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Accuracy of generic musculoskeletal models in predicting the functional roles of muscles in human gait

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ABSTRACT

Biomechanical assessments of muscle function are often performed using a generic musculoskeletal model created from anatomical measurements obtained from cadavers. Understanding the validity of using generic models to study movement biomechanics is critical, especially when such models are applied to analyze the walking patterns of persons with impaired mobility. The aim of this study was to evaluate the accuracy of scaled-generic models in determining the moment arms and functional roles of the lower-limb muscles during gait. The functional role of a muscle was described by its potential to contribute to the acceleration of a joint or the acceleration of the whole-body center of mass. A muscle's potential acceleration was defined as the acceleration induced by a unit of muscle force. Dynamic simulations of walking were generated for four children with cerebral palsy and five age-matched controls. Each subject was represented by a scaled-generic model and a model developed from magnetic resonance (MR) imaging. Calculations obtained from the scaled-generic model of each subject were evaluated against those derived from the corresponding MR-based model. Substantial differences were found in the muscle moment arms computed using the two models. These differences propagated to calculations of muscle potential accelerations, but predictions of muscle function (i.e., the direction in which a muscle accelerated a joint or the center of mass and the magnitude of the muscle's potential acceleration relative to that of other muscles) were consistent between the two modeling techniques. Our findings suggest that scaled-generic models and image-based models yield similar assessments of muscle function in both normal and pathological gait.

1. Introduction

Biomechanical assessments of muscle function are often performed using generic models of the body. Generic musculoskeletal models (e.g., Amis et al., 1979; Delp et al., 1990; Holzbaur et al., 2005; Klein Horsman et al., 2007; Ward et al., 2009) are typically based on measurements obtained from cadaveric specimens or medical images, and are presumed to be representative of able-bodied adults. Scaled-generic models are created by scaling body-segment anthropometry, joint geometry, and muscle-tendon attachment sites in the model to corresponding parameters in individual subjects. Such scaling requires measurements of body mass and limb lengths, the latter often estimated from surface-mounted markers or from direct measurements of distances between anatomical landmarks. The accuracy of scaled-generic models in representing musculoskeletal anatomy remains largely untested, mainly because of the time-intensive nature of creating benchmark models from subject-specific medical images. Scheys et al. (2008a, 2008b) assessed the mechanical advantage (i.e., moment arms) of individual muscles computed from scaled-generic and image-based models, and found significant errors due to inter-subject anatomical variability and bony abnormalities. However, no study to our knowledge has determined the effects of scaling on muscle function during any task. Understanding the validity of using scaled-generic models to study movement biomechanics is critical, especially for patients with conditions such as cerebral palsy (CP), where bone and muscle abnormalities are the rule rather than the exception.

Magnetic resonance (MR) scanners provide high-resolution images that allow visualization of anatomical structures *in vivo*. From these images, geometrical model parameters can be found to describe joint locations and orientations, muscle attachment sites, and bony torsion (Scheys et al., 2006; Blemker et al., 2007). MR-based models are able to reproduce bone geometry accurately (Smith et al., 1989) and have been shown to closely approximate muscle moment-arm measurements obtained from cadaver specimens (Murray et al., 1998; Arnold et al., 2000). Although processing algorithms can expedite extraction of bone structures (Hoad and Martel, 2002; Zoroofi et al., 2004) and muscle paths (Scheys et al., 2009),

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