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Study on Ultrasonic Measurement of Radial Arterial Pressure and Diameter at the Same Position
超音波による橈骨動脈の血管径-血圧同位置計測に関する検討

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1. Introduction

Cardiovascular disease is one of the main causes of death in Japan, and arteriosclerosis is its main factor. For the diagnosis of atherosclerosis in an early stage, it is important to evaluate vascular endothelial function.[1)] We noninvasively estimated the viscoelastic coefficient, which represents the hysteresis of the stress-strain relationship at the time of vascular relaxation reaction, and the temporal changes of the viscoelastic coefficients.[2)] From *in vivo* experimental results, we showed the possibility of evaluating the vascular endothelial function and the viscosity of blood vessels before and after vascularization. However, the blood vessel diameter and the blood pressure were measured at different positions, and the delay time in the propagation of the pulse wave from the pressure sensor to the ultrasonic probe had to be estimated and corrected. Thus, there was a problem that accurate characterization of the vessel wall was difficult because of the error in the correction of the delay time.

In the present study, a conventional ultrasonic probe is employed to measure blood pressure waveform in order to make the same measurement position of the diameter and pressure using the same ultrasonic probe. Moreover, a hysteresis characteristics of the blood vessel wall were estimated.

2. Method

In order to transcutaneously measure the diameter and the pressure waveform at the same position, it is necessary not only to transmit and receive the ultrasonic waves but also to acquire the blood pressure waveform by one ultrasonic probe.

The low frequency responses of the ultrasonic transducer were derived using the Mason equivalent circuit. For the thickness longitudinal vibration of the piezoelectric material polarized along the thickness direction, mainly used in medical ultrasonic equipment, an equivalent circuit is shown in **Fig. 1**, where F_1 and F_2 are the forces, v_1 and v_2 are velocities, and medium with acoustic impedance $Z_L = -F_2/v_2$ is loaded to the acoustic terminal. The relationships among voltage V and

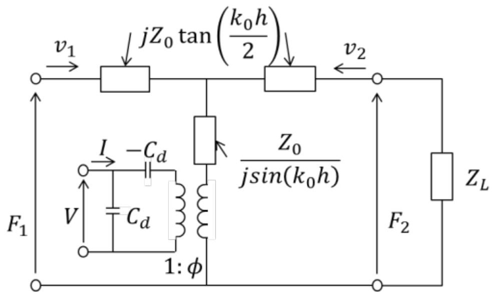

Fig. 1. An equivalent circuit of the thickness longitudinal vibration mode.

current I at the electrical terminal, F_1, F_2, v_1 and v_2 are shown as follows[3)].

$$F_1 = \frac{Z_0}{j\tan k_0 h} v_1 + \frac{Z_0}{j\sin k_0 h} v_2 + \frac{\phi}{j\omega C_d} I, \quad (1)$$

$$F_2 = \frac{Z_0}{j\sin k_0 h} v_1 + \frac{Z_0}{j\tan k_0 h} v_2 + \frac{\phi}{j\omega C_d} I, \quad (2)$$

$$V = \frac{\phi}{j\omega C_d} v_1 + \frac{\phi}{j\omega C_d} v_2 + \frac{1}{j\omega C_d} I. \quad (3)$$

When the frequency is sufficiently lower than the ultrasound resonance frequency, by assuming that one side of the piezoelectric element is free ($F_1 = 0$) and using the force F_2 due to the blood pressure, the voltage output V is given by

$$V = \frac{\phi}{\omega C_d}\left(1 - \frac{1}{K_t}\right)\frac{2}{Z_0 k_o h}\left(1 + j\frac{Z_0}{Z_L} k_0 h\right) F_2. \quad (4)$$

Eq. (4) shows that the voltage outputted by the piezoelectric effect depends on the applied stress. Therefore, the blood pressure can be detected using a conventional ultrasonic transducer, although the frequency of the blood pressure is fairly lower than the resonant frequency of the ultrasonic transducer.

3. *In vivo* Experiment and Result

For the radial artery of a human left hand at rest, the diameter and the electrocardiogram (ECG) were measured for 3 seconds using an ultrasonic diagnostic apparatus (ProSound F75; Hitachi Aloka Medical, Ltd), and the change of the diameter was measured by the phase-tracking method[4]. In addition, the waveform was simultaneously measured using an ultrasonic probe in which the several-tenth piezoelectric elements were connected in parallel to amplify the output voltage, and the ECG was simultaneously measured for 5 seconds by the electrocardiograph (ECG-1350; Nihon Kohden Co.). The blood pressure waveform measured by the ultrasonic probe is shown in **Fig. 2**.

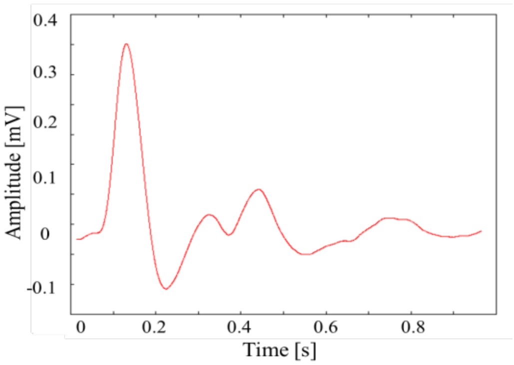

Fig. 2. The measured blood pressure in the radial artery by the ultrasonic probe.

Since the measured waveform is very similar to the waveform obtained by differentiating the general blood pressure waveform[2], the time integration method was applied to the waveform shown in Fig. 2 and the absolute value was obtained by the calibration using the maximum and minimum of blood pressures measured in the right hand radial artery. After that, the time courses of the diameter and blood pressure were obtained by matching the timing of each waveform referring to the timing of the R-wave of the two ECG. The result is shown in **Fig. 3**.

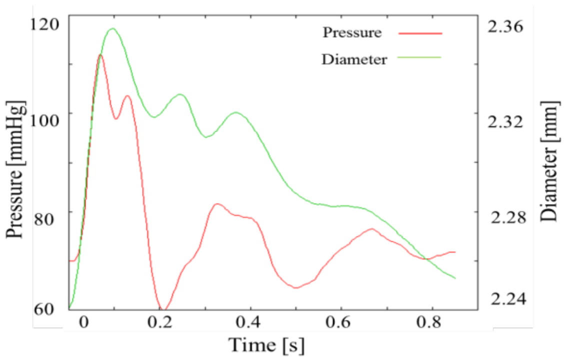

Fig. 3. Chronological change of arterial pressure and diameter in the radial artery.

Then a relationship between the diameter and blood pressure was obtained as shown in **Fig. 4**.

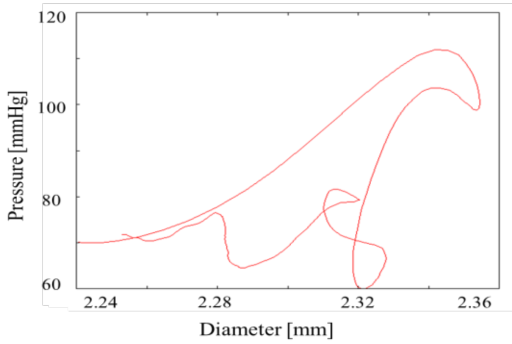

Fig. 4. Relationship between arterial diameter and pressure in the radial artery.

Although the waveform integrated with time to the measured waveform showed a sharp decline unlike the general blood pressure waveform, it will be improved by appropriately selecting the measurement conditions. Further, from the relationship between diameter and blood pressure, it is possible to confirm the hysteresis characteristic that the diameter expands with an increase in the blood pressure and then goes back with the decrease in the blood pressure. In the hysteresis, the elasticity is dominant during the period of the expansion and return is delayed by the viscosity. Therefore, it can be confirmed that the viscoelasticity is also evaluated by measuring the blood pressure waveform using the same ultrasonic probe.

4. Conclusion

In this paper, as a basic experiment for measuring diameter and blood pressure waveform at the same position, measurement of the blood pressure waveform using ultrasonic probe and the relationship between blood vessel diameter and pressure were demonstrated. From the relationship, the hysteresis characteristic of the artery wall during one heartbeat was obtained. It is considered that accurate hysteresis characteristics of the artery wall can be acquired by measuring the diameter and pressure waveform at the same position.

Reference

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