Exploring the heterogeneity of the triceps surae muscle mechanics using shear wave elastography

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Summary

In vivo characterization of skeletal muscle mechanics is essential to understand muscle behavior and adaptation. Shear wave elastography (SWE) enables the assessment of local muscle stiffness and provides insights into individual muscle mechanics. However, muscle behavior can be inhomogeneous within a muscle. In this case study, SWE recordings were obtained from 17 sites across the triceps surae muscles at five ankle angles to characterize local passive and active muscle mechanics and identify the key measurement sites to describe heterogeneous behavior. Shear moduli varied between muscles, with the most pronounced differences observed in the soleus, particularly at passive and low-level contractions.

Introduction

Ultrasound SWE quantifies local muscle stiffness by calculating shear modulus from shear wave propagation velocity. In addition to being length- and activation-dependent [1,2], shear moduli vary between muscles and measurement sites [1-3], suggesting heterogeneous mechanical behavior linked to functional differences. This case study aimed to identify the measurement sites needed to characterize the heterogeneous behavior of the triceps surae muscles.

Methods

SWE recordings were obtained from 17 muscle sites across the triceps surae muscles from one healthy volunteer (female, 28 years old). Surface EMG was recorded from gastrocnemius medialis (GM), lateralis (GL), and soleus (SOL) muscles. Experiments were performed at five ankle angles (from 55° plantar flexion (PF) to 15° dorsiflexion (DF)) at the passive state and submaximal isometric contractions (25% and 75% of maximum voluntary contraction (MVC) ankle moment). Pennation angles were calculated from B-mode images.

Results and Discussion

Pennation angles decreased from PF to DF, indicating muscle lengthening. Passive shear moduli increased exponentially with DF across most sites (Figure 1), demonstrating typical passive behavior. GM exhibited the highest shear modulus and the most pronounced increase, followed by GL and SOL, suggesting that GM operates at longer lengths. *GM-distal* tend to be less stiff while *GL-proximal* tend to be stiffer than the muscle belly sites. Within SOL, *SOL under-GM-belly* showed a greater increase in shear modulus with ankle angle changes, while *SOL under-GL-belly* increased less, mirroring GM and GL characteristics, respectively. These site-specific differences may reflect local muscle strain variations. Given that SOL and the gastrocnemius heads share an aponeurosis, the observed similarities in behavior may be linked to mechanical interactions.

Shear moduli increased with contraction intensity. At 25% MVC, *GM-proximal* was stiffer than other GM sites, and *SOL under-GM/GL-belly* were stiffer than more distal sites. At 75% MVC, site-dependent differences diminished (Figure 1). While SOL shear moduli remained unaffected by ankle angle, GM and GL shear moduli tend to increase with DF, except for a notable drop in GM shear moduli at 15° DF.

Conclusions

Shear moduli differed among muscles and measurement sites, with SOL displaying the greatest heterogeneity due to its complex, multi-compartment structure. The relation between local variations in shear modulus and triceps surae force production warrants further investigation. A computational model could provide deeper insights into this relationship, and our findings will serve as validation for such a model.

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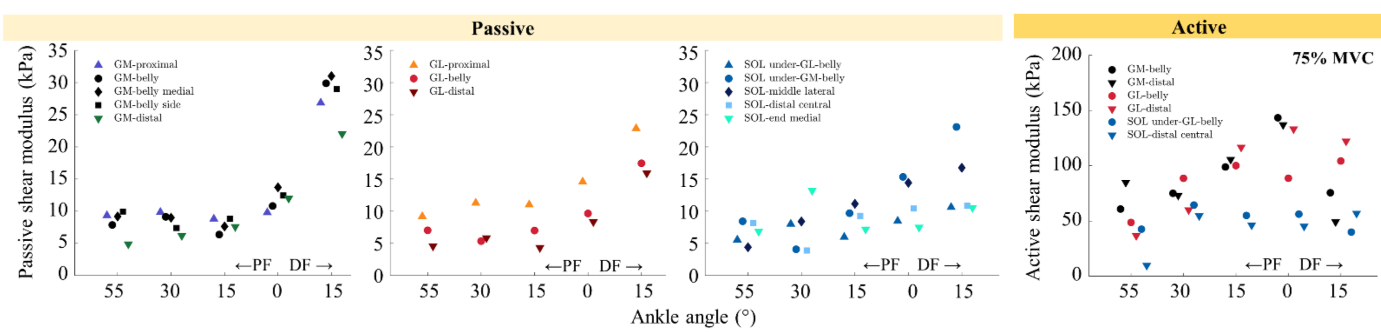

Figure 1: Shear moduli of GM, GL, and SOL muscles at passive state and at 75% MVC measured at ankle angles from 55° PF to 15° DF.