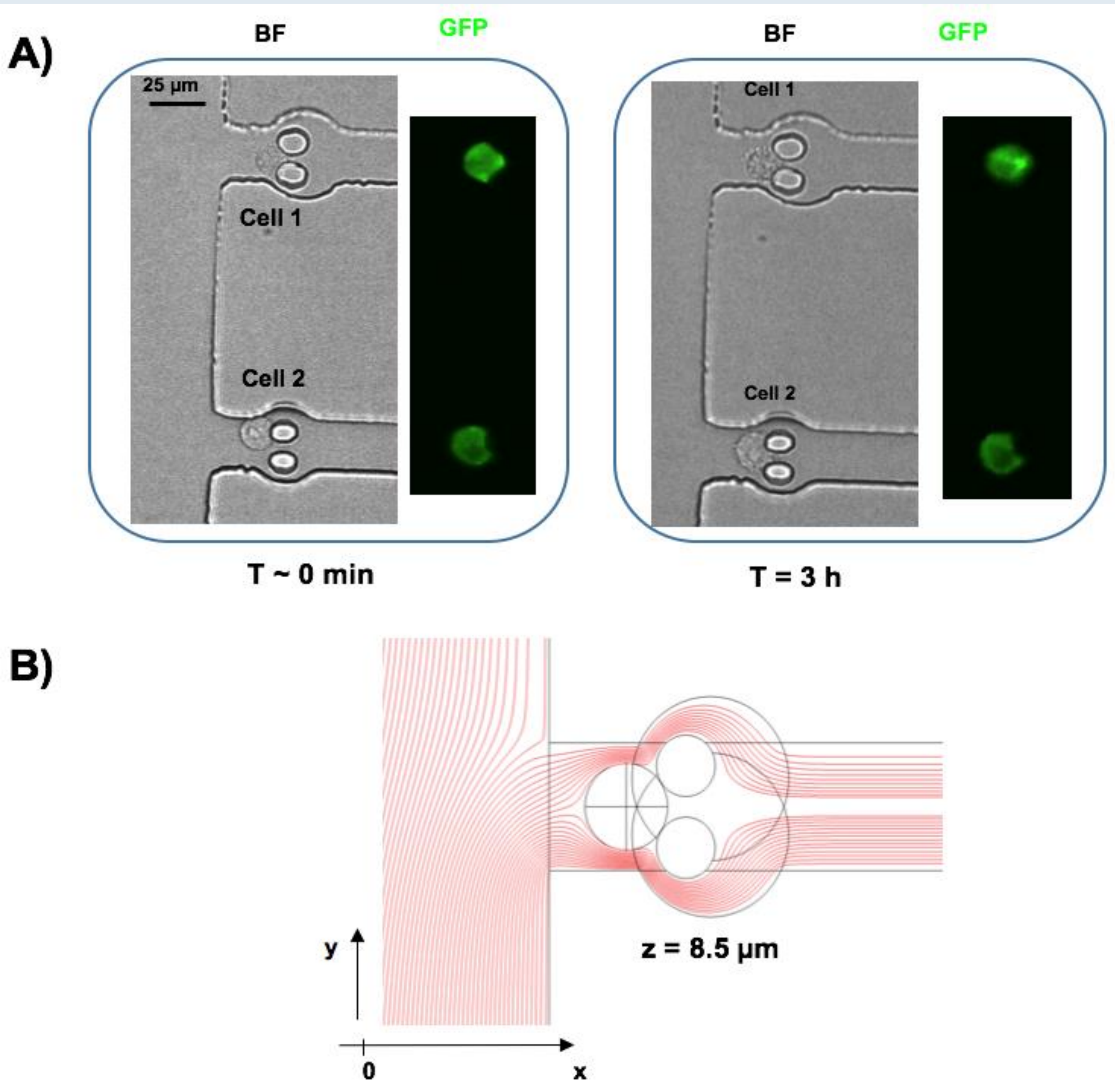

COMSOL® Simulation of a Single Biological Cell Trapped in a Microfluidic Channel

Optimize the external static pressures applied in a microfluidic chip containing individual pillars traps for biological cells undergoing a maximal physiological shear stress (1.33 Pa).

M. Socol[1], A. Naillon[2], B. Charlot[3] and M. Mougel[1]

[1]IRIM, CNRS, Montpellier, France. [2]Univ. Grenoble Alpes, CNRS, Grenoble INP, 3SR, Grenoble, France. [3]IES, University of Montpellier, CNRS, Montpellier, France.

Abstract

We used COMSOL® simulation tools to estimate the shear stress undergone by a Hella cell trapped in a microfluidic channel. For that, we draw a 17 microns sphere blocked by 2 pillars of 10 microns in diameter. The goal of this study is to compare the maximal shear stress (τ) on the bead surface for an average speed of the flow of 239 µm/s (measured using nanometric fluorescent beads for a given external pressure couple).

The evolution of the streamlines in the vicinity of a trapped 17 µm bead was simulated with COMSOL Multiphysics® and no local recirculation flow appeared when v_{4i} = 239 µm/s. The simulation showed a maximal shear rate of 1000 s^{-1} which corresponded to a shear stress (τ) = 1 Pa. This value is close to physiological conditions since circulatory lymphocytes or endothelial cells in blood capillaries undergo a maximal shear stress of 1.33 and 0.72 Pa, respectively (Ref. 1).

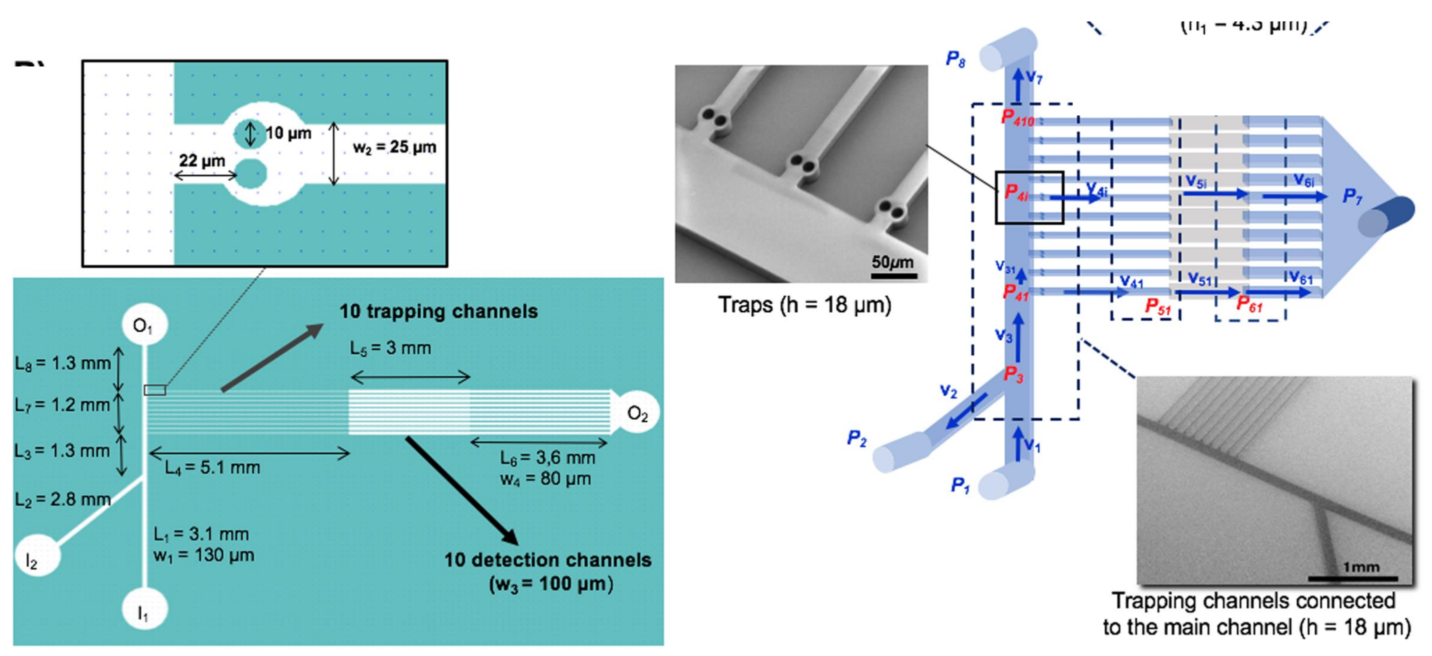

FIGURE 1. Left: Drawing of the microfluidic chip. Right: MEB of the traps and trapping cell region; the flow direction, average speeds, the external and internal pressures are shown for each channel sections.

Methodology

We have developed a simple microfluidic system (Ref. 2) containing 10 individual traps (2 pillars of 10 microns in diameter) for biological cells. For a given external pressures couple, the average speed in each channel section is theoretically calculated using the reduced Stokes equation: $\frac{\partial^2 v(y,z)}{\partial y^2} + \frac{\partial^2 v(y,z)}{\partial z^2} = -\frac{\Delta P}{\mu L}$

To evaluate experimentally the average speed, nanometric fluorescent beads were introduced in the flow. To visualize the stream lines and validate calculus, the hydrodynamic model including the pillars and cells presence was completed by finite element computational fluid dynamics simulation (COMSOL®).

Results

The results can be seen in Figure 2. In the COMSOL simulation the biological cell was assimilated with a 17 microns sphere. Taking the experimentally average speed in the trap containing section channel (239 µm/s), we obtained 3D velocity profile distribution (left panel). The simulation showed a maximal shear rate of 1000 s^{-1} which corresponded to a shear stress (τ) = 1 Pa. This value is close to physiological conditions since circulatory lymphocytes or endothelial cells in blood capillaries undergo a maximal shear stress of 1.33 and 0.72 Pa, respectively (Ref. 1).

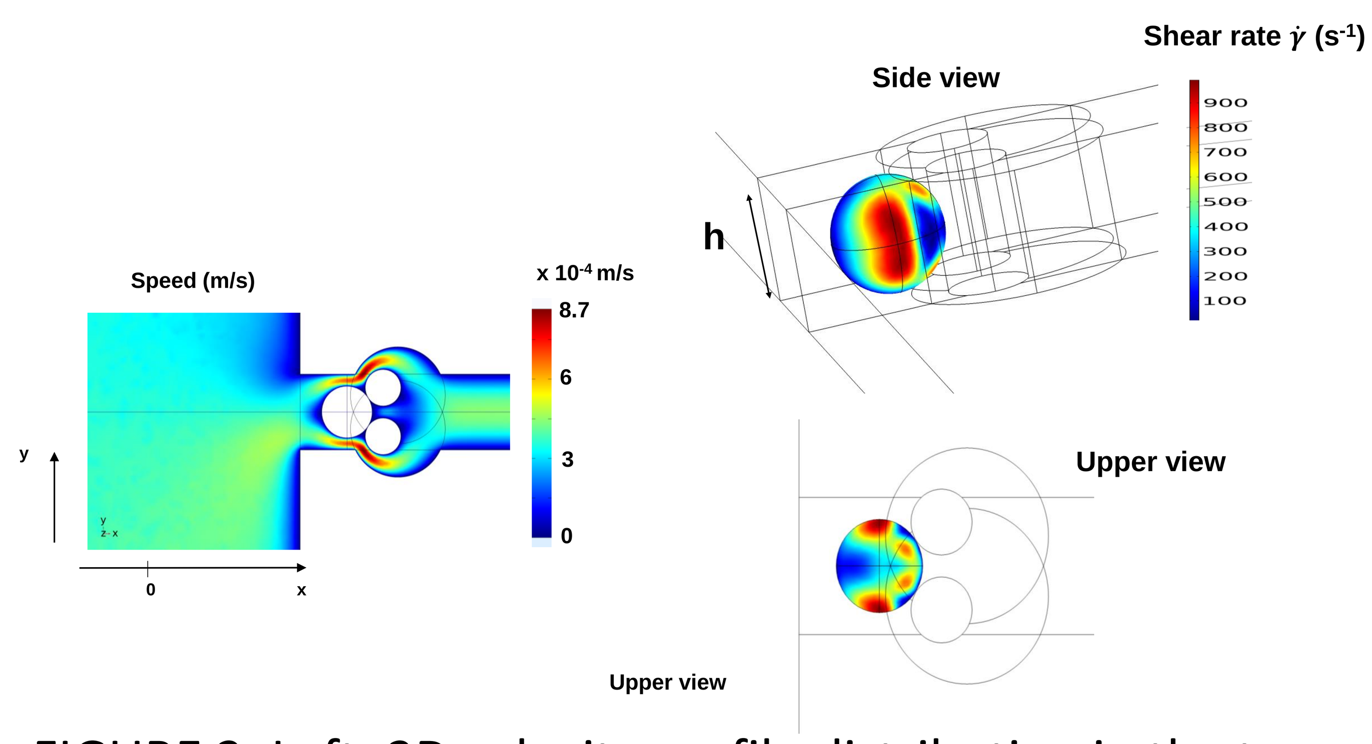

FIGURE 2. Left: 2D velocity profile distribution in the trap region. The average speed in the trap containing section channel was 239 µm/s Right: Side and upper view of the pillars region blocking a 17 microns sphere when shear rate is evaluated in each mesh grid point.

REFERENCES

1. J. Dupire et al, “Full dynamics of a red blood cell in shear flow”, *PNAS*, (vol.109), 2012.
2. J. Eid et al, “Viro-fluidics: Real-time analysis of virus production kinetics at the single-cell level”, *Biophysical Reports*, (vol.2), 2022.

Institut de Recherche en Infectiologie de Montpellier