A NOVEL APPROACH FOR EXPERIMENTAL DERIVED MUSCLE PARAMETERS OF THE SOLEUS MUSCLE

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INTRODUCTION

A muscle's architecture influences the force it can produce and where on the length tension curve it operates. Being able accurately describe a muscle would be of great advantage for clinical research and critical for those who are creating musculoskeletal models.

The soleus is one of the strongest muscles in the body and along with the gastrocnemii produce approximately 90% of the plantarflexion moment at the ankle. The soleus plays a critical role for maintaining posture, balance, and gait [1]. At high knee flexion (> 100°) the gastrocnemii become shortened and are unable to produce significant force. With the knee in this position the plantarflexion moment would be primarily the product of the soleus. The force produced by the soleus can then be approximated from the plantarflexion moment and moment arm of the Achilles tendon. The force along with fiber length and pennation angle through the range of ankle motion would allow for the characterization of the soleus muscle architecture and force-length relationship.

The purpose of this paper is to present a novel approach, which utilizes ultrasound, to characterize the architecture of a muscle and present a study of the soleus describing its isometric force, fiber length, and pennation angles through normal range of motion.

METHODS

8 healthy male subjects (23.1 ±2.3 yrs, 1.8 ±.06 meters, 80.8 ±11.6 kgs) participated in the study. The experimental protocol was approved by the Human Subjects Review Board at the University of Delaware. All subjects submitted written informed consent prior to testing.

Muscle parameter measurements were taken with the subjects in a kneeling position (Figure 1) in an isokinetic dynamometer (Biodex System 3, Shirley, NY). Plantarflexion moments at maximum voluntary contraction (MVC) and ultrasound images (Aloka SSD-5000, Tokyo, Japan; 60 mm linear probe, B-mode, 10 MHz) of the belly of the soleus muscle were recorded simultaneously at 5 degree increments from 25° dorsiflexion to 20° plantarflexion. Knee angles were maintained at a flexion angle of 120° to 125° to minimize the contribution of the gastrocnemii to the plantarflexion moment. The Achilles tendon moment arm was found using a hybrid method combining a 7 camera motion analysis system

Figure 1: Subject positioning

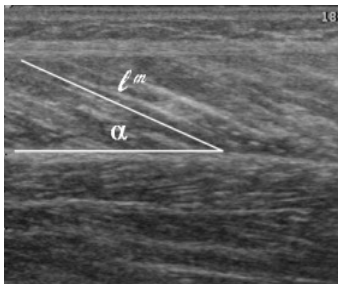

Figure 2: Ultrasound image with pennation angle (α) and fiber length (l^m) highlighted

(Qualysis AB, Gothenburg, Sweden) and ultrasound images [2].

Pennation angles and fiber lengths were determined using ultrasound console functions at each ankle angle (Figure 2). The optimal fiber length for each subject was defined as the fiber length at the ankle angle which produced the maximum force. Fiber lengths and forces at all angles were normalized to the maximum force and optimal fiber length and then plotted.

RESULTS AND DISCUSSION

Table 1 reports the compiled muscle parameters measured the soleus muscle. Specifically, we report

the values between 25° dorsiflexion to 20° plantarflexion. The results show a variety of interesting trends. The moments, forces, and fiber lengths all decrease with increasing plantarflexion angle. The moment arms and pennation angles increase with increasing plantarflexion angle. Peak force was produced with the ankle in twenty degrees dorsiflexion with a corresponding optimal fiber length of 38 mm. This is interesting because optimal fiber length corresponds to the ankle angle at which maximum moments are required during gait. Our pennation angles and fiber lengths show consistent trends with data reported by others [3]. The moments however between studies are significantly different. This discrepancy is believed to be from different positioning of the subjects in each study.

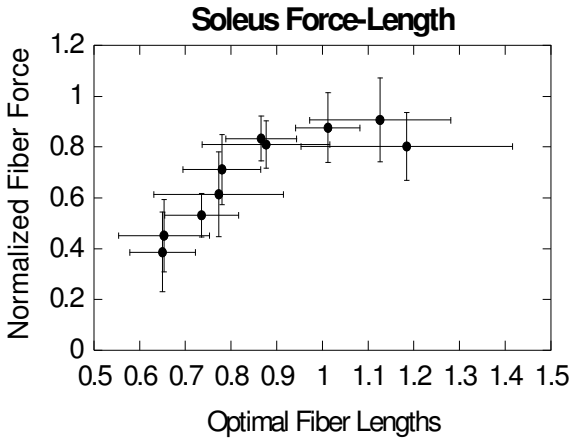

Figure 3: Normalized fiber force and length with vertical and horizontal bars showing standard deviations.

Figure 3 illustrates the normalized force-length relationship for the soleus muscle. The operational range for normalized fiber length is .65 to 1.18. The soleus is weakest at around 20 degrees plantarflexion producing only about 38.7% of the maximum force.

CONCLUSIONS

The objective of this paper set out to describe the architectural parameters of the soleus. Previous works reporting these measures have used MRI in their approach which can be quite costly and time consuming and thus is not ideal when attempting to characterize the muscle architecture for many subjects. The method presented herein uses ultrasound which is much less expensive and timely. Care should be taken when comparing moments between studies in which different positioning is used. We selected the kneeling position in an effort to isolate the soleus. With the exception of the moment our results are consistent with other methods. The parameters and force tension relationship reported of the soleus should benefit future studies of how the soleus and other plantarflexor muscles of the ankle contribute to posture and gait.

REFERENCES

1.Perry A, *Gait Analysis*, McGraw-Hill, Inc., New York, 1992.
2.Cowder J, et al., *ASME Summer Bioengineering Conference*, 2008.
3.Maganaris CN, *Acta Physiol Scand*. **172**:279-285, 2004

Table 1: Muscle parameters through ankle range of motion from 25° dorsiflexion(-) to 20° plantarflexion(+)

Ankle Angle (deg)	-25	-20	-15	-10	-5	0	5	10	15	20
Moment (Nm)	63.4 ±38.2	66.1 ±35.3	66.8 ±36.3	66.8 ±33	62.9 ±26.7	55.6 ±28.6	45.1 ±18.6	42.5 ±15.6	33.7 ±14.9	27.2 ±10
Moment Arm (mm)	38.4 ±4.6	38.6 ±5.3	39.3 ±5.1	40.6 ±5.7	40.8 ±5	41 ±5.9	42.1 ±5.8	42.7 ±6.5	42.5 ±5.1	42.1 ±5.8
Fiber length (mm)	39.8 ±5.7	38.1 ±3.9	34.4 ±4	29.9 ±6.2	29.5 ±5.2	26.1 ±4.6	25.7 ±3.1	24.7 ±2.4	20.9 ±1.8	20.9 ±1.9
Fiber Pennation (deg)	20 ±3.8	22.9 ±4	24.5 ±4.9	27.5 ±4.1	27.3 ±5.3	28.5 ±5.3	31.9 ±5	32.4 ±7	36.2 ±5.2	36.9 ±4.9
Tendon Force (N)	1894 ±611	1945 ±452	1899 ±737	1859 ±587	1697 ±395	1484 ±473	1186 ±228	1065 ±246	787 ±309	648 ±215
Muscle Force (N)	2005 ±841	2111 ±738	2038 ±789	1965 ±644	1864 ±523	1672 ±603	1383 ±333	1229 ±288	975 ±385	808 ±250