ESTIMATING THE SPECIFIC TENSION OF MUSCLE IN VIVO: A SIMULATION STUDY

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INTRODUCTION

The specific tension of muscle is an intrinsic property of muscle; it is defined as the maximum muscle force normalized with respect to muscle cross sectional area. Several authors have reported values for specific tension measured *in vivo*. These values vary widely, for example from 62 kPa (Ikai & Fukunaga, 1962) to 155 kPa (Maganaris et al., 2001). *In vivo* estimates rely on imaging procedures for the estimation of cross-sectional areas and external measures of joint moments.

There are a number of methodological problems with *in vivo* specific tension estimation including: not all muscles may be fully activated, co-activation of agonists and antagonists, variations in force output due to the force-length properties of muscle, and accounting for the moment arms of the muscles.

The purpose of this study is to demonstrate the variation in specific tension of the gastrocnemius and soleus with ankle and knee joint angles during plantar flexion using a model of the human triceps surae.

METHOD

When specific tension is estimated *in vivo* muscle cross-sectional areas and maximum muscle moments are measured. Then given the muscle moment arms the muscle forces can be estimated, assuming that the contributions of the muscles to the moment are proportional to their cross-sectional areas. In this study a simulation model was used to provide estimates of muscle moments at the ankle joint during isometric plantar flexions.

The force produced by the muscle model (F_M) can be described by,

$$F_M = q.F_{\max}.F_L$$

Where q is the active state of muscle, which was assumed to be 1, (i.e. maximal) for the simulated maximum isometric efforts. The maximum isometric force $(F_{\max})$ is based on the cross-sectional data presented in Out et al. (1996). The force-length properties (F_L) of the muscles are modeled as a parabolic function (Gallucci & Challis, 2002), with the optimum fiber length based on the number of sarcomeres comprising fibers in the muscles (Out et al., 1996).

The muscle model comprises a contractile component and a series elastic component for a muscle that crosses both the knee and the ankle joint (gastrocnemius) and a muscle that crosses only the ankle joint (soleus). The series elastic component is assumed to have a linear stress-strain curve, and an iterative process was used to estimate the muscle force for the soleus and gastrocnemius for a range of ankle and knee angles (Gallucci and Challis, 2002).

The maximum specific tension of these muscles was based on the data of

Lannergren and Westerblad (1987), who presented a value of 375 kPa based on an isolated single fiber preparation. Muscle specific tension was estimated for a range of ankle and knee angles, and compared to this criterion value.

RESULTS

The model moment-angle data in figure 1 is representative of experimental data (Sale et al., 1982). There were significant variations in specific tension with ankle and knee angle (figure 2). In this figure a 90° ankle angle and a 180° knee angle would represent the normal anatomical position.

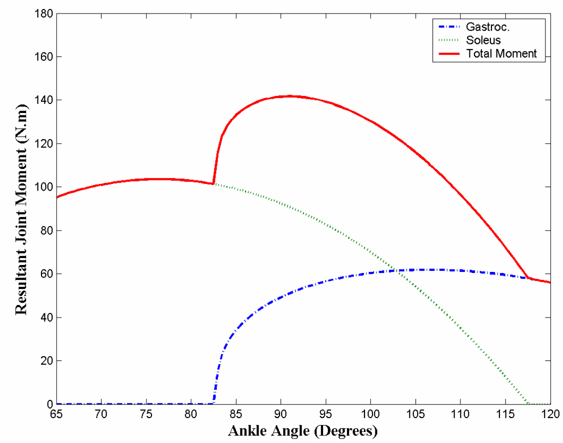

Figure 1: Variation in moment-ankle angle relationship with knee flexed to 90 degrees.

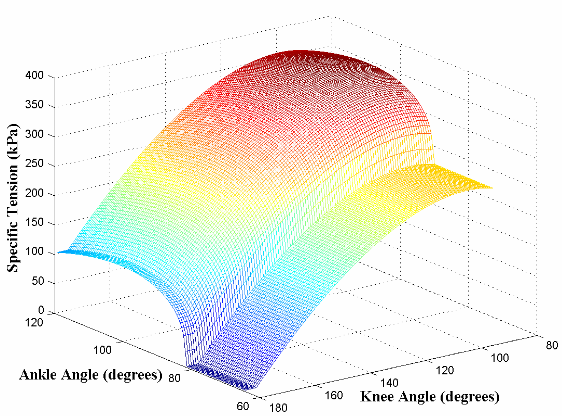

Figure 2: Relationship between angle and knee angles and specific tension.

DISCUSSION

The model demonstrates that the joint angles at which the moment measures are made strongly influence the estimated specific tension. This factor could easily account for the variations in specific tension measured *in vivo* that are reported in the literature. Further variability could be introduced *in vivo*: the model did not take into account sub-maximal effort on the part of subjects or inaccuracy in cross-sectional area, and moment arm measurements. The results presented here are specific to the model used, but represent a similar physiological system, and highlight the some of the problems of estimating specific tension *in vivo*.

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ACKNOWLEDGEMENTS

This research was in part supported by a grant from The Whitaker Foundation.