THE INFLUENCE OF GASTROCNEMIUS GEOMETRY ON ITS ACTION AT THE KNEE DURING STANCE

Saryn R. Goldberg[1], Frank C. Anderson[2], and Scott L. Delp[2,3]
[1] Physical Disabilities Branch, National Institutes of Health, Department of Health and Human Services, Bethesda, MD, USA
[2] Biomechanical Engineering Division, Mechanical Engineering Department, Stanford University, Stanford, CA, USA
[3] Bioengineering Department, Stanford University, Stanford, CA, USA
email: goldbergs@cc.nih.gov, web: http://pdb.cc.nih.gov

INTRODUCTION

The gastrocnemius plays an important role in support of the body during stance [1] and in preparation of the limb for swing [2,3]. However, the action of this muscle at the knee is unclear; some dynamic analyses show that gastrocnemius acts mainly to flex the knee during double support [2], while others demonstrate that the muscle accelerates the knee into extension [3]. To clarify the action of gastrocnemius at the knee, we systematically altered the ratio of the moment arms of gastrocnemius to determine how changes in the geometry of this muscle affect its capacity to accelerate the knee during stance. Our objective was to determine the knee-to-ankle moment arm ratio that would result in zero knee acceleration, as this ratio represents the ratio at which muscle function changes from knee flexion to knee extension.

METHODS

To calculate the acceleration of the knee joint generated by various gastrocnemius geometries, we fixed a 3-dimensional model of the lower extremity with a 2-degree-of-freedom ankle and 2-segment foot [4] in positions corresponding to every 2% of normal stance phase kinematics [4], assumed rigid contact of the foot with the ground [1], and applied moments about the knee, ankle, and subtalar joints corresponding to a range of knee-to-ankle moment arm ratios for gastrocnemius. Specifically, for each stance phase position, the ankle moment was set to 1 Nm, the subtalar moment was set to its normal size relative to this ankle moment, and the knee moment was varied until the knee was not accelerated. The relative values of the ankle and subtalar moments were chosen to correspond to those generated by gastrocnemius during normal gait [4]. Values for the knee-to-ankle moment arm ratio that gave rise to zero knee acceleration were insensitive to the absolute sizes of the knee and ankle moments; only their ratio mattered.

RESULTS AND DISCUSSION

The knee-to-ankle moment arm ratio for gastrocnemius that resulted in zero knee acceleration was near or below a value of 0.4 until about 55% of the gait cycle (Figure 1). After the metatarsal joint left the ground, leaving only the toe in contact, the ratio rose dramatically to values ranging from 1.2 to 1.8 (Figure 1). Experimental data from cadavers places the knee-to-ankle moment arm ratio for gastrocnemius above 0.4 and below 0.7 for nearly all of stance [5,6,7] (Figure 1). This suggests that gastrocnemius, when generating force, would accelerate the knee into flexion for most of stance. After metatarsal-off, however, any normal moment arm ratio would result in gastrocnemius acting to extend the knee (Figure 1). Given that gastrocnemius flexes the knee during most of stance but extends it in late stance, it is difficult to determine

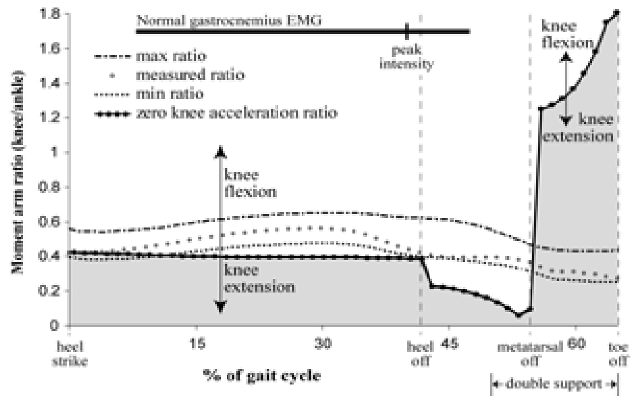

Figure 1. The gastrocnemius knee-to-ankle moment arm ratio that resulted in zero acceleration of the knee during stance compared to ratios estimated from experiments [5,6,7] and normal gastrocnemius EMG activity [8]. Ratios above (below) the zero-knee-acceleration ratio would accelerate the knee into flexion (extension). The measured ratio was based on data collected from a single specimen [5]. The max and min ratios were based on data from separate knee and ankle joint studies and represent the theoretical extremes of this ratio during stance [5,6,7].

the net action of this muscle. Since gastrocnemius typically generates the largest forces near heel-off [4,8], and since forces generated at the beginning of a movement are the most influential in determining the resulting net action over a period of time [2], it is likely that gastrocnemius acts in net to flex the knee. This is likely true even over double support, when gastrocnemius is generating force due to muscle deactivation. Indeed, perturbation analyses support this conclusion [2]. However, further investigation is needed before such conclusions can be drawn definitively. Specifically, future work will determine how other modeling variables, such as the way in which the foot and its contact with the ground are represented, affect the action of gastrocnemius at the knee.

REFERENCES

1. Anderson FC, et al. *Gait & Posture* **17**, 159-169, 2003.
2. Goldberg SR, et al. *J Biomech* **37**, 1189-1196, 2004.
3. Neptune RR, et al. *J Biomech* **34**, 1387-1398, 2001.
4. Anderson FC and Pandy MG. *J Biomech Eng-T ASME*, **123**, 381-390, 2001.
5. Spoor CW, et al. *J Biomech* **23**, 1247-1259, 1990.
6. Magnaris CN, et al. *Eur J Appl Physiol* **83**, 363-369, 2000.
7. Magnaris CN. *Clin Anat* **16**, 215-223, 2003.
8. Perry J. *Gait Analysis*, SLACK Inc., Thorofare, NJ, 1992.

ACKNOWLEDGEMENTS

This work was supported in part by NIH R01 HD38962.