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Estimation of Rate of Change in Thickness of Myocardium by Measuring Time Variation of Ultrasonic Integrated Backscatter during a Cardiac Cycle

超音波後方散乱特性の時間変化計測による心筋厚み変化速度推定

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1. Introduction

For diagnosis of heart disease such as myocardial infarction, hypertrophic cardiomyopathy and dilated cardiomyopathy, noninvasive myocardial tissue characterization is important. Integrated backscatter (IB) from the heart wall, which is able to measure the phenomenon at wavelength less than about 500 μm, is getting attention as a quantitative tissue characterization method. IB is obtained by averaging ultrasonic scattering power from a region in tissues. IB from the heart wall shows cyclic variation, *i.e.*, the magnitude decreases during systole and increases during diastole1). In conventional methods for measurements of IB, a region of interest (ROI) is manually assigned in a B-mode image and, thus, it is difficult to obtain IB from the same site during a cardiac cycle.

In this study, by applying the phased tracking method2) to multiple points, which were set in the heart wall along an ultrasonic beam, we measured IB in the same site of the heart wall during a cardiac cycle with better time resolution and spatial resolution in the axial direction. Furthermore, the interference cycle of the IB signal was calculated to estimate the rate of change in thickness of the wall.

2. Method

By introducing the phased tracking method, which estimates displacement of an object with a high degree of accuracy using the phase shift of RF signal, a ROI set in the heart wall along an ultrasonic beam is accurately tracked. By setting the ROI between two adjacent points along the beam, the instantaneous position and the size of the ROI corresponding to displacement and change in thickness of the heart wall are automatically determined. Thus, we can measure the IB in the same site of the heart wall at each time.

The RF data were acquired at a frame rate of 888 Hz using a 3.75-MHz sector-type probe of ultrasonic diagnostic equipment (ALOKA SSD-6500). The sampling frequency of the RF signal was 15 MHz. At the time of electrocardiographic R-wave, N layers with a thickness of $\Delta d = 2463$ μm were assigned in the interventricular septum (IVS) from the right ventricular (RV) side to the left ventricular side along an ultrasonic beam with intervals of $\Delta d/4 = 616$ μm and, then, we calculated the IB in each layer in one cardiac cycle. The thickness Δd was determined from the duration of an ultrasonic pulse transmitted from the probe. $IB_i(t)$ of the i-th layer from the RV surface ($i = 0$) at time t is given by3)

$$IB_i(t) = 10\log_{10}\frac{1}{\Delta d(t)}\int_{x_{1i}(t)}^{x_{2i}(t)} \left|z(t,\xi)\right|^2 d\xi, \qquad (1)$$

where $z(t,\xi)$ is the quadrature demodulated signal of the ultrasonic pulse scattered by the object at depth position ξ at time t, and x_{1i} and x_{2i} are the top and the bottom of the i-th layer ($i = 0, 1, 2, \ldots, N\text{-}1$).

Then, the interference cycle of IB signal in the time (frame) direction is estimated. When intramyocardial scatterers move in response to changes in thickness of the heart wall, the interference state of multiple scattered waves varies. If the distance between two scatterers is varying due to the change in thickness, the rate of change in distance of scatterers, that is, the rate of change in thickness, is determined by estimating the cycle of the change in IB. In this study, the interference cycle was obtained manually and by the Fourier transform and, then, the rate of change in thickness was estimated. Average rate of change in thickness at each layer v_i is given by

$$v_i = \frac{\lambda}{2}\cdot\frac{1}{T_i} = \frac{c_0}{2f_0}\cdot\frac{1}{T_i}, \qquad (2)$$

where λ is wavelength of ultrasound, T_i is interference cycle of the i-th layer, c_0 is the acoustic velocity, and f_0 is ultrasonic center frequency. Also, the rate of change in thickness obtained by the phased tracking method v_{ip} is given by4)

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$$v_{ip} = \left| v(x_{2i};t) - v(x_{1i};t) \right|, \qquad (3)$$

where $v(x_{1i};t)$ and $v(x_{2i};t)$ are velocity of the top and the bottom of the i-th layer.

3. Result

Figure 1 shows IB signal of RV side from ejection period to isovolumetric relaxation period. IB signal obtained by *in vivo* measurement contained low-frequency and high-frequency components. First, we calculated their interference cycles manually. For low-frequency component, the interference cycle was 0.17 s and the corresponding interference frequency (inverse of interference cycle) was 5.9 Hz. During this period, average rate of change in thickness, calculated by eq. (2), was 1.51 mm/s. For high-frequency component, average interference cycle, which was obtained by dividing the interference cycle of low-frequency component of 0.17 s by the number of dips of six, was 0.028 s and the interference frequency was 36 Hz corresponding to the average rate of change in thickness of 9.17 mm/s.

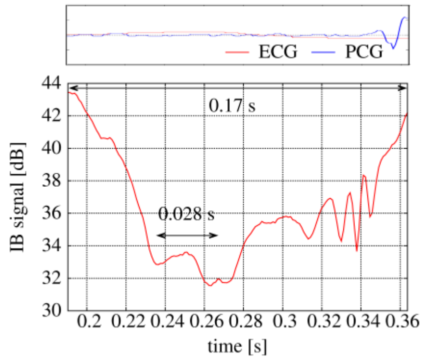

Fig. 1. IB signal from ejection period to isovolumetric relaxation period.

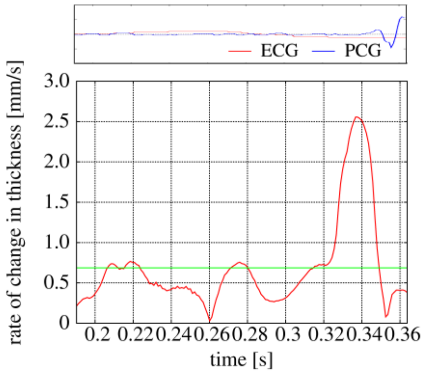

Fig. 2. Rate of change in thickness from ejection period to isovolumetric relaxation period obtained from phased-tracking.

Figure 2 shows the rate of change in thickness of RV side from ejection period to isovolumetric relaxation period obtained by the phased tracking method. Average rate of change in thickness during this period was 0.69 mm/s (green line). Thus, low-frequency component in Fig. 1 was considered to correspond to the rate of change in thickness. Also, a large change in thickness, which is not measured by the phased tracking method, is suggested to exist by the high-frequency component. To examine this component, spectra of IB signals were averaged.

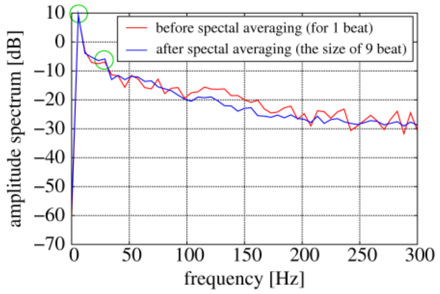

Fig. 3. Amplitude spectrum of IB signal from ejection period to isovolumetric relaxation period.

Figure 3 shows amplitude spectrum of IB signal obtained in Fig. 1 by applying the discrete Fourier transform (DFT) with a Hanning window with a length of 170 ms (154 points). There were two peaks under 50 Hz (green circle), close to two interference frequencies of low-frequency and high-frequency component (5.9 Hz and 36 Hz) calculated manually in Fig. 1. Frequency components over 50 Hz was considered to be noise from the average spectrum, but there was still peak around 36 Hz after spectral averaging. As shown by this result, it is necessary to examine the number of spectral averaging or improving frequency resolution by adding zero points to distinguish true peaks from noise.

4. Conclusion

In this study, we estimated the rate of change in thickness using the interference cycle of the IB signal. The rate of change in thickness of manual estimation and obtained by DFT were nearly equal to that obtained by the phased tracking method. These results show the possibility to estimate the rate of change in thickness with better spatial resolution using the interference cycle of the IB signal.

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