Computational Biophysics in COMSOL®

FSI-Simulations of Cells in a Microfluidic Device

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Motivation

The mechanical properties of biological cells are promising biomarkers to differentiate for example cell phenotypes, cell states or the healthiness of cells [1, 2]. Real-time deformability cytometry (RT-DC) allows probing the elasticity of ~1000 cells / s by imaging the cells flowing through a microfluidic channel [1]. In this project, we set up a new numerical model to incorporate not only elasticity but also viscoelasticity.

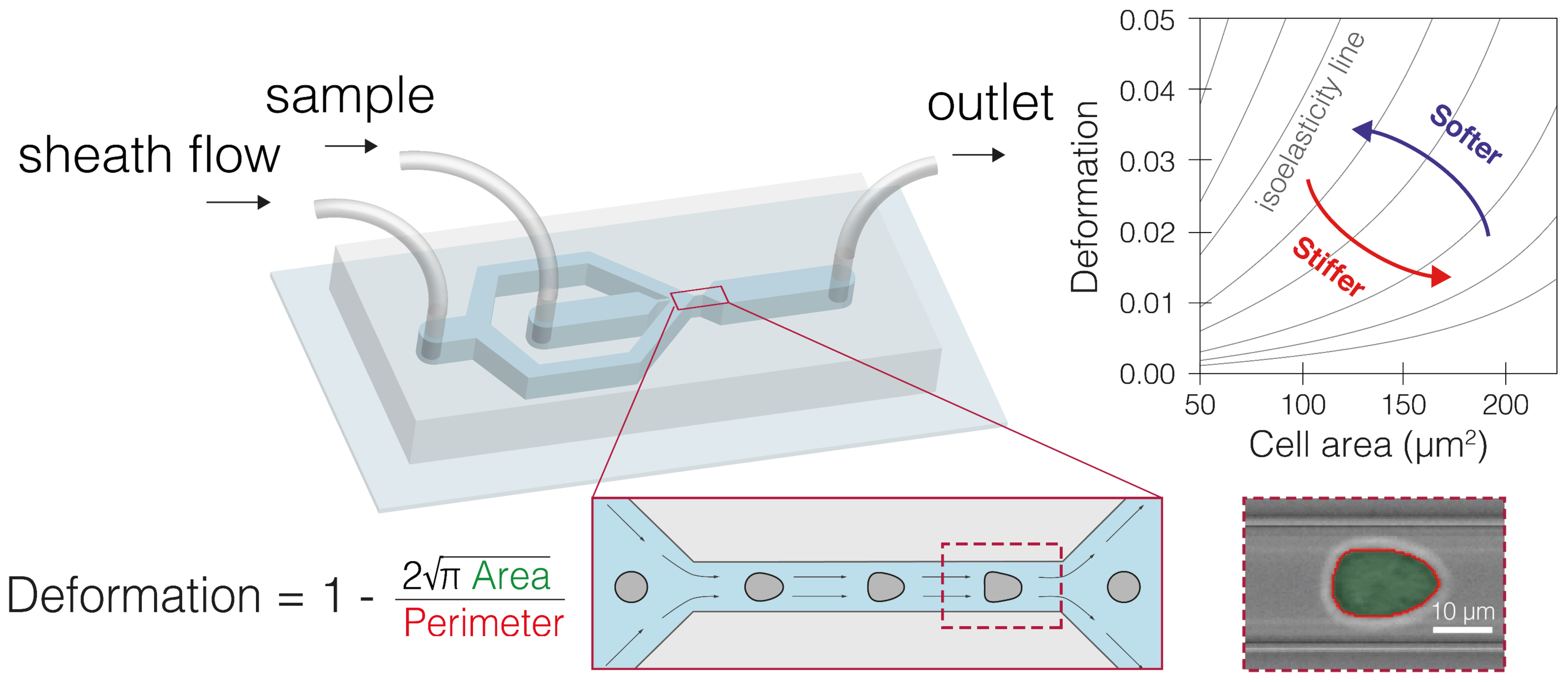


Figure 1. RT-DC schematic, the characteristic shape of the cells in the flow channel and the area-deformation plot with isoelasticity lines (adapted from [2]).

Computational Methods

We use a 3D two-way coupled FSI model to simulate the fluid flow (Laminar Flow interface) and the cell (Solid Mechanics interface with nearly incompressible, neo-Hookean hyperelastic material and Kelvin-Voigt viscoelasticity). The Moving Mesh interface with a swept mesh in the channel avoids numerical artifacts from re-meshing.

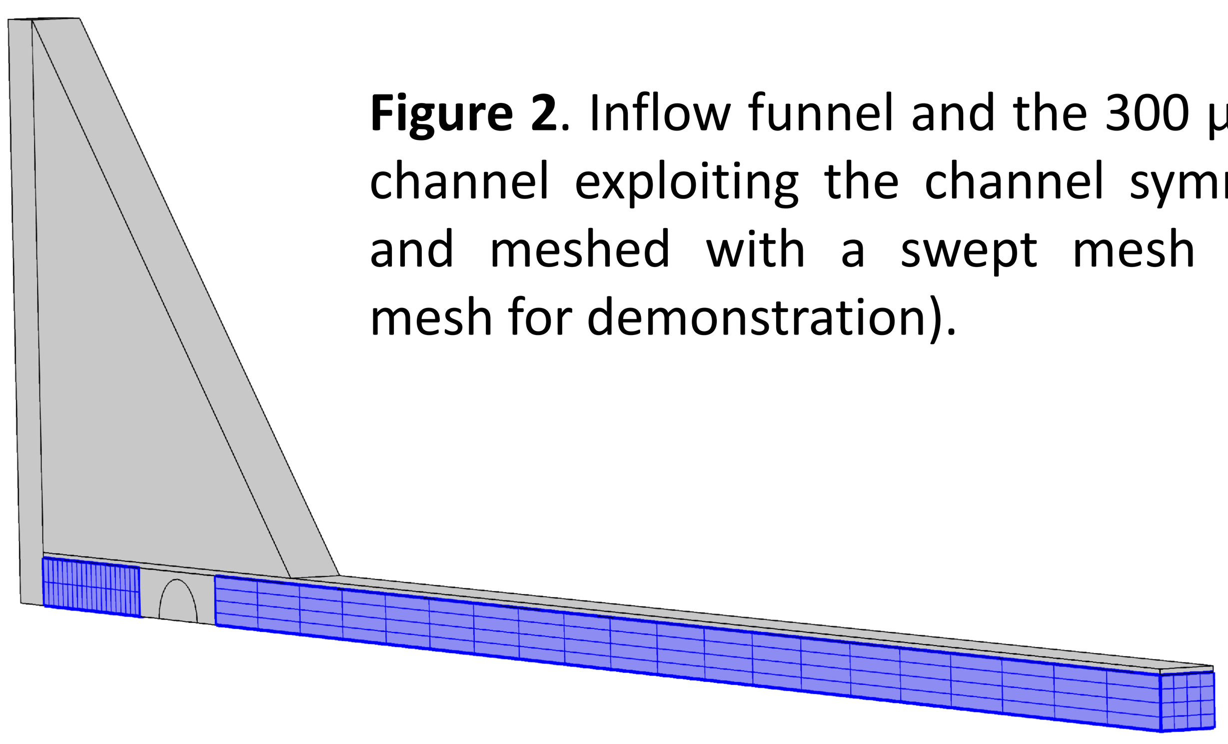


Figure 2. Inflow funnel and the 300 µm long channel exploiting the channel symmetries and meshed with a swept mesh (coarse mesh for demonstration).

Results

The stationary deformations of the cells correspond with previous numerical experiments and experimental data. The viscosity significantly influences the evolution of the deformation towards the stationary state.

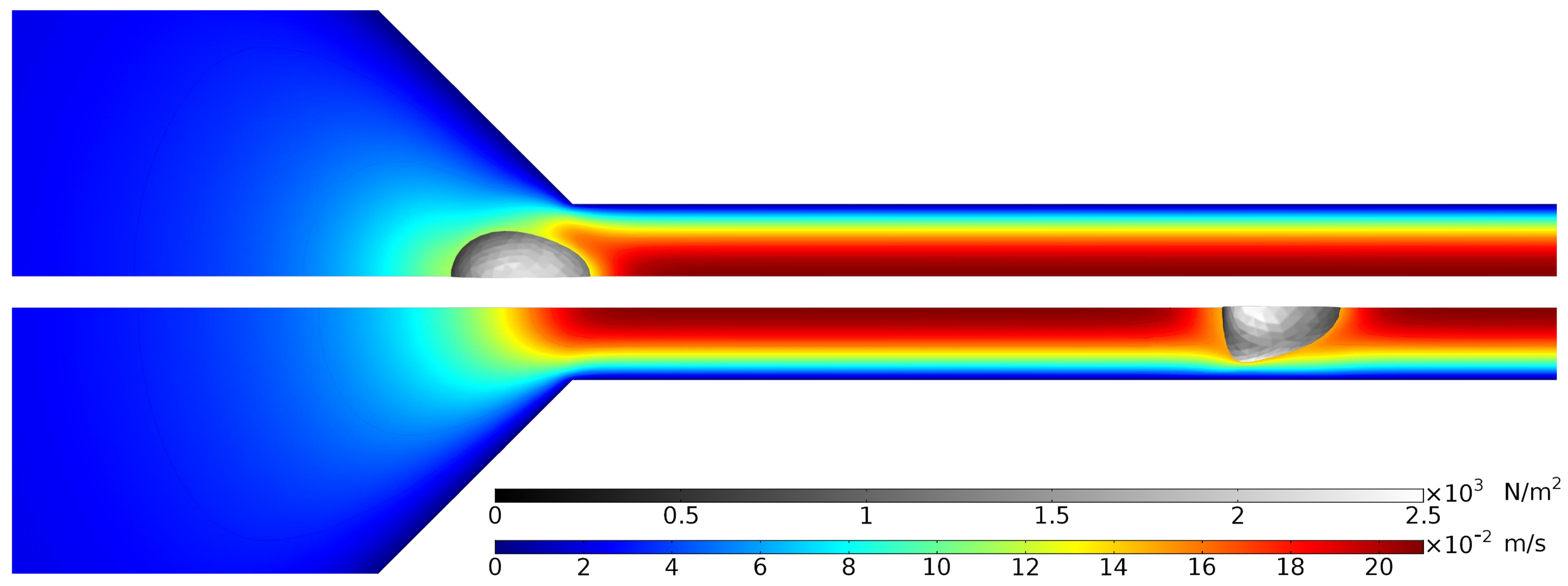
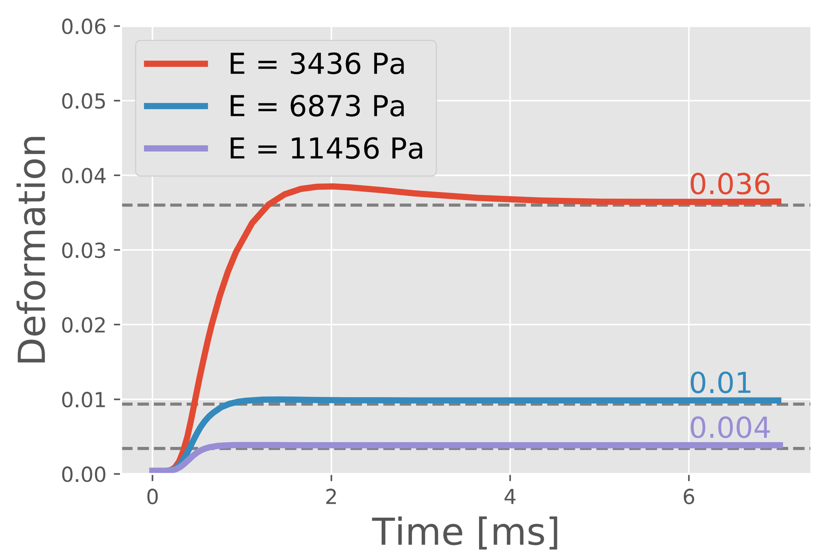


Figure 3. Two-way coupled FSI simulation of the fluid channel and the cell at two different points in time: at the channel entry and after reaching the stationary deformation.



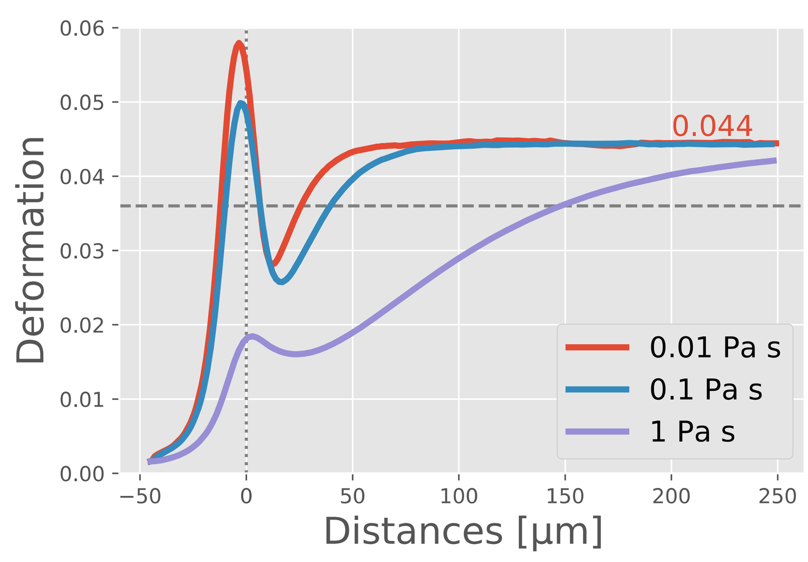


Figure 4. Deformations for three different Young's moduli in a 3D cylindrical channel. The dotted lines indicate the corresponding results from Mokbel et al. 2017.

Figure 5. Deformation of a cell with E = 3436 Pa for different viscosities around the channel entry (x = 0). The deviation from the stationary deformation is due to the square channel.

Conclusion

Our new numerical framework in COMSOL® reproduces previous experimental and numerical results and extends the model with viscoelasticity. Hopefully, this will allow us to probe not only elasticity but also viscoelasticity in RT-DC and pave the way for new biophysical insights.

1. Otto et al., Real-time deformability cytometry: on-the-fly cell mechanical phenotyping, Nat. Methods, 2015
2. Urbanska et al., "Single-cell mechanical phenotype is an intrinsic marker of reprogramming and differentiation along the mouse neural lineage", Development, 2017
3. Mokbel et al., "Numerical Simulation of Real-Time Deformability Cytometry To Extract Cell Mechanical Properties", ACS Biomater. Sci. Eng., 2017