The measurement of anisotropic elasticity in skeletal muscle using MR Elastography

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Introduction

Magnetic resonance elastography (MRE) is a non-invasive method for measuring the elasticity of human tissue proposed by Muthupillai et al. [1]. Several studies on measuring the elasticity of skeletal muscle fiber have been reported [2, 3]. Among five anisotropic elasticity properties in the transverse isotropic material such as skeletal muscle tissue which has directional structure, only one of them has been measured in these studies. In this study, two of the transverse isotropic shear moduli are measured with different shear wave propagation direction. These anisotropic elasticity properties are potentially important for accurate assessment of human tissue character in physiological and pathological conditions.

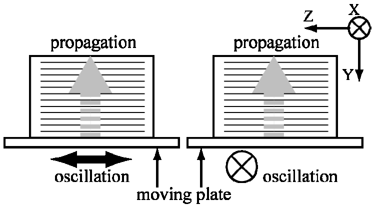

Fig.1 : Oscillation system for measuring a foot of pig.

Methods

In this study, two different shear waves were imaged by MRE. One was a wave which propagated or vibrated parallel to the muscle fiber orientation (parallel wave) and the other was one which propagated and vibrated orthogonal to the muscle fiber orientation (orthogonal wave). Two types of actuators were utilized for generating shear wave (Fig.1 and Fig.2). Two of the independent elastic properties ($S_{44}=2G_{yz}$, $S_{66}=2G_{xy}$ in the stiffness matrix) were measured by estimating the wavelength of corresponding MRE images.

Two experiments were performed. In the first experiment, a foot of pig was examined *ex vivo* to measure two transverse isotropic shear moduli G_{xy} and G_{yz}. Mechanical oscillations were applied as shown in Fig.1. All the MRE images were acquired with Magnetom Sonata (Siemens AG, Erlangen, Germany) with 100Hz mechanical oscillation. To acquire MRE images, a modified gradient echo sequence was applied including a sinusoidal MSG of 25mT/m whose direction and frequency were identical to those of mechanical oscillation. Images with ten phase offsets were obtained to estimate the wavelength accurately. For extracting shear waves, a spatio-temporal directional filter [4] was applied to these images in order to suppress reflection waves. Finally, the shear moduli were calculated from the wavelength of the extracted waves with an estimation of tissue density as 1 g/cm^3. In the second experiment, a forearm of a healthy young volunteer was examined *in vivo* using actuators as shown in Fig.2. While oscillation conditions, MRE sequences and the calculation method of shear moduli were same as those in the first experiment, images with only four phase offsets were acquired in this *in vivo* experiment to reduce total acquisition time.

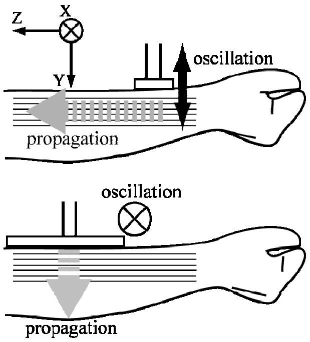

Fig.2 : Oscillation system for measuring a forearm.

Results and Discussion

Acquired MRE images are shown in Fig.3. Shear moduli in the directions parallel (G_{yz}) and orthogonal (G_{xy}) to the muscle fiber were averaged in the square area shown in each image. The averaged shear moduli were 21.4 (SD: 9.6) kPa and 12.9 (SD: 3.7) kPa in the pig *ex vivo* study, and 14.3 (SD: 8.1) KPa and 6.6 (SD: 16.0) KPa in human *in vivo* study, respectively. The shear moduli of the same pig specimen were measured by a viscoelastic analyzer (Rheogel-E4000, UBM, Kyoto, Japan). The resulting shear moduli of 21.1 (SD: 2.7) kPa (G_{yz}) and 14.8 (SD: 4.6) kPa (G_{yz}) corresponded well with the measurements of MRE. The shear modulus parallel to the muscle fiber direction (G_{yz}) in human *in vivo* study was comparable to that of previous studies [2, 3].

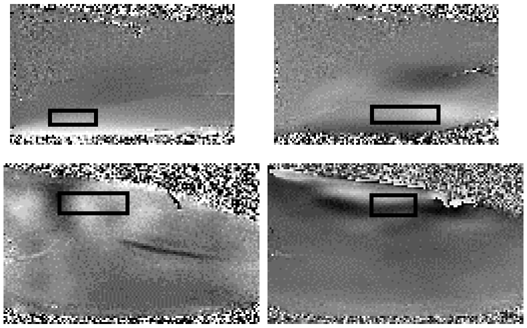

Fig.3 : MRE images.
Top left : parallel wave in pig's study.
Top right : orthogonal wave in pig's study.
Bottom left : parallel wave in the in vivo study.
Bottom right : orthogonal wave in the in vivo study.

Conclusion

In this study, two of the transverse isotropic shear moduli were measured with different shear wave propagation directions. Experimental results showed that the transverse isotropic material such as skeletal muscle tissue had different shear moduli parallel to and orthogonal to the fiber direction.

Reference

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