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Visualization of shear wave propagation generated by dual acoustic radiation force
双方向音響放射圧により生じる剪断波伝播の可視化

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1. Introduction

Measurement of soft tissue hardness is an important technique to diagnose the malignant lesions. We have reported a method that estimates tissue hardness using ultrasound acoustic radiation force irradiated from two opposite horizontal directions. The method aimed at the quantitave and noninvasive valuation of viscoelastic property of soft tissue.[1]

We want to know propagation of shear wave by showing the measured result in three dimensional space, and apply it to evaluation of regional viscoelasticity of biological tissue. In the present study, we measured the ultrasound propagation through a homogeous phantom. The shear wave originates from the vibration caused by acoustic radiation force. We applied the acoustic radiation force to a phantom that simulates uniformly soft biological tissue. We measured how displacements are caused and shear waves propagate by generating vibration with acoustic radiation force by using ultrasound.

2. Materials and Method

In the present study, we use two acoustic radiation forces of the same amplitude whose frequencies are f_0 and $(f_0 + \Delta f)$. When the two acoustic forces are crossed each other, an acoustic pressure of the frequency Δf is generated in the intersectional space.[2] The acoustic radiation force $P_R(z,t)$ is given by

$$P_R(z,t) \approx \frac{\alpha p_0^2}{\rho_2 c_2^2} e^{-2\alpha \cdot z} \left(1 + \cos 2\pi \Delta f t\right), \qquad (1)$$

where α , p_0 , ρ_2 and c_2 are attenuation coefficient, sound pressure, density and sound speed of the object, respectively.

When an acoustic radiation force of Eq. (1) is generated in the phantom, locally vibrated displacement is generated, and shear wave propagates from the focal point. We measured the amplitude of this shear waves using another ultrasound as follows along two kinds of directions.

First, as shown in **Fig. 1(a)**, we measured shear waves along the direction vertical to irradiation direction of acoustic radiation force, and observed the state of the shear wave propagation. Next, as shown in **Fig. 1(b)**, we measured shear waves along the direction lateral to irradiation direction of acoustic radiation force, and observed the state of the shear wave propagation.

We used two point-focus transducers to irradiate ultrasound which is superimposed two continuous sinusoidal waves, whose center frequencies are 1 MHz and 1 MHz+10 Hz for generating vibration, and used an ultrasonic diagnostic equipment (Hitachi-Aloka Pro Sound F75) with the linear probe whose center frequency is 7.5 MHz (Hitachi-Aloka UST-5415) for measurement. The frame rate was 495 Hz and the scan line interval was 3.3 mm. The number of beams used in the measurement was 11, where we numbered the beams from 0 to 10. As shown in Fig. 1, we selected a point in the center beam, and the foci of two point-focus transducers were set at the point.

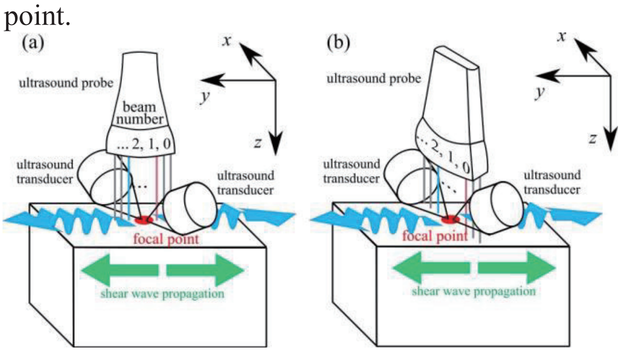

Fig. 1. Experimental setting used in the present study (a) in the vertical direction and (b) in the lateral direction.

3. Result

Figure 2 shows the displacement of shear waves inside the phantom at the depth of 1.9 mm in the vertical and lateral directions to irradiation direction of acoustic radiation force. Both in the vertical and lateral directions, the displacement in the phantom showed the shear wave propagating at a frequency of 10 Hz.

In Fig. 2(a), the displacement has a phase shift with respect to the beam position. The displacement measured at the point in the beam 5

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had the smallest phase shift. As the beam position was distant from the center beam, the amplitude of the displacement became small and its phase shift became large. This result may be caused by the propagation of the shear wave, indicating the superiority of the proposed method in evaluating share wave propagation.

In Fig. 2(b), phase shift appeared in the displacements of all beams. However, unlike the phenomenon shown in Fig. 2(a), the amplitude of the displacement in beam 9 did not decrease sufficiently compared with the center beam. In addition, the phase shifts in beams 3, 5 and 7 were almost the same with each other. This result indicates that the displacement might be caused not only by the shear wave propagation, but also by the phantom vibration originated from the acoustic radiation force. This result shows the necessity to remove the influence of the acoustic radiation force on the displacement measurement.

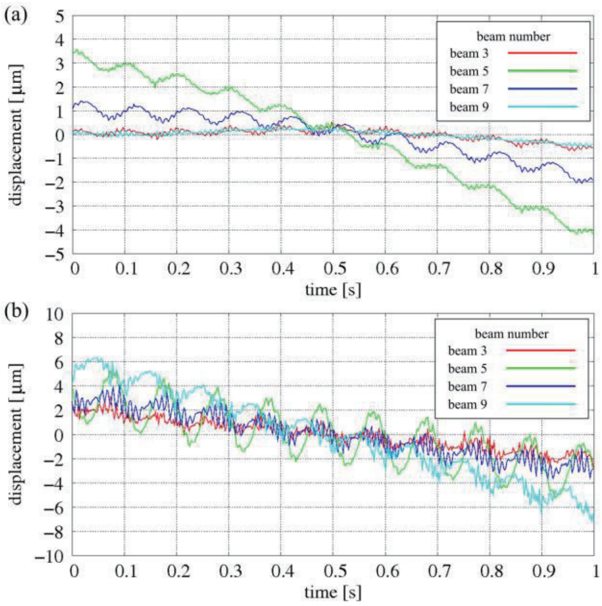

Fig. 2. Displacements of shear waves at the depth of 1.9 mm (a) in the vertical direction and (b) in the lateral direction.

Figure 3 shows the displacement of the phantom in the vertical and lateral sections, where we employed the band-path filter from 8 to 12 Hz and the displacement was normalized by the maximum displacement. In the vertical section, the vibration propagated from the region around the focal point of the two acoustic radiations. In contrast, in the horizontal section, two linear displacements appeared along the acoustic radiation axes. These results also show that the acoustic radiation force causes displacements directly and its effect on the displacement did not eliminated completely in this experimental setting. Therefore, it is necessary to remove the effect of the acoustic radiation force on the visualization of the shear wave propagation at least in the lateral section measurement.

In addition, the change of the amplitude is observed clearly around focal position, where this should be directly caused by the acoustic radiation force, not by the shear wave propagation. This phenomenon shows that the accurate visualization of the shear wave propagation requires the measurement of the region which is far from the focal point to suppress the effect of the acoustic radiation force.

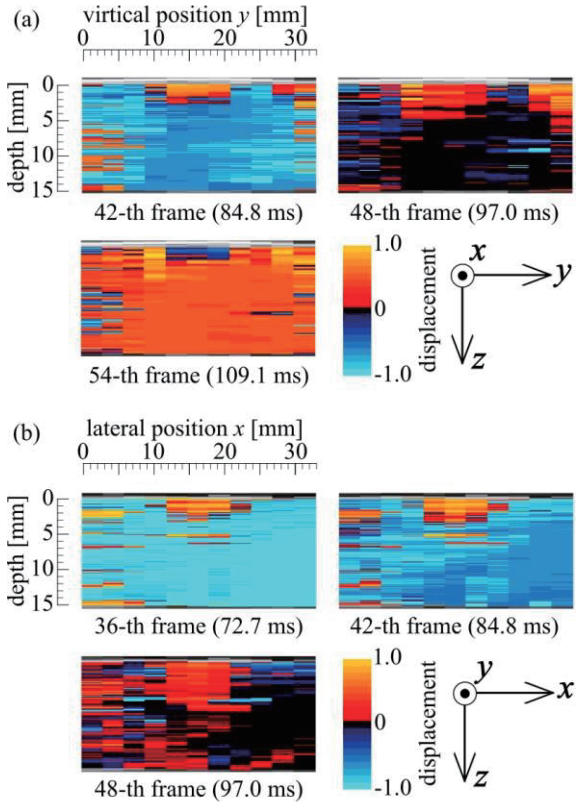

Fig. 3. Displacement mapping in the B-mode images of (a) vertical direction and (b) lateral direction.

4. Conclusion

We have reported the propagation of shear waves inside the phantom in the vertical and lateral sections. We succeeded to observe the displacements caused by the shear wave propagation from in the vertical section. In the lateral section, the displacement may be caused not only by the shear wave propagation but also by the acoustic radiation force. These results show that the suppression of the effect of the acoustic radiation force on the displacement is necessary to evaluate the viscoelastic properties accurately using shear wave propagation.

Reference

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2. K. Tachi, H. Hasegwa and H Kanai: Jpn. J. Appl. Phys. **53** (2014) 07KF17.