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Shear Wave Transmissivity Measurement by Color Doppler Shear Wave Imaging

カラードプラせん断波映像法によるせん断波透過率測定

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1. Introduction

Shear wave imaging (SWI) is a promising method in order to estimate the stiffness of tissue. Several methods have been proposed as SWI and they have been applied to various tissues, for example, breast, liver and thyroid gland, in which the hardness of the tissue is sensitive to diseases. We have proposed a novel SWI method (Color Doppler SWI: CD SWI) for continuous shear wave which is excited by a mechanical vibrator[1,2]. In this method, shear wave propagation inside the tissue is appeared directly on the color flow map of conventional ultrasound imaging system without adding any extra function to the imaging system. Shear wave velocity map is reconstructed by PC from the video-captured shear wave propagation map. In CD SWI, two conditions are required to obtain shear wave maps. First one is shear wave frequency condition, which defines the available shear wave frequency. Second one is shear wave displacement amplitude condition, which defines minimum displacement amplitude of the shear wave.

In this paper, a novel measurement method of shear wave transmissivity of tissue boundary is proposed. In CD SWI, shear wave wavefront is appeared if the shear wave displacement amplitude is larger than the threshold value which is defined by the shear wave displacement amplitude condition. Hence, if shear wave wavefront maps are acquired by changing the displacement amplitude of the excited shear wave, shear wave amplitude map is easily obtained from these maps. From the difference of shear wave amplitude around the tissue boundary, shear wave transmissivity of tissue boundary, which is a valuable index of the difference of tissue stiffness, such as normal and diseased tissues, can be derived. The feature of the method is shear wave transmissivity is measured quantitatively with a spatial resolution which is higher than that of shear wave velocity mapping.

2. Method

Shear wave is excited by a vibrator and the wave propagates in tissue. Then, displacement amplitude of shear wave excited by vibrator a_0, that of incident shear wave at tissue boundary a_1, that of transmitted shear wave a_2 are given by

$$a_0 = KV \tag{1}$$
$$a_1 = A_D A_T a_0 = K A_D A_T V \tag{2}$$
$$a_2 = T_u a_1 = K T_u A_D A_T V \ , \tag{3}$$

where K is a constant and V is the applied voltage to the vibrator. A_D, A_T and T_u are shear wave absorptions by shear wave diffraction, that by tissue absorption and the transmissivity of tissue boundary, respectively.

In CD SWI, shear wave wavefront is appeared if the following condition (Shear wave displacement amplitude condition) is satisfied.

$$a \geq a_{TH} \ , \tag{4}$$

where

$$a_{TH} = \frac{1}{8}\lambda \ , \tag{5}$$

and λ is the wavelength of ultrasonic wave.

The applied voltage to the vibrator V_1 to appear the incident shear wave's wavefront at the boundary is

$$K A_D A_T V_1 = a_{TH} \tag{6}$$

On the other hand, the applied voltage to the vibrator V_2 to appear the transmitted shear wave is

$$K T_u A_D A_T V_2 = a_{TH} \tag{7}$$

From eqs.(6) and (7), transmissivity of the boundary T_u is derived as follows

$$T_u = \frac{V_1}{V_2} \tag{8}$$

3. Experimental set-up

Fig.1 shows an experimental set-up. Shear wave is excited by linear vibration actuator and the amplitude of shear wave is controlled by oscillator. Color flow map was acquired by conventional

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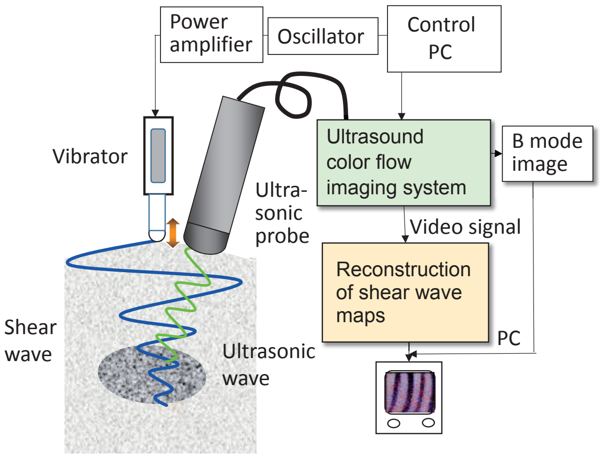

Fig.1 Experimental set-up.

ultrasonic imaging system (Hitachi, EUB-8500), with 6.6MHz linear probe. Video signal was fed into PC and shear wave maps were reconstructed on PC. Shear wave frequency was set to 276.5Hz, which was m=1 in the shear wave frequency condition[1].

4. Results

Fig.2 is an example of shear wave's wavefront map which is acquired for graphite powder mixed agar gel phantom. A sphere of diameter 10mm is

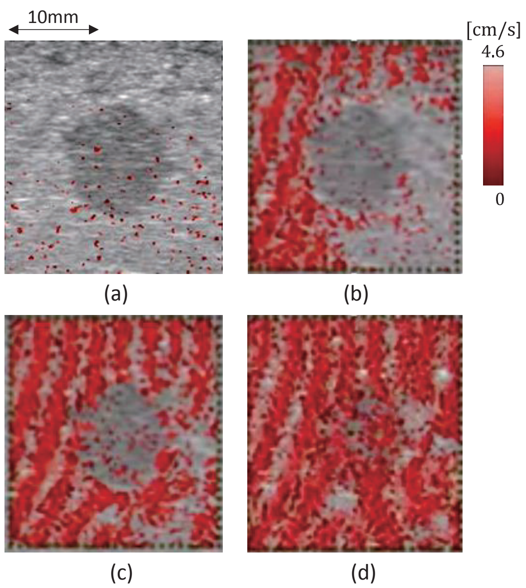

Fig.2 Shear wave’s wavefront maps for different voltage of oscillator.

at the center of the phantom. Shear wave velocities of surrounding gel and the sphere are 2.3 and 5.1m/s, respectively at the shear wave frequency of 276.5Hz. Figs.2 (a)-(d) are shear wave's wavefront maps for the oscillator voltage are 0, 0.09, 0.15 and 0.27V, respectively. When the applied voltage is low (Fig.2 (b) and (c)), shear wave's wavefront appears only on the surrounding gel. However, the wavefront appears on the whole area in Fig.2 (d), which is consistent with the discussion in section 2.

Fig.3 shows wavefront appearance index *Wa* which is measured for the different oscillator voltage. *Wa* is defined as

$$W_a = \frac{1}{nT}\Sigma_i^{nT} V_{CFI}(x,z,i)/V_n \ , \qquad (9)$$

where T, V_{CFI} and V_N are the period of shear wave appeared on color flow image (CFI), flow velocity on CFI and maximum flow velocity, respectively. *Wa* values which were averaged on ROI A (left of the boundary) and ROI B (right of the boundary)

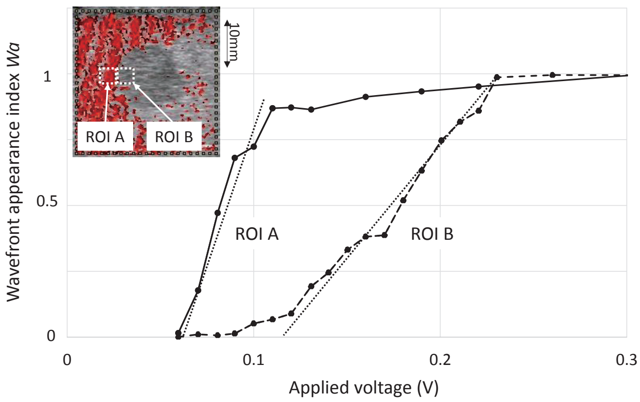

Fig.3 Shear wave transmissivity measurement of boundary between ROI A and ROI B.

were shown. From the zero crossing voltages of *Wa*, the shear wave transmissivity of the boundary between two ROIs was measured by eq.(8). The result was 0.56, which was consistent with the theoretical value of 0.61.

5. Conclusion

Quantitative measurement of tissue stiffness with high spatial resolution is required in medical diagnoses. However, it is difficult to increase spatial resolution in conventional shear wave velocity measurement, because a spatial average processing is needed to obtain a stable image. We proposed a novel method that can measure the transmissivity of tissue boundary. Transmissivity of boundary is a valuable index which shows the difference of stiffness of two tissues. Feature of the proposed method is that the shear wave transmissivity can be measured with high spatial resolution, which is important in medical diagnoses.

References

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2. Y. Yamakoshi et al. Jpn. J. Appl. Phys. **54** (2015) 07HC16.