3P5-25

Proceedings of Symposium on Ultrasonic Electronics, Vol. 30 (2009) pp. 571-572
18-20 November, 2009

Simple analysis of a pulse wave to estimate the viscoelastic properties of blood vessel wall - Effect of age on the averaged blood flow velocity -

血管の粘弾性評価を目的とした簡便な脈波解析法の検討 －平均的な血流速度波形と年齢－

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1. Introduction

Arteriosclerotic disease has become a problem in this aging society. Since it is difficult to cure after the onset of symptoms, early detection of arteriosclerosis is very important. It is known that there is a correlation between arteriosclerosis and the characteristics of the blood vessel. From this point of view, the evaluation of the blood vessel has become an important purpose[1].

In the previous research, we focused on the pulse wave to evaluate the viscoelastic property of blood vessel wall and suggested a technique to analyze the wave[2]. However, the technique needs the blood flow velocity waveform obtained by an ultrasonic diagnostic equipment, which gives us a big barrier for a simple in vivo measurement. In this study, we propose a simple and noninvasive technique to estimate blood vessel characteristics from the observed pulse wave without the ultrasonic diagnostic equipment.

2. Methods

2.1. Pulse Wave and Estimation of Reflected Wave

The evaluation of a pulse wave has become important for screening arteriosclerosis, because the wave reflects the characteristics of blood vessel. The pulse wave arises from displacement changes of the surface skin caused by pressure in the blood vessel. The pressure wave is composed of a forward wave and a backward wave. The forward wave is caused by blood flow coming from the constriction of the heart. The backward wave is generated by the reflection of the forward wave at the peripheral arteries. Therefore, the pulse wave is a wave synthesized from the displacement component due to the forward wave and backward wave. In this study, we call the observed displacement component due to the forward wave, “the incident wave” and that due to the backward wave, “the reflected wave”. Because the reflected wave is generated by the backward wave which propagates to the peripheral artery, it depends strongly on the viscoelastic properties of the vessel wall. Therefore, the evaluation of blood vessels may be possible by investigating this reflected waveform.

In the previous research, we suggested the techniques to estimate the incident wave and extracted the reflected wave from the observed pulse wave. An outline of the technique is shown below[2].

I) Changes in the cross section of the blood vessel were estimated from the blood flow velocity waveform using the one-dimensional continuity equation.
II) The forward pressure wave was estimated by substituting the cross section changes into elastic model.
III) A Voigt model was used to estimate the incident pulse wave from the forward pressure wave. The relaxation time was adopted as a parameter to estimate the optimum incident wave.
IV) The estimated reflected wave was obtained by deleting the incident wave from the observed pulse wave.

2.2. Averaged Blood Flow Velocity Waveform

The separation technique needs measurement of the blood flow velocity. For more simple technique, we produce averaged blood flow waveforms experimentally as a substitute for the waveforms. In this study, we investigate the applicability of the waveform for the separation technique. The procedure of producing averaged wave is as follows.

i) Observed data was first categorized according to each age group since the blood flow velocity contour changes due to heart rate and age[1].
ii) The data was normalized by time interval between maximum amplitude and incisures point.

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iii) Averaged blood flow velocity waveform is obtained.

3. Experiments

3.1. Subjects

The experimental subjects were 33 healthy men in their twenties to sixties. The characteristics of the pulse wave and the blood flow velocity change remarkably due to the physiological state. Therefore, subjects refrained from meal, exercise, and smoking for more than two hours before the experiment. The measurement was started after the subjects lay down for ten minutes in a room at 25℃.

3.2. Measurement

The electrocardiogram (ECG), the pulse wave and the blood flow velocity were measured simultaneously. Details of this measurement system are as follows[2].

First, electrodes were installed on both right hand and left foot to measure the ECG. The pulse wave was measured at the left common carotid artery. For the pulse wave measurement, we used a piezoelectric transducer (Murata MA40E7R). The observed signal of the pulse wave was amplified 40 dB by a pre-amplifier (NF 5307). Then, it was recorded with a data logger (Keyence NR-500). The blood flow velocity was measured at the right common carotid artery. The blood flow velocity was obtained by a Doppler blood flow measurement using ultrasonic diagnostic equipment (Toshiba Medical Systems Aplio SSA-700A). The center frequency of the ultrasonic pulse used (Toshiba Medical Systems Probe PLT-1204AT) was 12 MHz.

4. Results and Discussion

Observed blood flow waveforms of 15 subjects and averaged waveform in their twenties are shown in Fig. 1. The standard deviations of the observed waves were from 0.031 to 0.082, telling that the similarity of the blood flow velocity waveform. Averaged blood flow velocity waveforms in age groups are shown in Fig. 2. The contour of averaged blood flow velocity changes dramatically due to the age. This seems to result from decreasing the force of cardiac contraction with the age[1].

We then applied the observed personal blood flow velocity waveform and averaged waveform to the separation technique. Figure 3 shows the results of pulse wave separation of one subject. There is little difference between incident waves estimated by both waveforms. The results of other subjects show the same tendency. The separation of the pulse wave seems possible with the suggested averaged blood flow velocity waveforms.

5. Conclusion

A simple technique to evaluate a pulse wave is proposed. By comparing reflected waves estimated from personal and averaged blood flow velocity waveform in each age group, we found a small difference. This tells us the possibility of vessel wall evaluation with this simple technique.

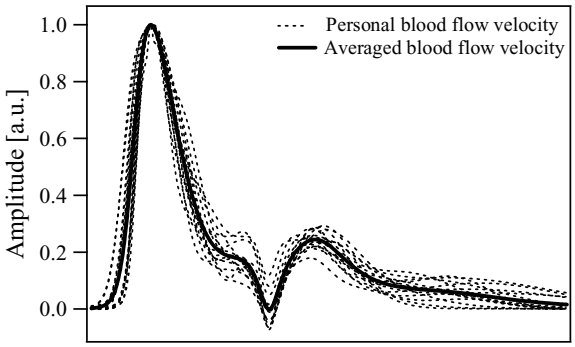

Fig. 1 Personal and averaged blood flow velocity waveforms in their twenties.

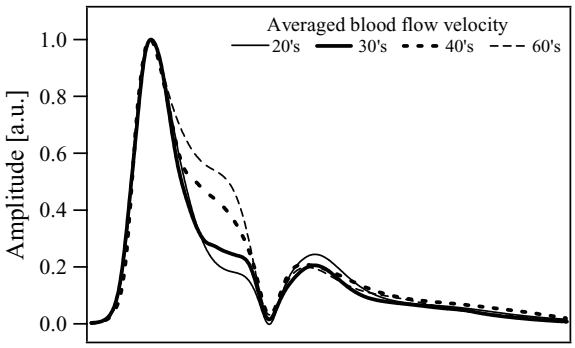

Fig. 2 Averaged waveform in each age group.

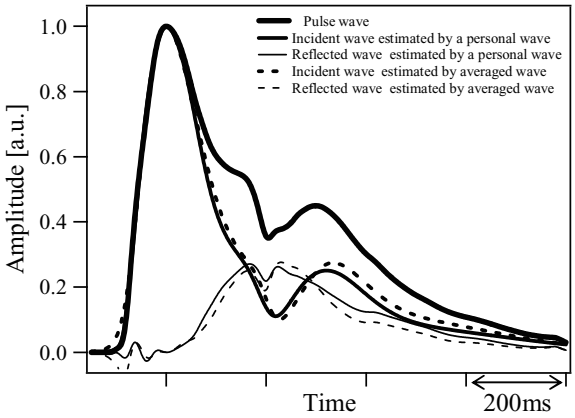

Fig. 3 Results of wave separation of one subject in his twenties by personal or averaged blood flow velocity waveforms.

References

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