INFLUENCE OF MUSCULOSKELETAL GEOMETRY ON MODEL-BASED PREDICTIONS OF PLANTARFLEXOR FUNCTION DURING GAIT

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INTRODUCTION

Gait simulations have become ubiquitous tools for studying muscle function in normal and pathological states. However, almost all current gait models utilize average musculoskeletal geometry [4], which cannot account for the variability in function that arises due to differences in musculoskeletal geometry. This issue is particularly salient for biarticular muscles, in which the capacity to induce motion at one joint is highly dependent on its moment arm at the neighboring joint. For example during standing, models suggest that the gastrocnemius will induce dorsiflexion if its knee flexor moment arm is greater than 50% of its plantarflexor (pf) moment arm [1]. This non-intuitive function may extend to gait where empirical studies have shown that stimulating the gastrocnemius can induce limb flexion while stimulating the soleus induces limb extension [2,3]. The goal of this study was twofold: a) assess whether generic gait simulations can correctly delineate the dynamic function of the gastrocnemius and soleus, and b) investigate the effect of known variations in gastrocnemius geometry on predictions of dynamic muscle function.

CLINICAL SIGNIFICANCE

Skeletal deformities and surgical procedures can significantly alter the moment arms of muscles in the lower extremity. Hence, an understanding of the sensitivity of muscle function to variations in musculoskeletal geometry is relevant for identifying the causes of pathological gait, and for planning treatment to correct movement abnormalities.

METHODS

All gait simulations were performed using a 3D, 31 degree of freedom gait model with 44 musculotendon units acting about the hip, knee and ankle of each limb [4]. A computed muscle control (CMC) algorithm [5] was used to determine muscle activations that drove the model to optimally track measured kinematics during a normal, overground gait cycle (1.43 m/s). Muscle excitation and EMG activities were compared to ensure the simulation reflected normative coordination patterns. We then increased the excitation of the soleus or medial gastrocnemius between 20-30% of the gait cycle, and reran the simulation. The induced differences between the nominal and perturbed joint angle trajectories were used to quantify dynamic muscle function. This process was repeated using musculoskeletal geometries in which the gastrocnemius insertion was varied by +/- 1cm (as seen in [6]), which varied the knee flexion-to-ankle pf moment arm ratio (r_K/r_A) from 0.42 to 0.67. We compared the model predictions to our experimental measures of dynamic muscle function [5]. In the experiments, the gastrocnemius and soleus were electrically stimulated from 20-30% of the gait cycle and induced changes in joint angles were measured in 10 healthy young adults [3].

RESULTS

The generic gait model predicted unique function for the individual plantarflexors, with gastrocnemius inducing hip and knee flexion and ankle dorsiflexion, and the soleus inducing hip and knee extension and ankle plantarflexion (Fig. 1). Model predictions were sensitive to musculoskeletal geometry, with a physiologic increase in relative size of the gastrocnemius knee flexor moment arm doubling the amount of flexion induced at the hip and knee.

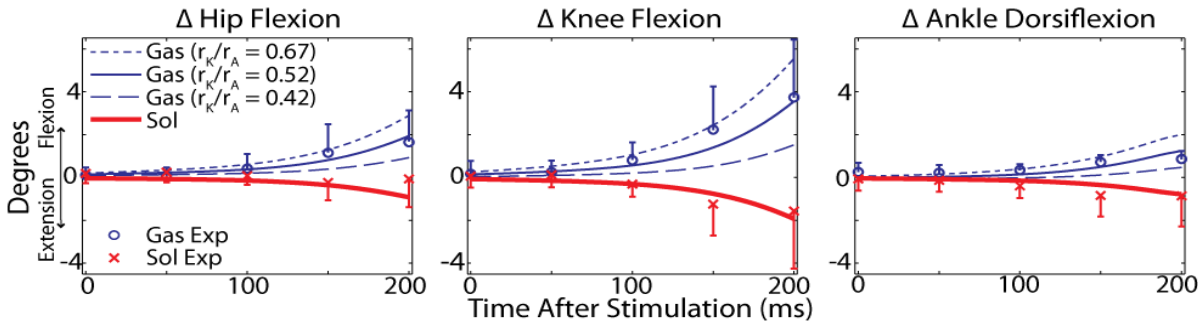

Figure 1: Change in hip flexion, knee flexion, and dorsiflexion as a result of excitation of the gastrocnemius (blue) and soleus (red). Experimental results are presented with error bars signifying one standard deviation [3]. Nominal model predications are represented by the solid lines (r_K/r_A = 0.52). Dashed lines indicate altered moment arm ratios (r_K/r_A = 0.67 and 0.42).

DISCUSSION

This study shows that dynamic gait simulations based on a generic musculoskeletal model [4] can correctly discriminate the disparate function of the gastrocnemius and soleus during normal walking. However, we also show that gastrocnemius can exhibit marked variations in function within a normal physiological range of musculoskeletal geometry [6]. These results demonstrate that caution should be taken when generalizing muscle function predictions based on generic models, and that the use of patient-specific musculoskeletal geometry should be considered when using gait models to assess pathologies and plan treatment.

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DISCLOSURE STATEMENT

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