FOOT MODEL CHOICE AFFECTS MUSCLE-TENDON UNIT ELONGATION IN GAIT

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Summary

Musculoskeletal models often rely on generic scaled bone geometries and simplified joint motion which may affect ankle plantar flexor muscle-tendon unit (MTU) lengths. Compared to subject-specific anatomy and joint motion derived from biplanar videoradiography (BVR), this study showed OpenSim-derived soleus MTU elongations were similar in all phases except mid-stance; however, tibialis posterior elongations varied substantially due to uncaptured arch motion in the models.

Introduction

Ankle plantar flexor muscle force is critical for propulsion in human gait [1]. Predicting individual muscle forces is a complex multi-variate optimization problem, affected by many parameters, including MTU length. Musculoskeletal models typically use scaled, generic bone geometry and simplified joint motion, especially in the foot, to compute MTU length [2]. By comparison, BVR methods can capture highly accurate joint kinematics on subject-specific bone morphology. Therefore, to determine the effects of bone geometry and simplified arch joint motion, we compared soleus and tibialis posterior MTU elongation across rigid, multi-segmented, and BVR-based foot models.

Methods

The right foot and ankle motion of six participants (4F, 2M, mean ± 1SD, 24.2 ± 3.0 years, 1.70 ± 0.08m, 69.10 ± 8.28 kg) was recorded during the stance phase of walking using BVR, while optical motion capture (OMC) measured whole-body motion (125 Hz). Three models were used to compute and compare MTU elongation: Rigid, Mobile, and Anatomic. The Rigid and Mobile models were scaled from a modified D'Hondt musculoskeletal OpenSim model with generic bone geometry, and joint angles during stance were computed using inverse kinematics [3]. The Rigid model constrained motion within the foot, whereas the Mobile model permitted motion at the subtalar, midtarsal, tarsometatarsal, and metatarsophalangeal joints. For the Anatomic model, CT scans of each participant's right foot and ankles were segmented and tessellated to create 3D, subject-specific bone meshes. Soleus and tibialis posterior MTUs were wrapped over the bone meshes at each frame of stance using an established algorithm [4]. MTU lengths were computed in all models as the distance between the origin and insertion points. MTU elongation ranges were measured in each phase of stance and a one-way repeated measures ANOVA with a Bonferroni correction for multiple comparisons tested for differences between models.

Results and Discussion

The Rigid model's soleus elongation ranges were comparable to the Anatomic model and significantly larger than the Mobile model only during mid-stance ($p<0.05$) (Figure 1). In contrast, the Mobile model's tibialis posterior elongation range was significantly less than the Anatomic model in mid- and terminal stance. Additionally, both the Rigid and Mobile models shortened significantly less than the Anatomic during pre-swing (all $p<0.05$). Disagreement with the Anatomic tibialis posterior during foot propulsion suggests that the foot joint definitions in the Mobile model do not support the arch motion necessary for both gradual MTU lengthening through mid- and terminal stance and substantial MTU shortening in pre-swing. Similarly, the Rigid model does not articulate the arch recoil mechanism, explaining its limited shortening in pre-swing.

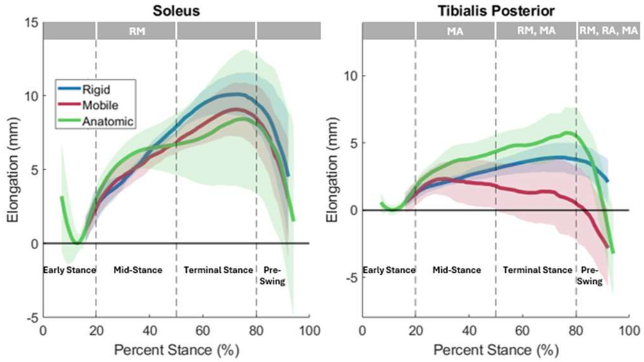

Figure 1: MTU elongation over stance (Mean ± 1s.d.); significant differences between models per stance phase shown by RM (Rigid-Mobile), RA (Rigid-Anatomic), and MA (Mobile-Anatomic).

Conclusions

The BVR-based Anatomic model captures muscle-specific effects of arch recoil that are absent in the Rigid and Mobile models. Future work will compute muscle forces to determine if subject-specific morphology and detailed joint motion is necessary for accurate lower limb musculoskeletal modelling.

Acknowledgements

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References

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