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Accurate Evaluation of Viscoelasticity of Radial Arterial Wall by in vivo Measurement of Arterial Pressure and Diameter at the Same Position

血圧－血管径の同位置計測による橈骨動脈壁の高精度粘弾性 in vivo 評価

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1. Introduction

Cardiovascular disease is one of the primary causes of death in Japan, and it is mainly caused by atherosclerosis. For the diagnosis or athersclerosis in an early stage, it is important to evaluate vascular endothelial function[1)]. We have reported a method that reveals the transient change in viscoelasticity with respect to arterial pressure and wall thickness during flow-mediated dilation (FMD)[2)]. However, the value of viscoelasticity estimated by the method had a large variance because it was difficult to measure thickness of the radial arterial wall. Furthermore, the method employed a high-frequency (22 MHz) ultrasound device with a single beam, where the setting was different from a commercial ultrasound diagnostic apparatus. In the present study, we used a commercial ultrasound device with a 7.5 MHz probe to measure arterial diameters. In addition, we compared diameter and viscoelasticity of plural subjects during FMD.

2. Materials and methods

2.1 Measurement of arterial pressure and diameter

The arterial blood pressure waveforms at two points were measured using two pressure sensors placed at a distance of 74 mm on the left radial artery. We estimated the pulse wave velocity by estimating the time delay using the cross-correlation function between the arterial blood pressure waveforms in order to correct the propagation time from the pressure sensor to the ultrasound probe. Thereby, it can be measured the pressure sensor and ultrasound probe apparently at the same position. Since pressure sensor cannot measure blood pressure values, we measured blood pressure values in the right radial artery by using a sphygmomanometer and calibrated absolute value of the waveform measured on left radial artery.

The change in arterial diameter was measured using 7.5 MHz ultrasound probe and applying the phased-tracking method[4)] to the received RF signals.

2.2 Viscoelasticity estimation

We assume that the viscoelastic properties of arterial wall follow the Voigt model. We estimate the elasticity and viscosity from the following equation of the pulse pressure $P(t)$ with respect to arterial pressure and diameter:

$$\hat{P}(\mathrm{t}) = E_p \int \dot{\varepsilon}(t)\, dt + \eta_p \dot{\varepsilon}(t), \qquad (1)$$

where $\hat{P}(t)$ is the modeled pulse pressure, $\dot{\varepsilon}(t)$, E_p, and η_p show strain rate of diameter, elasticity, and viscosity, respectively. In addition, we estimated diameter and viscoelasticity by using three beams near the center of radial artery.

2.3 In vivo measurement of FMD reaction

The left radial arteries of 4 healthy male subjects (22-24 years old) were measured We placed a cuff on the upper arm of the subject in order to perform avascularization to obtain the FMD reaction. For the measurement of each radial artery, ultrasound RF echoes (transmit center frequency: 7.5 MHz) were acquired at a sampling frequency of 30.0 MHz, where the frame rate was 252 Hz. Blood pressure waveforms were acquired at sampling frequency of 1.0 Hz . This acquisition was repeated every 20 seconds for 3 minutes before avascularization (5 minutes) and every 10 seconds for 5 minutes after recirculation.

3. Result

Figure 1 shows the measured relationships between pressure and diameter in radial artery with and without correction of the change in pulse wave velocity. By considering the propagation time, the directions of hysteresis loops were corrected from counterclockwise to clockwise. This result validates the correction because direction of hysteresis loops in general viscoelastic body is clockwise.

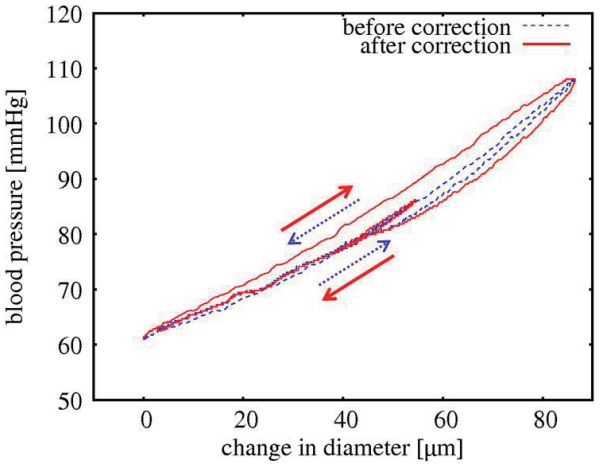

Fig.1 Measured relationships between arterial pressure and diameter with and without correction the pulse wave velocity (blue and red lines, respectively).

Figure 2 shows the transient change in the diameter measured during FMD in 4 subjects. In all subjects, the diameter shows more than 10% increase after avascularization. This result validates the correction because it is considered that the value of healthy people is more than 6%.

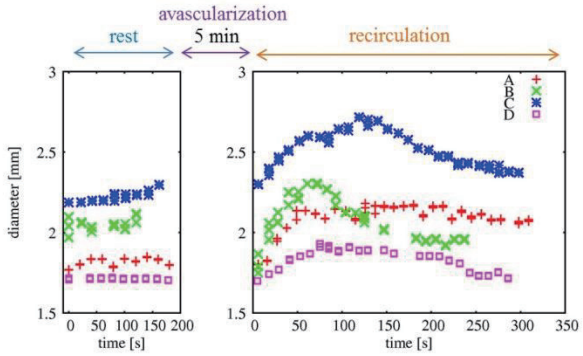

Fig. 2 Transient change in the diameter during FMD in 4 subjects.

Figure 3 shows the transient change in the estimated viscoelasticity during FMD reaction. In subjects A and B, the elasticity shows a large rate of change (about 30%) than the diameter after avascularization. This result shows possibility to evaluate vascular endothelial function by using elasticity of arterial wall.

Figure 4 shows the transient change in the estimated viscosity during FMD reaction. The variation of the viscosity is smaller than previous study, indicating the effectiveness of the proposed compensation method. The small variation may be due to the high accuracy in estimating arterial diameter compared with that in estimating arterial wall thickness. In subjects A and B, the viscosity decreased after avascularization. This result shows the possibility of the proposed method to elucidate viscosity of arterial wall because the temporal changes of elasticity and viscosity were similar.

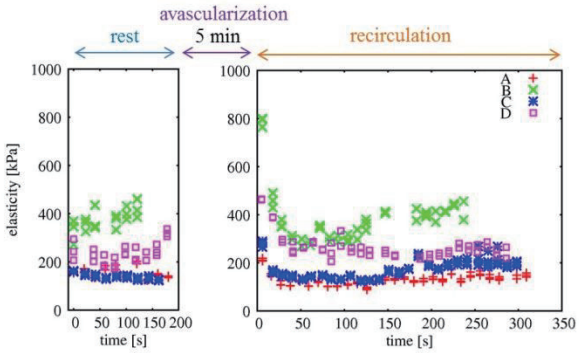

Fig. 3 Transient change in the elasticity during FMD reaction in 4 subjects.

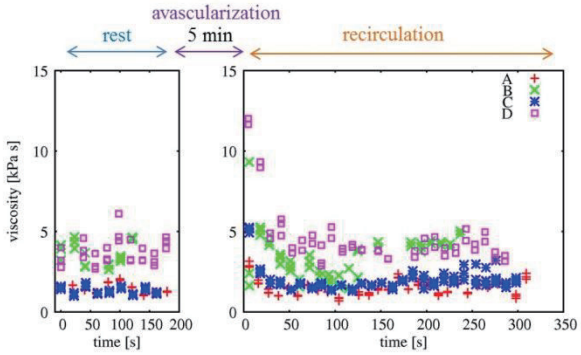

Fig. 4 Transient change in the viscosity during FMD reaction in 4 subjects.

4. Conclusion

In the present study, we propose a method that estimates viscoelastic properties that uses two pressure sensor for arterial pressure measurement and a commercial ultrasound diagnostic device with a 7.5 MHz probe for arterial diameter measurement at the same position. We have measured arterial diameters and viscoelastic properties during FMD reaction in 4 subjects, and the result shows the similarity between arterial diameters and viscoelastic properties after avascularization. As a result, the proposed method has a potential to evaluate vascular endothelial function using viscoelasticity and to elucidate viscosity of arterial wall which has not yet been realized.

References

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