ANKLE PLANTAR FLEXOR FORCE CAPACITY DURING TOE WALKING

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INTRODUCTION

Toe walking, a gait deviation associated with a variety of neurological disorders, has been suggested to provide a compensatory advantage due to an observed reduction in net plantar flexor moment in terminal stance compared to heel-toe walking [1, 2]. Perry et al. [3], however, showed that although the net plantar flexor moment decreased during toe walking, muscle activity recorded from the plantar flexors increased, reflecting the need for greater muscle effort (defined by the level of motor unit recruitment). They hypothesized that the dichotomy between increased muscle activity and decreased joint moment was due to a reduction in force generation capacity associated with the increased plantar flexion angle. The goal of the present study was to explicitly test this hypothesis using forward dynamical simulations of toe and heel-toe walking to assess the force generating capacity of the plantar flexors by examining each muscle's contractile state (i.e., fiber activation, length and velocity).

METHODS

Forward dynamical simulations of toe and heel-toe walking were generated using dynamic optimization and a previously described 2D musculoskeletal model developed using SIMM [4], which consisted of a trunk and two legs (femur, tibia, patella and foot for each leg) and fifteen individual muscle actuators per leg [5]. The muscle force generating capacity was governed by normalized force-length and force-velocity relationships (Fig. 1). Muscle excitation patterns were modeled using block patterns and parameter optimization using a simulated annealing algorithm to fine-tune the onset, duration and magnitude of the individual muscle excitation patterns such that the simulations reproduced group averaged experimental kinematic and ground reaction force data previously collected from 10 able-bodied subjects during toe and heel-toe walking [3]. From the walking simulations, individual muscle fiber lengths and velocities during stance were determined from the model and normalized to the optimal fiber length and maximum contraction velocity of each muscle, respectively.

RESULTS AND DISCUSSION

Despite a two-fold increase in soleus (SOL) activation during toe walking, the corresponding SOL muscle force averaged over the stance phase decreased by 13%. Similarly, a 40% increase in gastrocnemius activation during toe walking only produced a 2% increase in muscle force. The lack of increased force production with greater activation was attributed to a poor contractile state during toe walking, primarily muscle fiber lengths (Fig. 2) that were too short on the active force length relationship (Fig. 1A) as a result of the increased plantar flexion angle. The average fiber velocities were similar

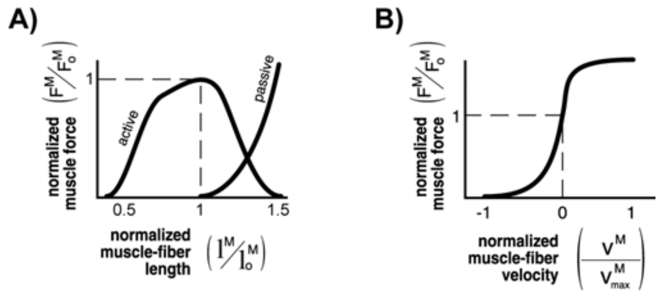

Figure 1: Governing intrinsic muscle properties used in the model: A) normalized force-length and B) force-velocity relationships [4]. With deviations from the muscle fiber's optimal length and increasing rates of shortening, the ability of a muscle to produce force decreases.

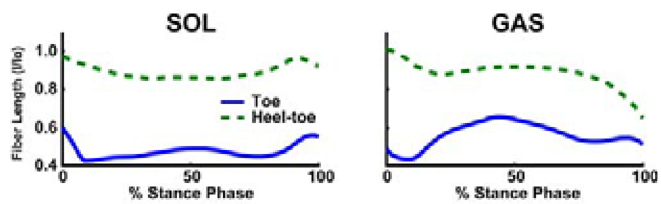

Figure 2: Simulation soleus (SOL) and medial gastrocnemius (GAS) muscle fiber lengths during the stance phase normalized to their optimal lengths.

between the two walking tasks. These results were consistent with Hampton et al. [1] who showed that plantar flexor force decreased during toe walking. Their study used a static decomposition of the ankle joint moment derived from inverse dynamics. However, their analysis did not consider the contractile state of the muscles (i.e., fiber activation, length and velocity) in their assessment of muscle effort. Our simulation-based analysis suggests that toe walking may not be an advantageous compensatory strategy as previously suggested [1, 2] due to the increased muscle activation necessary to overcome the poor contractile state [3]. However, it is possible that spasticity and prolonged equinus foot posture may alter the intrinsic muscle properties such that peak muscle force is generated at shorter fiber lengths [6]. Assessing this possibility remains as future work.

REFERENCES

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