MEASUREMENT OF VELOCITY FIELDS IN MICROVESSELS USING HIGH RESOLUTION PIV TECHNIQUE

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Since endothelial cells are subject to flow shear-stress, it is important to determine the fine velocity distribution in microvessels for studies of mechanical interactions between blood and endothelium. Recently, particle image velocimetry (PIV) is a quantitative method of measuring velocity fields instantaneously in experimental fluid mechanics. The authors have been developed a high-resolution PIV technique, which can improve the dynamic range, spatial resolution and measurement accuracy. In this paper, the proposed method is applied to visualized images of the arteriole in the rat mesentery using the intravital-microscope and the high-speed digital video system. The obtained velocity profile corresponds to a theoretical value.

INTRODUCTION

Since endothelial cells are subject to flow shear-stress, it is important to determine the fine velocity distribution in microvessels for studies of mechanical interactions between blood and endothelium. Historically, many different blood flow measurement techniques have been proposed. For larger blood vessel, there are the electromagnetic blood flowmeter and ultrasonic Doppler flowmeter. The practical and currently used method for microcirculation is the dual slit method [1-2], which measures the passage of the blood flow signal between two predetermined points together with the dual window method. However, this technique is based on the assumption that blood flow passes both points under the same condition. In the laser Doppler velocimetry (LDV) [3-4], the measurements that can be made for each probe area and depth are limited to a few millimeters, which gives rise to spurious signals are reduces the accuracy.
Recently, particle image velocimetry (PIV) is a quantitative method for measuring velocity fields instantaneously in experimental fluid mechanics [5]. A number of PIV methods, such as cross-correlation method, particle tracking method and iterative correlation method and so on, have been proposed. These techniques have been applied to a flow in microvessels [6]. However they are not suitable for microcirculation because of the measurement accuracy and spatial resolution.

The authors have proposed a high-resolution PIV technique using a gradient-based sub-pixel analysis, called adaptive PIV technique [7]. A pixel unit displacement is obtained using the iterative cross-correlation method while a sub-pixel displacement is calculated by the use of the so-called spatio-temporal derivative method. The error is analytically assessed by means of the Monte Carlo simulations. PIV images with known a displacement are generated synthetically and it have been found that the root-mean-square (RMS) error is of the order of 0.01 pixels even with the small interrogation window size, for instance 8×8 pixels or less. Thus, the method can achieve high sub-pixel accuracy and high spatial resolution compatibly.

METHODS AND RESULTS

Figure 1 shows a schematic view of experimental setup. Rats were anesthetized with thiobutabarbital sodium intraperitoneously and allowed to respire spontaneously. An intestinal loop was mounted on the stage of an intravital microscope with water-immersion objective lends. The mesentery was placed on an observation window and perfused with Krebs-Ringer solution maintained at 37 degrees. The images consists of 512 × 512 pixels with 8 bit gray level at a rate of 1000 frames /sec. Figure 2 shows a blood flow image of microvessel in rat mesentery magnified 40-fold. Figure 3 shows an instantaneous velocity distribution in an arteriole of 30 μm. It is found that the velocity distribution with high spatial resolution and highly measurement accuracy is obtained. The velocity profile appears to be blunt at the center of the vessel and steeper near the wall. Time-series of the velocity profiles of the arteriole was obtained. Averaged velocity profiles shows the blood flow volume was constant at vessel cross-sections. The arteriole velocity profile was blunt at center region of the vessel cross-section and sharp profiles at near wall region, this suggests the shear stress on the vessel wall is higher than expected. The results show that the proposed method is very useful to measure the blood flow velocity profiles with high accurate, temporal and spatial resolution.

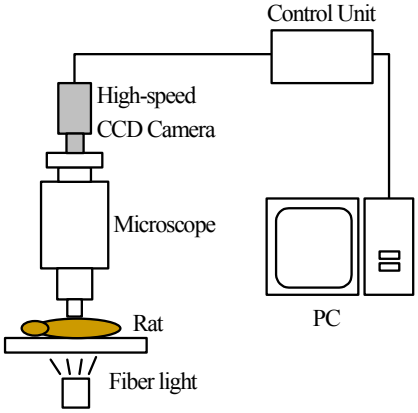

Figure 1. The schematic view of experimental setup for measuring blood flow of a microvessels in rat mesentery.

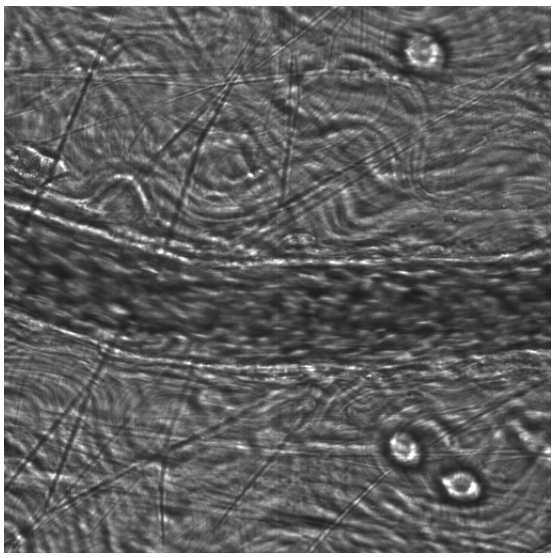

Figure 2. Visualized image on blood flow in arteriole.

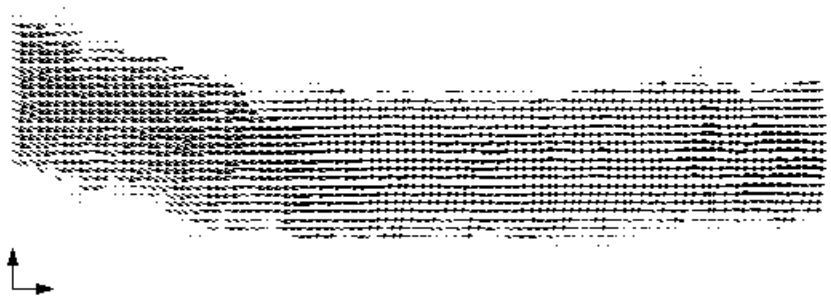

Figure 3. Instantaneous velocity distribution on blood flow in arteriole.

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