EXPERIMENTALLY DERIVED MUSCULOTENDON PARAMETERS FOR THE HUMAN SOLEUS: FIBER LENGTH, PENNATION ANGLE AND ISOMETRIC FORCE

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INTRODUCTION

The soleus is the dominant plantar flexor and plays a key role in maintaining posture and balance [1]. The soleus has been associated with risk of falling and is prone to contracture resulting in reduced range of motion with adverse affects on gait and balance. Accurately characterizing the force-length properties of the human soleus is important for basic clinical research and critical for those constructing musculoskeletal models if such models are to further our understanding of gait and posture in healthy and pathological populations.

The purpose of this paper is to report *in-vivo* values of optimal fiber length, pennation angle, maximum isometric force and the operating range for the soleus across a range of ankle angles typical of normal gait.

METHODS

Seven healthy male subjects participated in this study. All subjects submitted written informed consent prior to testing. Musculotendon parameters for the soleus were determined as follows. Firstly, subjects were positioned kneeling in a Biodex dynamometer (Figure 1). Knee flexion was maintained at 120-125 degrees throughout testing to minimize force contribution from the gastrocnemii. Subjects performed two maximum isometric contractions at each of 10 joint angles ranging between 20 degrees of plantar flexion and 25 degrees of dorsiflexion. A rest period was provided between trials to minimize fatigue. A previously described technique for computing Achilles tendon moment arm was applied at each of the joint angles tested [2]. Isometric force was calculated by dividing the plantar flexion moment by the Achilles tendon moment arm. Fiber length and pennation angle were measured from the sonograms. Fiber length at the ankle angle isometric force was maximal was defined as optimal fiber length. Fiber length and forces at all other angles were normalized to optimal length and maximum force.

Figure 1. Subject positioning.

RESULTS AND DISCUSSION

Subject characteristics and muscle parameters defining the force-length relationship are given in Table 1. Optimal length computed in this study agreed closely with values reported by Maganaris [3]; however isometric force between studies differed significantly. We believe this to be largely related to subject positioning.

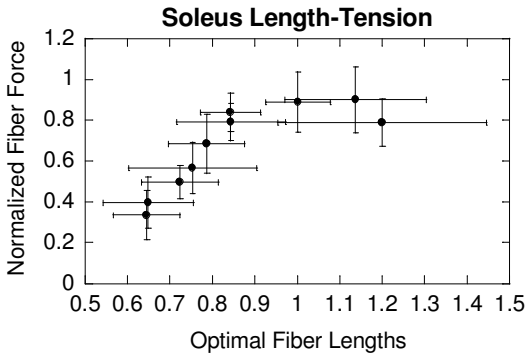

Figure 2: Normalized fiber force and length with vertical and horizontal bars showing standard deviations. See Table 1 for subject averages and standard deviations.

Figure 2 illustrates the length tension relationship for the subjects in our study. Normalized fiber length ranged from 0.62 to 1.14 optimal lengths. The soleus was weakest when tested in 20 degrees of plantar flexion generating approximately 35% of its maximum isometric force. Peak isometric force occurred with the ankle dorsiflexed at 18.1 degrees.

CONCLUSIONS

Peak plantar flexion moment during stance occurs when the ankle is dorsiflexed between 10 and 15 degrees. Based on the results of our study we suggest the soleus operates near optimal length when the torque demands during stance are greatest. Average values and deviations reported in this study combined with an approximation of the operating range for the soleus will benefit future work examining how the ankle plantar flexors contribute to gait and posture.

ACKNOWLEDGEMENTS

NIH RR016458, AR46386 & AR48212

REFERENCES

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2. Cowder J, et al., *ASME Summer Bioengineering Conference*, 2008.
3. Maganaris CN, *Acta Physiol Scand.* **172**:279-285, 2004

Table 1: Subject characteristics and architectural measures of 6 healthy male subjects. Angle indicates ankle angle corresponding to peak isometric force. MA = moment arm; OFL = optimal fiber length

Age (yrs)	Height (m)	Weight (kg)	Angle (°)	Moment (N·m)	MA (cm)	Force (N)	Penn (°)	OFL(cm)
22.4 ± 1.3	1.78 ± 0.05	79.4 ±11.67	18.1 ± 3.6	69.8 ± 29.4	3.7 ± 0.4	1840 ± 629	25.0 ± 4.1	3.6 ± 0.6