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Separation of Forward and Reflected Pulse Waves in Carotid Artery Using Directional Filter

方向性フィルタを用いた頸動脈脈波の進行波・反射波の分離

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1. Introduction

Pulse wave is a pressure wave propagating along the artery, and its propagation velocity is related to the elasticity of the arterial wall. Therefore, the pulse wave velocity method is proposed for non-invasive evaluation of the arterial wall elasticity [1]. In the conventional pulse wave velocity method, the pulse wave velocity is measured typically between brachial and ankle arteries and would be useful for screening of the global change in elasticity of the arterial tree. Although it is clinically useful in terms of noninvasive assessment of the arterial wall elasticity, the regional elasticity cannot be evaluated.

High frame rate ultrasound was recently introduced in medical ultrasound imaging [2,3]. This method was first used for imaging propagation of the shear wave induced by ultrasonic acoustic radiation force [4]. The temporal resolution of high frame rate ultrasound is over 1000 Hz, and the rapid propagation phenomenon of the pulse wave can be observed in a very local segment of about 10 mm [5,6].

In measurement of the pulse wave in the carotid artery, it was reported that there was a reflected wave from the distal arterial tree [7-9]. It may provide useful clinical information if we can extract the reflected wave which contains the information of the distal arterial tree. Also, it would be better to suppress the reflected wave to estimate the pulse wave velocity because the reflected wave should interfere with the forward wave. In the present study, I have tried to separate the forward and reflected wave using a directional filter.

2. Materials and Methods

The common carotid artery of a 41-year-old healthy man was measured with a linear array ultrasonic probe at a nominal center frequency of 7.5 MHz. Ultrasonic echo signals received by individual transducer elements were acquired by a custom-made ultrasound scanner at a sampling frequency of 31.25 MHz. The beamforming procedure was performed off-line on the ultrasound echo signals.

The transmit-receive sequence is described in [8]. In the present study, the number of emissions of plane waves for creation of one image frame was set at 4, and each plane wave was emitted using 96 transducer element. In each transmission, 24 focused receiving beams were created at intervals of 0.1 mm, and the aperture used to create one focused receiving beam consisted of M = 72 elements. Consequently, one image frame consisted of 24 × 4 = 96 focused receiving beams was obtained by four times emissions of plane waves.

A phase-sensitive axial motion estimator [10] was applied to the beamformed RF signal in each scan line to obtain the velocity of the posterior wall in each scan line. Temporal differentiation was applied to the resultant velocities to obtain acceleration waveforms.

3. *in vivo* Experimental Results

Figure 1 shows the accelerations measured in 96 scan lines. In Fig. 1, accelerations in about 60 ms around the positive peak corresponding to the ejection of the heart were displayed. The smaller arterial longitudinal distance corresponds to the smaller distance from the heart.

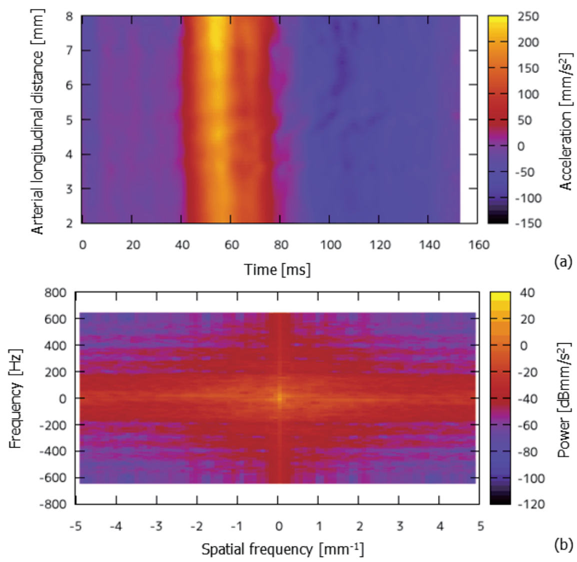

Fig. 1: (a) Accelerations of posterior wall of carotid artery measured in 72 scan lines. (b) Two dimensional power spectrum of accelerations in (a) obtained by two dimensional Fourier transform.

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Figure 1(b) shows two dimensional power spectrum obtained by applying the two dimensional Fourier transform to the spatio-temporal distribution of accelerations in Fig. 1(a). Based on the general solution of the wave equation, the components of the forward pulse wave exist in the second and fourth quadrants in the two dimensional frequency spectra. On the other hand, the components of the reflected pulse wave exist in the first and third quadrants. Therefore, the forward pulse wave can be obtained by setting frequency spectra in the first and third quadrants to be zero and applying the inverse Fourier transform to such modified two dimensional frequency spectra. Similarly, the reflected wave is obtained by setting frequency spectra in the second and fourth quadrants to be zero and applying the inverse Fourier transform to the modified two dimensional frequency spectra.

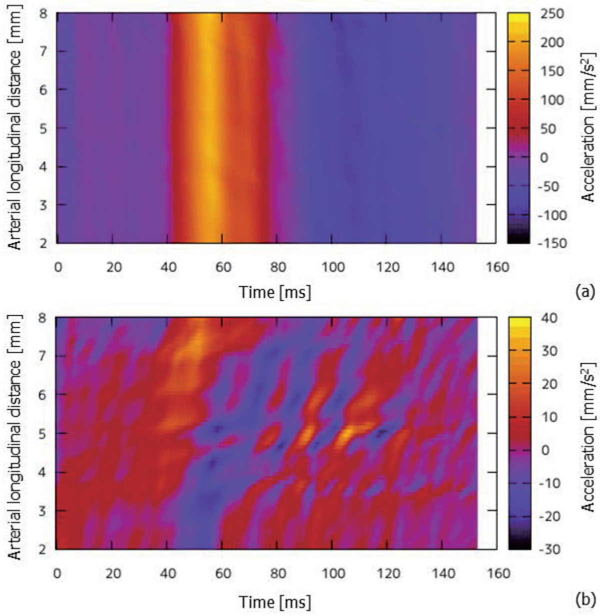

Fig. 2: (a) Accelerations obtained by inverse Fourier transform of components in the second and fourth quadrants in Fig. 1(b), corresponding to forward wave. (b) Accelerations obtained by inverse Fourier transform of components in the first and third quadrants in Fig. 1(b), corresponding to backward propagating wave.

Figures 2(a) and 2(b) show accelerations corresponding to the forward and backward propagating waves, respectively, obtained by applying the inverse Fourier transform to the modified two dimensional frequency spectrum.

By removing the components propagating in the backward direction from the forward wave, as shown in Fig. 2(a), the wavefront of the forward wave became more smoother. Figure 2(b) shows the removed backward propagating components. As we can see, the magnitudes of the backward propagating components are very small and noisy. Thus, it is necessary to confirm whether the reflected wave can be identified by the proposed method in the future investigation using a phantom.

Figure 3 shows the acceleration waveforms obtained in the 49th scan line. Red and green curves show the forward and backward propagating components, respectively. It was found that the first forward and backward waves arrived at about 40 ms and 60 ms, respectively.

6. Conclusion

In the present study, the acceleration the carotid arterial wall was measured at high temporal resolution and analyzed using two dimensional Fourier transform for separation of forward and backward propagation waves.

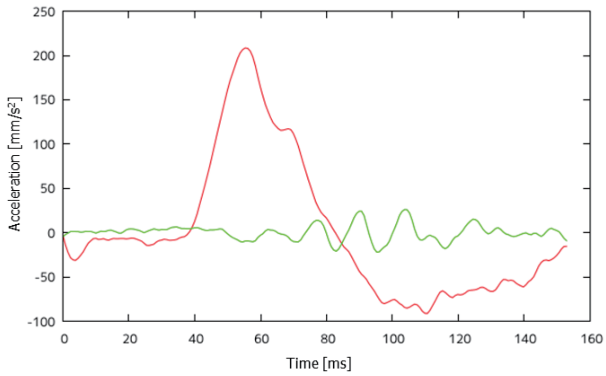

Fig. 3: Acceleration waveforms obtained in 36th scan line. Red: forward wave. Green: backward propagating wave.

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