NON-INVASIVE MEASURMENT OF PASSIVE LENGTH-TENSION PROPERTIES OF HUMAN GASTROCNEMIUS MUSCLE FASCICLES, TENDONS, AND WHOLE MUSCLE-TENDON UNITS IN VIVO

[1]Phu Hoang, [2]Gabrielle Todd, [2]Robert Gorman , [2]Simon Gandevia and [1]Rob Herbert
[1]School of Physiotherapy, University of Sydney, Australia; email: R.Herbert@fhs.usyd.edu.au
[2]Prince of Wales Medical Research Institute, University of New South Wales, Australia

INTRODUCTION

We present a new method for non-invasive measurement of passive length-tension properties of human gastrocnemius muscle fascicles, tendons, and whole muscle-tendon units *in vivo*. The method relies on the assumption that the gastrocnemius is the only muscle that crosses both the ankle and the knee, so changes in ankle torque-angle properties that accompany changes in knee angle can be attributed to changes in the length of gastrocnemius. The contributions of muscle fascicles and tendons to elongation of the muscle-tendon unit are determined with ultrasonography.

METHODS

Passive ankle torque and ankle angle data were obtained as the ankle was rotated through its full range of motion with the knee in a range of positions. Changes in the length of the whole muscle-tendon unit (MTU) of gastrocnemius were calculated from joint angles and anthropometric data. Passive length-tension curves of the whole gastrocnemius MTU were extracted from torque-angle data based on the assumption that passive ankle torque is the sum of torque due to structures which cross only the ankle joint (this torque was a 6-parameter function of ankle joint angle) and a torque due to the gastrocnemius muscle (a 3-parameter function of knee and ankle angle). Parameter values were estimated with non-linear regression and used to reconstruct passive length-tension curves of the gastrocnemius [1].

We have examined the reliability of the measures of length-tension curves of gastrocnemius MTU by measuring length-tension curves from 11 subjects on three occasions, twice on the same day and on a third occasion at least one week later. The curves were reproducible with average root mean square error was 3% and 6% of maximal passive tension for pairs of measurements within a day and a week apart respectively.

Simultaneously, ultrasonography was used to measure changes in length of muscle fascicles. The methods were similar to those described by Kubo *et al.* [2]. Changes in tendon length were then calculated as change in length of the muscle-tendon unit minus change in length of muscle fascicles. Passive length-tension curves of muscle fascicles and of the tendon were then generated.

Passive length-tension curves provided estimates of muscle-tendon slack length (the length below which there was no tension). The length of muscle fascicles at muscle-tendon slack length provided estimates of muscle fascicle and tendon slack lengths. These were used to calculate strains of muscle-tendon, muscle fascicle and tendon.

RESULTS AND DISCUSSION

An example of a passive length-tension curve of the gastrocnemius MTU from one subject is shown in Figure 1. The mean (± SEM) maximum passive tension from 9 subjects was 280 ± 22 N, the mean slack length of the muscle-tendon unit was 41 ± 1 cm, and the mean maximum in vivo length was 50 ± 1 cm. The muscle-tendon slack length is within the physiological range but close to the shortest in vivo length.

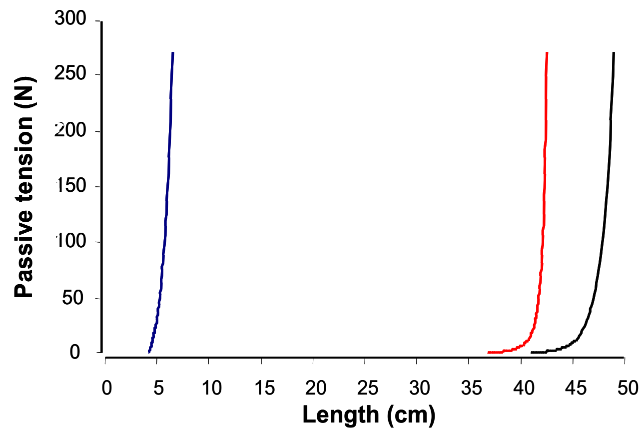

Figure 1: Passive length-tension curves of gastrocnemius muscle-tendon unit (black line, using method in ref [1]), fascicles (blue line, using ultrasonography), and tendon (red line, by subtraction) of one subject. For this subject, the tendon contributed 71% to the total lengthening of the whole muscle tendon unit.

The figure also shows passive length-tension curves of muscle fascicles and tendons. Even at these low passive tensions, tendons undergo functionally important elongation. In the subject shown in the figure, tendon contributed 71% of the total lengthening of the whole MTU. The mean contribution of muscle fascicles and tendons to the changes of the whole MTU from measurements of 9 subjects was 36 ± 4% and 64 ± 4% respectively. These confirm findings of our previous studies in animals [3] and humans [4].

The mean slack length of muscle fascicles (n = 9) was 3.5 ± 0.2 cm. This is similar to the recent findings of Muraoka and colleagues [5]. Average maximum in vivo passive strain of muscle fascicles and tendon was 91 ± 9% and 11 ± 2% respectively.

CONCLUSIONS

The new method enables measurement of passive length-tension properties of human gastrocnemius in vivo. It shows that, even with passive tension, strains in the whole tendon (extramuscular tendon plus aponeurosis) of human gastrocnemius are very large, and tendon elongation accounts for most of the change in muscle-tendon length.

REFERENCES

1. Hoang et al. *J Biomech* **DOI**:10.1016/jbiomech.2004.05.046.
2. Kubo et al. *Acta Physiol Scand* **170**, 127-135, 2000.
3. Herbert R & Crosbie J. *Eur J Appl Physiol & Occ Physiol* **76**, 472-479, 1997.
4. Herbert et al. *J Physiol* **539**, 637-645, 2002.
5. Muraoka et al. *J Biomech* **DOI**:10.1016/jbiomech.2004.06.012.