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Experimental study on the pressure wave propagation in the artificial arterial tree in brain

人工脳内動脈樹の圧力波伝搬に関する実験的検討

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1. Introduction

Cardiovascular disease (CVD), including heart disease and stroke, is considered to be one of the leading causes of death in the world [1]. The initial symptom of CVD is arteriosclerosis, which can be suddenly fatal before medical treatments. Then, detecting arteriosclerosis in its early stage is necessary. We have suggested a new technique based on the measurement of the pulse wave. In our former studies, the pulse wave of young and elderly patients was measured at the left common carotid artery using a piezoelectric transducer. The characteristics of their arterial walls appeared remarkably on the pulse waveform. The pulse waveform of each patient looked different due to the various conditions of their arteries [2,3].

We have therefore attempted to elucidate the complex propagation phenomena of these waves by physical experiment using viscoelastic tubes. The results of previous experiments verified that pulse waveform might change due to arterial stiffness in brain [3-6].

The aim of this study is to observe the reflected wave from an occlusion in the artificial arterial tree in brain. This model was composed of 5 types of arteries presented in **Fig. 1**. In order to validate the measured waveform, we also discuss the results with the theoretical estimation by a 1D model [5,6].

2. Viscoelastic tube

Five viscoelastic tubes with different configuration were fabricated using polyurethane gel (Asker-C 5, Exseal Corp). The diameter and thickness of each tube are shown in **Table 1**. According to a tensile test (Shimadzu Ez-test), the Young's modulus of the tubes were 180 kPa.

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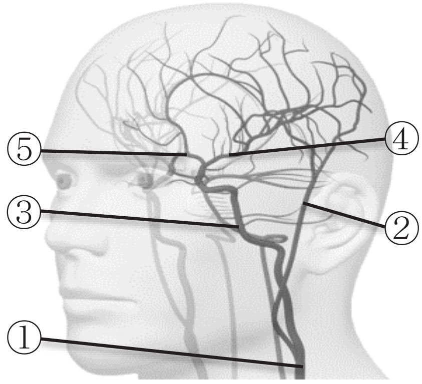

Fig. 1 A map of cerebral arteries.

Table 1 Details of the arterial tree in brain [7].

No.	Name	Diameter	Thickness
①	Left Carotid Artery	8.0	2.0
②	External Carotid A.	6.0	2.0
③	Internal Carotid A.	6.0	2.0
④	Middle Cerebral A.	4.0	1.0
⑤	Anterior Cerebral A.	4.0	1.0

Unit in mm

3. Measurement of pressure wave

As shown in **Fig.2**, an experimental system consisted of a pump (TOMITA Engineering) mimicking the heart and the arterial tree in brain. The pump ejected a half cycle of a sinusoidal wave to the tubes as an input flow. The ejection time and volume were 0.3 s and 4.5 ml, respectively. The inner pressure in the arterial tree was measured by a pressure sensor (Keyence AP-10S). Determined as the distance between the heart and the left common carotid artery, the measurement point was located 280 mm away from the ejection point. A stainless rod was set as a cerebrovascular occlusion at the point A which was located 3140 mm away from the ejection point. Two stainless rods were also inserted at points B and C to imitate reflections at vascular beds. To observe a reflected wave separated from the pulse wave, the total length of the tubes, namely from ejection point to points B and C, was set to 6200 mm, which was sufficiently longer than the input wavelength of 4.8×10^3 mm. It enabled us to only observe the reflected wave from the point A.

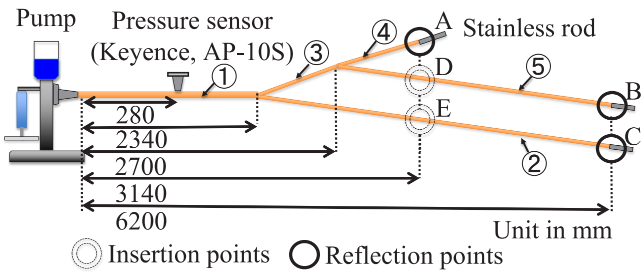

Fig. 2 Experimental system.

4. Experimental results and discussion

The previous studies confirmed that wave reflection did not occur at the artificial arterial bifurcation and that the bifurcation angles did not affect pulse waveform [5]. Under these conditions, **Figure 3** shows two observed pressure waveforms. The result [a] represents the waveform reflected from the points A, B and C. The first peak observed around 0.2 s was the incident wave ejected by the pump. The reflected wave from the point A was observed around 0.8 s. The amplitude of this reflected wave P_A was 1.03 kPa. Next, we inserted additional stainless rods into points D and E. The result [b] shows the total reflection of incident wave from the points A, D and E. We could see the incident wave around 0.2 s. Afterward, the total reflection from the points A, D and E was observed around 0.8 s. The amplitude of this total reflection P_B was 4.31 kPa. The reflection coefficient was estimated to be 24 % by dividing P_A by P_B, as shown in **Table 2**. The propagation distance of the reflected wave was much longer than the actual length of cerebral arteries. Therefore, it can be concluded that the reflected wave from an occlusion in the middle cerebral artery is probably observable at the left common carotid artery in vivo.

Next, 1D theoretical model was applied to obtain the theoretical estimation [5,6]. The comparison of measured and theoretical waveforms can be seen in **Fig. 4**. The optimum parameters to evaluate the measured data were also determined, as shown in **Table 3**. As a result, the theoretical estimation was in good agreement with the measured waveform.

5. Conclusion

The reflected pulse wave from the middle cerebral artery occlusion in a brain artery model was observed at the left common carotid artery experimentally. The critical stenosis in a cerebral artery possibly causes changes on the pulse waveform as a reflected wave. The experimental data showed agreement with the waveform obtained from the 1D theoretical model.

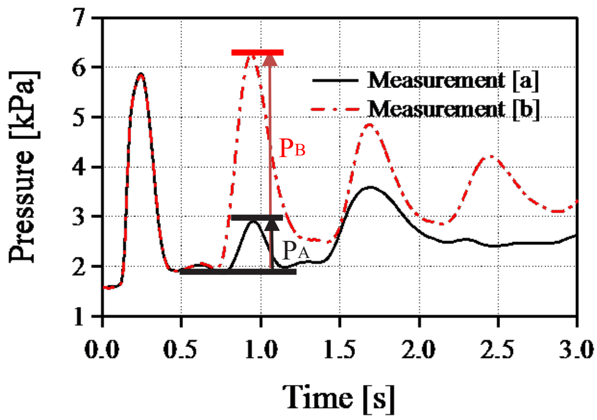

Fig. 3 Estimation of reflection coefficient of reflected wave P_A.

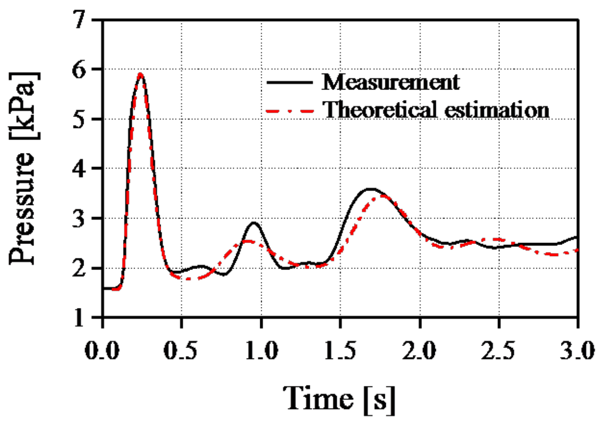

Fig. 4 Measured data and theoretical estimation.

Table 2 Estimated reflection coefficient.

No.	Name	Reflection coefficient
④	Middle Cerebral A.	24 %

Table 3 Estimated optimum value of each parameter.

Definition	Variable	Optimum value
Young's modulus	E	218 kPa
Viscosity of tube wall	η	0.088
Nonlinear term	ε_p	0.051
Velocity profile factor	α	1.0
Friction term	C_f	14.0

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