Tubular pinch effect of red blood cells at low Reynolds number in *in vitro* models of microvascular bifurcations

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Abstract

Introduction

The radial position of red blood cells (RBCs) is one of the factors affecting the phase separation at microvascular bifurcations. In our earlier study [1] we showed an inversion of the Zweifach-Fung effect and we hypothesized that it was due to a RBC depletion in the central region of the parent vessel. The aim of this study is to investigate *in vitro* the radial distribution of RBCs in a parent vessel of a microvascular bifurcation which could help to explain the observed inversion of the Zweifach-Fung effect.

Methods

The polydimethylsiloxane microdevice, fabricated with the standard process of soft-lithography, embeds a symmetric bifurcation (Fig.1a) with rectangular cross-section ($height = 8\mu$m, $width = W = 13\mu$m). We prepared a suspension of porcine RBCs at 5% of base hematocrit to reproduce blood density and viscosity, similarly to [1]. We performed the experiment in a pressure-controlled mode by setting a hydrostatic pressure difference between the fluid level in the reservoir and the outlet of the device equal to $\Delta P = 12 cmH_2O$, which led to a Reynolds number of Re=0.008 in the parent vessel. A particle-tracking algorithm was used to analyse the image sequence, compute the RBC velocity and the particle coordinates in longitudinal and radial direction. Flux (RBCs/second) and line density (RBCs/m) profiles in function of the radial coordinate were derived from these data.

Results

We found cell-depleted regions close to the walls, in line with previous studies [2], and along the central axis of the channel (Fig.1b). Our results showed also two symmetric RBC-enriched regions (equilibrium positions) at $y* = y/[W/2] = \pm 0.5 - 0.6$, where the maximum line density was 3.3 times higher than in the center of the channel.
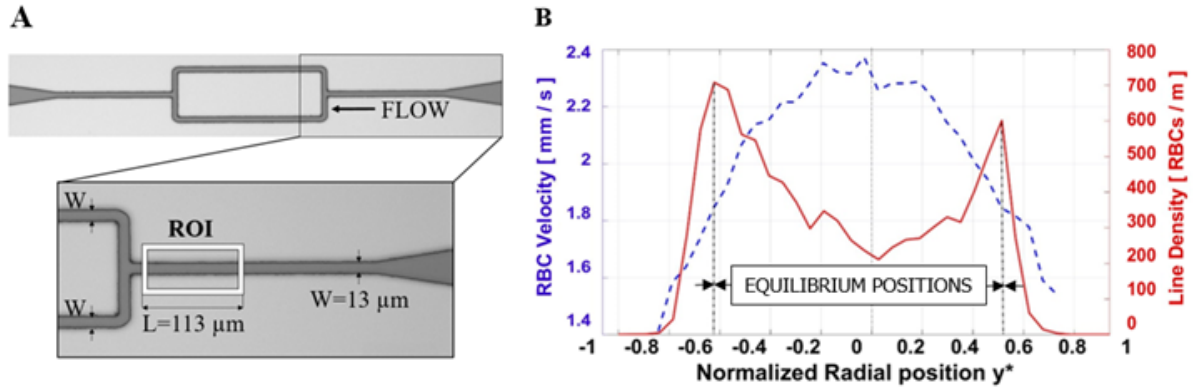
Fig.1: (A) Design of the microvascular bifurcation. A white frame highlights the region of interest (length=L, width=W). Images are acquired with a high-speed camera (frame rate=298 s^{-1}); (B) Red cell Velocity (dash line) and Line Density (solid line) profiles in function of the normalized radial position y*= y / [W/2], where y is the radial coordinate and W/2 is half width of the microchannel.

Fig. 1: (**A**):Design of the microvascular bifurcation. The region of interest for the experiment has been highlighted in white. Images are acquired with a high-speed camera ($frame\ rate = 298s^{-1}$); (**B**): Red Cell Velocity (dash line) and Line Density (solid line) profiles in function of the normalized radial position $y* = y/[W/2]$, where y is the radial coordinate and $W/2$ is half width of the microchannel.

Discussion

We reported for the first time, to the best of our knowledge, a tubular pinch effect [3] of deformable RBCs at physiological hematocrit and Reynolds number (Re<1) in channels with a width comparable to RBC size. Lima et al. [2] showed similar behaviour for wider channels and same levels of hematocrit; few experimental [4] and computational [5] studies reported tubular pinch effect for deformable RBCs but only for higher Reynolds numbers (Re>1). The observed phenomenon for low Reynolds and low haematocrit, could explain the inversion of the Zweifach-Fung effect and its consequences on RBC partition at microvascular bifurcations. These results may be of interest for other microfluidic applications.

Acknowledgments

References

1. Clavica, F., et al., (2016). Sci Rep, 6:36763 p1
2. Lima R., et al., (2008). J Biomech, 41 p218
3. Segré, G., Silberberg, A., (1961). Nat, 189 p209
4. Di Carlo, D., et al., (2007). P Natl Acad Sci Usa 104:48 p18892
5. Hyakutake, T., et al., (2006). J Biomech, 72 p134