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

Ryo Nagaoka1, Ryosuke Iwasaki2, Mototaka Arakawa1, Kazuto Kobayashi3, Shin Yoshizawa2, Shin-ichiro Umemura2, and Yoshifumi Saijo1 (1 Biomedical Imaging Laboratory, Graduate School of Biomedical Engineering, Tohoku Univ.; 2 Wave-Triggered Nanomedicine Laboratory, Graduate School of Biomedical Engineering, Tohoku Univ.; 3 Devision of Research and Development, Honda Electronics Co. Ltd.)

1. Introduction

Elastography1) is a technique that estimates a tissue stiffness. Especially, shear wave imaging2,3) 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. Additionally, there is a problem about heating by push beam4).

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 on5-7). 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 \( V(u(x, z; t), w(x, z; t)) \), where \( u \) is a particle velocity along a lateral direction \( x \), \( w \) is a particle velocity along an axial direction \( z \), and \( t \) is a parameter with slow time. It’s considered that the propagation wave consists of 4 types: \( c_{ls} \), a longitudinal wave propagating along \( x \) direction, \( c_{ls} \), a longitudinal wave along \( z \), \( c_{s} \), a shear wave along \( x \), and \( c_{s} \), a shear wave along \( z \). In this present paper, only the longitudinal wave \( c_{ls} \) and the shear wave \( c_{s} \) are focused on. A phase difference of the Hilbert transformed axial particle velocity \( \psi(x, z; t) \) was used to estimate the two propagation velocity. The phase difference are expressed respectively as

\[
\phi_x(x, z_0; t_0) = \sum_{i=-N_t}^{N_t} \beta^*(x, x_0; t_0) \beta(x, z_0; t_0 + \tau)
\]

(1)

and

\[
\phi_z(x_0, z; t_0) = \sum_{i=-N_z}^{N_z} \beta^*(x_0, z_0; t_0) \beta(x_0, z; t_0 + \tau)
\]

(2)

where \( \phi_x(x, z_0; t_0) \) is the phase difference between a reference position \( X \), an interest position \( x \) at a fixed depth \( z_0 \) at time \( t_0 \), \( \phi_z(x_0, z; t_0) \) 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 \( N_t \) 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 output. In this paper, the propagation wave velocity was measured with the flow output of 15 cc at fixed pulse rate of 60 Hz.

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 propagation wave velocity estimated by the proposed 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>
<thead>
<tr>
<th>Tissue Phantom</th>
<th>SWV (3.39 \pm 0.45)</th>
<th>(C_{LZ} ) (0.68 \pm 0.22)</th>
<th>(C_{SX} ) (3.12 \pm 0.43)</th>
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<tbody>
<tr>
<td>Artery Phantom</td>
<td>SWV (7.13 \pm 0.49)</td>
<td>(C_{LZ} ) (1.70 \pm 0.61)</td>
<td>(C_{SX} ) (5.01 \pm 0.68)</td>
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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.

References