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In vivo stiffness evaluation of carotid artery by pulse wave analysis

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ABSTRACT

Arteriosclerosis causes the increase of aortic stiffness and is now one of the most important cardiovascular diseases. Although the very precise evaluation technique has been developped using ultrasonography, early detection and screening of arteriosclerosis is still difficult. This is because no serious symptom can be observed in the early stage. An easier evaluation technique of the aortic stiffness is the measurement of pulse wave, which is the displacement of the skin surface caused by the intravascular pressure. The pulse wave velocity (PWV) and cardio–ankle vascular index (CAVI), are considered to depend on the Young's modulus of the arterial wall and to reflect the aortic stiffness [1,2]. However, the system still needs cuffs to the extremities and is a little complicated for the simple and daily monitoring. We have then challenged a new simple in vivo technique to evaluate the pulse wave in the carotid artery, which can be a good indicator of artery in the brain [3,4].

The pulse wave was measured by a commercial piezoelectric ultrasonic transducer (MA40E7R, Murata Manufacturing Co., Ltd., Japan). At low frequencies, it works as a displacement sensor. We then measured the pulse wave on the skin surface of the neck on the left common carotid artery using this transducer. The measured displacement wave was amplified (NF 5307, NF Corp., Japan) and digitalized (NR-500, NR-HA08, Keyence Corp., Japan) at a sampling frequency of 10 kHz. We also measured blood flow velocity at the left common artery using an ultrasonic Doppler system (Prosound α, Hitachi Aloka Medical Ltd., Japan). The center frequency of the ultrasonic probe (UST-5412, Hitachi Aloka Medical Ltd.) was 12 MHz. The simultaneous measurements of the pulse wave and blood flow velocity were achieved by making use of the electrocardiogram (ECG) signal as a trigger of two different systems.

The subjects were in their 20s to 60s who did not have previous history of cardiovascular diseases and were not taking vasoactive agents. They provided written consents to participate in the study, and the protocols used were approved by the medical ethics committee of Doshisha University. Before measurements, the subject refrained from eating, exercising, and smoking, for more than 2 hours. The subjects then laid down in the supine position for 10 minutes in a quiet room at 25 ^{o}C.

It is well known that the pulse wave is composed of overlapped two components, incident and reflected waves. The latter is the one which reflected at the vascular beds and gives us information of the viscoelastic properties of the artery. Therefore, we have tried to extract the reflected wave from the measured pulse wave, following the steps below.
1) Assuming that the blood vessel is an elastic tube, the forward pressure wave was estimated from the blood flow velocity.

2) Considering the visco-elasticity of the artery, the forward displacement wave (incident wave) was estimated from the calculated pressure wave using a Kelvin–Voigt model
3) The reflected wave was obtained by subtracting the estimated incident wave from the measured pulse wave.
We have already reported that the pulse wave measured at the carotid artery includes the wave reflected at the vascular bed in the brain [3,4]. The extracted reflected wave amplitudes (ARW) seemed to depend on the age.

Actually, ARW showed clear dependence on the age without the effect of sexuality (Fig. 1(a)). Of interest is the good correlation between ARW and cardio–ankle vascular index (CAVI). The good correlation seemed not to depend on the maximum and minimum pressures.

In this study, pulse wave was successfully measured by a piezoelectric ultrasonic transducer. The reflected wave showed clear dependence on age and good correlation with the CAVI data. This system is not yet suitable for in vivo handy measurement of artery, because it needs the blood flow measurement. However, the pulse measurement system itself is simple, not expensive; and convenient. The next step for more convenient system is then expected.

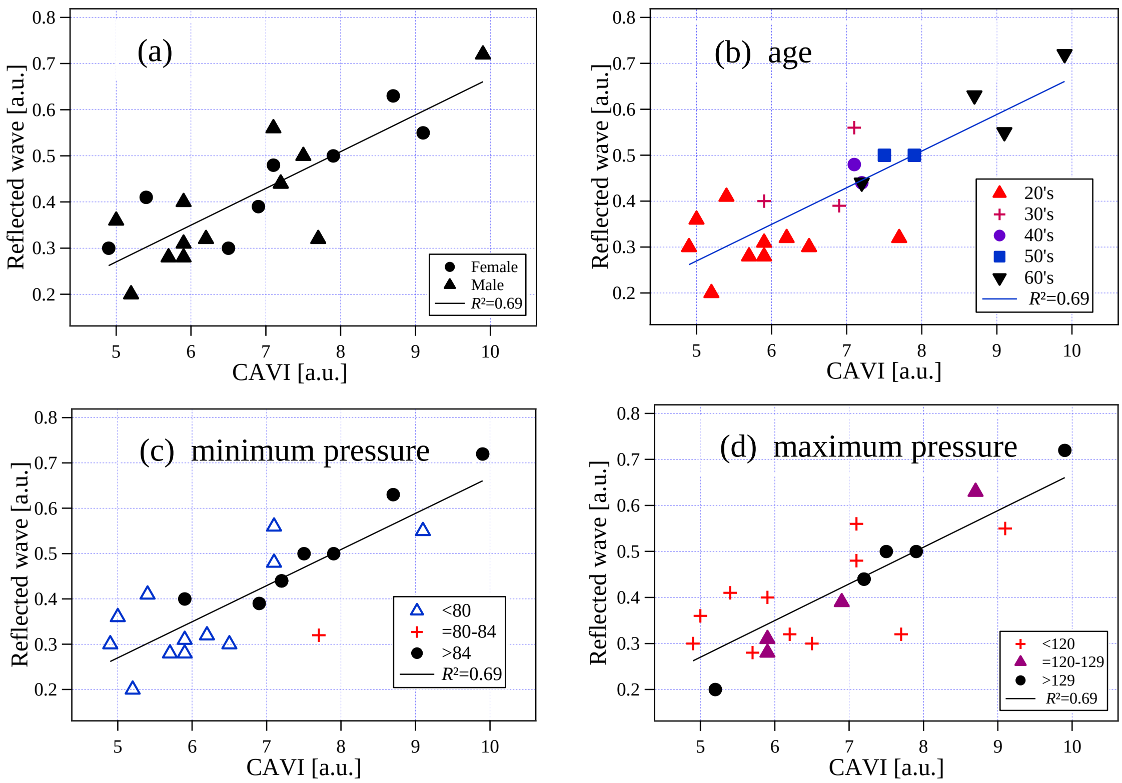

Fig.1 Comparison of ARW and CAVI data. (a) Comparison of female and male data, (b) effects of age, (c) effects of minimum pressure, and (d) effects of maximum pressure.

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