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Evaluation of properties of shear wave propagation in tissue using viscoelastic phantom

粘弾性ファントムを用いた生体組織せん断波伝搬特性の検討

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1. Introduction

In diffuse hepatic disease, it is known that the shear modulus of diseased tissues increases with increasing tissue fibrosis. Therefore, as a quantitative evaluation method of diffuse hepatic disease, a method called shear wave elastography focusing on the viscoelastic properties of the liver is used in clinical practice. This is a method of generating a shear wave in the liver from the outside and calculating the propagation speed of the shear wave. The shear wave propagation velocity changes depending on the shear modulus and the viscosity of the tissue. For this reason, attention has been paid as a method capable of quantitatively evaluating the viscoelastic properties of the structure.

Shear wave elastography function is currently implemented in each manufacturer's ultrasonic diagnostic apparatus. However, in clinical practice, it is reported that the shear wave propagation speed regardless of the measurement of the same tissue differs depending on the equipment [1].

Therefore, in this report, in order to investigate the shear wave propagation velocity and attenuation depended on the frequency of shear wave and the viscoelastic properties of the tissue, using laser Doppler vibrometer and the ultrasonic diagnostic apparatus for experiments, propagation of shear wave was measured.

2. Experiments and Analysis Method

Two types of phantoms are prepared, one is made from elastic material with low viscosity, and the other is made from viscoelastic material with high viscosity. The frequency effects on the shear wave propagation were examined by exciting burst waves of different frequencies on these phantom surfaces and measuring shear wave propagation in the phantom.

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2.1 Relationship between Shear Wave Speed and Viscoelastic Properties

The response of the viscoelastic tissue can be approximated by the Kelvin-Vogt model, the shear wave propagation speed is shown as the following equation.

$$c_s = \sqrt{\frac{2\{G^2 + (2\pi\mu f)^2\}}{\rho\{G + \sqrt{G^2 + (2\pi\mu f)^2}\}}} \qquad (1)$$

Here, c_s[m/s] is shear wave propagation speed, G[Pa] is shear modulus, μ[Pa] is shear viscosity, f[Hz] is the frequency of shear wave and ρ[kg/m^3] is density of tissue. c_s is a function of frequency, and the higher frequency is, the faster shear wave propagation speed is by viscosity.

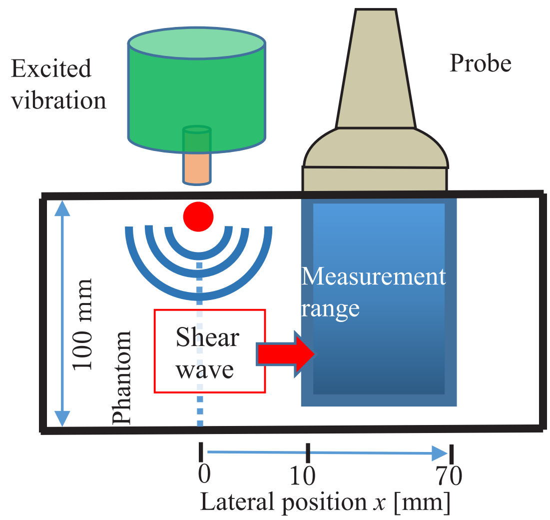

Fig. 1 Configuration of equipments

2.2 Experiments Method

Figure 1 shows the configuration of equipments when shear waves propagating inside the phantom are measured with an ultrasonic diagnostic apparatus for experiments. A vibrator generates a burst wave of 50 Hz to 200 Hz and propagating wave is measured with transducers of an ultrasonic diagnostic apparatus.

2.3 Analysis Method

At each measurement position, the shear wave propagation waveform with time is obtained by visualizing the displacement amplitude along the depth direction. The shear wave propagation waveform with time at x = 10 mm, when the viscoelastic phantom is vibrated at 50 Hz, is shown in **Fig. 2**. **Figure 3**(a) is a plot of shear wave propagation waveforms with time at a depth of 10 mm. The waveforms are plotted from the top in order of closer position from excited point. Figure 3(b) shows the frequency analysis in the time direction with respect to each of the waveforms in Fig. 3(a). Correlation is taken for each measurement position adjacent to the shear wave propagation time waveform shown in Fig. 3 (a), and the propagation time of each measurement position is calculated. From correlation results, the shear wave velocity is calculated as shown in Fig. 3 (c).

3. Results and Discussion

Measurement results of shear wave in the elastic phantom and viscoelastic phantom using laser doppler vibrometer and ultrasonic diagnostic apparatus are shown in **Fig. 4**. In this figure, the share wave velocity is shown as a function of frequency. From this result, it was observed that shear wave velocity depends on the frequency in viscoelastic phantom. From comparison between results the shear wave velocity in each phantom with laser doppler vibrometer and ultrasonic diagnosis apparatus, it is found that the increasing amount in the shear wave speed caused by the increment of frequency is different between the phantom surface and inside. This may be due to the fact that the propagating wavefront of shear wave inside the phantom is tilted with respect to the direction of the ultrasonic beam. In addition, the amplitude of shear wave becomes smaller as the measurement position is far from the excitation position, and the attenuation of the viscoelastic phantom is larger than that of the elastic phantom.

4. Conclusion

In this report, the shear waves at different frequencies were generated for each phantom, and examined frequency effects for shear wave propagation in viscoelastic material. Using laser doppler vibrometer and ultrasonic diagnosis apparatus, it is observed the frequency dependence in viscoelastic phantom.

References
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2. T. Shiina: Jpn. J. Med ultrasonics **40** (2013) 309.

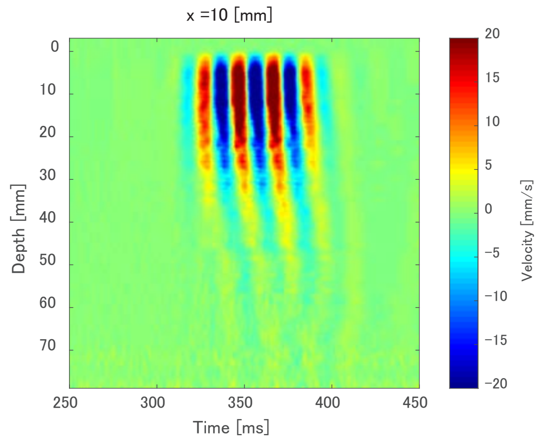

Fig. 2 Propagation wave

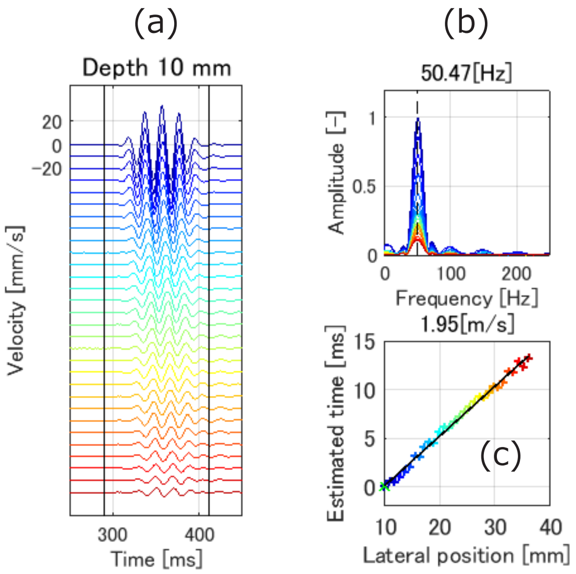

Fig. 3 Method of calculation of shear wave velocity

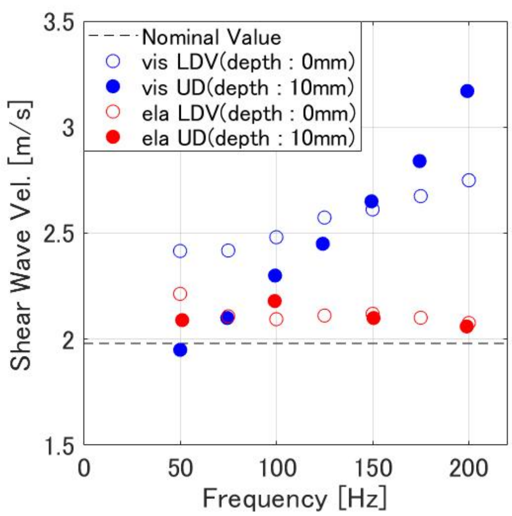

Fig.4 Frequency response of shear wave propagation velocity in tissue-phantom