Accuracy of Hamstrings and Psoas Lengths Estimated with a Deformable Model

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Introduction

The medial hamstrings and psoas muscles are often lengthened surgically in an effort to correct crouch gait in persons with cerebral palsy. At present, it is difficult to predict which patients will benefit from these procedures. Several studies have suggested that analyses of the muscle-tendon lengths during crouch gait may help distinguish patients who have short muscles from those who do not have short muscles, and thus may provide a more effective means to identify appropriate candidates for surgery (e.g. Hoffinger *et al.* 1993, Delp *et al.* 1996). These studies have relied on "generic" models of the lower extremity with normal adult musculoskeletal geometry; however, many individuals who undergo these surgeries are children with femoral deformities. It is not known how variations in size, age, or femoral geometry affect the accuracy of muscle-tendon length calculations. Schutte *et al.* (1997) modified a generic model to investigate the sensitivity of hamstrings and psoas lengths to femoral anteversion angle. Hamstrings lengths computed with their "deformed" model were similar to the lengths calculated with their undeformed model; psoas lengths varied with deformation of the femur. Schutte *et al.* did not validate their model on the basis of patient-specific descriptions of anatomy, such as data from medial images. Hence, whether a generic model— deformed or undeformed— can provide reliable estimates of muscle-tendon lengths in persons with femoral deformities remains unclear. The purpose of this study was to determine if, and under what conditions, medial hamstrings and psoas lengths estimated with a "deformable" model of the lower extremity accurately characterize the lengths of the muscles in persons with crouch gait.

Statement of Clinical Significance

Before musculoskeletal models can be widely used to guide treatment decisions for crouch gait, the accuracy of the muscle-tendon lengths calculated with these models must be demonstrated. This study suggests that a generic model, in combination with simple normalization techniques, can provide reasonably accurate estimates of medial hamstrings lengths in most cases. Our data also show that the accuracy of psoas lengths estimated with a generic model can be enhanced with a small number of subject-specific parameters and algorithms for deforming the femur.

Methodology

A graphics-based model of the lower extremity with a "deformable" femur was developed. This model characterizes the geometry of the bones, the kinematics of the hip and tibiofemoral joints, and the paths of the medial hamstrings and psoas muscles for an average-sized adult male. The model is similar to deformable models we have used in previous studies (e.g., Arnold *et al.* 1997) with several notable improvements. For example, we defined "wrapping surfaces" to simulate interactions between the muscles and surrounding structures, and we developed new algorithms to alter the geometry of the proximal femur. These algorithms were based on careful inspection of the deformed femurs of four subjects with cerebral palsy constructed from MR images.

We evaluated our deformable model by creating detailed models of four individuals with crouch gait (ages 7-27 yrs) from an extensive set of MR images (Arnold *et al.* 2000a,b). We used these models, in conjunction with each subject's measured gait kinematics, to calculate the lengths of the semimembranosus, semitendinosus, and psoas muscles at the joint angles corresponding to walking. The muscle-tendon lengths calculated with the MR-based models were compared to the lengths estimated using four variations of the deformable model: *(i)* the undeformed model, *(ii)* the model scaled to the subject along anatomical axes, *(iii)* the model deformed to match the subject's femoral anteversion angle, called Deformed Model A, and *(iv)* the model deformed to match the subject's anteversion and neck-shaft angles, called Deformed Model B. The lengths of the muscles during crouch gait (L_i) were normalized at every 2% of the gait cycle based on the maximum averaged length (L_{max}) and the minimum averaged length (L_{min}) of the muscle during normal walking as follows:

$$\hat{L}_i = (L_i - L_{min}) / (L_{max} - L_{min}),$$