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cardiovascular biomechanics

Introduction

The volume content of red blood cells (RBCs) in blood is about 45%. They are highly deformable and show great resilience. Therefore, the mechanical properties of the RBC must be determined accurately for the modeling of transport through and coagulation of blood.

Aim

Characterization of dynamical, local parameters of RBCs under different flow conditions. The obtained data is used for the description of the constitutive behavior of blood.

Literature

Since the '70s several experimental techniques have been applied to RBCs, such as micropipette aspiration, the optical trap, and atomic force microscopy. These techinques involve a contact of a solid with the cell which results in extra friction forces. Moreover, cell deformation is local while the measured quantity (force) is global.

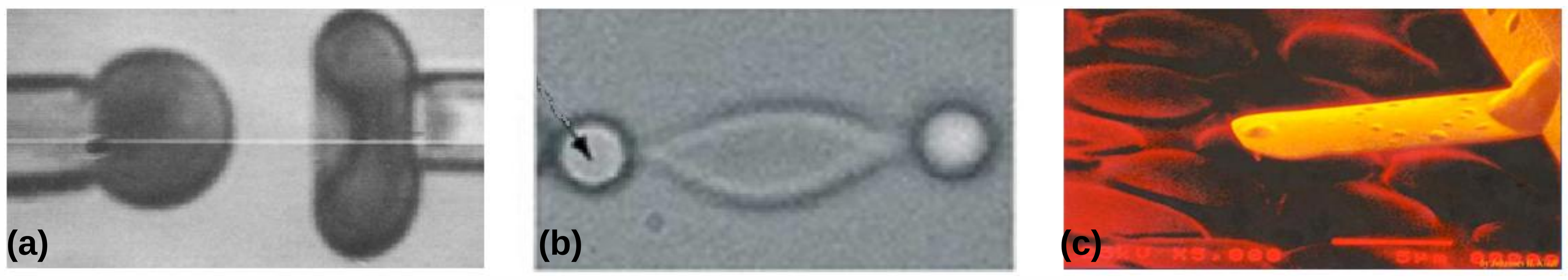

Figure 1: RBC experiments. **(a)** micropipette experiment [1]; **(b)** optical trap [2]; **(c)** atomic force microscope [3].

Microscopy

Diffraction phase microscopy (DPM) will be implemented which enables cell thickness measurements at equal lateral resolution as ordinary microscopy. Thickness is necessary for the inverse analysis determining cell properties.

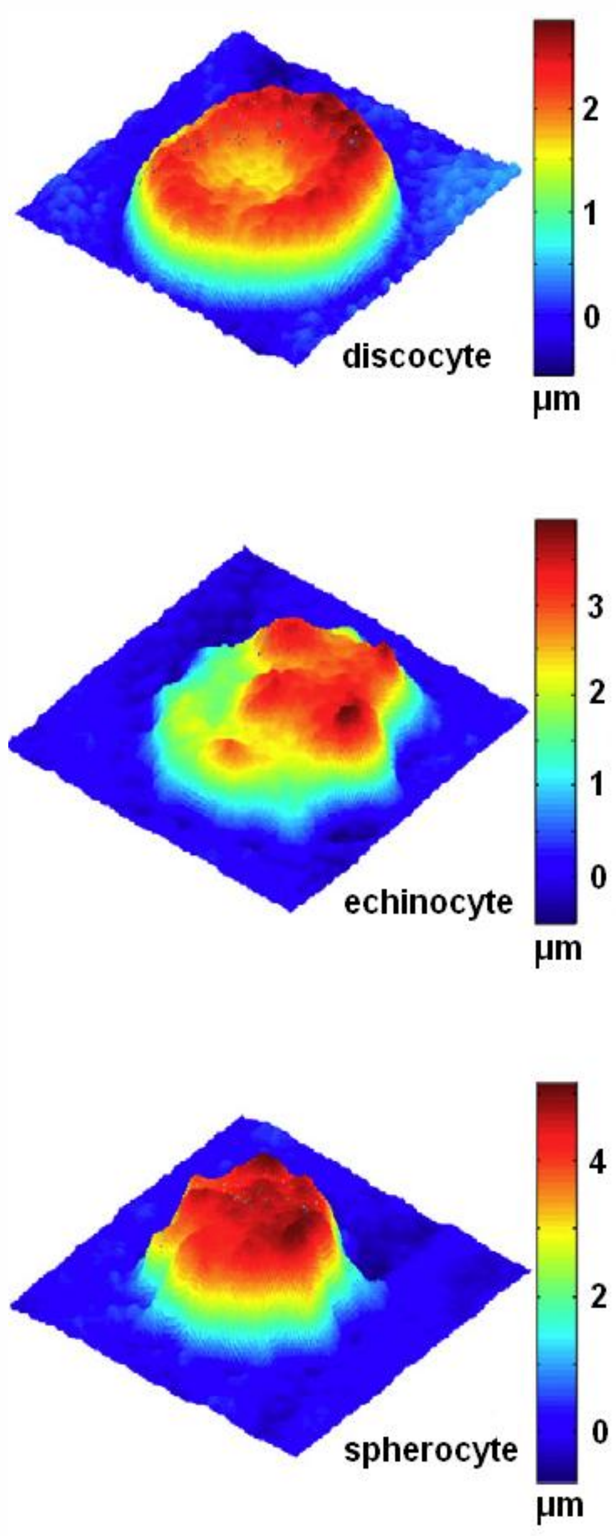

Figure 3: Three different RBC geometries, imaged using DPM. Interference patterns hold information about cell thickness, represented in the contours [4].

Innovation: contactless experiment

We designed a contactless experiment: elongation flow in a cross-slot geometry. Here, a RBC is deformed by the surrounding fluid only. Our measurements combined with a constitutive model can provide the mechanical characteristics by an inverse analysis. Problem: the RBC must be kept in the center. This situation is inherently instable, hence continuous correction has to be performed by an automated system.

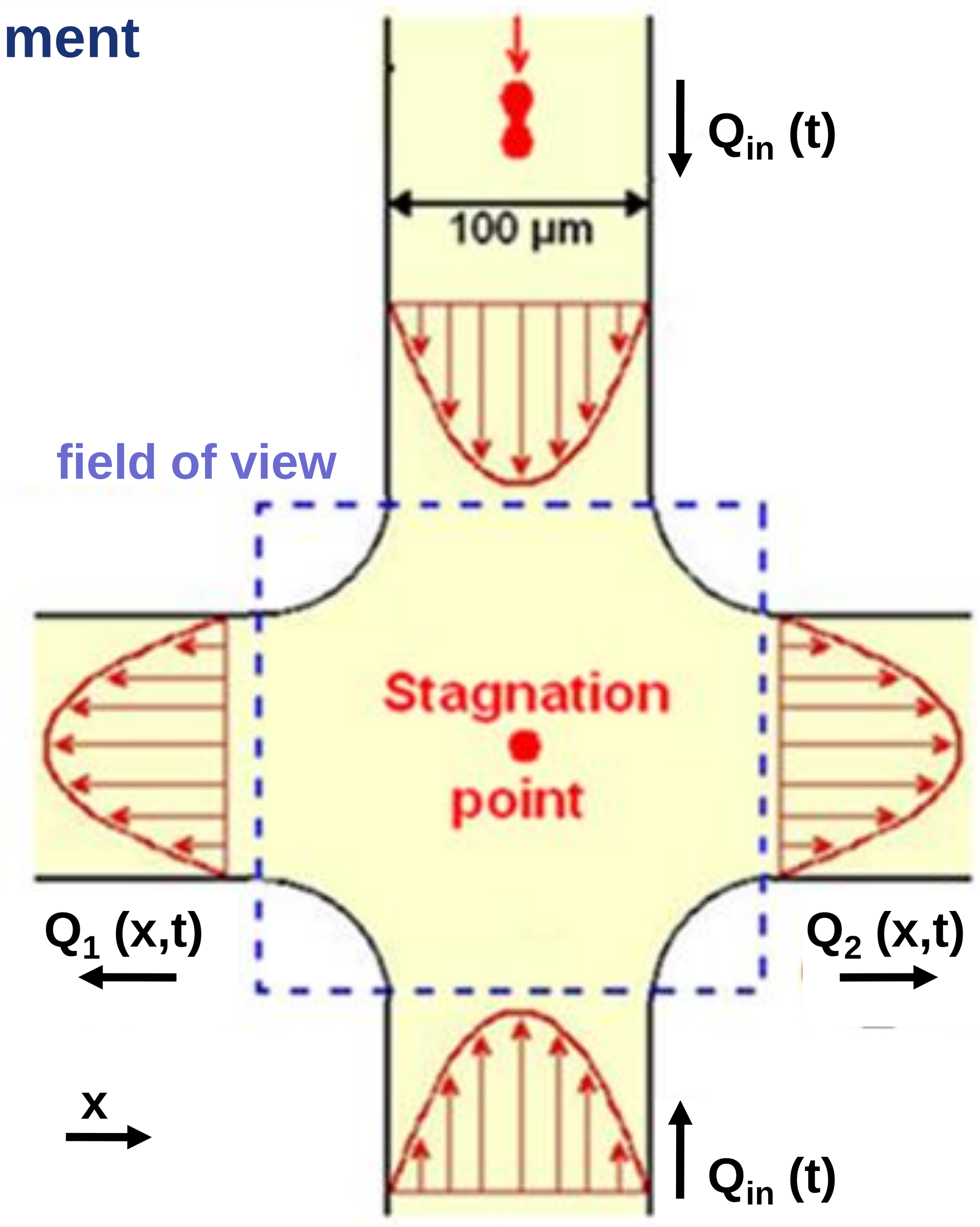

Figure 2: Cross-slot geometry. Fluid velocity is zero at the stagnation point. The cell is repositioned to the center by shifting the stagnation point. This can be achieved by changing the flow ratio of the outflow channels *Q1 : Q2*. Desired flow ratio is determined by a feedback loop that uses cell position *x* as input.

FEM Fluid-structure interaction model

A FSI model of the cross-slot, based on the fictitious domain method, is built. (Re)positioning of a RBC to the center is investigated. The boundary conditions of the outflow channels are determined every time step by the coupled feedback system. This model functions as a tool to perform studies to demanded system specifications in terms of valve dynamics, feedback frequency, image analysis, and channel dimensions.

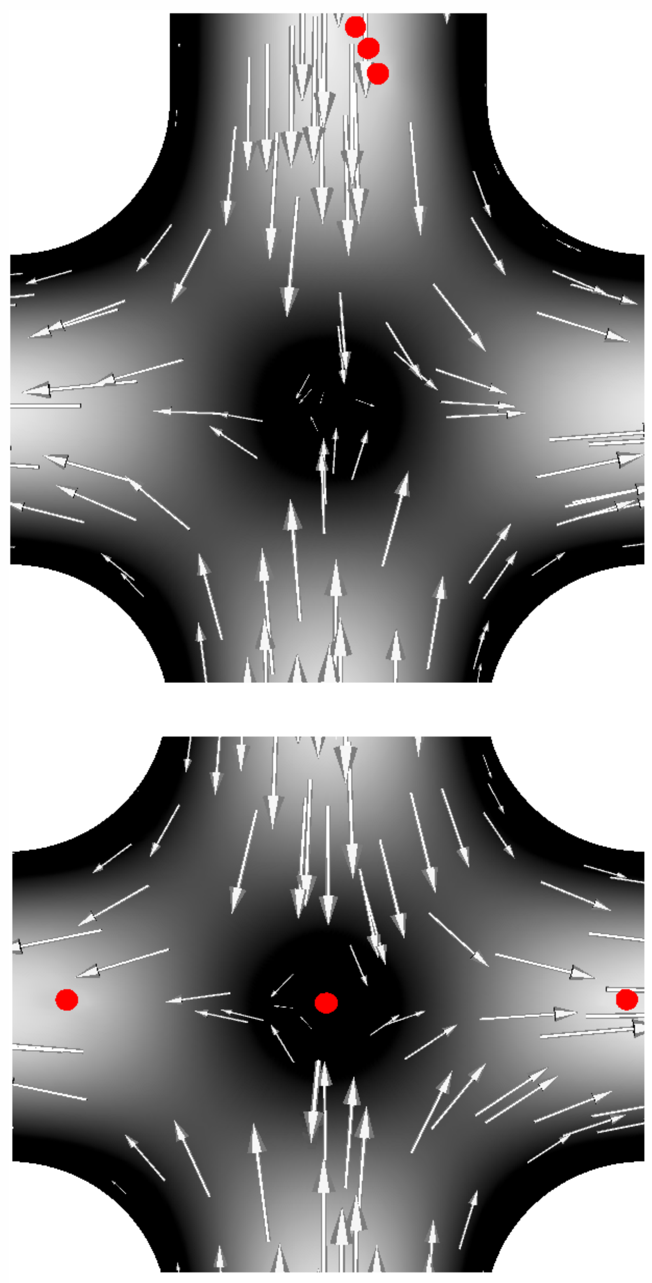

Figure 6: FSI results obtained with [6]. 2 frames, 2.4 seconds apart, that show trapping of the middle cell in the center.

Cross-slot experimental model

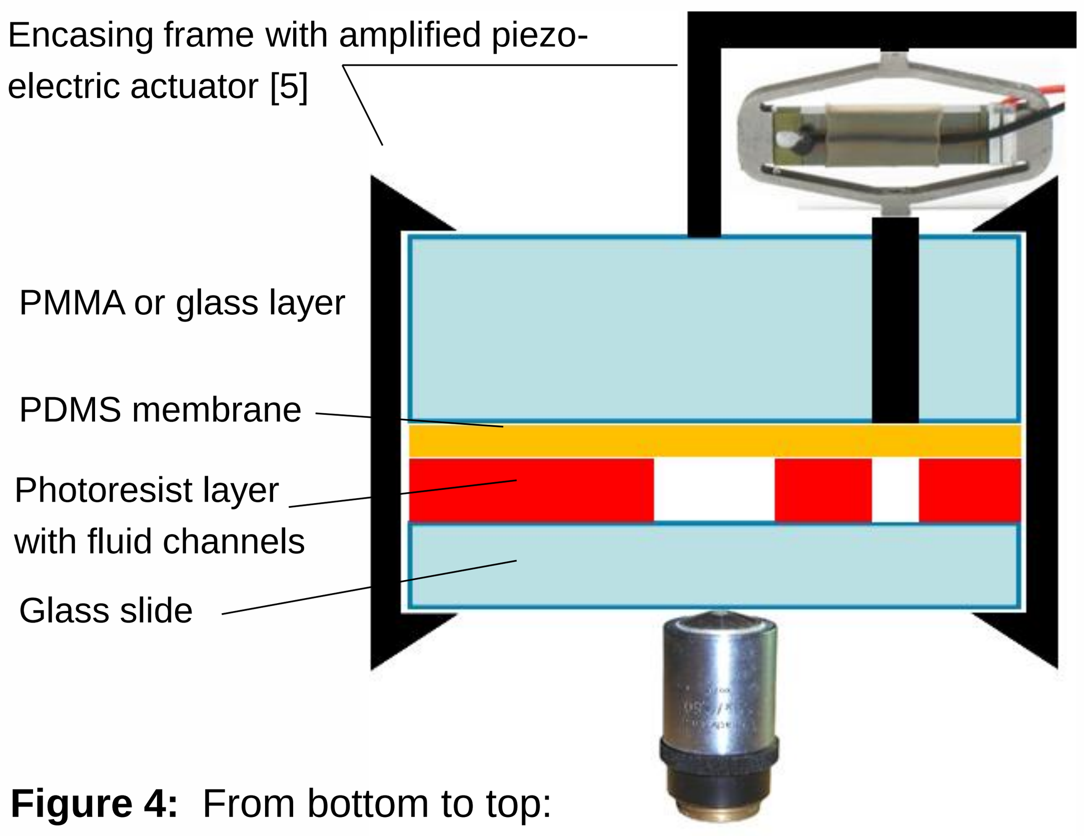

Figure 4: From bottom to top:
The objective focuses on the cross-slot, which is created in the photoresist layer with UV lithography. Channel is sealed by the PDMS that also functions as valve membrane.

Valve impedance

Q1 : Q2 should be varied between 0.1 and 10 to capture most inflowing cells. If the channel resistances R1, R2 are known, the desired valve resistance follows from Ohm's law. Valve resistance is altered by deflecting the membrane into the channel.

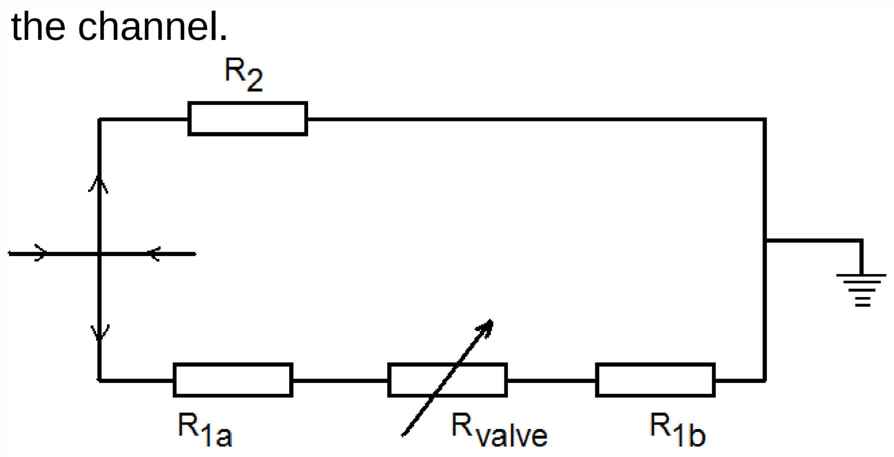

Figure 5: Electrical scheme representing the outflow channels. Ideal values for hydraulic impedances are set by tuning channel dimensions.

Conclusion

2D-FSI parameter studies provide a useful tool for the design of the cross-slot experiment. With the results of the FSI simulations, experimental setup components have been specified.

Future work

Now all the components of the experimental setup have to be built or ordered. After thorough calibration of valves and microscopy, RBCs can be tested. A detailed constitutive model of the RBC is necessary to perform the mechanical analysis.

References

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