MCB, vol.16, supplemental 2, pp.38-39, 2019

In Vitro Measurement of Blood Flow in Microvascular Network with Realistic Geometry

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Abstract: We measured a blood flow in a polydimethysiloxane micro channel to reflect the complex geometry of a microvascular network. A flow rate was compared between two working fluids: water and blood. The measured flow rate reflected the bifurcation effects on the apparent viscosity determined by hematocrit, as well as the effects of the surrounding flow channels as bypasses.

Keywords: Blood flow; microcirculation; red blood cells; apparent viscosity

1 Introduction

In vivo experiments have suggested that blood flow behavior in microcirculation is associated with the geometry of microvessels. However, it remains unclear how the geometrical structures of microvessels affect the blood flow. In this study, a polydimethysiloxane (PDMS) flow channel was fabricated to evaluate the complex geometry of microvascular networks in two dimensions, and the flow rate in the channel was measured for two working fluids; pure water and stored rabbit blood [Kodama, Aoki, Yamagata et al. (2019)]. We then demonstrated effects of hematocrit distribution following Zweifach-Fung bifurcation effects, and of bypasses.

2 Methods

Using the soft lithographic technique, a PDMS micro flow channel with a rectangular cross section was fabricated (Fig. 1). The widths of the channel ranged from 5 to 23 μm. Total length along the centerlines was 2946 μm. A channel thickness was $H = 10.5$ μm. Stored rabbit blood and pure water were used as working fluids. In pure water, fluorescent particles with 1μm diameters were suspended. The red blood cells and fluorescent particles were used as tracer particles for visualizing the working fluid flows. For perfusing a working fluid, the channel was connected to a 1-ml syringe comprising the working fluid via both a glass tube and a silicone tube. A flow was driven by a syringe pump (KDS 210, Kd Scientific, USA). A constant pumping speed was set to create a flow rate of 1.67×10^{-12} m^3/s at the syringe. In flow measurement, the test section (Fig. 1) was positioned on the stage of an inverted microscope (IX71, Olympus, Japan). To observe the moving tracer particles, a series of microscope images were recorded using a high-speed camera (FASTCAM Mini AX100, Photron, Japan) through a dry 40× objective lens with a numerical aperture of 0.75. The resolution of recorded data was 1 μm/pixel in space and 4000 frame/s in time. The focus of the microscope was fixed at the middle of the micro channel in the depth direction. To quantify the flow rate using the recorded microscope images, the entire flow channel was divided into 32 segments, and flow rates were determined from velocities of tracer particles. For blood, hematocrit was calculated by carefully counting the number of red blood cells.

DOI: 10.32604/mcb.2019.07285

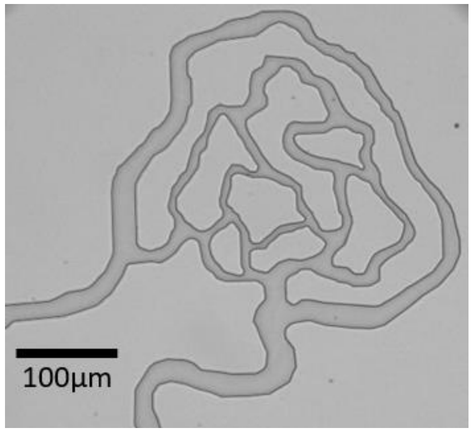

Figure 1: PDMS microchannel

3 Results

Measured flow rates were consistent with our fluid analysis [Kodama, Aoki, Yamagata et al. (2019)], confirming successful measurement a well-fabricated micro channel. For some measurement points, the flow rate was higher for blood than for water, and the flow rate was lower for the other points. According to the Zweifach-Fung effect, it is expected that in the two daughter blood vessels that branch from a parent blood vessel, the daughter blood vessel with a higher (lower) flow rate relative to the other daughter blood vessels has a higher (lower) hematocrit with more (less) red blood cells. In the daughter channel with the high (low) flow rate, this effect is likely to cause a decrease (increase) in the flow rate, along with an increase (decrease) in the apparent viscosity. We observed this behavior at 4 of 7 bifurcations, of which a result at the bifurcation site #1 is shown in Tab. 1 as an example. On the other hand, the bifurcation effects do not explain the other three bifurcations. For example, the ratio of the flow rate at the bifurcation site #4 (Tab. 1) was the same for both water and blood, even though both flow rate and hematocrit were the higher at the one daughter channel. This is likely to be due to effects of surrounding channels as bypasses, cancelling the bifurcation effects.

Table 1: Flow rate ratio and hematocrit at a pair of daughter channels. #1 and #4 indicate bifurcation sites

#	Flow rate ratio		Ht [%]	Major effects
	Water	Blood		
1	76: 24	61: 39	19 & 10	Bifurcation
4	81: 19	81: 19	16 & 0	Bifurcation ≅ Bypass

Acknowledgement: This study was partly funded by a Grant-in-Aid for Scientific Research (15H03915), JSPS.

References

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