

Young's Modulus using Shear Wave Elastography of Soleus Muscle at Maximum Squat Depth in Healthy Men

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Disclosures: The authors declare that they have no conflicts of interest.

INTRODUCTION:

Asians routinely perform deep squatting during daily life activities and farmwork. However, soleus muscle (SM) stiffness can lead to an inability to perform deep squatting. Ankle dorsiflexion ROM correlates with SM stiffness. However, whether SM stiffness affects the ankle dorsiflexion angle at the maximum squat depth remains unclear.

Previous studies have proposed methods for estimating tissue stiffness using ultrasound-based shear-wave elastography (SWE). SWE can measure Young's modulus of an SM with high reliability. Therefore, assessing the Young's modulus of the SM may be a valuable method for predicting the ankle dorsiflexion angle at maximum squat depth.

Therefore, this study aimed to clarify the relationship between the Young's modulus of the SM and the ankle dorsiflexion angle at maximum squat depth in healthy young males. We hypothesized that the Young's modulus of the SM affects the ankle dorsiflexion angle at the maximum squat depth. Furthermore, if this hypothesis was proven, decreasing the Young's modulus of the SM may help increase the ankle dorsiflexion angle at the maximum squat depth.

METHODS:

This cross-sectional study included 31 healthy young male participant (age; 27.0 [25.0–34.0] years, height; 1.73 [1.70–1.75] m, body weight; 64.3 [59.9–68.0] kg, BMI; 21.5 [20.7–22.6] kg/m²). The ethics committee of the institute approved this study, and the study protocol conformed with the Declaration of Helsinki. The ankle dorsiflexion angle at the maximum squat depth was measured as the angle between the vertical line to the floor and the line connecting the fibula head and the lateral malleolus using a goniometer (Figure 1). SM stiffness was measured using Young's modulus through SWE. Ultrasound images were recorded along the longitudinal axis of the tendon at ankle dorsiflexion angles of –10°, 0°, and 10°. One-way repeated measures, analysis of variance, and Bonferroni post hoc test were used to demonstrate the effects of ankle position. Pearson's product-moment correlation coefficients were used to analyze the correlations between relationships. The stepwise multiple regression analysis used the ankle dorsiflexion angle at the maximum squat depth as the dependent variable. Statistical significance was set at $p < 0.05$.

RESULTS:

Multiple regression analysis was used to identify the Young's modulus of the SM at 10° of ankle dorsiflexion (standardized partial regression coefficient $[\beta] = -0.497$) and the ankle dorsiflexion angle in the flexed knee ($\beta = 0.362$) as independent variables for the ankle dorsiflexion angle at the maximum squat depth.

DISCUSSION:

Herein, we investigated the relationship between the Young's modulus of the SM and the ankle dorsiflexion angle at the maximum squat depth in healthy young males using SWE. The results revealed that the ankle dorsiflexion angle at the maximum squat depth may reduce as the Young's modulus of the SM increases in healthy men.

The Young's modulus of the SM increased as the ankle dorsiflexed. The three-headed triceps surae, which comprises the gastrocnemius and soleus, works to plantar flex the ankle joint through its associated tendon, the SM. The gastrocnemius and soleus are elongated during ankle dorsiflexion. Therefore, a passive tension is generated in the SM with ankle dorsiflexion, which can increase the Young's modulus of the SM.

This study had some limitations. First, it only included healthy young males; therefore, our findings cannot be generalized to the entire population. Therefore, corresponding studies with participants of different ages and sexes should be conducted in the future. Second, electromyography was not used during SWE measurements. Consequently, monitoring muscle activity is necessary to ensure no muscle contraction. Third, Young's modulus only considers the SM. Therefore, the Young's modulus of muscles, such as the triceps surae, should also be examined to discover factors that confirm the relationship between ankle dorsiflexion angle at maximum squat depth and the Young's modulus of the SM is specifically related to the tendon.

SIGNIFICANCE/CLINICAL RELEVANCE:

Assessing the Young's modulus of the SM using SWE may help identify areas of SM stiffness. Improving the stiffness of the SM may increase the dorsiflexion angle at the maximum squat depth.



Figure 1 Measurement of the ankle dorsiflexion angle at the maximum squat depth