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Viscoelasticity estimation of radial artery by simultaneously measuring changes in pressure and diameter using single ultrasound probe

単一超音波プローブを用いた血圧と血管径の同時計測による橈骨動脈の粘弾性推定

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1. Introduction

Evaluation of vascular endothelial function is important for the ultra-early diagnosis of arteriosclerosis, and the flow-mediated dilation (FMD) testing is usually used for the evaluation. Our group has proposed a method of evaluating the viscoelasticity of the radial artery during the FMD reaction using an ultrasonic probe and pressure sensors.[1)] In the method, because it is important to measure the changes in the blood pressure and diameter at the same position, the time delay between them was corrected using the pulse wave velocity (PWV). However, it is difficult to determine the time delay because the PWV changes as the change in blood pressure within a heartbeat. In order to measure the blood pressure and the diameter at the same position using only an ultrasonic probe, we have demonstrated that the blood pressure waveform can be measured via the piezoelectric effect using the piezoelectric element of the ultrasonic probe.[2)] Furthermore, we have developed an ultrasonic probe simultaneously measuring them to estimate the changes of arterial viscoelasticity during FMD reaction from the measurement of the blood pressure and diameter continuously at the same position.[3)] In the present study, we demonstrate their stable and continuous measurements using the developed ultrasonic probe.

2. Method

Fig. 1 shows the schematic diagram of the experimental arrangement. The blood pressure was measured using the developed ultrasonic probe at the left radial artery. The linear array probe with 192 elements was customized by separating one center piezoelectric element from the ultrasonic transmitter/receiver unit to measure the blood pressure. The blood pressure was obtained by the piezoelectric effect of the piezoelectric element. The output from the piezoelectric element passed through an amplifier with a gain of 40 dB and a low-pass filter with a cutoff frequency of 30 Hz. The obtained output shows the differential of the blood pressure waveform.[2)] Therefore, the blood pressure waveform was obtained by integrating the measured waveform.

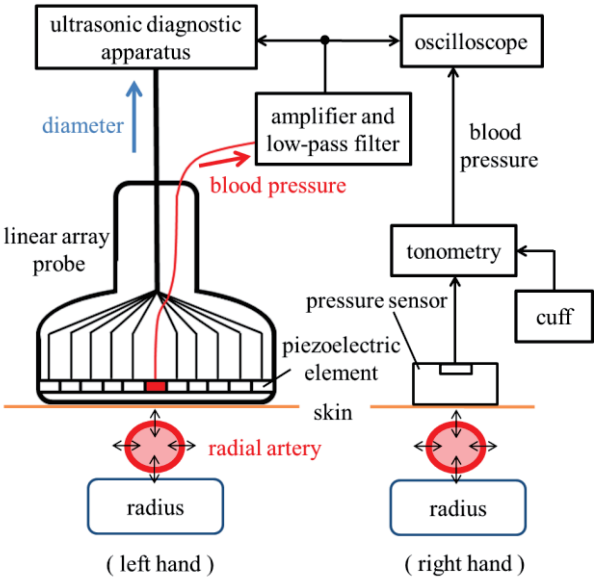

Fig. 1. Schematic diagram of the experimental arrangement.

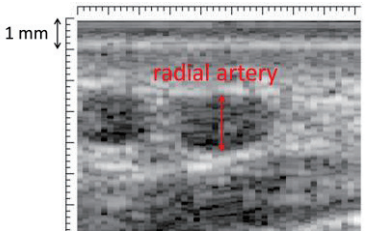

Fig. 2. B-mode image of the left radial artery.

The other 191 elements were used for the ultrasonic measurement. The probe was connected to an ultrasonic diagnostic apparatus (ProSound F75, Hitachi Aloka). The measurement position was set so that the center of the probe was above the radial artery while confirming the B-mode image as shown in **Fig. 2**. The phased-tracking method[4)] was used to estimate changes in diameter. The diameter was measured at a center frequency of 7.5 MHz, a sampling frequency of 40 MHz, and a frame rate of 252 Hz.

The values and waveforms of the blood pressure were monitored on the right radial artery using tonometry (Nihon Colin, JENTOW-7700). An electrocardiogram (ECG) was also measured. The

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subject was 23-year-old healthy male. The measurement was held at rest.

3. Results and Discussion

Blood pressure waveforms were obtained by one piezoelectric element of the ultrasonic probe and the tonometry for 5 successive heartbeats for 3 min at 1-minute intervals. **Fig. 3** shows blood pressure waveforms at 0 minutes (at the start of measurement) and after 3 minutes. The output from the element of the ultrasonic probe is voltage values so that it must be calibrated to the blood pressure values. Only the first beat in Fig. 3 (a) was calibrated using the systole and diastole pressures by tonometry, and all the other beats were calibrated using the relationship. From Fig. 3 (a), we confirmed that the blood pressure waveforms obtained from the piezoelectric element of the ultrasonic probe agreed to those obtained from the tonometry for 5 consecutive heartbeats. In addition, they are close even after 3 min from Fig. 3 (b). This result suggests that stable measurements were realized because the position and pressing force of the ultrasonic probe strongly affect the blood pressure waveform. By calibrating the blood pressures measured by the piezoelectric element of the ultrasonic probe in advance, the blood pressure waveforms could be continuously measured for several minutes.

Subsequently, blood pressure waveforms and diameters were measured using the single ultrasonic probe. **Fig. 4** shows the relationship between blood pressure and change in diameter obtained for each heartbeat separated by R-waves timing on the ECG for 3 consecutive heartbeats. Like the previous experiment, the blood pressure was calibrated using the systole and diastole pressures of the first beat by tonometry. The shapes of the waveforms agreed well each other, and the estimated viscoelastic moduli shown in the figure were similar.

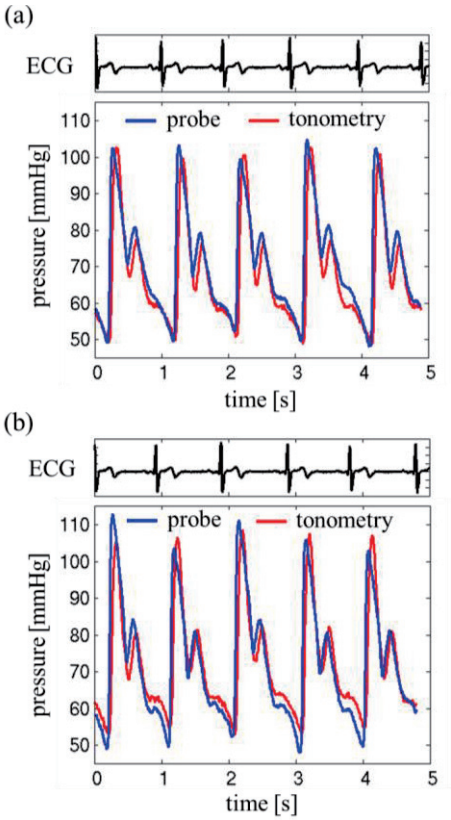

Fig. 3. Blood pressure waveform measured with tonometry and ultrasonic probe element.
(a) 0 min. (start of measurement) (b) after 3 min.

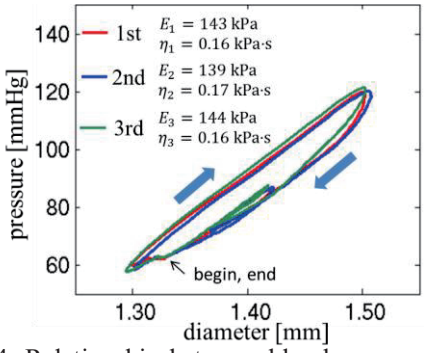

Fig. 4. Relationship between blood pressure and diameter. (E: elasticity η: viscocity)

4. Conclusion

In the present study, it was shown that the blood pressure waveforms and blood pressure values can be continuously measured for several minutes via the piezoelectric effect using the piezoelectric element of the ultrasonic probe by calibrating the blood pressure value in advance. In addition, the blood pressure and changes in diameter were measured simultaneously, and the viscoelastic moduli of the radial arterial wall for each heartbeat were estimated from the relationship between them.

Based on the above results, we can continually measure the relationship between blood pressure and change in diameter and estimate changes in viscoelasticity by calibrating the absolute value of blood pressure at the start of measurement. This study demonstrates the possibility of measuring changes in the viscoelastic moduli of the radial arterial wall during FMD measurement using the ultrasonic probe we developed.

Acknowledgment

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References

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