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Experimental study on pulse waveforms of various ages measured by piezoelectric transducer

圧電センサを用いた各年齢層の脈波波形の測定

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1. Introduction

The cardiovascular diseases, such as a myocardial infarction and stroke, are becoming a leading cause of mortality. One of the major cardiovascular diseases is arteriosclerosis, whose typical symptom is the increase of aortic stiffness. Pulse wave evaluation is suitable for screening arteriosclerosis. In our former studies, pulse wave measurement was performed on the skin of the neck at the left common carotid artery using a piezoelectric transducer. Pulse wave at the carotid artery is composed of two displacement waveforms: incident and reflected waves. Because the attenuation of the reflected wave during propagation changes due to viscoelastic properties of the artery, we have proposed a method to extract the reflected wave from the pulse wave [1-3]. We then have reported that there is a good correlation between the age of the subjects and the maximum amplitude of the reflected wave. However the age range of the patients was from their 20s to 60s (R^2=0.65) [4]. In this study, we focused on the characteristic pulse wave of elderly people from 70s to 90s. In addition, we measured the signature wave in her 90s.

2. Experiments

2.1 Subjects

The subjects were all in their 70s to 90s (5 males and 6 females). The subject laid down in the supine position for 5 minutes in a quiet room. They provided written consent before measurements, and the protocols used were approved by the medical ethics committee of Doshisha University.

2.2 Data Collection

We measured the pulse wave on the left common carotid artery using a piezoelectric transducer (MA40E7R, Murata Manufacturing Co., Ltd., Japan). The observed signal was amplified by 40 dB by a preamplifier (NF 5307; NF Corp., Kanagawa, Japan) and digitalized using a 14-bit analog-to-digital converter (NR-500; NR-HA08, Keyence Corp., Osaka, Japan) at a sampling

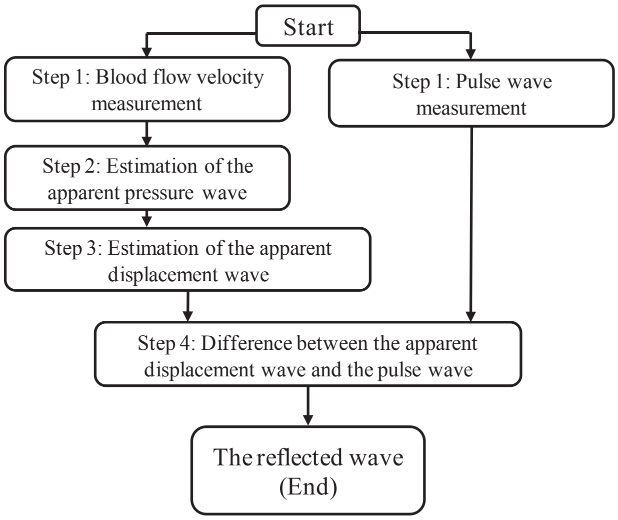

Fig. 1 Procedure for estimating incident and reflected waves.

frequency of 10 kHz. We also used ultrasonic Doppler system (LOGIQ e, GE Healthcare co.).The center frequency of the ultrasonic probe (12L RS, GE Healthcare co.) was 12 MHz.

2.3 Signal processing

The proposed method estimates the incident and reflected waves from the pulse wave and blood flow velocity. This method involves the following steps (**Figure 1**). Considering the viscoelasticity of the skin, we estimated the displacement of the skin surface generated by the pressure wave in eq. 1: (Step 3)

$$\varepsilon(t) = \frac{1}{\eta}\exp\left(-\frac{1}{\tau}t\right)\int_0^t P(t)\exp\left(\frac{1}{\tau}t\right)dt \quad (1)$$

where P, η and τ are respectively pressure, the viscosity constant and relaxation time. The term ε (t) is the displacement component of the incident wave. The incident waves were then estimated by changing $1/\tau$. First upstroke of the estimated pressure wave was fitted with that of the pulse wave, because the initial upstroke of the measured pulse wave is only composed of the incident wave.

3. Results and discussion

Figure 2 shows the observed pulse wave, estimated incident and reflected waves obtained

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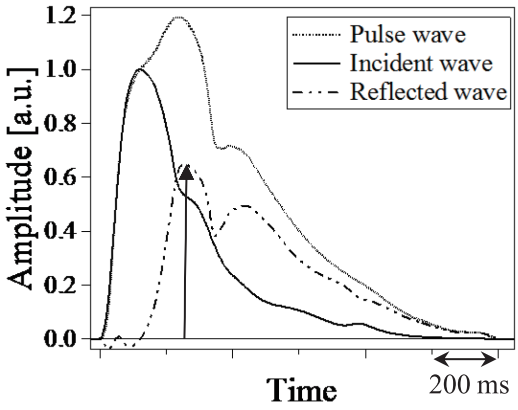

Fig. 2 The observed pulse wave, estimated incident and reflected waves obtained from the subject of 83 years old.

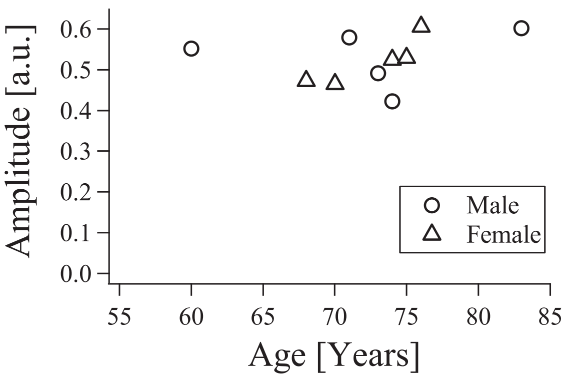

Fig. 3 Relationship between age and maximum value of the reflected wave.

from the subject of 83 years old. The maximum amplitude of the reflected wave is shown by an arrow. Fig. 2 shows relationship between age and maximum value of the reflected wave. We could separate the incident and reflected waves obtained from the subjects in their 70s to 80s.

Figure 3 shows pulse wave obtained from the patient in her 90s. **Figure 4** shows the typical pulse waveforms of various ages. The waveform depended on the age, which can be found as the changes of second peak position. As can be seen, the second peak which mainly comes from the reflected wave becomes strong and moves to the initial part of the wave. This is because the reflected wave propagates faster in the old artery.

In the waveform obtained from the patient in her 90s, we could not observe two clear peaks and could not separate the incident and reflected waves. The characteristic waveform in the patients of 90s indicates the hard artery. The initial upstroke of the measured pulse wave obtained from the patient in her 90s is composed of the incident and reflected wave because the reflected wave propagates faster in the hard artery. We could not estimate incident wave because reflected wave

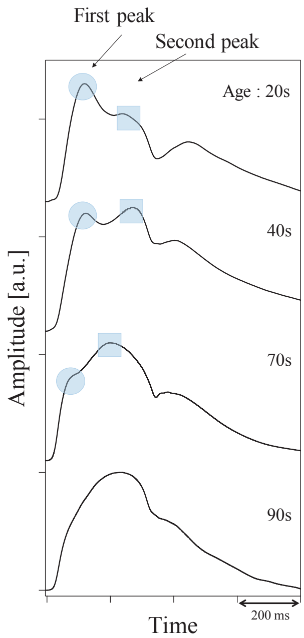

Fig. 4 The typical pulse waveforms of various ages.

overlap the upstroke of incident wave. We focused on the time interval between second and first peaks (Fig. 4). They were 0.117, 0.133 and 0.106 (20s, 40s, 70s). The time interval between second and first peaks obtained from the patient in her 90s may be from 0.112 to 0.145. There was no clear difference of time interval. Further discussion to characterize the waves is necessary.

These data indicates that the pulse waveform itself is also an important factor for the evaluation of artery of very old people

4. Conclusion

We focused on the characteristic pulse wave of elderly people from 70s to 90s. In the waveform obtained from the patient in her 90s, we could not observe two clear peaks and could not separate the incident and reflected waves. The characteristic waveform of 90s reflects the hard artery. These data indicates that the pulse waveform itself is also an important factor for the evaluation of pulse wave of very old people in addition to the analysis of reflected wave. We will also focus on the pulse waveform at the carotid artery.

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