of lower-limb musculature during locomotion.

ACKNOWLEDGMENTS

This study was supported by Grant-in-Aid for Japan Society for the Promotion of Science Fellows.

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