Blood flows on passive microfluidics – Role of blood physiology and biomechanical properties

D. Pasias[1], A. Passos[1] L. Koutsokeras[1], G. Constantinides[1], S. Balabani[2] and E. Kaliviotis[1,*]

1 Dept. of Mechanical Engineering and Material Science and Engineering, Cyprus University of Technology, Limassol, Cyprus

2 Dept. of Mechanical Engineering, University College London, London, United Kingdom

* Corresponding author: Tel.: +357 25002289; Email: e.kaliviotis@cut.ac.cy

Abstract. The study of blood flow and rheology is essential for understanding fundamental flow physics and blood behaviour in physiological/pathological conditions. Passive microfluidic flow has emerged as a promising platform for developing blood diagnostic tools for assisting in health monitoring. This work, describes recent work on passive blood flows in microfluidic devices, where the influence of blood physiology and blood biomechanical properties was studied. Hemorheological factors of human blood and erythrocyte suspensions where quantified, and the flow of samples in hydrophilic/superhydrophilic rectangular microchannels was characterised using micro-Particle Image Velocimetry and Particle-Tracking techniques. The effects of altered physiological factors, such as erythrocyte concentration (haematocrit), deformability and aggregation were investigated, and meniscus velocities, velocity profiles, local and bulk shear rates were derived and correlated. The findings suggested that viscosity and erythrocyte deformability and concentration affect negatively the velocity of blood in the channel. Interestingly, increased erythrocyte aggregation was observed to have a non-monotonic effect on the velocity of the fluids tested, favouring samples of normal deformability and reduced haematocrit. The relatively high shearing rates observed near the entrance of the channels seem to substantially minimise erythrocyte aggregation, therefore supressing the non-Newtonian nature of the samples for a substantial part of the channel length.

Keywords: Blood flow, Passive microfluidics, Blood Biomechanics, Blood rheology

1. Introduction

Microscale blood flow and rheological characteristics are fundamentally important, as they affect the efficiency of microfluidic devices. The area of microfluidics has been widely developed and received a considerable interest over the last decades [1]. Microfluidic devices are appropriate for small sample manipulation and are suitable for miniaturizing laboratory techniques. Passive flow devices have many benefits and are popular in blood diagnostics and medical applications: they are cost effective and simple in manufacturing, and can be designed as disposable. Furthermore, they have good potential to enhance improvements in areas such as blood characterization, drug discovery, biosensing and chemical synthesis, where handling small volumes is critical [2]. In this work, results on passive blood flows in microfluidic channels are presented, where the influence of blood physiology and blood biomechanical properties was studied.

2 Methods.

Blood samples were acquired according to the guidelines, and with the approval of the Cyprus Bioethics Committee (ref: ΕΕΒΚ/ΕΠ/2016/18). Hemorheological and physiological factors considered included erythrocyte concentration (haematocrit), aggregation and deformability, and sample viscosity. Haematocrits were fixed to 40% and 45%, except of those of whole blood, native samples. Erythrocyte deformability was decreased by heat treatment (measured by a Rheoscan D300 instrument), and erythrocyte aggregation was adjusted by the use of Dextran solutions, and measured by a Rheoscan A200 instrument. Velocity in the rectangular microchannels was characterised using micro-Particle Image Velocimetry, and Particle-Tracking techniques and tools (JPIV and Matlab-PIV) [3,4]. Fluid viscosity, was

examined using a Brookfield DV2T viscometer. Microchannels (see Figure 1) were produced by xurography techniques using microsope slides and double sided tape (Tessa, 100μm thickness). Channel surfaces were coated with TiO^2 for enhancing hydrophilicity (contact angles ~5°).

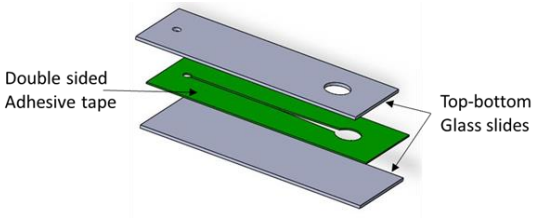

Fig. 1. Exploded schematic of the microchannel. The large hole is the filling well with an entrance width of ~5 mm leading to a ~1 mm exit, after 20 mm, with a convergence angle of ~3°.

3 Results and Discussion

Mean velocity curves as a function of channel distance are shown in Figure 2, illustrating high magnitudes at the initial stages of the flow.

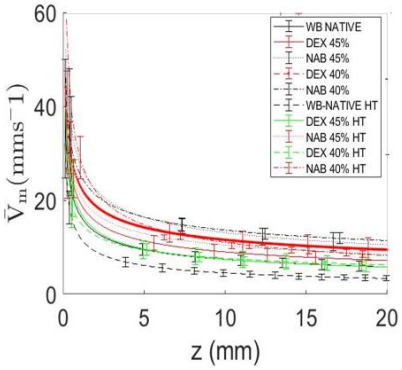

Fig. 2. Meniscus velocity in the channel for native whole blood (WB), Dextran suspensions (DEX), and for non-aggregative blood samples (NAB). The heat-treated counterparts of the samples, for reduced deformability, are noted with "HT", and the haematocrits are noted as 40% and 45%.

The resulted shear-rates from the meniscus velocity behaviour are presented in Figure 3, showing intense shearing near the entrance of the channel. The relatively high shearing rates observed near the entrance of the channels seem to substantially minimise erythrocyte aggregation, therefore supressing the non-Newtonian nature of the samples for a substantial part of the channel length. The 5% increase in haematocrit found to negatively affect the viscosity of the fluid, and also decrease the meniscus velocity in all cases. The increase of erythrocyte aggregation was observed to have a non-monotonic effect on the velocity of the fluids, favouring samples of normal deformability and decreased haematocrit.

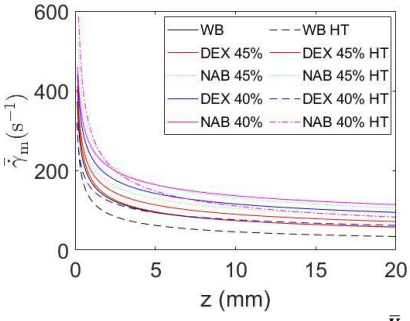

Fig. 3. Shear rates calculated as $\bar{\dot{\gamma}}_m(z) = \frac{\bar{V}_m(z)}{h}$ with h the channel gap at 100μm.

Figure 4 shows the combined effect of erythrocyte aggregation and viscosity on the meniscus velocity ($AI^*_{visc} = \overline{AI}^*$ x $\bar{\bar{\mu}}^*$, with $\overline{AI}^*$ and $\bar{\bar{\mu}}^*$ non-dimensional indices of aggregation and viscosity respectively).

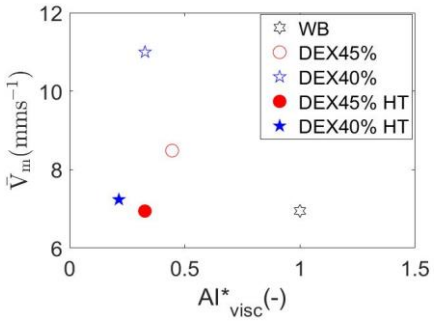

Fig. 4. The effect of aggregation and viscosity on the meniscus velocity.

4 Concluding remarks.

The results of the present study illustrated the need for considering the biomechanical and physiological properties of blood in the design of relevant devices and processes.

References

[1] Sackmann E.K, etal. (2014). The present and future role of microfluidics in biomedical research. Nature. 507(7491):181–9. 10.1038/nature13118.

[2] Kim, H., etal. (2023). Microfluidic systems for blood and blood cell characterization. Biosensors, 13(1) doi:10.3390/bios13010013

[3] Pasias D., etal. (2020). Surface tension driven flow of blood in a rectangular microfluidic channel: effect of erythrocyte aggregation. Physics of Fluids, 32, 071903 (2020); https://doi.org/10.1063/5.0008939.

[4] Pasias D., etal. (2022). Effects of biomechanical properties of blood on surface tension driven flows in superhydrophilic channels. Physics of Fluids, 34, 051907; https://doi.org/10.1063/5.0088643.