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Development of An Ultrasonic Probe to Measure Both Radial Arterial Pressure and Diameter at Identical Position for Early Diagnosis of Endothelial Function

内皮機能の早期診断のための血圧と血管径の同位置同時計測可能な超音波プローブの開発

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1. Introduction

As the factor of death, a rate of cardiovascular diseases is increasing in Japan. Arteriosclerosis is the main factor of the cardiovascular diseases. At the early stage of arteriosclerosis, lesions of vascular endothelial functions appear, and functions of generating vasodepressor material decrease. It is important to evaluate the functions as early as possible becauase the lesions are still reversible.

We have proposed an evaluation method of viscoelastic properties of the blood vessel wall measuring the arterial pressure and diameter.[1)] An ultasonic probe was set between two pressure sensors, and the time delay between the ultasonic probe and the pressure sensor was corrected by the pulse wave velocity (PWV) estimated by the two pressure sensors. However, it is difficult to accurately correct the time delay because PWV, caused by changes in blood pressure, varies during a heartbeat. We also proposed a method measuring blood pressure waveform by piezoelectric effect using elements of an ultrasonic probe.[2,3)] The blood vessel diameter and the blood pressure were measured at different timing and synchronized using electrocardiogram (ECG). However, it is difficult to accurately estimate viscoelasticity because of errors in pressure-diameter characteristics caused by the heartrate difference at each measurement.

In the present study, an ultrasonic probe is developed to measure both radial pressure and diameter at identical position simultaneously and estimate the hysteresis property of the arterial wall.

2. Principle

The main frequency components of a blood pressure waveform are less than approximately 12 Hz[4)] and far lower side of the bandwidth (usually several to 10 MHz) of the ultrasonic probes. The piezoelectric elements of ultrasonic probes can be used not only for transmission and reception of ultrasonic waves but also for measuring blood pressure waveforms.[2,3)] When the piezoelectric element is used for measuring the blood pressure, the measured waveform becomes a derivation of the blood pressure waveform because electric charges detected by the piezoelectric effect are extracted as currents by the external circuit. Therefore, the blood pressure waveform can be obtained by integrating the voltage waveform at the load resistance in the output circuit.

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3. Method

The schematic view of an experimental arrangement is shown in **Fig. 1**. A linear array probe with 192 channels was customized by cutting the central piezoelectric element from the transmitting and receiving unit of ultrasonic waves. A piezoelectric element was used to detect the blood pressure. The other 191 channels were used for the measurement of diameter by ultrasound.

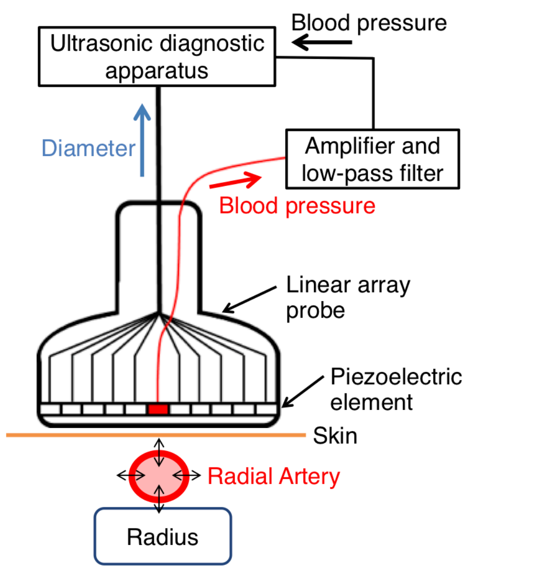

Fig. 1. Schematic view of experimental arrangement.

The customized probe was connected to an ultrasonic diagnostic apparatus (Hitachi Aloka, Prosound F75). The phased-tracking method was applied to determine boundary to estimate the change in diameter.[5)] It was measured with a center frequency of 7.5 MHz at a sampling frequency of 40 MHz and a frame rate of 252 Hz.

To measure the blood pressure waveform, output voltage from the piezoelectric element was amplified with amplifier having an amplification factor of 100, filtered with a low-pass filter with a cut-off frequency of 30 Hz, and inputted to the external port of the ultrasonic diagnostic apparatus. The blood pressured waveform was obtained integrating the measured waveform.

Electrocardiogram was also measured. To obtain absolute blood pressure, the voltage measured by the piezoelectric element was calibrated with the systolic and diastolic blood pressures measured in the right radial artery by tonometry (Nihon Colin, JENTOW-7700).

The blood pressure and diameter were simultaneously measured in the left radial artery of a 22-year-old healthy male. This probe has an advantage enable to confirm the measurement position of the blood pressure by B-mode image.

4. Results and Discussion

Figure 2 shows B-mode image of the left radial artery. **Figure 3**(1) shows electrocardiograph, blood pressure waveform, and diameter change. The timing of rises of both blood pressure and diameter change during systole was almost same. Both blood pressure and diameter returned to each value after a heartbeat. Figure 3(2) shows a relationship between blood pressure and arterial diameter between two R-waves of ECG obtained from Fig. 3(1). The times indicated by labels a, b, c, and d are same in Figs. 3(1) and (2). The diameter expanded linearly with an increase in the blood pressure and then gradually returned due to a decrease in blood pressure with viscosity. The hysteresis characteristic in Fig. 3(2) resembled to that in Ref. 1. Therefore, the relationship between the blood pressure and the diameter change was successfully obtained using a single ultrasonic probe.

5. Conclusion

In this paper, an ultrasonic probe was developed to simultaneously measure radial blood pressure and diameter. The relationship between the blood pressure and the diameter change during a heartbeat was measured and the hysteresis characteristics caused by the viscoelasticity of the blood wall was confirmed. Hereafter, we will evaluate vascular endothelial functions by measuring viscoelasticity changes caused by flow mediated dilation (FMD) reaction.

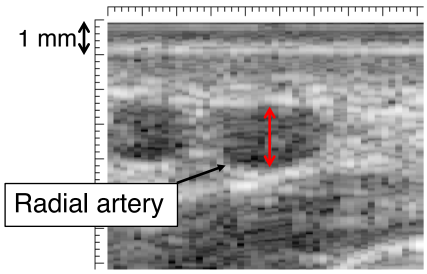

Fig. 2. B-mode image of the left radial artery.

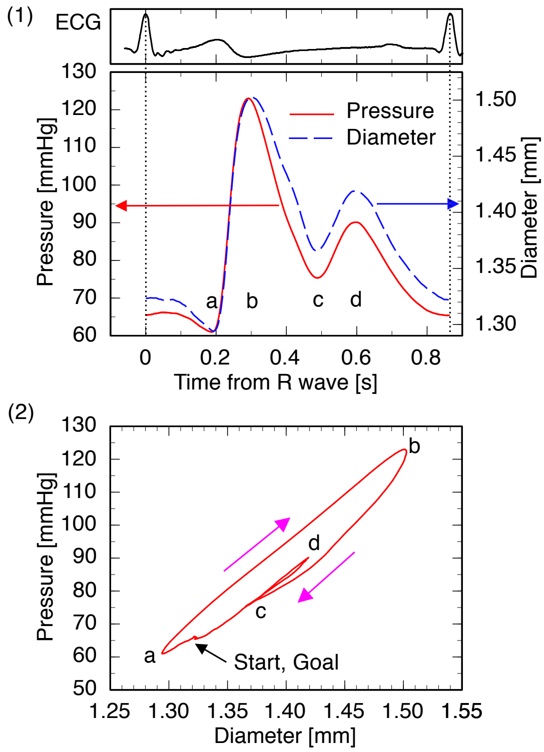

Fig. 3. (1) Waveforms of arterial pressure and diameter. (2) Relationship between arterial pressure and diameter.

Acknowledgment

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