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A Study on Mechanism of Temporal Variation in Ultrasonic Integrated Backscatter from Human Heart Wall

ヒト心臓壁の超音波後方散乱の時間変化の発生機序に関する検討

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1. Introduction

Ultrasonic integrated backscatter (IB) from the heart wall reflects myocardial deformation on the order of a wavelength (about 500 μm). Therefore, it has been employed for a quantitative tissue characterization of the myocardium. Several researches have focused on the difference between the maximum and minimum values of IB during one cardiac cycle, and most of them have not investigated temporal variations of IB in detail. In this study, we calculate IB with the myocardial velocity measurement using a high temporal and axial resolution method. We investigate the regional variation of IB during one cardiac cycle, and propose a hypothesis for its mechanism.

2. Materials and Methods

Heart wall has a translational motion due to the heart beat, and the heart wall thickness changes due to the expansion and contraction of the myocardium. Therefore, it is necessary to track the position and size of the region of interest at each time. In this study, we use the phased tracking method to measure the IB from the same area of the heart wall [1]. In each beam, beam direction displacement $\Delta x(n)$ from the n-th frame to $(n+1)$-th frame is represented by the equation using the phase shift $\Delta\theta(n)$ of the reflected signal as

$$\Delta x(n) = \frac{c_0}{4\pi f_0}\Delta\theta(n), \qquad (1)$$

where c_0 is the sound velocity in the heart and f_0 is the center frequency of the ultrasound. Since this technique enables to estimate the displacement of the object with a high degree of accuracy, we track the both ends of the region of interest in each beam. We change the position and width of the region of interest in response to translation and thickness change of the heart wall, and measure the IB from the tracked region.

We acquired RF signals in a left long-axis ultrasound image of the heart of a 22-year-old normal male subject with a high temporal resolution of 579 Hz-frame rate using a 3 MHz sector probe. Five ultrasonic beams are set sparsely every 10 degrees. At a time of R-wave in the electrocardiogram we set measurement layers in the heart wall of 616 μm thick at 38.5 μm intervals in the depth direction, and calculated the IB during one cardiac cycle. IB value of the i-th layer in the n-th frame is represented by

$$IB_i(n) = 10\log_{10}\frac{1}{\Delta D(n)}\int_{x_{1i}(n)}^{x_{2i}(n)} |z(n,x)|^2\,dx, \qquad (2)$$

where $z(n,x)$ is the received signal at the depth x of the n-th frame, $x_{1i}(\mathrm{n})$ and $x_{2i}(n)$ are the positions of the upper and lower ends of the i-th layer and $\Delta D(n)$ is the size of the region of interest in the depth direction.

In this study, we employed time averaging of IB with a Hanning window of a 69-ms width and calculated the variation of IB during 1.74 ms, a frame interval.

3. Results

Figure 1 shows the variation of IB in interventricular septum and left ventricular posterior wall during one cardiac cycle superimposed on the M-mode image. In diastole, the sign of the variation of IB aligned in a depth direction. In addition, the sign was found to change about 60-100 ms intervals and formed a striped pattern.

Figure 2 shows the IB at three different depth layers in interventricular septum and the change in heart wall thickness during the striped pattern appeared in the variation of IB, that is from 0.60 s to 1.03 s. Plural extreme values of IB appeared almost simultaneously among all depths. The change in thickness of interventricular septum was about an ultrasound wavelength ($\lambda = 500$ μm). Since the thickness change of each measurement layer was much smaller than the wavelength, this result indicates that a small change in thickness compared with a wavelength can change the IB value. It is considered to the change in thickness occurs by each measurement layer expands and

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constructs at same time.

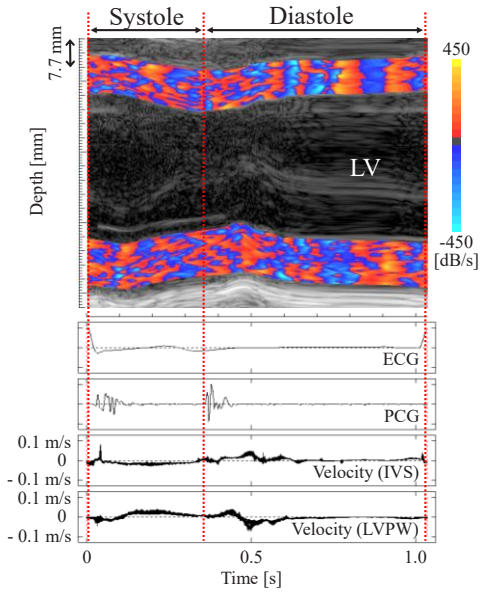

Fig. 1 Variation of IB during one cardiac cycle in interventricular septum (IVS) and left ventricular posterior wall (LVPW). ECG and PCG denote electrocardiogram and phonocardiogram, respectively.

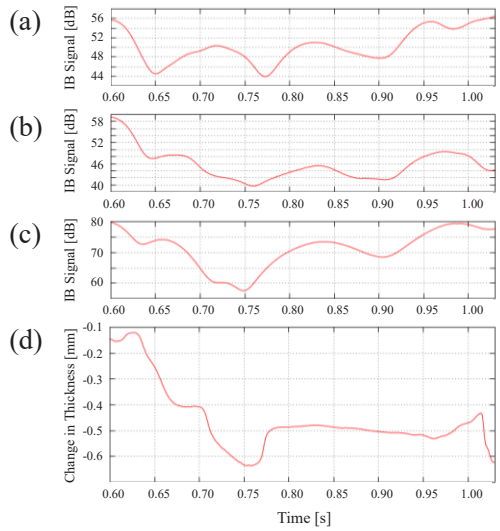

Fig. 2 IB signal ((a) upside, (b) middle, (c) downside) and (d) change in thickness in interventricular septum.

Figure 3 shows the model of the change in IB. The myocardium is the layer structure, each of which consisting of three or four myocardium fibers (70-100 μm), the layer boundary (0-50 μm) includes collagen fibers abundantly [2]. Therefore, the layer interval is about 100 μm, that is, the interval is about $\lambda/5$ assumed in this study. When scattering intensity and intervals of scatter are uniform, the scattered waves cancel each other out regardless of the expansion and contraction of the myocardium, resulting in a low IB value at almost all times. In contrast, when scattering intensity and intervals of scatter are non-uniform, a slight change in thickness varies the interference state of the scattered waves, resulting in the change in IB. Since the change in thickness during the latter part of diastole is sufficiently smaller than $\lambda/2$, the change of IB values may be caused by the process shown in Fig. 3(b).

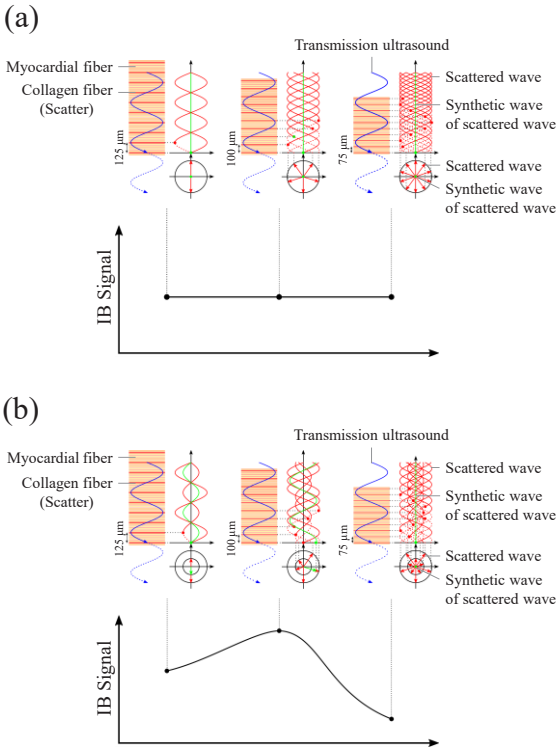

Fig. 3 A model showing change in interference state of scattered wave and IB value with change in thickness in myocardium when scattering intensity of scatter is uniform (a) and non-uniform (b).

4. Conclusion

In this study, we calculated the variation of IB in interventricular septum during one cardiac cycle. We found that extreme values of IB appeared almost simultaneously among all depths during the latter part of diastole. Also, we found that the thickness change of each measurement layer was much smaller than the wavelength. From this, the expansion and contraction synchronized with the depth direction of the myocardium fibers and non-uniformity of the scattering intensity of the scatter were shown.

References

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