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Evaluation of arterial stiffness by pulse wave at back and forth of the carotid bifurcation

脈波を用いた動脈硬化簡易検査手法の研究−頸動脈分岐前後の脈波波形解析の検討−

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1. Introduction

Pulse wave evaluation is suitable for screening arteriosclerosis. Pulse wave 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 at the left common carotid artery [1-3]. There was a good correlation between the age of the subjects and the maximum amplitude of the reflected wave obtained by *in vivo* measurement (R^2=0.65) [4]. The common carotid artery branches into two types of carotid arteries: the internal carotid artery supplies blood to the brain and the external carotid artery supplies blood to the face and scalp.

Our purpose is creating the user-friendly systems for screening arteriosclerosis. If the pulse wave depends on the measurement position at the carotid artery, the patients cannot use this system at home.

In this study, we focused on the measurement positions, and checked the reflected waves obtained at back and forth of the carotid bifurcation.

2. Experiments

2.1 Subjects

The subjects were 7 men in their 20s who do not have previous history of cardiovascular diseases. They did not take vasoactive agents, eating, exercising, and smoking, for 2 hours before measurements. The subject then laid down in the supine position for 10 minutes in a quiet room at 25 degrees Celsius.

2.2 Data Collection

We measured the pulse wave on the left common carotid artery and left internal carotid artery using a piezoelectric transducer (MA40E7R, Murata Manufacturing Co., Ltd., Japan). We also used ultrasonic Doppler system (Prosound, Hitachi Aloka Medical Ltd., Japan). The center frequency of the ultrasonic probe (UST-5412, Hitachi Aloka Medical Ltd., Japan) 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:

Step 1: Pulse wave and blood flow velocity at the carotid artery are measured.

Step 2: We estimate the forward pressure wave, making use of the blood flow waveform. The cross-section of the blood vessel was estimated from the blood flow velocity waveform using the equation of continuity:

$$\frac{\partial A}{\partial t} + \frac{\partial (Au)}{\partial x} = 0 \qquad (1)$$

where A and u are the cross-section and blood flow velocity. The forward pressure wave was then calculated using the changes in cross-section according to the elastic model shown in eq. (2):

$$P(t) - P_0 = \frac{1}{Cs}(A(t) - A_0) \qquad (2)$$

where P_0, A_0, and C_s represent the initial pressure, initial cross section, and compliance of artery, respectively.

Step 3: Considering the viscoelasticity of the skin, we estimated the displacement of the skin surface generated by the pressure wave in eq. (3):

$$\varepsilon(t) = \frac{1}{\eta}\exp\left(-\frac{1}{\tau}t\right)\int_0^t P(t)\exp\left(\frac{1}{\tau}t\right)dt \qquad (3)$$

where η and τ are the viscosity constant and relaxation time, respectively. The term $\varepsilon(t)$ is the displacement component of the incident wave.

Step 4: The reflected wave was obtained by subtracting the estimated incident wave from the measured pulse wave.

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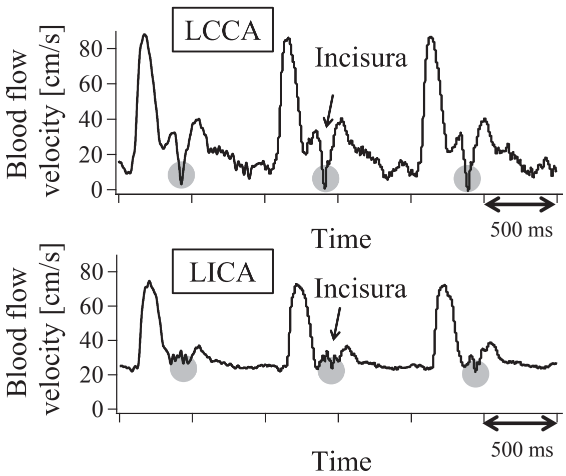

Fig. 1 Blood flow velocity in his 20s.

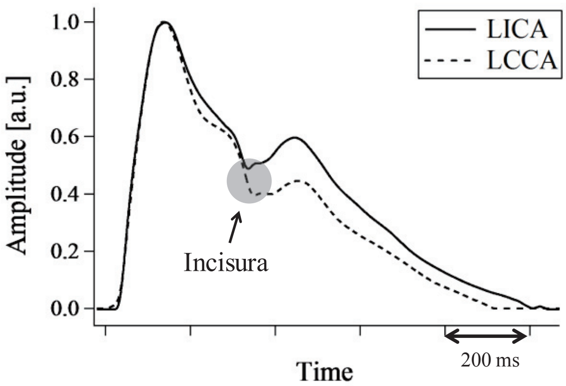

Fig. 2 Pulse waves in his 20s.

3. Results and discussion

We compared the blood flow velocity waveforms at the left common carotid artery (LCCA) with those at the left internal carotid artery (LICA). Fig. 1 shows blood flow velocity waveforms. The waveform changed depending on the measurement positions. Particularly, it significantly changed near the incisura. One reason of this change seems to depend on the non-uniformity of blood flow at the carotid bifurcation.

We also compared the pulse waves at LCCA with those at LICA. Fig. 2 shows pulse waveforms. The waveform changed depending on the measurement positions.

Fig. 3 shows examples of the separated waves observed in the subject aged 22 years. The maximum amplitude of the reflected wave is indicated by an arrow. Fig. 4 shows the correlation between the maximum amplitudes of reflected waves measured at LCCA with those at the LICA (R^2=0.83). These data indicate that the evaluation technique using the reflected wave is possibly independent of the measurement positions in the carotid artery, in spite of the difference in pulse wave and blood flow velocity.

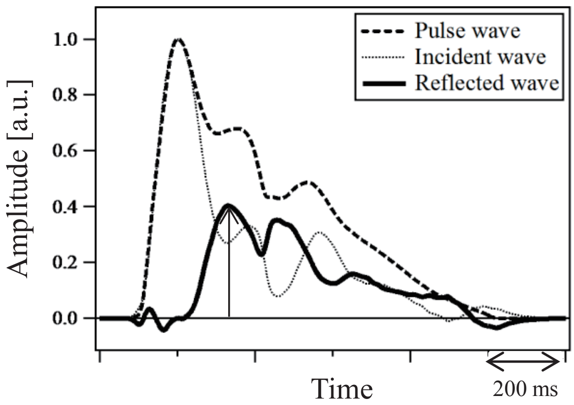

Fig. 3 Result of separated waves in his 20s.

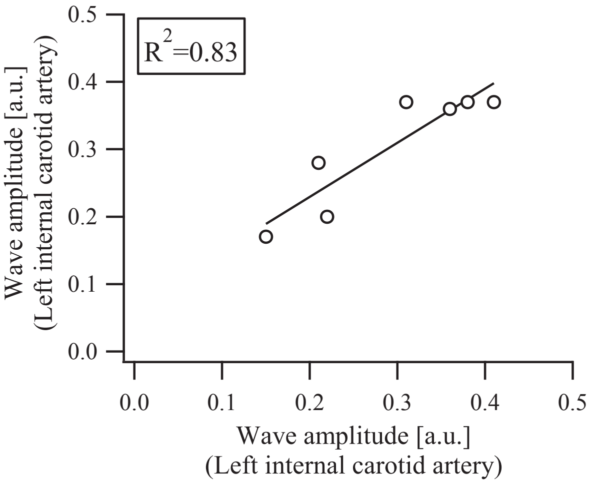

Fig. 4 The maximum amplitudes of reflected waves obtained from LCCA and LICA.

4. Conclusion

We focused on the reflected wave obtained at back and forth of the carotid bifurcation. In LCCA and LICA, the maximum amplitudes of estimated reflected waves were similar. These data indicate that the evaluation techniques using the reflected wave are possibly independent of the measurement positions in the carotid artery. Therefore, this method is considered to be user-friendly and good for screening.

References

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