Measurement of Ultrasonic Scattering from Nylon Phantom Mimicking Bundle of Myocardial Fibers
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ABSTRACT

Purpose: Direction of myocardial fibers in a healthy human heart wall are homogeneously aligned in a plane which is parallel to the luminal surface of the heart wall. However, in a hypertrophic cardiomyopathy heart wall, the directions of myocardial fibers are disarrayed. For evaluation of such a change in the structure of myocardial fibers, the angle dependence of ultrasonic scattering in relation to the fiber direction was investigated in this paper.

Experiment: In this study, we measured the ultrasonic echoes from a copper wire and from nylon fibers which mimics a bundle of myocardium fibers. We focused on ultrasonic scattering properties in relation to the azimuth and elevation angles of insonification and reception relative to the fiber direction.

Results: Experimental results showed that the amplitude of the reflected echo from the nylon fibers became the maximum when the ultrasonic beam was insonified parallel to the direction of the fiber in the azimuth angle. On the other hand, in the case of the perpendicular insonification, the echo amplitude became the minimum. These results suggested the possibility of diagnosis of cardiomyopathy by measuring the angle dependence of scattering.

INTRODUCTION

Directions of myocardial fibers in a healthy human heart wall change gradually from the epicardium to the endocardium and are homogeneously aligned in each plane which is parallel to the luminal surface of the heart wall [1, 2, 3]. However, in a heart wall affected by the hypertrophic heart disease, the myocardial fiber direction becomes disarrayed [4]. Therefore, it is important to diagnose the structure of myocardial fibers for differentiation of normal hearts from those affected by the hypertrophic heart disease. It is expected that ultrasonic scattering from a heart wall characterizes such a change in the direction of the myocardial fiber. Basic researches on backscattered echoes from myocardium have been conducted for the quantitative tissue characterization [5].

Baldwin et al. measured the ultrasonic myocardial attenuation with changing the angle of ultrasonic propagation relative to the myocardial fibers for the quantitative ultrasonic cardiac tissue characterization. By measuring ultrasonic backscattering from myocardium at each insonification angle $\theta$ relative to the direction of the myocardial fibers, it was shown that the ultrasonic attenuation in the myocardium is maximum when $\theta$ is zero (parallel) to the myocardial fibers and it has the minimum when $\theta$ is $90^\circ$ (perpendicular) [1, 5]. In previous studies, it was found that ultrasound integrated backscatter from myocardium exhibits cyclic variation during cardiac cycles [6, 7]. One of the reasons is
considered to be the change in the angles between the ultrasonic beam and the direction of myocardial fibers [8].

In this study, we focused on ultrasonic scattering properties in relation to the azimuth and elevation angles of insonification relative to the fiber direction. For this purpose, ultrasonic echoes from a copper wire and nylon phantom (with a diameter of less than the wavelength) which mimics a bundle of myocardial fibers were measured as a function of the insonification angle.

**Methods**

An experimental setup is illustrated in Fig. 1. As shown in Fig. 1(a), two focused transducers were used for transmitting and receiving of ultrasonic pulses. The transmitting and receiving elevation angles are $\phi_1$ and $\phi_2$, respectively. In this paper, ultrasonic echoes from a metal copper phantom or a bundle of nylon fibers are measured by changing the angles, $\phi_1$, $\phi_2$, and azimuth angle $\theta$. During the experiment, focal points of these transducers are required to be set at the same point on the phantom. By keeping the focal points at the same point, the object was revolved around the point to change the azimuth angle $\theta$. Furthermore, the elevation angle $\phi$ was changed by moving the transducers along

![Diagram](image)

**Fig. 1.** Illustrations of (a) the measurement, (b) a custom-made apparatus, and (c) experimental setup.
a circle whose center is the same point on the phantom. To realize such operations, a custom-made apparatus was used. The measurement apparatus is shown in Fig. 1(b).

Both transducers for transmission and reception are single element concave transducers (Tokimec 7Z10I-PF30-C-K445). Focal distances of the transducers were 30 mm and the center frequency is 7.0 MHz. The wire phantom is placed in a water tank as shown in Fig. 1(c) and is fixed on the center of the cylindrical pedestal. The azimuth angle $\theta$ of insonification relative to the fiber direction is changed by rotating the pedestal. There is a hole of 20 mm in diameter at the center of the top of the pedestal in order to receive only the signal reflected from the object. A sinusoidal wave of one cycle was applied to the transmitting transducer. The signal reflected from the object was received by the receiving transducer. The digitized data were acquired after averaging the reflected signals 128 times using a digital oscilloscope (Tektronix TDS220).

A copper wire is 170 micrometers in diameter. In the measurement of the bundle of nylon fibers, the echo from the object are received by a hydrophone (Panametrics SPRH-1000). The diameter of a human myocardial fiber (10-15 $\mu$m) is thinner than the wavelength of ultrasound (400-500 $\mu$m) used in ultrasonic diagnostic equipment. Therefore, ultrasonic echoes from human myocardium fibers are scattered waves. The objects used in this study are a copper wire and a nylon fiber. They are 170 $\mu$m and 150 $\mu$m in diameter, respectively. The wavelength of insonified ultrasound was 214 $\mu$m. Thus, ultrasonic echoes were also scattered waves. In the measurement of the bundle of nylon fibers, the echo from the object are received by a hydrophone (Panametrics SPRH-1000).

Results

Figures 2(a) and 2(b) show the received RF signals when the ultrasonic beam was insonified parallel to the wire ($\theta = 0^\circ$) at two settings of the elevation angles ($\phi_1 = \phi_2 = 30^\circ$ and $50^\circ$), respectively. As shown in Fig. 2, the negative peak value was measured at each setting of the azimuth and elevation angles.

Figure 3 shows the angular dependence of the maximum amplitude (negative peak value) of the reflected signals at each azimuth angle $\theta$. The amplitude of the reflected signal changed with azimuth angle, $\theta$. Although the pedestal was revolved three times, reproducible measurement were done with respect to the azimuth angle $\theta$. At the same elevation angle ($\phi_1 = \phi_2$), the amplitude became the maximum when the ultrasonic beam was insonified parallel to the wire ($\theta = 0^\circ$ and $180^\circ$). On the other hand, when the ultrasonic beam was insonified perpendicularly to the wire ($\theta = 90^\circ$ and $180^\circ$), the amplitude

![Fig. 2. Examples of the received signals from the wire ($\theta = 0^\circ$). (a) $\phi_1 = \phi_2 = 30^\circ$. (b) $\phi_1 = \phi_2 = 50^\circ$.](image-url)
Fig. 3. Maximum amplitude of the received signals at each azimuth angle \( \theta \). (a) \( \phi_1 = \phi_2 = 30^\circ \). (b) \( \phi_1 = \phi_2 = 40^\circ \). (c) \( \phi_1 = \phi_2 = 50^\circ \). (d) \( \phi_1 = \phi_2 = 60^\circ \). (e) \( \phi_1 = \phi_2 = 70^\circ \).

Fig. 4. Maximum amplitude of the received signals at each angle difference \((\phi_2 - \phi_1)\) between receiving and insonification elevation angles, \( \phi_1 \) and \( \phi_2 \). (a) \( \theta = 0^\circ \). (b) \( \theta = 90^\circ \). (c) from an aluminum plate.

Figure 4 shows the change in the maximum amplitude of the received signals at each difference in elevation angles \((\phi_2 - \phi_1)\). The azimuth angle \( \theta \) was kept at \( 90^\circ \) in Fig. 4(a) and \( \theta = 0^\circ \) in Fig. 4(b), respectively. Figure 4(c) shows the echo amplitude from a flat aluminum plate measured by similar procedure as in Fig. 4(b).

In the case of insonification perpendicular to the wire \((\theta = 90^\circ)\), the amplitude does not change so much with respect to \((\phi_2 - \phi_1)\), and decreases as the angle difference \((\phi_2 - \phi_1)\) increases. On the other hand, in the case of insonification parallel to the wire direction \((\theta = 0^\circ)\), amplitudes became the maximum when the angle difference \((\phi_2 - \phi_1)\) is zero degree. When the absolute value of the angle difference is larger than 20 degrees, the amplitudes was almost zero. Echoes from the aluminum plate were maximal when the angle difference \((\phi_2 - \phi_1)\) is zero. These results suggest that the wire acts as an interface in the case of parallel insonification \((\theta = 0^\circ)\). As shown in Fig. 5, the signals from the
bundle of nylon fibers showed the similar tendency to those from the wire relative to the azimuth angle $\theta$.

**CONCLUSIONS**

In this study, in order to investigate the angle dependence of ultrasonic scattering from the wire phantoms, we constructed an experimental system to change the elevation and azimuth angles. The amplitude of the reflected signals from the wire and from the bundle of nylon fibers changed with azimuth angle $\theta$. The maximum amplitude of the received signals at each angle difference ($\phi_2 - \phi_1$) was not changed so much by the insonification elevation angle $\phi_1$ in the case of insonification perpendicular to the wire ($\theta = 90^\circ$). On the other hand, in the case of insonification parallel to the wire ($\theta = 0^\circ$), the wire acts as an interface. These result suggested a possibility of diagnosing cardiomyopathy by measuring the ultra sonic scattering depending on the fiber direction.

**REFERENCE**