TORQUE-ANGLE-VELOCITY RELATIONSHIP OF HUMAN TIBIALIS ANTERIOR

Sang-Hoon Yeo[1], Jin Min Kim[1], Jasper Verheul[2], Brogan Ling[1]

[1]School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham, United Kingdom
[2]Cardiff School of Sport and Health Sciences, Cardiff Metropolitan University, Cardiff, United Kingdom
Email: s.yeo@bham.ac.uk

Summary

We investigated the influence of the length and velocity of the Tibialis Anterior (TA) on its force production and muscle architecture. Sixteen healthy participants performed voluntary ankle dorsiflexion at 50% of their maximum voluntary contraction using a motorized dynamometer, while the pennation angle of the superficial layer of the TA was monitored using ultrasound. Dorsiflexion torque and the corresponding pennation angle were measured at different ankle angles and angular velocities under isometric, concentric, and eccentric conditions. Results showed that torque-angle and torque-angular velocity relationships resembled the expected patterns of the Hill-type muscle model, suggesting that the dorsiflexion mechanics of the ankle can be well interpreted using the force-length and force-velocity relationships of the TA. Results also indicated a systematic variation in pennation angle across angles and velocities, but this variation differed from that of torque, suggesting that force alone may not be the sole determinant of TA architecture.

Introduction

Studies have investigated the mechanics of the Tibialis Anterior (TA) and its architectural variations, yet only a few have validated muscle models of the TA, particularly in dynamic scenarios. A remaining question in muscle mechanics remains the relationship between muscle architecture and force [1]. This study examined the force-length-velocity relationship of the TA in vivo using human participants and explored its correlation with muscle architecture, represented by pennation angle.

Methods

Sixteen healthy participants (age 20.56 ± 0.96 years, height 170.27 ± 7.59 cm, weight 68.72 ± 8.19 kg) with no recent lower limb injuries were recruited. They performed dorsiflexion at 50% of their Maximum Voluntary Contraction (MVC) while seated on a motorized dynamometer (Biodex® System 3). The level of contraction was self-controlled with practice, as participants monitored a real-time electromyogram (EMG) level indicator displayed on a screen in front of them. The knee was fully extended, and the foot was secured to align the ankle joint with the dynamometer axis (Figure 1).

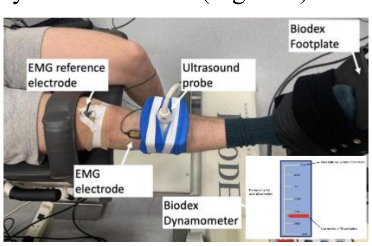

Figure 1 A top view of the experimental setup. The inset shows the EMG level indicator displayed to participants.

Muscle activity and architecture were recorded via ultrasound (Vivid iq, 12L-RS probe) and surface EMG (Bagnoli Desktop System). Each participant completed 39 trials across 13 conditions: seven isometric (ankle angles: -30° to 20°) and six isokinetic trials (concentric and eccentric contractions at 30, 60, and 90°/s). Data were processed using MATLAB, with torque normalized by subtracting passive torque. Pennation angle was tracked by hybrid ultrasound-based muscle tracking method [2].

Results and Discussion

The torque-angle relationship exhibited a bell-shaped curve, peaking at -5° (negative number means plantarflexion). Torque significantly increased from -20° to 0° ($p < .001$) and declined sharply from -10° to -30° ($p < .001$). Nonlinear regression confirmed a second-order polynomial fit ($R^2 = 0.390$). Torque-angular-velocity relationship also showed distinct concentric and eccentric trends. Concentric contractions followed Hill's equation ($R^2 = 0.851$), while eccentric contractions were best fitted by a second-order polynomial ($R^2 = 0.343$). A three-dimensional regression ($R^2 = 0.814$) modelled torque-angle-angular-velocity interactions, demonstrating high correlation.

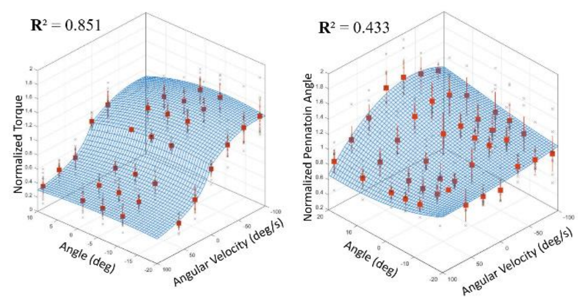

Figure 2 Angle and angular-velocity dependencies of TA torque and pennation angle

On the other hand, pennation angle (normalized to that at 0°) analysis showed different nonlinear changes with angle and angular velocity. Model selection suggested that a third-order polynomial surface for angle and a second-order polynomial for angular velocity provided a reasonable fit for the dataset, resulting in an R^2 value of 0.4329.

Conclusions

This study highlights the torque-angle and torque-angular velocity dependencies of TA muscle. The results indicate that force production of TA can be well predicted by conventional force-length and force-velocity relationship. However, the pennation angle showed different dependency, suggesting a complex relationship between force and muscle architecture.

Acknowledgement

This work was financially supported by the Biotechnology and Biological Sciences Research Council (grant no. BB/S003762/1 to S.-H.Y.)

References

[1] Verheul J & Yeo SH (2022) IEEE TBME 70(4), 1114-1124.

[2] Azizi E, Roberts TJ (2014) J Exp Biol. 217(3):376-81