A new optical feedback interferometer for measuring red blood cell velocity distributions in individual capillaries: a feasibility study in microchannels

Lucie Campagnolo, Sophie Roman, Julien Perchoux, Sylvie Lorthois

To cite this version:

Lucie Campagnolo, Sophie Roman, Julien Perchoux, Sylvie Lorthois. A new optical feedback interferometer for measuring red blood cell velocity distributions in individual capillaries: a feasibility study in microchannels. Computer Methods in Biomechanics and Biomedical Engineering, Taylor & Francis, 2012, 15, Supplément 1; pp.104-105. hal-00714045

HAL Id: hal-00714045

https://hal.archives-ouvertes.fr/hal-00714045

Submitted on 3 Jul 2012

A new optical feedback interferometer for measuring red blood cell velocity distributions in individual capillaries: a feasibility study in microchannels

L. CAMPAGNOLO[1, 2], S. ROMAN[3], J. PERCHOUX[1, 2], S. LORTHOIS[3]

[1]CNRS, LAAS, 7 avenue du colonel Roche, F-31400 Toulouse, France
[2]Univ de Toulouse, INP, LAAS, F-31400 Toulouse, France
[3]Institut de Mécanique des Fluides de Toulouse, UMR CNRS 5502, France

Keywords: microfluidic; optical feedback interferometry, dual-slit

1 Introduction

The dynamics of blood flow in microvascular networks is of great importance in the exchange of nutrient and waste substances between blood and living tissues. In these vessels of diameter less than 100µm, the development of quantitative methods for measuring the velocity of red blood cells (RBCs) is still challenging. In this context, the Dual-Slit (DS) technique, a temporal correlation technique first introduced by Wayland and Johnson [1], is commonly used. Our group has recently shown that, provided that several operational conditions are fulfilled, this technique can provide a precise measurement of the transverse velocity profile of RBCs, i.e along the *x* axis in Fig. 1. The measured velocities are maximal velocities in the depth of the channel, i.e. *y* direction [2]. However, this technique requires expensive equipment (high speed camera) and the related data-treatment is time consuming. Moreover, the duration of the acquisition is long (typically 2 to 40s). For these reasons, *on line* measurements, especially in cases of transient regimes, are not possible. The aim of the present work is to determine whether Optical Feedback Interferometry, a new optical technique in the microfluidic domain which is based on the optical feedback effect in laser diodes, can be used to perform quantitative measurements of RBCs velocity in channels of size less than 100µm. Optical Feedback Interferometers (OFI) are indeed compact, low cost and simple sensors. They are known for providing much shorter response times than DS, currently lower than 10ms, while keeping the precision of traditional Laser Doppler Interferometers. This technique has been previously applied and validated to measure velocity profiles in 300µm diameter channels [3], but its feasibility in smaller channels is still to be demonstrated. For that purpose, the velocity profiles obtained by OFI and DS are compared, using PDMS microchannels and spheric monodisperse particle suspensions in set-up configurations where the DS has been previously validated [2].

2 Methods

Particle suspensions (0.1%(v/v)) are prepared from a concentrated stock solution of 4µm diameter latex microspheres (In Vitrogen).
The flow is controlled in rectangular PDMS micro-channels of size 20µmx100µm using a syringe pump (PHD 22/2000 Harvard Apparatus) and Hamilton Gastight glass syringes.

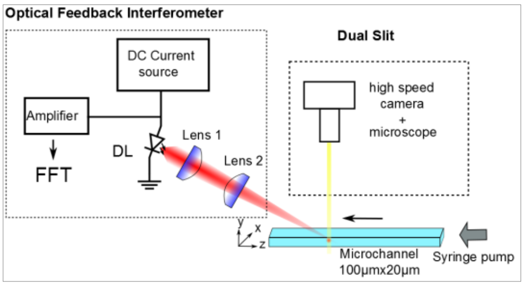

Figure 1: OFI (left) and DS (right) set-ups.

First, the DS technique is applied. In this technique, the channel under study is trans-illuminated and two photo-sensors (slits) are positioned, separated by a known distance, L_s, along the vessel axis (*z* direction in Fig. 1). In our case, the slits are regions of interest (1x3pixels²) on images of particle flows recorded using a high speed video camera (PCO Dimax). The time modulation of light, produced by the passage of the particles flowing through the channel, is deduced by performing the sum of grey levels in both slits at each time step. For various distances L_s between the two slits, a cross-correlation velocity, $V_{ds}=L_s/T_d$, is obtained, where T_d is the time delay for which the cross-correlation between the two signals is maximum. For an optimal L_s [2], the final velocity at a given point on the *x* axis represents the maximal velocity in the *y* direction. Finally, the slits are successively positioned in the *x* direction to obtain a profile of RBCs maximal velocities.

***Corresponding author. Email: Lucie.Campagnolo@alumni.enseeiht.fr**

Then, the OFI technique is applied to the same microfluidic set-up. The optical feedback effect occurs when a portion of the light emitted from a laser is reflected from an external target and re-enters the laser cavity [4]. For flow measurement, light scattered from a single moving particle that is suspended in a fluid is shifted in frequency by the Doppler Effect. The light suffering from optical feedback mixes with the initial light, causing optical interferences inside the laser cavity. By amplifying and analyzing the laser junction voltage in the frequency domain, the velocity of the particle can be calculated [5]. The OFI dedicated experimental set-up was as follows. The laser was a commercial Firecomms Vertical-cavity surface-emitting laser (VCSEL) lasing at 667 nm. A dual-lens system has been used to minimize the sensing volume, and therefore improve spatial resolution. The optical head was mounted on a computer controlled 3-axis motorized micrometer translation stage, and the focus point was stepped through the channel along the *x* axis to reconstruct the flow profile. The VCSEL terminal voltage was AC-coupled to a low noise amplifier module and then fed into an analog-to-digital converter for digital signal processing on computer.

For practical purpose, optical system collects light backscattered from a number of different particles. Therefore, the frequency spectrum contains a distribution of frequencies which corresponds to a distribution of particle velocities. For this configuration, the maximum velocity in the sensing volume can be associated with the 3dB cutoff frequency of the Doppler spectrum [5].

Both experimental set-ups are represented on Fig.1

As shown by Roman et al. [2], in the conditions of this experiment for the DS technique, the measured velocity at each point in the *x* direction corresponds to the maximal velocity in the depth of the channel (*y* direction). Similarly, due to the optical configuration, the maximal velocity in the depth of the channel is also measured by the OFI technique.

3 Results and Discussion

In order to validate the OFI technique, the laser spot was first focused in the middle of the channel, and the pumping rate was set from 0.1 to 1 µL/min. The cutoff frequency position varies linearly with the flow rate, showing good agreement with theory (data not shown).

Both reconstructed profiles, as well as the newtonian theoretical profile [6], normalized by the maximal measured velocity, are plotted on Fig. 2. The profile shapes are similar for the two techniques showing that OFI is suitable for measuring velocity distributions in such channels.

These preliminary results demonstrate the feasibility of OFI measurement in microchannels of size below 100µm. The next step will be to use both sensing techniques simultaneously in the same experiment in order to perform quantitative comparisons. The technique will then be applied on RBCs flow. This promising low-cost technique brings the possibility of real time applications, such as *in-vivo* blood flow measurements. Moreover, OFI technique may have the potential for simultaneous measurement of hematocrit (RBCs volume fraction).

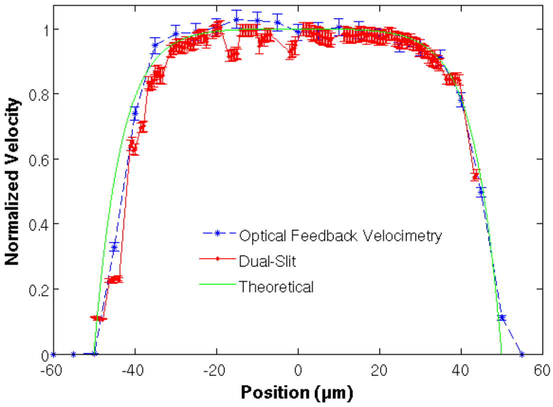

Figure 2: Normalized profiles of maximal velocity measured in a rectangular PDMS channel (100µmx20µm), using OFI (blue curve) and DS (red curve).

References

[1] Wayland H., Johnson P.C., Erythrocyte velocity measurement in microvessels by a two-slit photometric method, *J Ap Phys*, **1967**, 22:333-340.

[2] Roman S., Lorthois S., Duru P., Risso F., An optimized technique for red blood cells velocity measurement in microvessels, accepted to be published in *J. Biomech.*, abstracts of the *18th Congress of the European Society of Biomechanics*, **2012**.

[3] Nikolic M., Lim Y.L., Wilson S.J., Rakic A.D., Campagnolo L., Perchoux J., Bosch T., Flow profile measurement in micro-channels using changes in laser junction voltage due to Self-mixing effect, *Sensors IEEE*, **2011**, 1394-1397

[4] Petermann, K., External optical feedback phenomena in semiconductor lasers. *IEEE J. Quantum Electron.*, **1995**, 1:480-489.

[5] Riva C., Benedek G. B., and Ross B., Laser Doppler Measurements of Blood-Flow in Capillary Tubes and Retinal Arteries, *Investigative Ophthalmology*, **1972**, 11:936.

[6] Patzek T. W., Silin D; B., Shape factor and hydraulic conductance in noncircular capillaries I. One-phase creeping flow. *J. Colloid Interface Sci.*, **2001**, 236,295–304.

Acknowledgments

This work has been partly supported by BQR 2011 INPT VLAM and GDR CNRS 2760. We also thank David Bourrier from "Plate forme technologique du LAAS-CNRS".