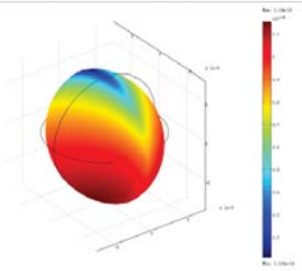
Simulation of cell deformation in a microfluidic cross-slot device

Technische Universiteit Eindhoven University of Technology

SIMULATION OF CELL DEFORMATION IN A MICROFLUIDIC CROSS-SLOT DEVICE



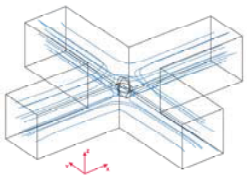
Guansheng Du[1,2,3], Qun Fang[2], Jaap den Toonder*[1,3]

[1]Eindhoven University of Technology, [2]Zhejiang University, [3]Philips Corporate Technologies

Introduction

It is well known that a number of serious diseases affect the mechanical properties of cells, e.g. cancer, malaria, cardiac myopathy). The ability to measure cell mechanical properties, therefore, could provide a good diagnosis method. We propose a special microfluidic device, in which a fluid flow provides the hydrodynamic force that deforms the cells. The measurement of the extent of deformation enables to estimate the cell stiffness. The aim of our study is to investigate the effectiveness of approach, and to obtain an optimized design of the cross-slot geometry.

The device priciple



Our basic microfluidic device is a cross-slot device. It contains two fluid inlets and two fluid outlets. A cell is positioned at the center and fixed there by continuous control of the pressures at the two inlets. The cell experiences an elongational flow that deforms it.

Computational methods

We carried out finite element method software Comsol to calculate the pressure and stress distribution around the cell boundary at different conditions. The solution was then transformed to MATLAB, in which the cell deformation was calculated as a standard linear solid [1]. To quantify the deformation, we use the so-celled Taylor deformation parameter:

$$D_{xy} = \frac{Y_t - X_t}{Y_t + X_t}$$

where the X_t and Y_t are the cell radius in the X-direction and Y-direction, which are time-dependent.

The channel structures (Fig.1) are based on the cross-slot. To obtain better cell deformation and cell control results, two improved structures were also investigated.

Figure 1: The cross slot designs used in the simulation. Design A: channel width and height are both 40 μm. Design B: the width is 50 μm, which is gradually narrowed to 15 μm in the x-direction and to 30 μm in the y-direction. Design C: channel width is 50 μm, narrowed to 15 μm in the x-direction, and the outlet channels in the y-direction contain obstructions.

Computational results

We set a reference condition in our calculation, in which the inlet velocity is 10 mm/s, the liquid has density 1000 kg/m^3 and viscosity 1 mPa·s the channel height and width are both 40 μm. We choose endothelial cell as our reference cell, whose radius is 7.5 μm, with elastic constants K_1 = 22.5 Pa, K_2 = 37.5 Pa, and viscosity η = 1.7 ×10^3 Pa·s. [1] Both the cell and liquid are incompressible. The reference result is the red line in the following pictures.

Channel designs

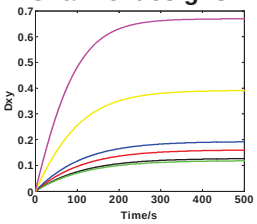


Figure 2: The deformation D_{xy} as a function of time for six different designs. Design 1-4 are on the basis of structure A, but the channel width are 100 μm (green), 80 μm (black), 40 μm (red), 30 μm (blue) respectively. Design 5 (yellow) and 6 (pink) are structure B and C respectively.

Inlet velocity

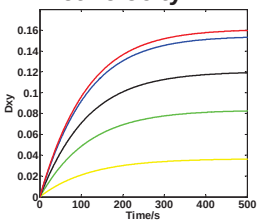


Figure 3: The deformation D_{xy} as a function of time for five different inlet velocities, v = 2 mm/s (yellow), 4 mm/s (green), 6 mm/s (black), 8 mm/s (blue), 10 mm/s (red).

Liquid viscosity

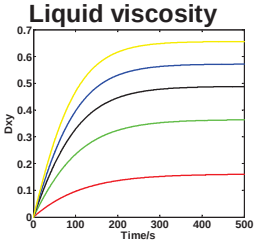


Figure 4: The deformation D_{xy} as a function of time for five different liquid viscosities η_{Liquid} = 1 mPa·s (red), 3 mPa·s (green), 5 mPa·s (black), 7 mPa·s (blue), 10 mPa·s(yellow).

Cell types

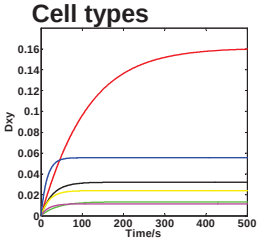


Figure 5: The deformation D_{xy} as a function of time for six different cell types, endothelial cells (red), fibroblasts (green), chondrocytes (black), chondrocyte nuclei (yellow), rat osteosarcoma cells (pink), bovine chondrocytes (blue). [2]

Conclusion and future work

Substantial cell deformation can be obtained with use of the cross slot device. Currently, we are fabricating the cross slot designs to be used in future experiments of cell deformation.

[1] Sato, M., Ohshima N., Nerem R.M., J. of Biomech., 461-467, 29, 1996

[2] Lim C.T., Zhou E.H., Quek S.T., J. of Biomech., 195-216, 39, 2006