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Anisotropy Measurement of Shear Wave Propagation by External Excitation

外部加振によるせん断波伝搬の異方性計測

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1. Introduction

Shear wave elastography (SWE) techniques provide quantitative measurement of soft tissues elastic properties. Among SWE, Color Doppler Shear Wave Imaging (CD SWI), which uses signal processing unit in conventional ultrasound color flow imaging (CFI) instrument in order to reconstruct the wavefront of continuous shear wave excited from the tissue surface by a small vibrator, has been proposed[1,2].

CD SWI has the potential for breast cancer diagnosis and many other clinical applications, including musculoskeletal rehabilitation assessment. However, organs such as muscular tissues are composed of fibers, which induces highly anisotropic mechanical behavior and elastic properties. In this paper, we investigated the feasibility of measuring muscle fiber anisotropy by combining CD SWI and direction-enhancement images.

2. Method

Fig. 1 shows the experimental system. A chicken muscle was embedded in an agar-block phantom. The fiber direction of the chicken muscle was parallel to the lateral direction (x-direction) of linear array probe. In this study, we employed an ultrasound color Doppler imaging system (ALOKA, ProSound α7) with a linear probe (7.27 MHz, UST-5412, field of view width: 36 mm) and a small-sized (40 mm in diameter) vibrator (PUI Audio, Inc., ASX04004-R), which was designed for sound speaker to generate low frequency sine-wave excitation. We utilized an actuator head which is a half sphere with a diameter of 20 mm, which was designed for generating a spherical shear wave. In CD SWI, shear wave frequency is chosen among several frequencies that satisfy the shear wave frequency condition depending on the PRF of ultrasound scanner. The shear wave frequency was set to 200.7Hz. The actuator was placed at the upper left position of region of interest (ROI). In order to reconstruct shear wave maps, CFI on ultrasound scanner was recorded as a moving picture and the CFI was fed into a PC via a video capture device. A two-dimensional directional filter was applied to extract the shear wave component propagating in parallel and perpendicular to the fiber direction of chicken-muscle. Fourier analysis and the directional filter were applied and the shear wave maps, such as shear wave direction, shear wave velocity, and shear wave propagation maps, were reconstructed.

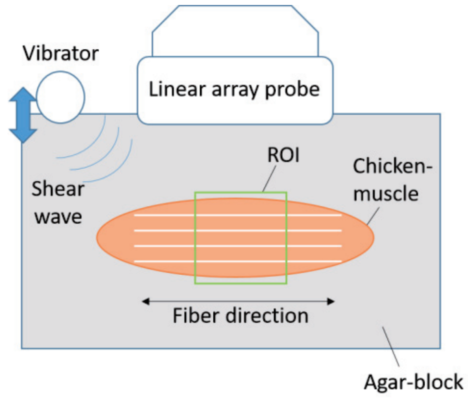

Fig. 1 Experimental system layout and ROI position.

3. Results

Fig. 2 shows the observed B-mode image and CFI image for the chicken-agar phantom. The depth setting for B-mode images was set to observe up to a

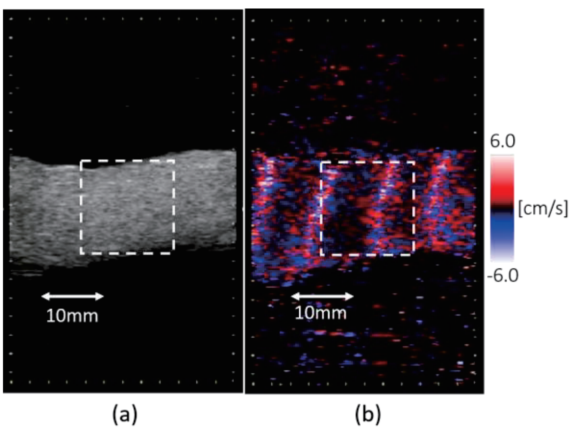

Fig. 2 Chicken phantom image. (a) B-mode image, (b) CFI

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depth of 70 mm. The frame rate of CFI was set to 20 Hz. We see that the shear wavefront propagates along the fiber direction of the chicken muscle. Even though the sample was located at a depth of about 30-40mm, the wavefront propagating in the depth direction was hardly observed.

Fig.3 shows the effect of the directional separation filter. Fig. 3(a-1) and (a-2) are wavenumber spectrum of shear wave separated in the x- and z-direction by applying directional filter. Fig. 3(b-1) and (b-2) are wavenumber spectrum applied with Wiener filter to suppress noise components at higher spatial frequencies.

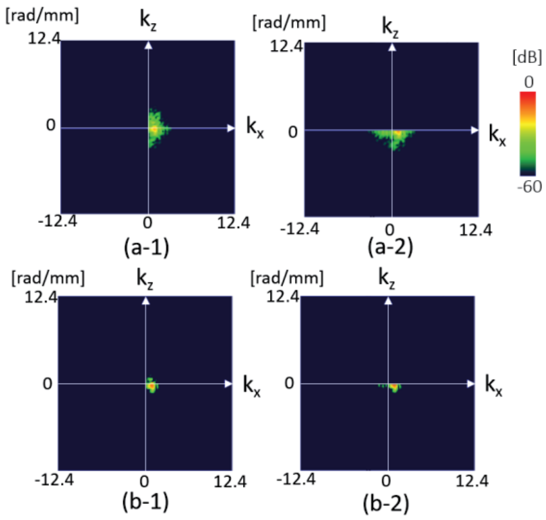

Fig.3 Wavenumber spectrum separated in x-direction and z-direction (a-1),(a-2) and applied Wiener filter (b-1),(b-2)

Fig.4 shows the shear wave propagation map, the shear wave velocity map and the shear wave direction map. Fig.4(a-1)-(c-1) show the result of applying x-direction enhancement. Fig.4(a-2)-(c-2) show the result of applying z-direction enhancement. We see that that shear waves propagate from left to right in the x-direction enhanced image and from top left to bottom right in the z-direction enhanced image. The shear wave propagation map in the x- and z-direction enhanced image clearly shows different wavefront spacing. Almost homogeneous shear wave velocity maps were reconstructed in both filtered images.

Fig.5 shows the comparison of the shear wave velocities measured in the x- and z-direction enhanced images, respectively. The shear wave velocities measured by the x- and z-enhanced images were 3.71 ± 0.26 m/s (mean and SD), 2.45 ± 0.10 m/s.

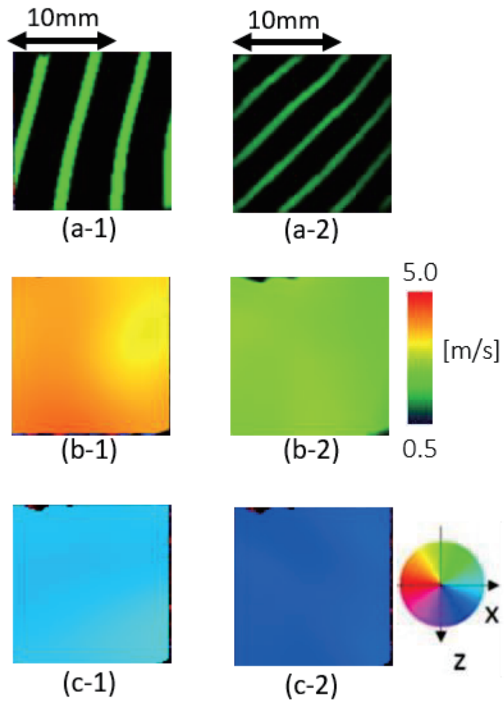

Fig.4 Shear wave maps measured in the chicken phantom. (a) Shear wave propagation map, (b) velocity map and (c) direction map. (a-1)-(c-1) and (a-2)-(c-2) were observed by x- and z-direction enhancement, respectively.

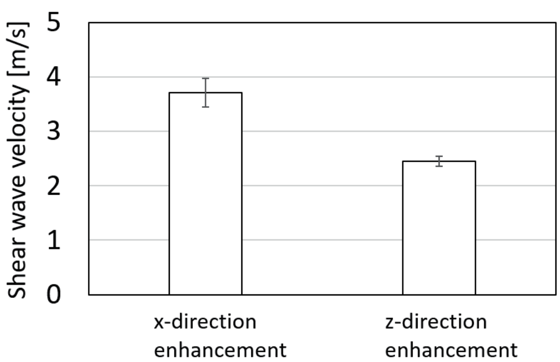

Fig. 5 Shear wave velocity obtained from x- and z-directional enhanced images

4. Conclusions

In this paper, we investigated the feasibility of anisotropy measurement of muscle fibers by combining CD SWI and directional enhancement measurement. The results showed that the angle dependence of the shear wave propagation velocity on the fiber direction in an experiment using a chicken-muscle phantom.

References

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