FUNCTIONAL IMPLICATIONS OF OPTIMAL MUSCLE FIBER LENGTHS OF THE ANKLE PLANTARFLEXORS

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INTRODUCTION

Computer models of the lower limb that characterize the geometry and force-generating properties of muscles are widely used. Models of the lower limb have been created primarily from descriptions of muscle architecture published by Wickiewicz et al. (1983) and Friederich and Brand (1990). These reports of muscle architecture were based on a small number of subjects, three and two, respectively, and the models that incorporate these data have several limitations. One important limitation is that lower-limb models predict that the ankle plantarflexors generate force over a more narrow range of ankle angles than human subjects do (Delp et al., 1990). Two possible reasons for this discrepancy are; the assumption that all fibers within a muscle are the same length is incorrect or the fiber lengths reported in previous studies are incorrect.

Ward et al. recently measured lower extremity muscle architecture in 20 subjects (submitted to ASB 2007). The purpose of our study was to evaluate the functional consequences of the new architecture data—specifically, to model how differences in the optimal fiber lengths of the ankle plantarflexors affect their force-generating capacities over a range of ankle angles.

METHODS

We developed two models of the ankle plantarflexors. The first was based on data reported by Wickiewicz et al. (1983) and the second was based on the data reported by Ward et al. (2007). The two models had identical bone geometry, muscle paths, and joint kinematics. As a result, differences in the relationship between muscle fiber length and ankle angle arose solely from differences in muscle architecture.

Wickiewicz et al. (1983) reported the cross-sectional area of gastrocnemius as a single muscle instead of separating the two heads. For the model based on these data, we divided cross-sectional area between the two compartments according to proportions used by Delp et al. (1990).

For the model based on the optimal fiber lengths reported by Ward et al., we estimated tendon slack lengths (L^T_s) by making adjustments until we obtained the L^T_s value that produced a fiber length that matched the experimentally derived fiber lengths at the same joint angles measured in the specimens. This process resulted in tendons that produced too much passive force during dorsiflexion. We lengthened the tendons slightly, 9.0, 6.1, and 6.6% for soleus, and medial and lateral gastrocnemius respectively, so that passive forces were more consistent with experimental results (Siegler 1988).

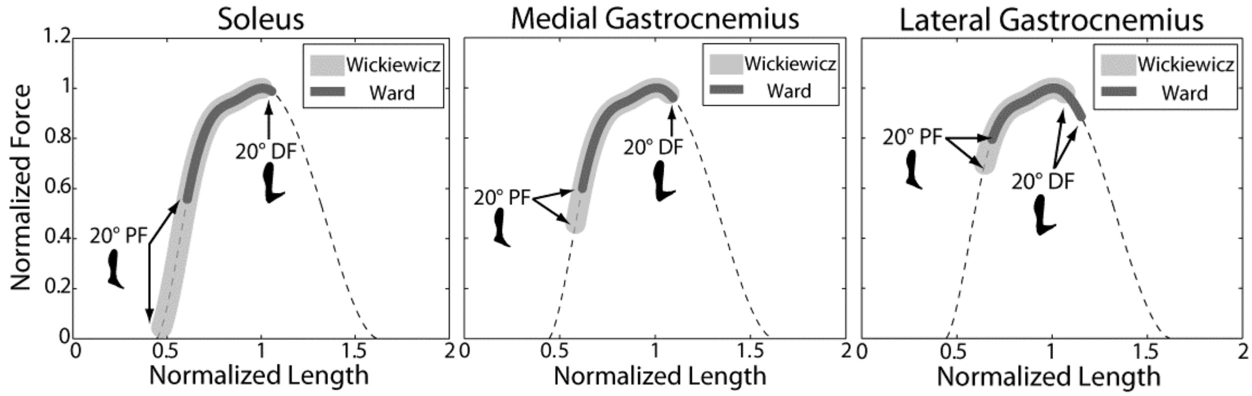

Figure 1: Normalized force-length curves for soleus, and medial and lateral gastrocnemius. The models of soleus and medial gastrocnemius with properties based on the architecture data of Ward et al. (2007) operate on a more narrow region of the force-length curve and maintain greater force-generating capacity over a 20° plantarflexion to 20° dorsiflexion range of motion than models of these muscles based on architecture data from Wickiewicz et al. (1983).

RESULTS AND DISCUSSION

Average optimal fiber length of soleus was significantly longer in the data from Ward et al. (2007) compared to the data reported by Wickiewicz et al. (1983; Table 1). This produced a substantial change in the force-generating characteristics of the soleus. Soleus was able to exert a greater fraction of its maximum force over the 20° plantarflexion to 20° dorsiflexion range of motion with the longer fiber length (Figure 1). Additionally, the slightly longer fibers of the medial gastrocnemius reported by Ward et al. increased the muscle's force-generating capacity over the range of motion. Lateral gastrocnemius had similar fiber lengths in the two data sets; thus, the range of operating lengths was similar in the two models.

These changes represent a significant improvement for musculoskeletal modeling because the plantarflexors are predicted to exert force over a broader, more experimentally-consistent range of ankle angles than previous models. This result is particularly important for creating simulations of actions such as walking and jumping in which the plantarflexors generate large moments about the ankle. Previous simulations based on shorter fiber lengths result in over-activation of these muscles to compensate for the fact that they were predicted to exert low forces when the ankle joint was plantarflexed.

Table 1: Mean optimal fiber lengths ± SD (cm) for the major plantarflexors in the two data sets.

	Wickiewicz	Ward
Soleus	2.39±0.09*	4.40±0.99 §
Medial Gas	4.34±0.43**	5.10±0.98 §
Lateral Gas	6.22±1.19**	5.88±0.95 §

* n = 2; ** n = 3; § n = 20

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