POSTURE AND ACTIVATION DEPENDENT VARIATIONS IN SHEAR WAVE SPEED IN THE GASTROCNEMIUS MUSCLE AND APONEUROSIS

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INTRODUCTION

Musculotendon tissue interactions are strongly dependent on the morphological and mechanical characteristics of the aponeurosis [1]. Despite its mechanical significance, the material properties of the aponeurosis are not well understood. In fact, the literature reports conflicting results concerning the relative stiffness of tendon and aponeurosis tissue [2, 3], which may arise from the challenge of collecting repeatable measures from the *in vivo*, intact aponeurosis. The newly developed elastography technique of Supersonic Shear Imaging (SSI) may address this challenge. This novel ultrasonic method uses acoustic radiation force to induce transient shear waves within tissue, which are then tracked using high frame rate imaging [4]. In prior studies, SSI has shown promise in obtaining repeatable mechanical measures from the relaxed gastrocnemius [5], and has also demonstrated the ability to capture an increase in muscle stiffness with contraction [6].

In the current study, we investigated the capability of SSI to characterize load and posture dependent changes in aponeurosis tissue stiffness. It was hypothesized that shear wave speed, which is related to tissue stiffness [7], would be greater in the aponeurosis than the muscle, and would increase in both tissues with contraction. We also investigated the effect on shear wave speed of varying the knee angle, which modulates the length of the biarticular gastrocnemius.

METHODS

Data were collected from five healthy young adults. Subjects were asked to lie prone on an examination table while ultrasonic shear wave data were collected from the lateral gastrocnemius (AixPlorer Scanner, Supersonic Imagine, Aix en Provence, France). Five SSI images were collected during passive relaxation and active isometric contraction of the gastrocnemius at knee angles of 0°, 45° and 90°.

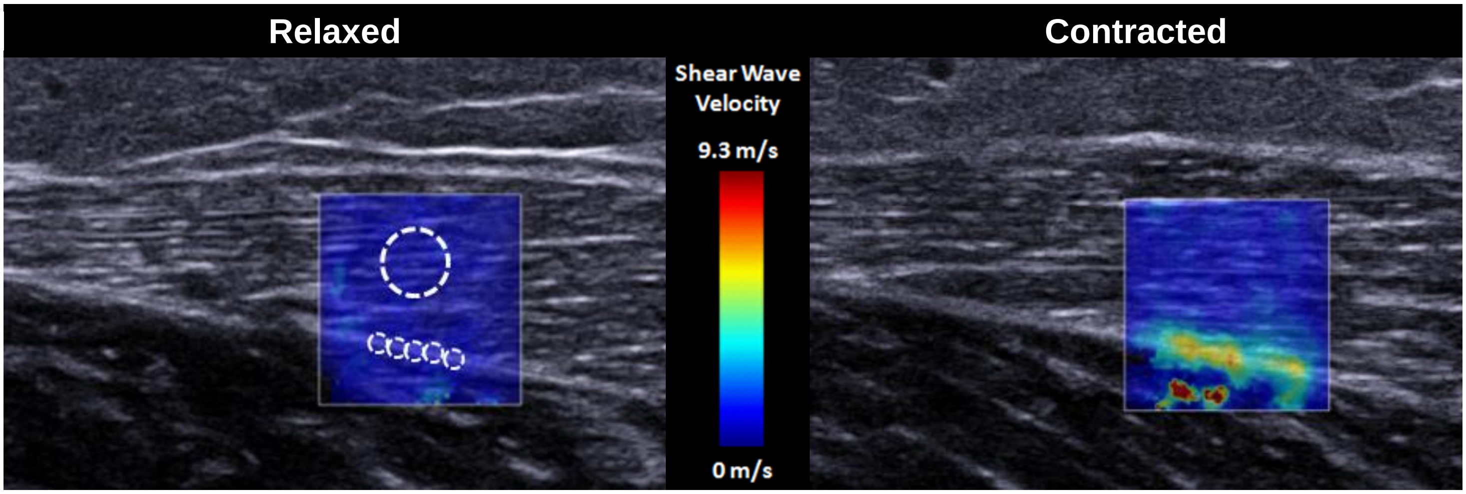

Figure 1: Representative B-mode images with shear wave speed information collected at a 45° knee angle. Average shear wave speeds were obtained from a 4 mm diameter ROI within the muscle belly and from five 1 mm diameter ROIs along the aponeurosis as shown in the image on the left. The increase in shear wave speed along the aponeurosis with active muscle contraction is clear from the bright yellow color noted along the anatomical structure.

Following data collection, shear wave speeds within the tissues were obtained from regions of interest (ROIs) manually placed within the muscle belly and along the aponeurosis (Fig. 1). Paired t-tests were used to evaluate the influence of contraction state and knee angle on shear wave speed.

RESULTS AND DISCUSSION

The muscle shear wave speeds ranged from 2.1-4.4 m/s, which is comparable to results reported previously for the gastrocnemius [5, 6]. As hypothesized, the aponeurosis demonstrated significantly higher shear wave speeds than the muscle for all knee angles. Also as hypothesized, shear wave speed increased significantly for both tissues when contracted at all knee angles, except the muscle at a 90° knee angle.

An increase in knee flexion led to a significant decrease in shear wave speed in the aponeurosis in the relaxed state, with a similar trend noted in the muscle (Fig. 2). This is consistent with the lower passive stiffness that is expected in the shortened gastrocnemius in a flexed knee posture (90°). Muscle shear wave speed was found to be highest when the muscle was active and lengthened (0°, extended knee). Aponeurosis stiffness also increased in the contracted state, but there was no significant effect of knee angle on stiffness, which may indicate the tissue is beyond the toe region of the stress-strain curve for all contracted states.

The results from this preliminary study suggest that SSI is capable of distinguishing posture and activation dependent changes in the mechanical properties of the gastrocnemius and aponeurosis tissues. Hence, this new, noninvasive, quantitative technology has substantial potential for both basic biomechanics and clinical applications. For example, it may be feasible to use the shear wave speed measures to characterize changes in tissue mechanical properties with injury, exercise and clinical treatment. We note that direct evaluation of the free tendon remains challenging due to the high stiffness of tendon which facilitates shear wave speeds that may exceed the current maximum measurable speed of the scanner (16.3 m/s). While elastic modulus can be ascertained from shear wave speed in homogeneous isotropic materials [4], further work is needed to better understand shear wave propagation in fibrous tissues with complex architectures.

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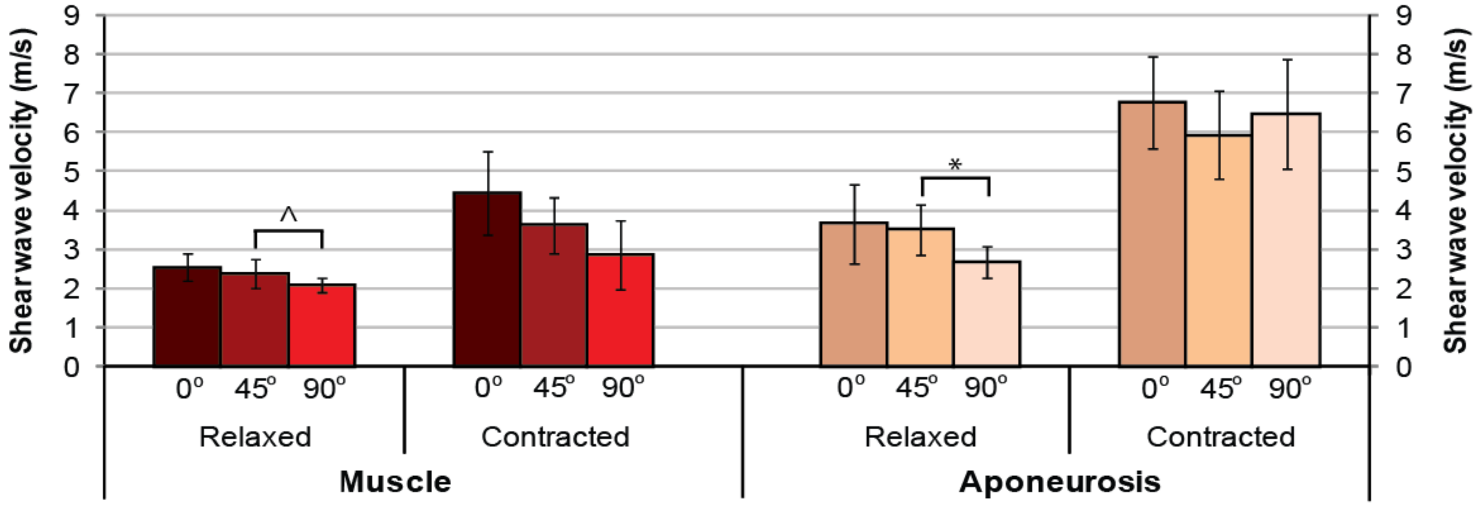

Figure 2: The effect of knee angle (0°, 45° and 90°) on average shear wave speeds (mean ± SD) in the muscle and aponeurosis tissues. *p < 0.05, ^p < 0.10