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Pulse wave measurement by piezoelectric sensor -For the evaluation of the arteriosclerosis-
圧電センサを用いた脈波の測定と動脈硬化診断への応用

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1. Introduction

According to the study of the World Health Organization in 2011, 17,300,000 deaths due to cardiovascular diseases were reported in 2008 [1]. One of the major cardiovascular diseases is the arteriosclerosis, whose typical symptom is the increase in aortic stiffness.

Our group has focused on retrieving information carried by the pulse wave. The pulse wave has two components, incident and reflected waves. The incident wave is the displacement wave of the skin surface caused by the forward pressure wave coming from the heart. Reflected waves are also displacement waves caused by the backward pressure wave which reflected at the vascular beds. The backward pressure wave is then attenuated during the propagation along the artery [2-4]. The direct non-invasive observation of these pressure waves is preferable for the screening purposes, because it is simpler and safer compared with a catheter-type sensor [5-8]. We have suggested a new method to extract reflected wave information from the measurement of blood flow velocity and pulse wave [9].

In a previous study, our suggested method showed a clear relationship between the patients' ages and reflected wave amplitudes [9]. We also checked the correlation between the maximum amplitude of the reflected wave and the CAVI (Cardio Ankle Vascular Index) values [9]. The effects of blood viscosity and artery stiffness on the pressure wave propagation were then investigated using numerical simulations and experiments and found that the effects of blood viscosity on the reflected wave was comparatively small [10]. In this study, the effect of the heart rate on the reflected wave is investigated.

2. Experiments

A. Subjects

The subjects were 13 men in their 20s to 60s who do not have previous history of cardiovascular diseases and were not taking vasoactive agents. They provided written consents to participate in the study, and the protocols used were approved by the medical ethics committee of Doshisha University. Before measurements, the subject refrained from eating, exercising, and smoking, for more than 2 hours. The subjects then laid down in the supine position for 10 minutes in a quiet room at 25 degrees Celsius.

B. Data Collection

We measured the electrocardiogram (ECG), pulse wave, and blood flow velocity simultaneously. We also measured the pulse wave on the skin surface of the neck on the left common carotid artery using a piezoelectric transducer (MA40E7R, Murata Manufacturing Co. Ltd., Japan). The resonant frequency of the sensor was about 40 kHz. The observed signal was amplified 40 dB by a preamplifier (NF 5307, NF Corp., Japan) and digitalized using a 14-bit analog-to-digital converter (NR-500, NR-HA08, Keyence Corp., Japan) at a sampling frequency of 10 kHz. We also measured blood flow velocity at the left common artery. We used two ultrasonic Doppler systems ((A) Prosound α, Hitachi Aloka Medical Ltd., Japan. (B) Aplio SSA-700A, Toshiba Medical Systems Corp., Japan). The center frequency of the ultrasonic probes (UST-5412, Hitachi Aloka Medical Ltd. or PLT-1204AT, Toshiba Medical Systems Corp., Japan) was 12 MHz. In this study, these two systems were used to discuss the pulse wave evaluation and applicability of our method.

3. Results and discussion

Fig. 1 shows an example of the separated waves observed in a subject aged 22 years. The pulse wave was divided into three blocks, from the start to half of the initial upstroke (T_1), from the peak to the incisura (T_2), and from the incisura to the end (T_3). We then obtained the time intervals of the three blocks. The blood flow velocity was also divided into three blocks. **Fig. 2** shows the relationships between heart rate and these time intervals. The results show that only T_3 depends on heart rate. Actually, the reflected wave amplitude showed a

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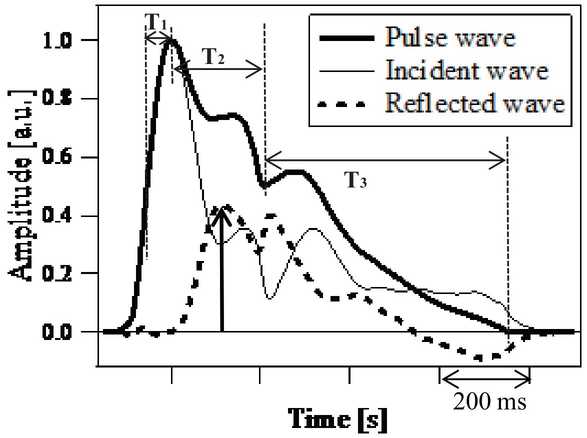

Figure 1. A wave separation result for a subject aged 22 years. The maximum amplitude of the reflected wave is indicated by an arrow.

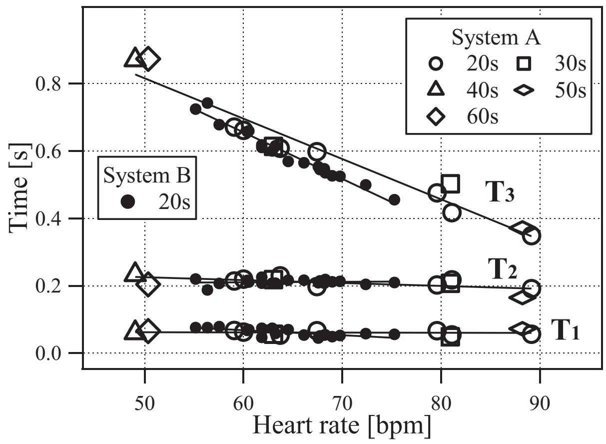

Figure 2. Relationship between heart rate and the interval of each part.

dispersion but it did not depend on the heart rate. The changes of heart rate have little effect on the first part of the pulse wave, during the time from the initial upstroke to the incisura (T_1). In this area, the reflected wave and the incident wave usually overlap. One reason for this is that, maximum values of the reflected waves often exist before or around the incisura. We then normalized only T_3 interval into 0.8 sec (**Fig. 3**), to check the effect of heart rate on the reflected wave. **Fig. 4** shows the reflected wave amplitude before and after normalization. The normalization did not affect the amplitudes and the tendency was similar in the data obtained from different ultrasonic Doppler systems.

4. Conclusion

To check the stiffness of the arteries, we have proposed a method to analyze the reflected wave in the pulse wave. The maximum amplitudes of the reflected waves increased with age. The amplitudes of reflected waves were not strongly affected by the heart rate. These results were not dependent of two ultrasonic Doppler systems used.

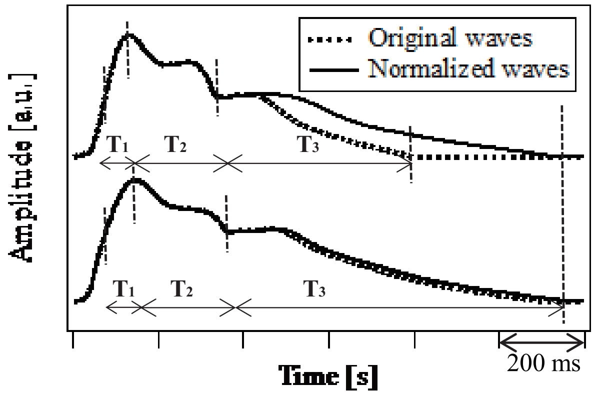

Figure 3. Pulse waves which heart rate are 75bpm and 55bpm, normalized into same heart rate.

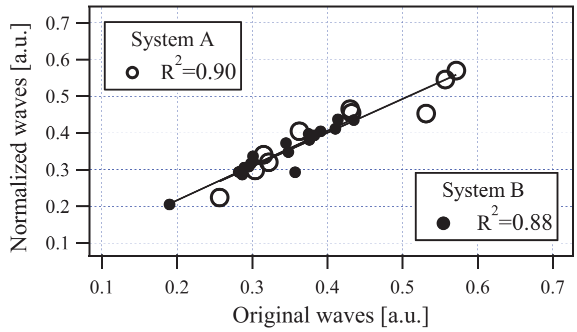

Figure 4. Relationship of reflected wave amplitude obtained from original and normalized waves.

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