

Observation of Anisotropic Properties of Skeletal Muscle in MR Elastography via a Needle Device

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Introduction:

Magnetic Resonance Elastography (MRE) is an MRI-based method for imaging the mechanical properties of tissue [1]. The technique has been shown to be capable of measuring the elasticity of skeletal muscle [2, 3]. The MRE needle driver developed in our laboratory [4] is possible to introduce shear motion directly to adjacent muscle by vibrating the needle. The objective of this study was to conduct an *in vivo* human study to show the anisotropic properties of muscle with the acoustic wave generated by an inserted moving needle.

Methods:

12 healthy male volunteers were studied in this study. The subjects were positioned left decubitus. Mechanical excitation was applied at the soleus muscle using the longitudinal motion of needle. The needle driver consisted of a piezoelectric bending element (D220-A4-503YB, Piezo Systems, Inc.) and a sterilized pure silver needle with 0.4mm in diameter, 50mm long, which was disposed after use. The MRE was performed in a 1.5 Tesla Scanner (Signa Horizon Echo Speed with version 5.51 software, General Electric Medical Systems, Milwaukee, WI, USA) with a modified phase-contrast MRI technique to image induced shear waves as they propagate through tissue. In addition to standard MRI imaging gradients, the MRE sequence incorporated oscillating, motion sensitizing field gradients synchronized to the frequency of the propagating waves. Data acquisition parameters were: TR 150ms, TE 50ms, flip angle 30°, acquisition matrix 256x64, FOV 24cm, acquisition time 115.2s per slice. The frequency of mechanical excitation was fixed at 100Hz. Six phase offsets were applied to obtain the image of propagation of the shear waves. Wavelengths were estimated from the wave images along various propagating directions with respect to the needle, including parallel and perpendicular to the muscle fibers. The measured wavelengths (which are proportional to square root of the elasticity) were statistically tested using one-way ANOVA.

Results and Discussion:

MRE image is shown in Figure 1. In all cases, the shear waves demonstrated an oval pattern of propagation from the needle driver. Muscle is usually assumed to have transverse isotropic symmetry, with the axis of symmetry along the muscle fibers. Under this assumption, out-of-plane displacement from a point source propagates along a plane containing the muscle fibers with theoretical wave speeds that vary with angle and form an ellipse with the major axis along the muscle fibers [5]. The wave speeds along the major and minor axis are determined purely by the parallel and perpendicular shear moduli c_{44} and c_{66} respectively. The observations thus suggest that transverse isotropy is a good assumption for muscle and that *in vivo* values for the shear moduli of muscle can be determined using MRE. Figure 2 shows box plots of wavelengths for propagation along these axes from the needle. One-way ANOVA testing demonstrated that the wavelength for propagation along the muscle fibers (D1 and D3) was significantly longer than that for propagation perpendicular to the fibers (D2 and D4) ($P < 0.0001$). These wavelengths correspond to parallel and perpendicular shear moduli (c_{44} and c_{66}) of 6.0 kPa and 4.1 kPa respectively.

Conclusion:

In this study, shear moduli with different shear wave propagation directions were measured. Experimental results showed that the waves propagating outwards from the needle formed an oval-shaped wave pattern, consistent with theoretical expectations for the variation of shear wave speed with propagation direction. The results indicate that the anisotropic properties of skeletal muscle and presumably other tissues can be readily measured using this simple, needle-based MRE technique, suggesting the feasibility of using anisotropy as an independent tissue characterization parameter.

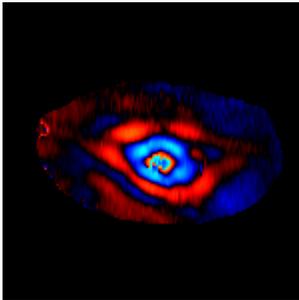


Figure 1 Wave image with needle inserted at soleus muscle

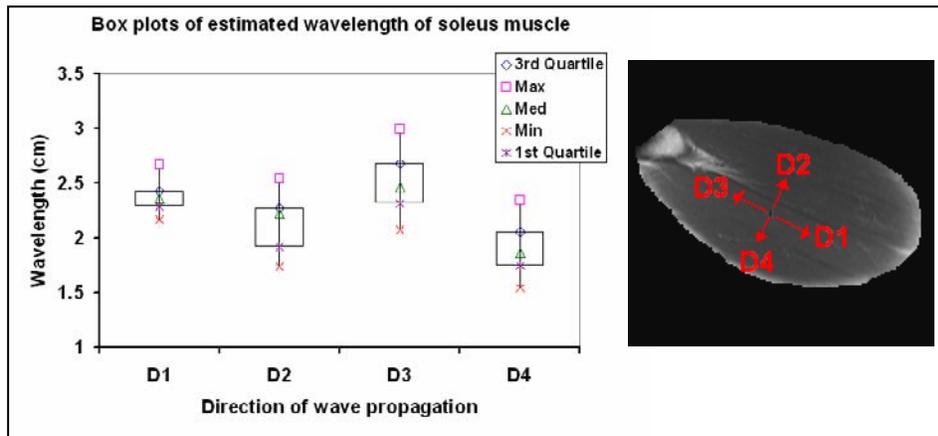


Figure 2 Variations of averaged wavelengths according to the direction of wave propagation from the needle. D1 and D3 represent the wave propagation along muscle fibers while D2 and D4 represent propagation perpendicular to fibers.

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