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Effect of True Aneurysm on Pressure Wave in Artificial Arteries

真性動脈瘤が模擬血管内の圧力波伝搬に与える影響

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1. Introduction

Cardio vascular disease (CVD) is one of the causes of death in the world[1)]. The initial symptom of CVD is arteriosclerosis. Image processing methods, including MRI and ultrasonography, are currently used for the detection of the arteriosclerosis. However, these techniques may not be sufficiently effective for the screening of arteriosclerosis in brain. Therefore, we have proposed a new simple screening method based on the measurement of a pulse wave at the carotid artery[2)].

Pulse wave is the displacement of skin surface caused by the intravascular pressure from the heart. This consists of the incident wave and reflected wave. In the cardiovascular disease that occurs in the brain, the incident wave is caused by the input flow ejected from the heart and propagates over the long arteries from the heart to brain. This wave is eventually reflected at the vascular beds in brain and returns to the common carotid artery as reflected waves[2,3)]. We then focused on the evaluation of brain artery by measuring the pulse wave at the common carotid artery[3-5)]. We have tried to elucidate the complex propagation phenomena of these waves by experiments using artificial artery[2,4)]. We found that the pulse waveform changed due to arterial stiffness and most of the reflected waves measured at the common carotid artery came from the vascular beds in brain[2)].

As the progress of the arteriosclerosis, a true aneurysm is often formed in the arterial wall. In this study, in order to evaluate the true aneurysm by the pressure wave, artificially tubes with artificial aneurysms were fabricated. The effects of the true aneurysm on the pressure wave were then investigated. The measured pressure waveform was also discussed with the theoretical estimation of the 2D theoretical model[6)].

2. Artificial artery

Figure 1 (a) shows an example of the artificial artery and aneurysm. A straight tube and three types

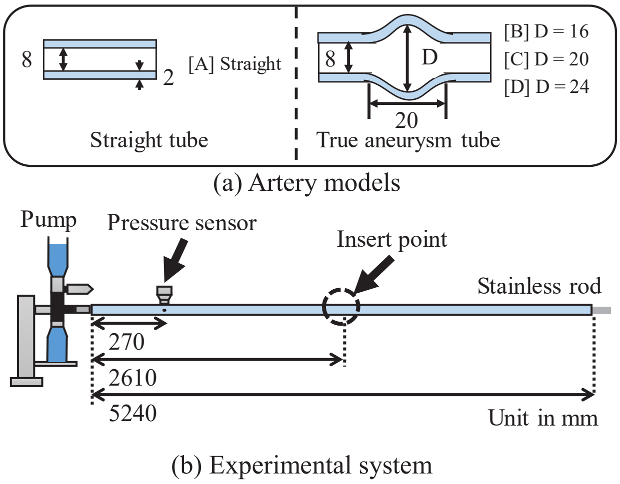

Fig.1 Experimental system and artery models.

of the tube with a true aneurysm were fabricated using silicone gel (Momentive Performance Materials). The mold of tubes with the true aneurysm was made by a 3D printer (3D systems, CubeX). The inner diameter of the straight tube and the tubes with the true aneurysms were 8, 16, 20 and 24 mm (D = 8, 16, 20 and 24), respectively[7)]. The tube thickness was 2 mm. The Young's moduli of the tubes measured by a tensile-test (Shimadzu Ez-test) were approximately 150 kPa. It is known that Young's moduli of senior subject's arteries have been reported as 60-140 kPa[3)].

3. Measurement of pressure wave

The system in Fig. 1 was composed of a pump (TOMITA Engineering) mimicking the heart and straight or true aneurysm tubes. The input flow velocity waveform ejected by the pump was a half cycle of a sinusoidal wave. The ejection time and volume were 0.3 s and 4.5 ml, respectively. The end of the tube was occluded. The inner pressure in the tube was measured by a pressure sensor (Keyence, AP-10S) at the point 270 mm away from the pump (expected measurement position of pulse wave at the carotid artery). A true aneurysm was placed at the insert point in Fig. 1 (b). To avoid the superposition of reflected waves from the aneurysm and the end, the total length of the tubes was set to 5240 mm, which was longer than the pressure wavelength of 4.8 m.

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4. Results and discussions

Figure 2 shows four measured pressure waveforms. Result [A] represents the reference wave in the straight tube without the aneurysm. The first strong peak measured around 0.3 s was the incident wave from the pump. The second strong peak observed around 1.6 s was the reflected wave from the end of tubes. The results [B], [C] and [D] show the small reflected waves from the true aneurysms around 0.8 s. The amplitude of the reflected wave from the true aneurysm [D] was larger than those from the true aneurysms [B] and [C] since the inner diameter was larger. These reflections are due to the bad impedance matching of the tubes at the aneurysm.

Figure 3 shows the comparison of the measured waveform and theoretical estimation obtained from the 2D theoretical model[6]. The optimum simulation parameters were determined by changing the stiffness term, viscosity of the tube wall and nonlinear term during simulation. Table 1 shows these optimum parameters obtained by comparing the experimental waveform of the straight tube with the theoretical estimation.

Next, a multilayer model with laminar flow was applied to estimate wave propagation[6]. In the case of an aneurysm with inner diameter of 24 mm[D], peaks around 0.8 s were also found in both experiment and theoretical estimation, showing the pressure wave reflected from the aneurysm. Here at around 1.6 s, the reflected wave from the end was observed. We also found the wave of theoretical estimation was a little faster than that of the experimentally observed wave. One reason of this disagreement seems to come from the concept of laminar flow. As Ghigo et al. have reported, the flow in this model was assumed as simple laminar without vortex[6]. However, in the experiment, a vortex may occur as the inner diameter of the tube increased near the aneurysm. There is then a possibility that apparent propagation distance changed due to the complex flow near the aneurysm.

5. Conclusion

In this study, the effect of true aneurysm on the pressure wave in the artery was experimentally investigated using artificial arteries. As a result, we found that the true aneurysm in the artery affected the pressure waveform. Pulse wave at the artery shows similar behavior with the pressure wave. These results tell the possibility to evaluate aneurysm in the brain artery by the measurement of pulse wave at the carotid artery.

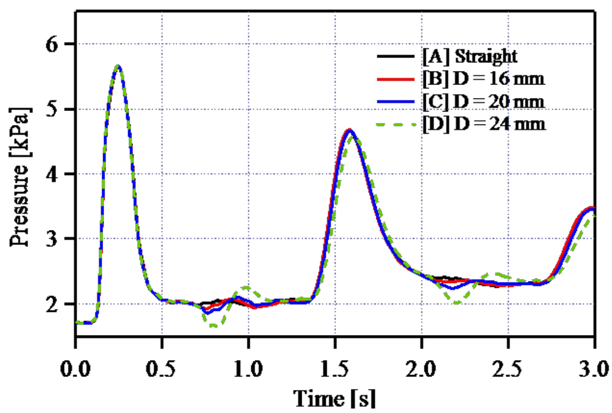

Fig. 2 Experimental results.

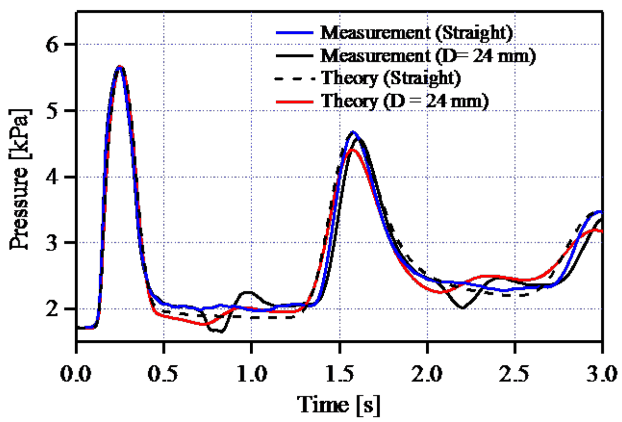

Fig. 3 Experimental results and theoretical estimation. (Straight and D = 24 mm)

Table 1 Selected parameters.

Definition	Variable	Optimum Value
Stiffness term	E (kPa)	178
Viscosity of the tube wall	η (cm^2/s)	3900
Nonlinear term	ε_p (normalized value)	0.09

References

1. WHO, Global status report on noncommunicable diseases, (2014).
2. M. Saito et al., J. Biomech. Eng. **133**, art. no. 121005, (2011).
3. W. W. Nichols et al., *McDonald's Blood Flow in Arteries*, 5th ed, H. Arnold, (2005).
4. Y. Yamamoto et al., Jpn.J.Appl.Phys., **50**, 07HF12, (2011).
5. X.-F. Wang, S. Nishi et al., J. Biomech. Eng. **49**, pp. 565-571, (2016).
6. A. R. Ghigo et al., J. Computational Phys., **350**, pp. 136-165, (2017).
7. K. Garg et al., J. Vasc. Surg. **55**, pp. 1618-1622, (2012).