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Proceedings of Symposium on Ultrasonic Electronics, Vol. 32 (2011) pp. 271-272
8-10 November, 2011

Evaluation of arterial stiffness by pulse wave analysis
脈波を用いた血管硬度の評価

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1. Introduction

Arteriosclerosis is a vascular disease that leads to cardiovascular disease and stroke. In the early stage of arteriosclerosis, aortic stiffness increases excessively compared to normal stiffness. Therefore, diagnosis of arterial stiffness is effective for reducing the incidence of those [1].

One present approach for the stiffness diagnosis is CAVI (Cardio Ankle Vascular Index) measurement. Because CAVI is estimated from the velocity of pulse wave propagating from heart to peripheral parts, the value shows average arterial stiffness [2].

However, the accuracy of CAVI method is inferior to those of diagnostic imaging methods like ultrasound diagnostic system. Furthermore, CAVI method is not simple for screening at home, because of installing cuffs on both upper arms and ankles. In addition, CAVI is sometimes poorly-reproducible.

Therefore, a more precise technique for evaluating the stiffness is required. We have proposed a new method with the pulse waveform because the analysis of the pulse waveform provides more information of artery than the CAVI method.

The pulse wave is displacement changes of the surface skin caused by pressure in the common carotid artery. Furthermore, the pulse wave is the mixture of the incident wave and the reflected wave. The incident wave is generated by the forward pressure wave. The reflected wave is generated by the backward pressure wave. The forward pressure wave is generated by blood flow due to the constriction of the heart. The backward pressure wave is generated by the reflection of the forward pressure wave at the peripheral arteries [1]. Propagation distance of the reflected wave is longer than that of the incident wave. Then, the reflected wave depends strongly on the viscoelastic properties of the vessel wall. Therefore, the evaluation of arteries is possible by investigating this reflected waveform.

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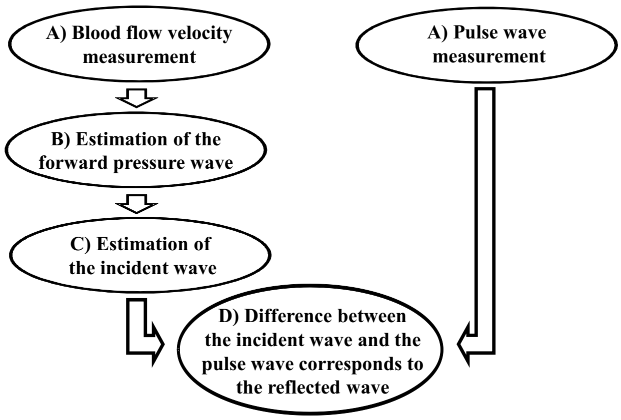

Fig. 1 Separation technique of the pulse wave.

In this study, we attempt to evaluate the relationship between age and the amplitudes of the reflected waves or CAVI. These are obtained from healthy subjects.

2. Methods

2.1. Estimation technique of reflected wave

We have suggested a separation technique to extract the reflected wave from the pulse wave [3]. The outline of the technique is shown in **Fig. 1**. The details of the technique are as follows. Here, the estimated reflected wave contains the information of the local stiffness from carotid to cerebral arteries [4].

A) The blood flow velocity wave and the pulse wave were measured.

B) <u>The estimation of forward pressure wave</u>
   1) Changes in the cross section of the artery were estimated from the blood flow velocity waveform using the one-dimensional continuity equation.
   2) The forward pressure wave was estimated by substituting the cross section changes into an elastic pipe model.

C) <u>The estimation of incident wave</u>
   Assuming a Voigt model, the incident wave was estimated from the forward pressure wave considering the relaxation time.

D) The reflected wave was estimated by deleting the incident wave from the pulse wave.

2.2. Pressure wave and flow velocity measurement

We measured electrocardiograms (ECGs), pulse wave, and blood flow velocity simultaneously. ECG signals were used as triggers to synchronize the measurements of pulse wave and flow velocity. The pulse wave was measured at one point on the left common carotid artery using a piezoelectric transducer (Murata MA40E7R). The observed signal was amplified to 40 dB by a preamplifier (NF 5307) and then recorded in a PC. Blood flow velocity was measured at the center of the left common carotid artery using an ultrasonic Doppler system (Toshiba Medical Systems Aplio SSA-700A). The center frequency of the ultrasonic pulse used (Toshiba Medical Systems Probe PLT-1204AT) was 12 MHz.

The characteristics of these data change markedly depending on physiological conditions. Therefore, measurements were done with the subject in the resting state. The subjects avoided eating, exercising, and smoking for more than 2 h and then lay down in the supine position for 15 min in a quiet room at 25°C before measurements.

2.3. CAVI measurement

This measurement was carried out immediately after the pulse wave measurement to prevent from changing physiological conditions. CAVI was measured by the blood pressure pulse wave tester (VaSera VS-1500A, Fukuda Denshi), installing cuffs on both upper arms and ankles.

3. Results and Discussion

Figure 2 shows an example of the estimation of the reflected wave. The arrow in this figure shows maximum value of the reflected wave. **Figure 3** shows the maximum values of the reflected wave as a function of age. From this figure, maximum values of the reflected waves increased owing to age. Furthermore, there seemed little difference between the amplitudes obtained from male and female subjects. **Figure 4** shows the relationship between CAVI and maximum values of the reflected wave. The result showed a moderate correlation (R^2=0.64), telling us the local carotid arterial stiffness from pulse wave technique has the relation with that of the average arterial stiffness estimated from CAVI measurement.

4. Conclusion

The relationship between amplitudes of reflected waves and CAVI was investigated. A clear correlation was found between the amplitudes and CAVI. Further study needs more data of subjects in various age groups. However, these data indicate that technique using the pulse wave is acceptable and useful for the evaluation of arterial stiffness.

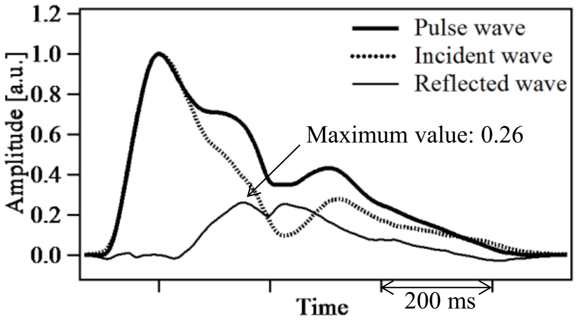

Fig. 2 Separation result of pulse wave.

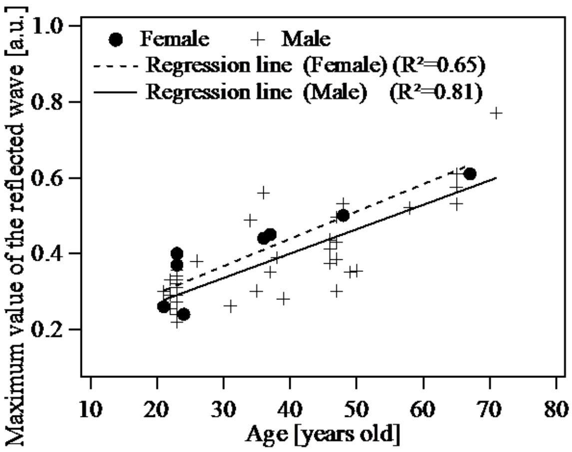

Fig. 3 Relationship between age and maximum value of the reflected wave.

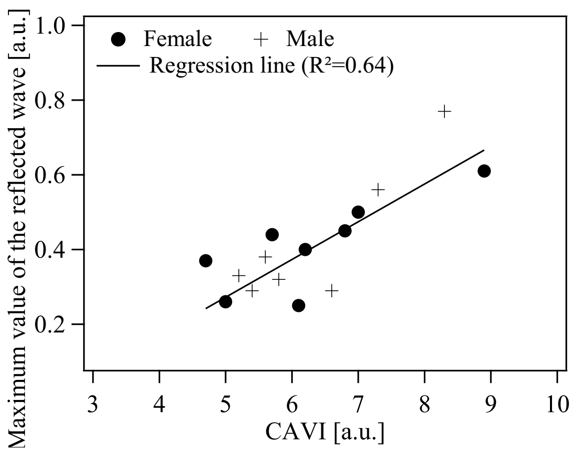

Fig. 4 Relationship between maximum value of the reflected wave and CAVI.

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