3J1-2

Velocity profile of flow in artificial blood vessel model with stenosis

狭窄を持つ人工血管モデル内における流速分布の検討

Hiroto Shimizu[1†], Toshikazu Miyawaki[1], Eriko Yamaguchi[2] , Kozue Saito[3] and Mami Matsukawa[1] ([1]Doshisha Univ; [2]National Cerebral and Cardiovascular Center; [3]Nara Medical Univ)

清水 啓仁 [1†]，宮脇 敏和 [1]，山口 枝里子 [2]，斎藤 こずえ [3]，松川 真美 [1] ([1] 同志社大学，[2] 国立循環器病研究センター，[3] 奈良県立医科大学)

1. Introduction

Carotid artery stenosis, which is one of the serious adult diseases, causes partial thickening of the vascular wall. This narrows the carotid artery and partially blocks the blood flow into the brain. Progress of the stenosis is more likely to cause cerebrovascular disease. The stenosis rate is defined by the North American Symptomatic Carotid Endarterectomy Trial (NASCET) method. It is clinically evaluated from the peak systolic velocity (PSV) obtained by the ultrasonic Doppler measurement [1]. However, it is often pointed that the blood flow velocity becomes maximum behind the stenosis in clinical scene [2]. It affects the estimation of the stenosis rate. The flow in a tube with a narrow part like stenosis often forms vortexes and accompanies the spatial distribution of fluid velocity, which may affect PSV. In this study, we experimentally investigated the flow in an artificial blood vessel with a stenosis using the Particle Image Velocimetry (PIV) method to check the velocity profile.

2. Fabrication of artificial blood vessel model

Figure 1 (a) shows an example of the artificial blood vessel model. Tube and stenosis were fabricated using the mixture of two silicone gels (Momentive Performance, TSE3062 and TSE3450). The mold of tubes with a stenosis was made by a 3D printer (3D systems, CubeX). The inner diameter and thickness of the straight tubes were 8 mm and 2 mm, respectively. The Young's moduli of the tubes were 150 kPa by a tensile test (Shimadzu, Ez-test). It is known that Young's moduli of senior subjects' arteries are in the range of 60-140 kPa [3]. In this model, the stenosis rate was 62.5% by the NASCET method, which corresponds to the stenosis between moderate and severe cases (Fig. 1(b)).

3. Experimental methods

PIV is a measurement method of the flow velocity profile from the movement of the tracer particles. Figure 2 shows the experimental system for PIV

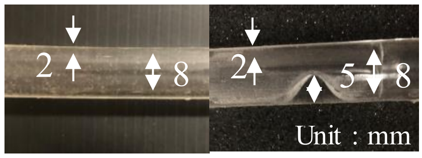

Fig.1 Artificial tubes.

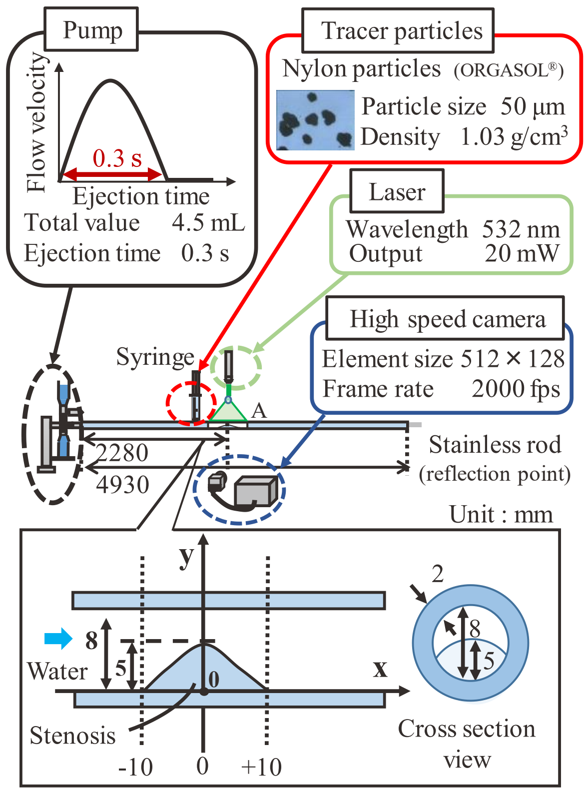

Fig.2 Experimental system.

measurements. The tube was filled with water where trace particles were dissolved. Its end was occluded by a stainless rod to prevent the water leaking. The diameter and density of nylon particles were 50 µm and 1.03 g/cm^3, respectively. The tube was long to avoid the effects of reflected flow from the end. The input flow was ejected by a piston pump (TOMITA Engineering) and its velocity waveform was a half cycle of a sinusoidal wave. The ejection time and volume were 0.3 s and 4.5 ml. The stenosis was placed at the point A as shown in Fig. 2. For the PIV measurements, a sheet-like laser beam (wavelength : 532 nm, output : 18 mw) were irradiated to the longitudial cross section of the tube. A high speed camera (Photron, Fastcam 2.1) was used for the measurement of flow velocity near the stenosis [4].

3. Results and Discussion

In the velocity profiles before stenosis (Fig.3), the flow velocity became maximum at y = 5 mm and decreased toward the wall. This is consistent with Hagen-Poiseuille's law [5]. The maximum velocity value at this position was 0.32 [m/s]. Similarly, the maximum velocity values near the stenosis ($0 \leq x \leq 10$) were estimated. The results are shown in Fig. 4. Here, the flow velocity behind the stenosis was larger than that around the stenosis (x = 0 mm), which was the narrowest part. The maximum velocity was 0.73 [m/s] at x = 3.75 mm at t = 0.56 s. The flow velocity profiles at this position are shown in Fig.5. Compared with Fig.3, very small negative flow velocity values were found around t = 0.6 s. Vector mapping of flow velocity near the stenosis ($0 \leq x \leq 10$ mm) at t = 0.56 s is shown in Fig.6. Thick arrows indicate the maximum flow velocity at each position. As shown in Fig.6, backflows were observed in the area from x = 5 mm to 10 mm behind the stenosis. It shows existence of vortexes. The water flow which passed though the stenosis has inertial force and visually water flow and vortex were separated into two layers. The vortexes apparently seemed to narrow the flow area like stenosis. The larger vortex diameter observed in the PIV image was about 6mm, which was larger than the height of stenosis (5mm). These data indicate that the flow velocity may become higher behind the stenosis due to vortex. We should continue carefully to evaluate the flow in the artery because PSV may change due to the vortexes in vivo.

5. Summary

The flow velocity in the artificial blood vessel model with a stenosis increased behind the narrowest part. The generated vortex seemed to act as an apparent stenosis. Therefore the vessel apparently the vessel becomes narrower than the stenosis part and the flow velocity value may increase.

References

1. Jpn. Soc. Vltrason Med, Terminology and Diagnostic Criteria Committee, Standard method for ultrasound evaluation of carotid artery lesions, 2017,
2. E.Yamaguchi et al., proc. Jpn Academy, Nenrosonology (2020).
3. W. W. Nichols et al., McDonald's Blood Flow in Arteries, 5th ed, CRC Press (2005).
4. Visual Information Soc. Jpn., PIV handbook, Morikita Publishing (2002).
5. J.R, Womersley, J. Physiol. , 127 (1955) 563.

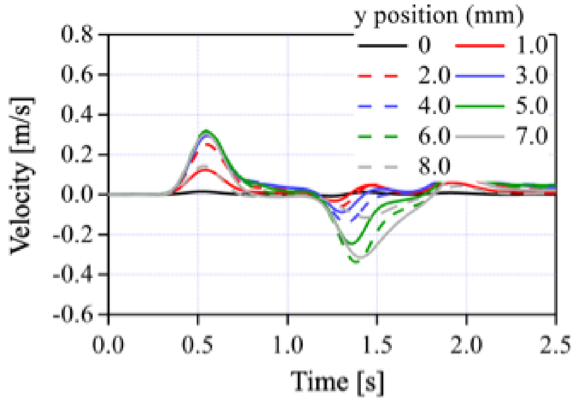

Fig.3 Flow velocity profile (x = -10 mm).

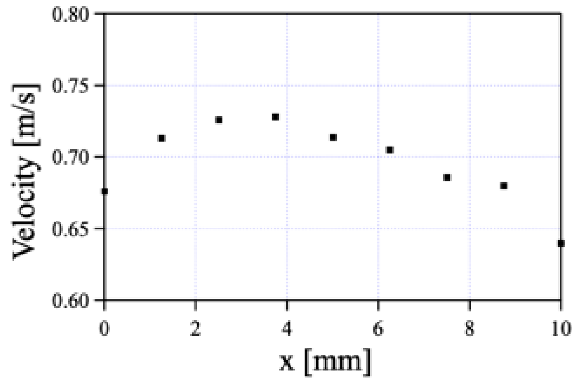

Fig4. Maximum flow velocity values.

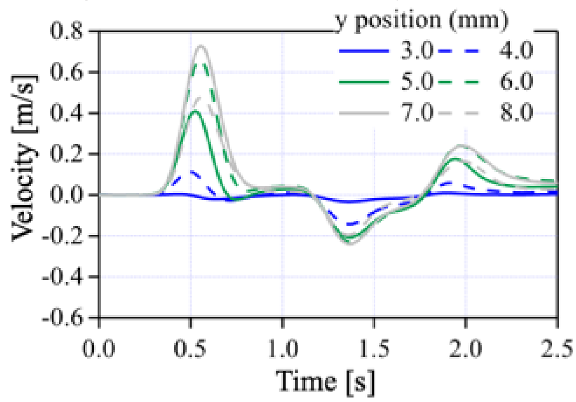

Fig.5 Flow velocity profiles (x = 3.75 mm).

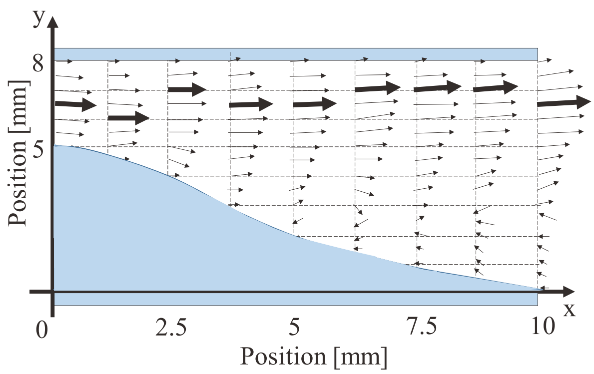

Fig.6 Vector mapping of flow velocity profiles.