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Accuracy verification in ultrasonic measurement method of arterial wall elasticity using phantom experimental system

動脈壁弾性率の超音波計測法のファントム実験系を用いた精度検証

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1. Introduction

Myocardial infarction and cerebral infarction, which are the leading causes of death in Japanese, are closely associated with arteriosclerosis. As the arteriosclerosis progresses, the elasticity of the arterial wall increases in the early stage. Since the lesion is reversible[1)] in this stage, it is effective to detect arteriosclerosis early. For the purpose, we have estimated the elasticity by measuring minute changes in arterial wall thickness caused by pulsation by the phased tracking method[2,3)] using ultrasound.

The verification of the accuracy in the ultrasound measurement is important. Since the true value of the elasticity is unknown in *in vivo*, we have verified the measurement accuracy of elasticity by the phantom experiments. In the previous study, since the long-axis view of the blood vessel was measured in *in vivo*, the long-axis view was measured also in the phantom experiments[4)]. When obtaining the change in thickness and the external radius, it is necessary to measure along the center of the short axis of the blood vessel. However, it is unknown in the long-axis view measurement whether the cross-section is measured along the center of the short axis of the blood vessel or not. Therefore, in the present study, B-mode images of the short-axis view of the blood vessel simulation phantom were acquired on the ultrasound measurement, and the received RF signal acquired at the position of their center axis was analyzed. The accuracy of the ultrasound measurement was verified by comparing the elasticity obtained by the ultrasound measurement with that obtained by the laser sensor.

2. Methods

2.1 Calculation of elasticity by measuring thickness change (ultrasound)

The phased tracking method[2)] obtains the change in the arterial wall thickness $\Delta h(t)$ that is accompanied by the pulsation. Assuming that the arterial wall is incompressible and elastically isotropic, the elastic modulus E_θ^h is calculated by Eq. (1).[3)]

$$E_\theta^h = \frac{3}{8}\left(1+\frac{2r_0}{h_0}\right)\frac{\Delta p(t)}{-\Delta h(t)/h_0}, \qquad (1)$$

where h_0 is the initial thickness, r_0 is the initial arterial radius, and $\Delta p(t)$ is the incremental internal pressure, respectively.

2.2 Calculation of elasticity by external diameter measurement (laser or ultrasound)

By measuring the change in the external diameter, the incremental elasticity E_{inc} is calculated by Eq. (2).[4)]

$$E_{\mathrm{inc}} = \frac{3}{2}\frac{r_0^2}{r_e^2 - r_0^2}\frac{\Delta p(t)}{\Delta r_e(t)/r_e}, \qquad (2)$$

where r_e is the external radius before deformation and $\Delta r_e(t)$ is the change from r_e by deformation. In the ultrasound measurement, the external radius was measured by the phased tracking method [5)].

2.3 Experimental environment

The experimental system is shown in **Fig. 1**. A linear probe with a center frequency of 7.5 MHz was used with the ultrasound diagnostic equipment (SSD-6500, Aloka). The sampling frequency was 40 MHz, the beam interval was 150 μm, and the frame rate was 286 Hz.

The laser sensor (IG-028, KEYENCE) composes of a light transmitter and a light receiver, and can measure the length of the region where the laser light is blocked, that is, the external diameter of the phantom can be measured.

A silicone tube with a hardness of 10° with an external diameter of 9 mm, an inner diameter of 7 mm, and a wall thickness of 1 mm was used as a blood vessel simulated phantom. A pulsatile pump unit (EC-8, FUYO) was used to simulate the *in vivo* condition of the circulation of blood. The fluid was water and the pressure sensor (PS-1KC, Kyowa) was used to measure the incremental internal pressure $\Delta p(t)$. The laser measurement was conducted in the air to improve the SN ratio, and the ultrasound measurement was applied in the water.

Since there was no delay time between the pressure sensors (i) and (ii) in Fig. 1, the pressure measured by sensor (i) was used to calculate the elasticity.

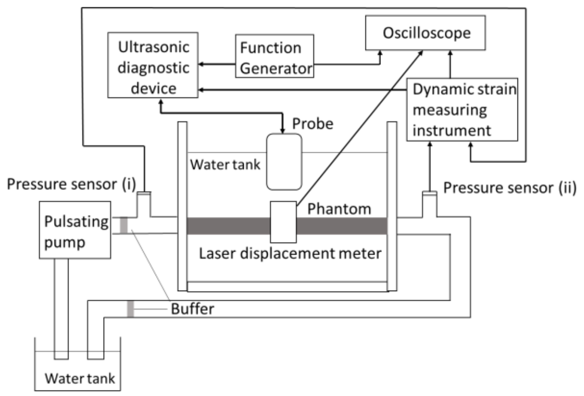

Fig. 1. Schematic diagram of the experimental system.

3. Result and Discussion

Figure 2 shows (a) B-mode image of the phantom in the short-axis view, (b) M-mode, (c) incremental internal pressure $\Delta p(t)$ and incremental strain $\Delta r_e(t)/r_e$, respectively. **Figure 3** shows the incremental strain and incremental internal pressure measured by ultrasound and laser. From Fig. 3, the slopes $\Delta p(t)/\{-\Delta h(t)/h_0\}$ and $\Delta p(t)/\{\Delta r_e(t)/r_e\}$ were obtained by the least squared method. The results of the elasticity calculated from Eqs. (1) and (2) are shown in **Table. 1**. The average and the standard deviation of elasticities measured in three cycles were calculated.

In the ultrasound measurement, the elasticity E_θ^h calculated from the thickness change $\Delta h(t)$ and the elasticity $E_{\rm inc}$ calculated from the external radius change $\Delta r_e(t)$ were approximately the same. On the other hand, there was a difference of approximately 9% in the elasticities $E_{\rm inc}$ calculated from the changes in the external radius $\Delta r_e(t)$ measured by the ultrasound and the laser. In Fig. 2 (b), the time difference from the peak of the incremental internal pressure to that of the strain was 0.021 s in the ultrasound and 0.043 s in the laser, respectively. It is considered that this is one of the causes of the difference in the elasticity in the ultrasound and the laser. The cause has to be examined in further study.

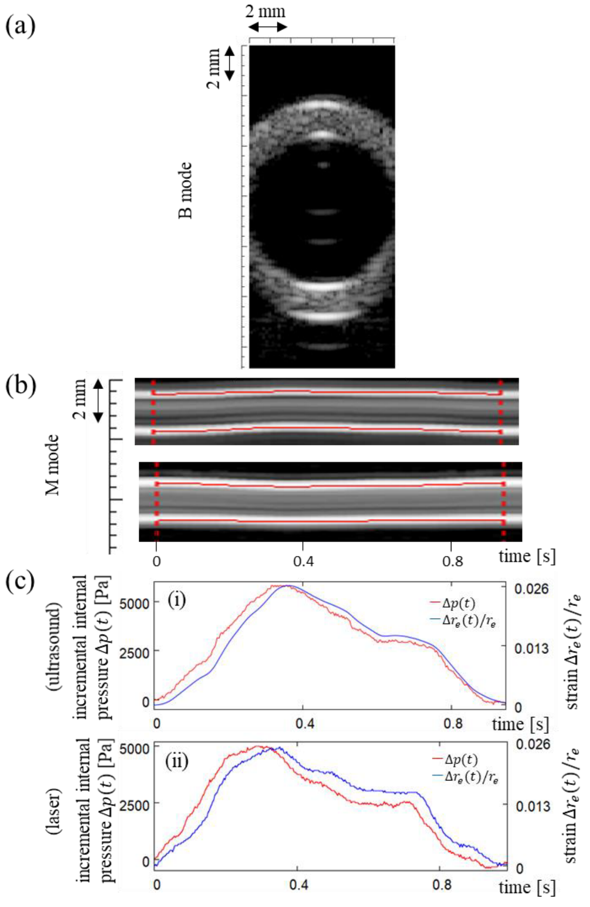

Fig. 2. (a) B-mode image. (b) M-mode image. (c) Incremental internal pressure $\Delta p(t)$ and strain $\Delta r_e(t)/r_e$ measured by (i) ultrasound measurement and (ii) laser measurement (1st cycle).

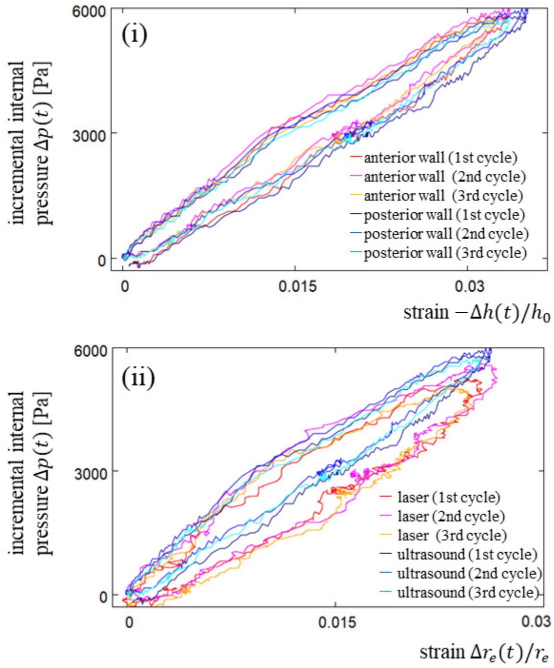

Fig. 3. (i) Strain $-\Delta h(t)/h_0$ and incremental internal pressure $\Delta p(t)$ of the anterior wall and posterior wall measured by ultrasound (3 cycles). (ii) Strain $\Delta r_e(t)/r_e$ and incremental internal pressure $\Delta p(t)$ measured by ultrasound or laser (3 cycles).

Table. 1. Elasticity E_θ^h and $E_{\rm inc}$ calculated from wall thickness change $\Delta h(t)$ and external radius change $\Delta r_e(t)$, respectively.

$E_{\rm inc}$ (Laser) [kPa]	$E_{\rm inc}$ (US) [kPa]	E_θ^h(US) [kPa]		
		anterior wall	posterior wall	average
448.9 ±1.34	489.7 ±0.28	499.8 ±1.99	486.3 ±2.42	493.1 ±7.18

4. Conclusion

In the present study, the elasticity was measured by ultrasound and laser in an experiment simulating *in vivo* condition. Stable results with small variations were obtained in each measurement in the ultrasound and the laser. On the other hand, the elasticity did not match between the ultrasound and laser measurements. In the future, we will investigate the cause of the difference in the time between the incremental internal pressure and the strain in the ultrasound and the laser measurements.

References

1. T. I. Pynadath and D. P. Mukherjee, Atherosclerosis **26**, 311 (1977).
2. H. Kanai *et al*., Circulation **107**, 3018 (2003).
3. H. Kanai *et al.,* IEEE Trans. UFFC **44**, 752 (1997).
4. H. Hasegawa *et al*., Jpn. J. Med. Ultrason. **28**, J3 (2001). [in Japanese]
5. S. Akiyama *et al*., Proceedings of Acust. Soc. Jpn.,75 (Mar. 2020). [in Japanese]