SUBJECT-SPECIFIC FORCE-LENGTH PARAMETERS OF THE ANKLE PLANTARFLEXORS IN YOUNG ADULTS

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INTRODUCTION

Neuromuscular aspects of human athletic activities are often investigated by computer simulations that actuate a musculoskeletal model with Hill-based muscle models. Many simulations solve tracking problems, where design variables within the simulation are optimized to minimize the error between the model's performance and the performances of human subjects (*e.g*. Neptune *et al*., 2000).

If simulations are performed on a subject-specific basis (tracking kinematics and kinetics from specific individuals; Neptune *et al*., 2000; McLean *et al.*, 2003), it is important to tune the parameters of the muscle models to the force production capabilities of each individual to faithfully simulate the muscle mechanics of the movement. However, muscle model parameters are often taken from the literature and are not derived on an individual basis.

Previous research has suggested the need for subject-specific muscle model parameters by demonstrating the sensitivity of simulation output to input parameter values, in particular the maximum isometric muscle force (*Fo*), the optimal contractile component length (*Lo*), and the unloaded series elastic component length (*Lu*) (Pandy, 1990; Scovil & Ronsky, 2006; Redl *et al*., 2007). It would seem important, therefore, to know how these parameters vary among individuals. If muscle model parameters vary considerably between individuals, they should be derived on an individual basis in order for simulations to be truly subject-specific.

The purpose was to determine subject-specific muscle model parameters for the plantarflexors in healthy young subjects, and to compare their values to values used for subject-specific simulations in the literature.

METHODS

Twelve young, active subjects (six males, six females) performed maximum isometric plantarflexion on a dynamometer. Trials were performed at five different ankle angles, and at two different knee angles to account for the biarticularity of gastrocnemius. Moment and angle data were sampled at 1000 Hz. Peak ankle joint moments developed at each angle were extracted to construct experimental ankle joint moment-angle (M-θ) relationships.

Simulations were performed at each joint configuration with a musculoskeletal model of the leg actuated by Hill models of soleus (SO) and gastrocnemius (GA). Simulations assumed full plantarflexor activation and no dorsiflexor co-activation. Muscle lengths and moment arms were estimated using OpenSim software and scaled to the segment lengths of each subject. *Fo*, *Lo*, *Lu*, and force-length parabola widths (W) for SO and GA were then optimized by genetic evolution to minimize the error between modeled and experimental M-θ curves.

RESULTS

Subject-specific results are presented for four subjects (two males, two females). The average error between experimental and modeled moments was < 5 Nm (*e.g.* Fig. 1). Moments and muscle forces dropped as the plantarflexion angle increased. Muscles operated on the ascending limb of the force-length relationship.

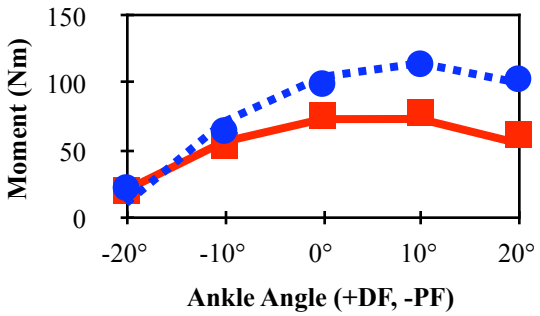

Figure 1. Modeled (symb.) and experimental (line) *M*-θ profiles with the knee **flexed** (—) and **extended** (· · · ·) for Subject #1.

Fo, Lo, and *W* varied substantially between subjects, with coefficient of variation (CV) values between 20-40%, while *Lu* was more consistent (CV: 2% for SO, 10% for GA). Table 1 shows results for these four subjects.

Table 1. Muscle model parameters for SO and GA in four subjects. N00: Neptune *et al*., 2000. M03: McLean *et al*., 2003.

	Fo (kN)		*Lo* (cm)		*Lu* (cm)		*W* (% *Lo*)	
Subj	**SO**	**GA**	**SO**	**GA**	**SO**	**GA**	**SO**	**GA**
#1 m	2.0	1.7	5.4	4.4	23.1	41.5	35	67
#2 f	2.2	2.8	3.4	7.7	22.1	35.5	52	60
#3 m	2.9	1.3	7.6	8.9	23.3	36.0	43	98
#4 f	1.8	0.9	6.1	6.9	23.2	32.8	82	100
Mean	2.2	1.6	5.6	7.0	22.9	36.7	53	81
SD	0.5	0.8	1.8	1.9	0.5	3.6	20	20
CV	21	49	31	28	2	10	38	25
N00	5.6	3.2	2.7	4.3	26.8	40.8	--	--
M03	2.8	1.6	3.0	5.1	26.8	40.1	1.0	0.9

DISCUSSION

Plantarflexor force-length parameters varied substantially between subjects. These findings were evident even though the subjects were similar in age and fitness level. Values for *Fo* were comparable to McLean *et al*. (2003), but were much smaller than Neptune *et al*. (2000). *Lo* tended to be longer than both referenced studies. *Lu* was relatively homogenous between subjects, and slightly shorter than the references. Further work is needed on other muscle groups.

The ranges of values exhibited for *Fo*, *Lo*, and *W* were similar to the ranges tested by Scovil and Ronsky (2006), who found that joint kinematics and ground reaction forces during locomotor simulations were highly sensitive to input values for *Fo* and *Lo*. Subject-specific simulations should therefore derive these parameters on a subject-specific basis in order to faithfully represent the muscle mechanics of the modeled individual. Applicable methods include modeling, optimization, and imaging (MRI, ultrasound).

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