Triceps Surae Mechanics Determined for Running Using a Multi-Segment Foot Model

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Summary

The purpose of this study was to examine the behavior of the triceps surae during running using a one-segment and a three-segment foot model. Experimental data were collected for eight subjects running providing lower limb kinematics and kinetics which were then used in one-segment and a three-segment foot model. These data were used in a muscle model to estimate the behavior of the triceps surae. Estimates of the active state, fiber length changes, and fiber velocities were all decreased for the three-segment foot model compared with the one-segment model. These data have implications for our understanding of the role of the triceps surae during running.

Introduction

To understand the mechanics of human movement models are formulated, but no model is a perfect representation of the system it is designed to represent. Choices about model complexity are important as they can impact our interpretation of the functioning of the musculo-skeletal system. Models designed to estimate muscle forces during gait have used a one-segment foot [1], a two-segment foot [2], and a three-segment foot [3]. Analysis of running gait has shown that a one-segment and three-segment foot model produce differences in ankle plantar/dorsi-flexion angles, angular velocities, power, and work [4]. In light of these changes the functioning of the triceps surae inferred from a one-segment foot model compared with a three-segment foot model could be different.

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Methods

Eight runners, all heel-strikers, provided voluntary written informed consent for the Institutional Review Board approved study. They ran barefoot down a 15 m runway at 3.1 m/s, while their motion was recorded at 150 Hz by an eight-camera motion capture system, and ground reaction forces were recorded at 1500 Hz. After processing the data were used to estimate lower limb joint kinematics and kinetics for both a one-segment and two-segment foot model (Figure 1).

The lower limb joint angles and angular velocities, from the experimental data, were used to determine the kinematics of the soleus and gastrocnemius muscle-tendon complexes. These data were input into a Hill muscle model to estimate muscle forces during the stance phase of running. The distribution of the ankle moment between the two muscles was based on the ratio of their cross-sectional areas. Muscle model parameters were based on literature sources [e.g., 5]. Seven key parameters determined the muscle model output, including the ratio of the muscle cross-sectional areas, therefore these parameters were systematically varied to assess their impact on model output. Over 15,000 simulations were performed.

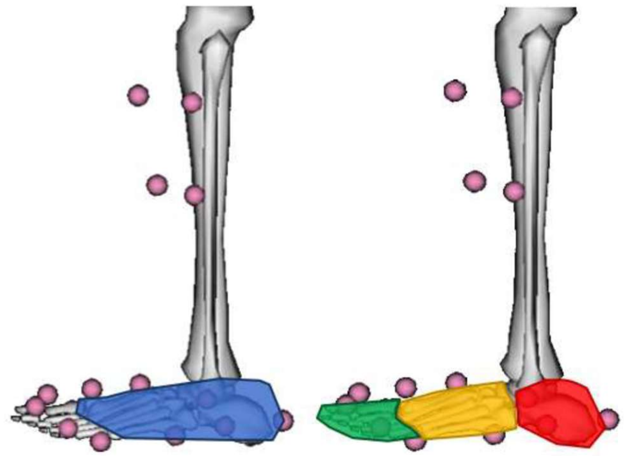

Figure 1: Illustrations of the two models of the foot.

Results and Discussion

For the soleus the muscle active state, fiber length changes, and velocity were generally lower for the multi-segment model compared with single segment model. These results were consistent across over 99% of simulations. A similar pattern of results was seen for gastrocnemius, which was consistent for over 96% of the simulations.

The results indicate that a single-segment foot model is likely to overestimate the muscle active state, fiber shortening, and fiber shortening velocities of the triceps surae, and consequently the metabolic cost of their actions during running. Similarly, the one-segment foot model overestimated by 22% the energy stored in the Achilles tendon.

Conclusions

This study demonstrates that the appropriate modelling of the human foot during running has an integral role in the conclusions that are drawn from simulations examining the function of the triceps surae.

References

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