3P5-12

Features of pulse waveform at the carotid artery for the estimation of cerebral arteriosclerosis

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1. Introduction

Arteriosclerosis often progresses without symptoms, which delays the diagnosis in the hospital. For simple and inexpensive screening of the carotid artery at home, we focused on the measurement of the pulse wave. We constructed a pulse wave measurement system using an inexpensive and commercially available piezoelectric sensor for ultrasound ranging[1)]. The pulse wave is a temporal variation of displacement of the skin surface caused by pressure waves propagating in the artery. The forward pressure wave is caused by blood flow coming from the constriction of the heart. The backward pressure wave is generated by the reflection of the forward wave at the peripheral arteries. We call the component of the pulse wave due to the forward wave, the incident wave, and that due to the backward wave, the reflected wave. The reflected wave depends strongly on the viscoelastic properties of the vessel wall. Therefore, the evaluation of carotid artery may be possible by investigating the reflected wave component.

If age dependence of pulse waveforms can be understood, it may be possible to screen for abnormal arterial stiffness. However, the pulse wave depends not only on arteries but also on the blood flow from the heart. Therefore, this study also examines age dependence of blood flow waveform of the carotid artery. This study is permitted by the ethics committees at Doshisha university.

2. Measurement method

50 healthy subjects were measured (ages: 20s-60s). They have no history of cardiovascular diseases and are not taking hypertension medications. The subjects lay on their back and in the resting state during measurements. Pulse waves were measured using a piezoelectric transducer (MA40 E7R, Murata Manufacturing)[1)]. The output of the transducer was digitized by our handheld system (ProAssist Corp.). Blood flow velocity was measured using an ultrasonic diagnosis system (LOGIQ-e, GE Healthcare Corp.). **Figure 1** shows the pulse wave measurement using the piezoelectric sensor. The representative waveform was obtained by the additive average of four consecutive waveforms and normalized.

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Fig. 1 Measurement system using a piezoelectric sensor.

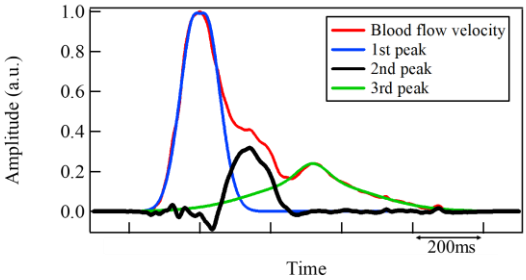

Fig. 2 Separation to three components of blood flow velocity waveform.

3. Waveform analysis

3. 1 Peak analysis

Figure 2 shows a blood flow waveform separated to three components. Both pulse wave and blood flow velocity have two peaks in systole and one peak in diastole. The respective components were obtained as follows.

1. The 1st peak was fitted by a Gaussian function.
2. Subtraction of the Gaussian function from the original waveform.
3. The subtracted wave was fitted by the Gaussian again to obtain the 3rd peak.
4. Subtraction of the Gaussian function again.
5. The 2nd peak can be obtained.

3. 2 Reflected wave

We have estimated the reflected wave in the pulse wave. A Voigt model was used to estimate the incident pulse wave from the blood flow velocity[2)].

$$\varepsilon(t) = \frac{1}{\eta} e^{-\frac{1}{\tau}t} \int_0^t p(t) \cdot e^{\frac{1}{\tau}t} dt$$

Where ε, p, η and τ are displacement, pressure, the viscosity constant and relaxation time, respectively. As Saito pointed[1)], the relaxation frequency (f=1/τ) is one parameter for estimating viscoelasticity of the vessel. We focused on the initial upstroke of the pulse wave to decide the parameter, because the upstroke of the pulse wave is composed only of the incident wave without the effect of the reflected wave.

4. Results and discussion

Figures 3 and 4 show the waveforms in their 20s and 60s. The variance σ of the waveforms was calculated using the average waveforms of each age group. σ increased with age, showing the individual differences. The variations may be due to lifestyle habits. In addition, σ of the pulse wave was larger across all age groups. This is reasonable because blood flow velocity depends on the individual heart's pumping function, whereas the pulse wave also includes information of arterial stiffness. This means the possibility to screen age related characteristics of cerebral arteries by only checking pulse waveforms and their variations. Next step is the extraction of features of pulse waves for screening.

Figure 5 shows the relation between peak values and relaxation frequency f. The correlation coefficients between the 2nd and 3rd peaks and f are R2 and R3, respectively. When f exceeds 120, the correlation between f and peak values of the pulse wave became smaller, which may suggest inadequate analysis. There was no correlation between the 3rd peak value of blood flow velocity and f. The strongest correlation was obtained at the 2nd peak of the pulse wave. The correlation between peak values of the pulse wave and f was stronger than that of blood flow velocity. Therefore, both the 2nd and the 3rd peaks values of the pulse wave can be good indicators for evaluating arterial stiffness.

Figure 6 shows the relation between peak values and age. A strong correlation was found in the 2nd peak of the pulse wave. These results show that the 2nd peak of the pulse wave may be useful for the evaluation of stiffness. It will be important to prioritize the 2nd peak of the pulse wave to know the vascular age.

5. Conclusion

The analyses of waveforms tells that the screening of arterial stiffness may be possible by examining the features of the pulse waveform measured at the neck. The 2nd peak of the pulse wave seems the most useful to estimate arterial stiffness. More measurement data can bring more information in the future to accurately understand the variation of the peak values and f in each age group.

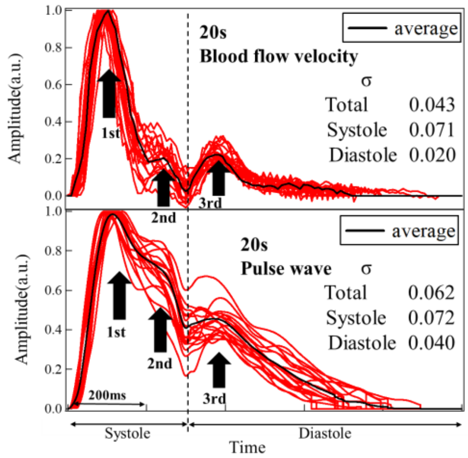

Fig. 3 Waveforms (20s).

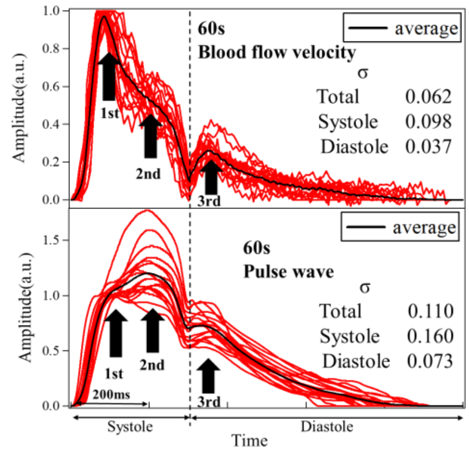

Fig. 4 Waveforms (60s).

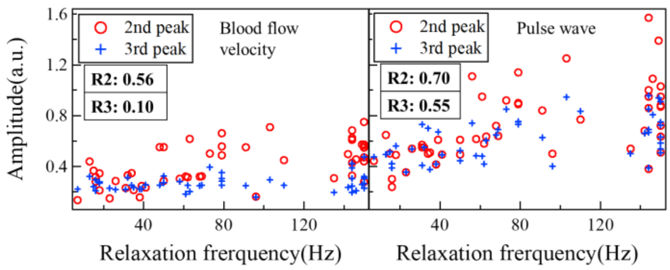

Fig. 5 Relation between peak values and relaxation frequency.

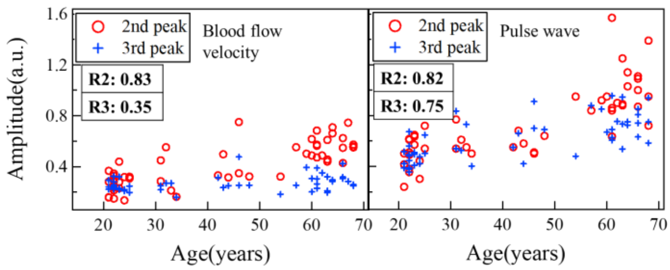

Fig. 6 Relation between peak values and age.

References

1) M. Saito, IEEE TUFFC. **59**, 2411 (2012).
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