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A Basic Study of Intrinsic Elastography Based on Propagation Velocity Distribution Induced by Artery Pulsation

拍動により生じる伝播波速度分布に基づいた弾性率推定方法に関する基礎検討

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1. Introduction

Elastography[1)] is a technique that estimates a tissue stiffness. Especially, shear wave imaging[2,3)] is more interested in. This modality can estimate the tissue stiffness by measuring shear wave velocity induced by push beam, which is generated by acoustic radiation force. Because push beam is a continuous wave for several hundred micro seconds, a decay of estimation accuracy attributed to out of focus might be generated due to tissue motions. Additionaly, there is a problem about heating by push beam[4)].

Without push beam, some research groups proposed estimation methods of the tissue stiffness from motions induced by electric stimulus, or physiological motions generated by breathing, heartbeat and so on[5-7)]. This passive elastography technique is based on the physiological-noise correlation.

We proposed a direct estimation method of the tissue stiffness from the motions induced by the pulsation, and named this method 'Intrinsic Elastography'. In this paper, a propagation wave velocity of a polyvinyl alcohol (PVA) is measured by the proposed method using a pulsation phantom. Moreover, the measured velocity is compared to shear wave velocity estimated by shear wave imaging.

2. Materials and methods

2.1 Intrinsic elastography

In this proposed method, pulsation was used as a vibration source instead of an external vibration source such as push beam. The motions induced by the pulsation travels in the tissue, and this propagation velocity is closely related to the stiffness of the soft tissue. A 2D particle velocity vector was defined as $\boldsymbol{V}(\boldsymbol{u}(\mathrm{x}, \mathrm{z};\, t), \boldsymbol{w}(\mathrm{x}, \mathrm{z};\, t))$, where $\boldsymbol{u}$ is a particle velocity along a lateral direction x, $\boldsymbol{w}$ is a particle velocity along an axial direction z, and t is a variable with slow time. It's considered that the propagation wave consists of 4 types: c_{lx}, a longitudinal wave propagating along x direction, c_{lz}, a longitudinal wave along z, c_{sx}, a shear wave along x, and c_{sz}, a shear wave along z. In this present paper, only the longitudinal wave c_{lz} and the shear wave c_{sx} are focused on. A phase difference of the Hilbert transformed axial particle velocity $\boldsymbol{\beta}(\mathrm{x}, \mathrm{z};\, t)$ was used to estimate the two propagation velocity. The phase differences are expressed respectively as

$$\varphi_x(x, z_0;\, t_0) = \frac{\sum_{i=-\frac{N_t}{2}}^{i=\frac{N_t}{2}} \beta^*(X, z_0; t+i)\cdot\beta(x, z_0; t+i)}{\left|\sum_{i=-\frac{N_t}{2}}^{i=\frac{N_t}{2}} \beta^*(X, z_0; t+i)\right|\left|\sum_{i=-\frac{N_t}{2}}^{i=\frac{N_t}{2}} \cdot\beta(x, z_0; t+i)\right|}, \quad (1)$$

and

$$\varphi_z(x_0, z;\, t_0) = \frac{\sum_{i=-\frac{N_t}{2}}^{i=\frac{N_t}{2}} \beta^*(x_0, Z; t+i)\cdot\beta(x_0, z; t+i)}{\left|\sum_{i=-\frac{N_t}{2}}^{i=\frac{N_t}{2}} \beta^*(x_0, Z; t+i)\right|\left|\sum_{i=-\frac{N_t}{2}}^{i=\frac{N_t}{2}} \cdot\beta(x_0, z; t+i)\right|}, \quad (2)$$

where $\varphi_x(x, z_0;\, t_0)$ is the phase difference between a reference position X, an interest position x at a fixed depth z_0 at time t_0, $\varphi_z(x_0, z;\, t_0)$ is the phase difference between a reference position Z and an interest position z at a fixed depth x_0 at time t_0, and Nt is a one-dimensional cross-correlation window. Each propagation velocity was calculated from a slope obtained by applying the least-square method to eq. (1) and eq. (2) ,respectively.

2.2 Pulsation phantom

Fig. 1 shows a schematic of a measurement system. The system consisted of a pulsatile/blood pump (Harvard apparatus, US), a pulsation phantom, and Verasonic™ ultrasound scanner (Redmond, WA). A 9.0 MHz linear probe were utilized to acquire raw RF data from the phantom. The data were sampled at

36 MHz with 16-bit resolution. Five plane waves at five different degrees (-6, 6, -3, 3, and 0) were transmitted with each time interval of 200 µs to acquire the received data for one spatial compound images. The time interval between spatial compound images corresponded to 1 ms, which was a frame rate of 1 kHz. The 2D particle velocity vector was measured using a simple modified 1D cross-correlation algorithm on successive B-mode images of each degree[8]. The pulsation phantom ,which was made of PVA[9,10], was composed of an artery phantom and a tissue phantom. A stiffness of the tissue phantom was about 20 kPa, a shear wave velocity of which was 2.6 m/s. The pulsatile/blood pump can control the pulse rate, ration of systole/diastole, and systole ouput. In this paper, the propagation wave velocity was measured with the flow output of 15 cc at fixed pulse rate of 60 Hz.

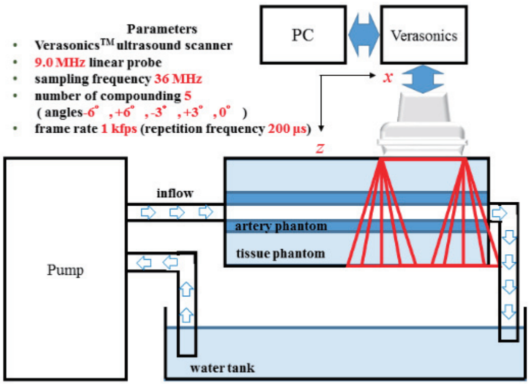

Fig. 1 schematic of a measurement system.

2.3 Shear wave imaging

The shear wave velocity (SWV) of the tissue phantom was measured by using shear wave imaging. The result was compared to the propgation wave velocity estimated by the propoased method.

3. Results

Fig.2 shows the spatial compound image of the pulsation phantom. The area of the phantom surrounded by a red square was the region of interest to measure the 2D particle velocity vector. Table 1 shows a summary of the result.

Table 1 SWV and propagation wave velocity

	SWV	c_{lz}	c_{sx}
Tissue Phantom	3.39 ± 0.45	0.68 ± 0.22	3.12 ± 0.43
Artery Phantom	7.13 ± 0.49	1.70 ± 0.61	5.01 ± 0.68

4. Discussions

The both propagation velocity estimated by the proposed method clearly classified each tissue, and showed a characteristic properties similar to the SWV. This indicated that the stiffness could be estimated from the intrinsic motions induced by the pulsation. The SWV and c_{sx} in the tissue phantom were greater than 2.6 m/s. It's considered that this reason is that the stiffness of the phantom increases with the flow pressure.

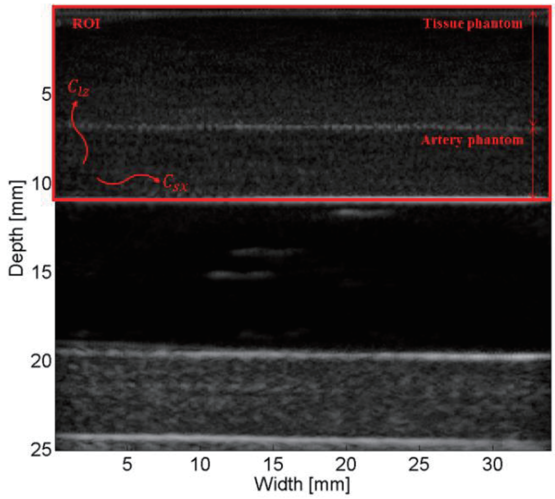

Fig. 2 spatial compound image of the phantom.

5. Conclusions

The two propagation velocity of the phantom were estimated by the proposed method using the pulsation phantom. Addtionally, the estimated propagation velocity was compared to a stiffness estimated by shear wave imaging. The both propagation velocity showed a characteristic properties similar to the SWV. These results showed a possibility that the tissue stiffness could be estimated based on the propagation velocity induced by pulsation.

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