INFLUENCE OF UPPER LIMB MODEL PARAMETERS IN ISOMETRIC AND ISOKINETIC TASKS

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Introduction

Subject-specific models could assist physicians in diagnosing impairments and informing personalized care. Yet, most subject-specific models are hindered by a limited understanding of how model parameters influence predictions [1]. Although parameter sensitivity has been explored for gait [2], little is known about parameter sensitivity for upper limb tasks. Additionally, to what extent current upper limb models can accurately represent both healthy and pathologic populations is unknown. Thus, the objective of this study was to characterize how muscle and bone parameters influence predicted muscle activations during isometric versus isokinetic upper limb tasks. We specifically evaluated a broad range of bone densities (BD), optimal fiber lengths (OFL), physiological cross section areas (PCSA), and pennation angles (PA) due to their influence on muscle force production and recruitment [3-5].

Methods

A total of 401 parameter sets were defined to characterize healthy and pathologic BD, OFL, PCSA, and PA. First, a baseline parameter set was defined based on a validated upper limb model that represents an average adult male [6]. Then, the other 400 parameter sets were defined by varying each parameter from the baseline 100 times. Parameter values varied in equal steps across reported ranges of upper limb atrophy, hypertrophy, osteoporosis, and osteopetrosis [3-5].

To assess how parameters influenced predicted muscle activations, computed muscle control simulations were performed in OpenSim 4.1. For these simulations, each parameter set was applied to two models (a full arm model [6] and a thumb model [7]) and 3 tasks (1 isometric, 2 isokinetic) were simulated. The isometric task was a 40N lateral pinch task. The isokinetic tasks consisted of a distal task (wrist extension from 0º to 50º to 0º), and a proximal task (elbow flexion from 90º to 110º to 90º). To minimize simulation time, the full arm model was used for the isokinetic tasks, while the thumb model was used for the isometric task. Given 401 parameter sets and 3 tasks, a total of 1,203 simulations were performed.

We compute the Pearson correlation coefficient between each of our four parameters (BD, OFL, PCSA, and PA) and the area under the muscle activation curve (AUC) for the 14 muscles shared across both models. A high correlation indicates predicted muscle activations are sensitive to changes in the parameter, whereas low correlation indicates little to no effect on muscle activations. To identify differences between parameters and baseline, an ANOVA was performed followed by multiple comparisons with a Bonferroni correction.

Results and Discussion

During the isometric task, BD and PA did not influence muscle activation during lateral pinch. BD and PA exhibited no correlation with AUC ($r=0$) for most muscles (Fig. 1). Post hoc testing found no significant difference ($p>0.99$) from baseline. This suggests that for subject-specific lateral pinch models, it may be superfluous to incorporate subject-specific PA and BD.

In contrast, BD and PA were influential during isokinetic tasks. Despite little correlation between AUC and parameters during the distal isokinetic task, post hoc testing revealed AUC significantly ($p<0.01$) differed from baseline for all parameters. Further, during the proximal isokinetic task, BD was strongly correlated ($r>0.75$, $p<0.001$) for three muscles, suggesting isokinetic tasks informs identification of subject-specific BD.

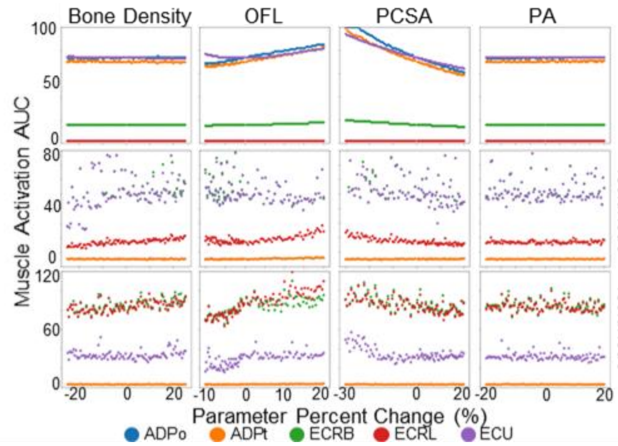

Figure 1: AUC of the muscle activation curve versus each parameter represented as percent change from baseline. Only five representative muscles are plotted due to space constraints. Correlations are indicated by non-horizontal lines. For example, OFL and PCSA have strong correlation ($|r|>0.8$, $p<0.01$) with AUC for most muscles during the isometric task. BD is correlated with AUC in the isokinetic tasks.

A difference between the isokinetic and isometric tasks is that muscle activations during isometric tasks were highly sequential, but isokinetic tasks resulted in increased variability (Fig. 1, higher spread in isokinetic tasks). It is believed the additional 41 muscles in the full arm model used for the isokinetic tasks provided compensatory solutions causing the variation. Due to strong correlations, it may be possible to create algorithms that identify subjects' PCSA and OFL from isometric tasks, and then use an isokinetic task to compute BD.

Significance

This work utilizes large datasets to capture the diversity of the human population and upper limb tasks to understand how subject-specific parameters influence hand model predictions.

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