Muscle Actions during the Stance Phase of Normal Gait: Implications for the Treatment of Crouch Gait

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Introduction

Tight hamstrings and other muscles that are thought to restrict movement are often lengthened surgically or injected with botulinum toxin in an effort to improve stance phase knee extension and hip extension in persons with crouch gait. At present, the outcomes of these procedures are inconsistent. Correction of crouch gait is difficult, in part, because *(i)* the factors that control extension of the hip and the knee during normal gait are not well understood, and *(ii)* the potential of individual muscles to produce flexion and extension of the joints during the stance phase has not been rigorously evaluated. Hence, a theoretical framework for elucidating which muscles contribute to crouch gait does not exist.

Dynamic simulation offers a powerful framework for determining the multijoint accelerations produced by muscles during movement, and knowledge of the accelerations produced by muscles provides important evidence for discerning the actions of a muscle on the body. The actions of muscles are not necessarily intuitive; e.g., motions of the knee may be influenced not only by muscles that cross the knee, but also by muscular moments that are generated at other joints (Zajac and Gordon, 1989). This study uses dynamic simulation to quantify the angular accelerations of the hip and the knee induced by the hamstrings, gluteus maximus, vasti, soleus, gastrocnemius, iliopsoas and other muscles during normal gait.

Statement of Clinical Significance

Improving the treatment of crouch gait and other movement abnormalities in children with cerebral palsy is challenging because currently there is no theoretical basis for determining the biomechanical causes of an individual's abnormal gait. Identification of the key factors that control hip and knee extension during normal gait— via dynamic models that enable the functional actions of muscles to be identified— is an essential step toward explaining the pathomechanics of crouch gait and the consequences of common interventions.

Methodology

The angular accelerations of the hip and the knee induced by the hamstrings and other muscles during the stance phase were determined based on the dynamic optimization solution for normal gait solved by Anderson and Pandy (2001). At each time step in the simulation, the contributions of a muscle to the angular accelerations of the joints were computed by applying the force of the muscle and the corresponding portion of the ground reaction force caused by the muscle to the model. All of the other muscular forces, gravitational forces, and force terms arising from angular velocities were set to zero. The portion of the ground reaction force caused by each muscle was estimated by assuming the foot to be in rigid contact with the ground (Anderson and Pandy, in press). The muscle-induced accelerations *per unit force* also were calculated to quantify the potential of each muscle to accelerate the joints toward flexion or extension during the stance phase.

Results and Discussion

Our dynamic analysis of muscle function shows that the gluteus maximus and the soleus, in addition to the vasti, make substantial contributions to knee extension during the stance phase of normal gait (Fig. 1B). In fact, per unit force, the gluteus maximus has greater potential than the vasti to accelerate the knee toward extension (Fig. 1D). The gluteus maximus, vasti, and the soleus also help to generate normal hip extension (Fig. 1A). These data suggest that the excessive hip and knee flexion of persons with crouch gait may be caused by insufficient capacity of the hip extensors, knee extensors, or ankle plantarflexors to accelerate the limb into extension. Abnormal forces generated by a tight iliopsoas or a spastic gastrocnemius may also contribute to crouch gait, since these muscles have the potential to accelerate the hip and the knee toward flexion (Figs. 1C, D). The hamstrings have little effect on stance phase knee motion in our simulation of normal gait (Figs. 1B); interestingly, analysis of the model reveals that the hamstrings have the potential to produce stance phase knee *extension* (Fig. 1D). This result suggests that tight hamstrings— a reputed cause of crouch gait— may not be the direct source of excessive knee flexion in some patients. This study emphasizes the need to consider how muscular forces contribute to multijoint movements when attempting to identify the causes of abnormal gait.

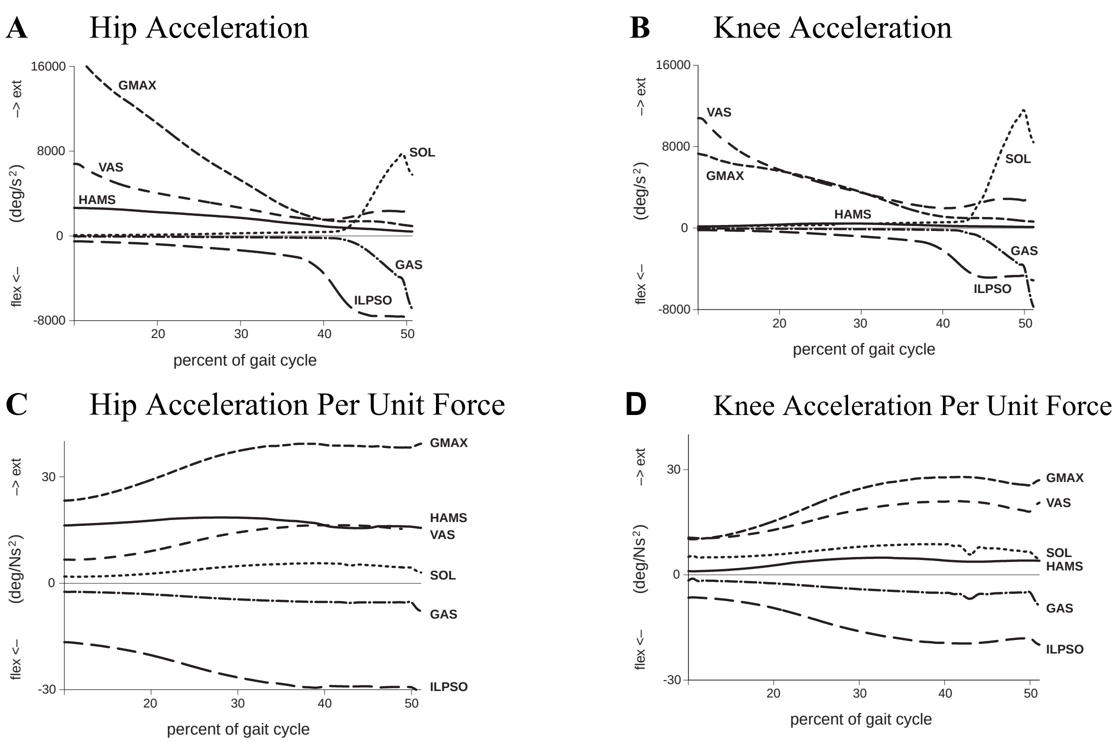

Figure 1. Angular accelerations of the hip and the knee (A, B) and angular accelerations per unit force (C, D) induced by the hamstrings *(HAMS)*, gluteus maximus *(GMAX)*, vasti *(VAS)*, soleus *(SOL)*, gastrocnemius *(GAS)*, and iliopsoas *(ILPSO)* during the single support phase of normal gait.

References

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