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THE FORCE-LENGTH CURVE OF THE HUMAN GASTROCNEMIUS IN VIVO.

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INTRODUCTION

The variation in isometric force produced with changing muscle length has been investigated extensively and ascending, plateau and descending limbs of this force-length relationship have been explained in terms of the cross bridge theory [1]. However, in vivo different skeletal muscles may operate over all or only part of the force-length curve, and for a given muscle, different individuals may be adapted to operate on different parts of the curve. The purpose of this study was to determine the force-length relationship for the gastrocnemius, which has not been reported previously in vivo for humans. A modified method based on the algorithm of Herzog & ter Keurs [2] was used to reconstruct the force-length curves of the muscle.

METHODS

Fourteen male and fourteen female subjects aged between 18 to 27 years performed maximal isometric plantar flexions in a Biodex dynamometer (females: mass $60.9 \text{ kg} \pm 10.0$, height $1.66 \text{ m} \pm 0.02$; males: mass $86.1 \text{ kg} \pm 11.9$, height $1.81 \text{ m} \pm 0.07$). Plantar flexion moments were recorded at five ankle angles: -15, 0, 15, 30 and 40 degrees, with negative angles defined as dorsi-flexion. These measurements were repeated for four different randomly ordered knee angles (0, 50, 90, 115 degrees of flexion) over two testing sessions four to ten days apart.

The change in normalised gastrocnemius muscle length was computed as a change from the reference position, defined as full knee extension and a 0 degree (neutral) ankle angle. The force in the Achilles tendon was computed from the active moment and the ankle moment arm [3]. The ankle moment arm was scaled according to the shank length of the subject. Robust regression techniques [4] were used to fit first and second order polynomials to each set of four forces measured at the same ankle angle, but at different knee angles. The second order equation was selected as long as it produced a monotonic relationship. This step produced five curves corresponding to different sections of the gastrocnemius force-length curve. The curves were separated along the vertical force axis by the monoarticular force contribution, but they overlapped in terms of the length change on the horizontal axis. The entire length change represented the length change produced by all of the various experimental joint configurations. In order to subtract out the mono-articular contribution from each data set, the polynomial equation of the first data set was used to predict the force value of the first data point in the second set, and the force difference was then subtracted from all the data points in this second set. This procedure was repeated for all subsequent sets. Points were then normalised to the maximum force, and second and first order polynomials were fitted to the entire normalised data set.

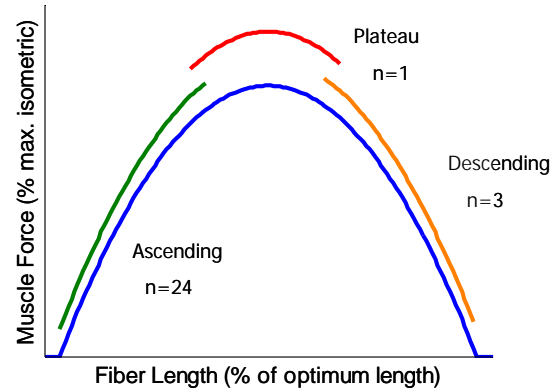


Figure 1: Number of subjects operating over each portion of the force-length curve.

RESULTS AND DISCUSSION

The majority of the 28 subjects operated over the ascending limb; however, three subjects operated over the descending limb, and one subject operated over the plateau region (Figure 1).

Sensitivity analyses indicated that the reconstructions of the force-length curves were robust to changes in the moment arm and maximal tendon stretch parameters used.

Previous work has also determined that there is variation in the portion of the force-length relationship that the rectus femoris operates over [5]. There was, however, a higher degree of consistency in the portion operated over for the gastrocnemius. This might be reflective of more consistent functional demands placed on the gastrocnemius.

CONCLUSIONS

In vivo variation exists, for the gastrocnemius, in the portion of the force-length curve operated over. The source of this variation, that is, whether it arises as a result of genetic expression or as a result of functional adaptation, is unknown, but the variation should be recognised when conducting modelling studies or when performing surgery.

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