Electronic Supplementary Information for the paper entitled

Cell Pinball: Phenomenon and Mechanism of Inertia-Like Cell Motion in a Microfluidic Channel

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1 Computational Simulation with COMSOL

The interaction between cell pinball and the fluid flow inside the microchannel under two circumstances are simulated using COMSOL 4.0a, a commercial finite element analysis (FEA) software for physics and engineering applications. The details are as follows:

1.1 Simulation environment and conditions:

Figure a1 shows the geometrical model of the simulation. The dimensions are $50\ [\mu\mathrm{m}]$ and $100\ [\mu\mathrm{m}]$ for the channel width and length and $8\ [\mu\mathrm{m}]$ and $0.2\ [\mu\mathrm{m}]$ for the diameters of cell pinball and the contact area. The distance between the centroid and the contact point is $3\ [\mu\mathrm{m}]$ $(\mathrm{S}=3)$, and they are on the same horizontal line along the direction of flow. The simulation is performed on a 2D plane, as a result, the height of the channel is neglected. The model of "Fluid-Solid Interaction" is employed for the simulations. The parameters for the fluid part are $\rho = 1000\ [\mathrm{kg}/m^3]$, $\mu = 0.001\ [Pa\ s]$ for the density and dynamic viscosity, respectively. Cell pinballs are considered as a linear elastic material with parameters of $\mathrm{E} = 5\ [\mathrm{kPa}], \nu = 0.49$ and $\rho = 1025\ [\mathrm{kg}/m^3]$ for the Young's modulus, Poisson ratio and density, respectively. The flow is set as laminar flow from the left to the right with the inlet mean velocity of $3.33\ [\mathrm{cm/s}]$. The contact is set as a fixed area.

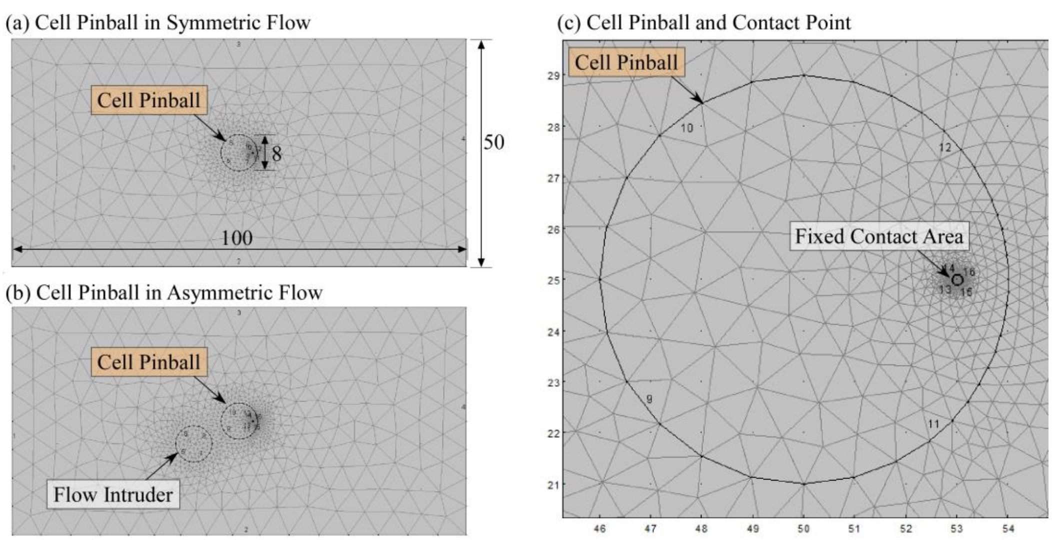

Figure a1 Geometrical model of cell pinball in COMSOL. (a) The case where only one cell pinball exists in the channel. (b) The case where an additional cell "Flow Intruder" co-exists in the channel. (c) The fixed contact area is set as fixed boundary condition.

1.2 Simulations with symmetric and asymmetric flow

Figure a2 shows the simulation results where Figure a2(a) and (b) are the results of symmetric and asymmetric flow, respectively. The flow in Figure a2(a) is symmetric because the cell pinball is located at the geometrical center of the simulation plane, and also the flow is set as laminar. Since the pinball is fixed at the contact area, the pinball is pushed by the flow against the fixed area, and results in the stress distribution as the color indicated in the figure. Because the pinball is considered as a linear elastic object, deformation is observed from the simulation result.

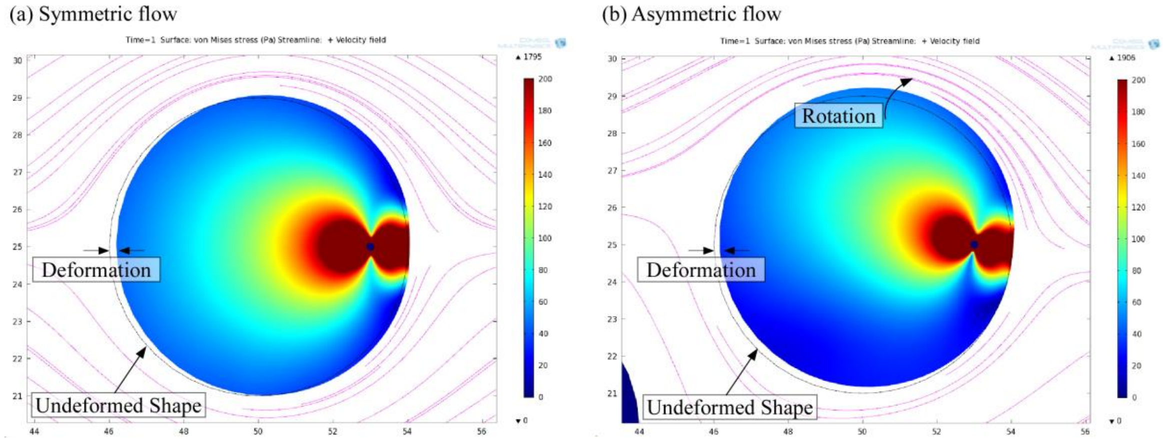

Figure a2 Simulation results where the color inside the cell pinball represents von Mises stress in Pascal, and the magenta curves represent streamlines of the flow. (a) The cell pinball deforms symmetrically in symmetric flow condition. (b) The cell pinball not only deforms but also rotates clockwisely with respect to the contact area.

On the other hand, the flow in Figure a2(b) is asymmetric because of the "flow intruder" in Figure a1(b). The pinball also deforms due to the flow and the fixed contact area. The main difference between the case of symmetric and asymmetric flow is that cell pinball rotates while the flow is not symmetric due to the unbalance of applied moment.

1.3 Summary

The rotations shown in the simulation result match to the observation of cell pinball in the experiments. However, the contact area is not firmly fixed as the simulation setting in the model proposed in this paper, and instead, the contact area is changed from time to time due to the deformation. Therefore, the actual stress cell experienced is expected to be less than the results obtained in the simulation.

2 Derivation of *S, the* Separation between Centroid Line and Contact Line

The separation between the centroid line and contact line on a cell pinball can be derived from its motion. Figure a3 illustrates a cell pinball moving in an infinitesimal step, and the motion can be realized by decoupling into rotational and translational motion as in Figure a3 (a) and (b), respectively. The position of the cell pinball is represented by the centroid, the black dots in Figure a3. During the infinitesimal step, the rotational motion around the contact point, the white dot in Figure a3, results in the motion in both *x* and *y* directions, and are

$$\Delta x_R = S\,(1 - cos\Delta\theta)$$

$$\Delta y_R = S\,sin\Delta\theta$$

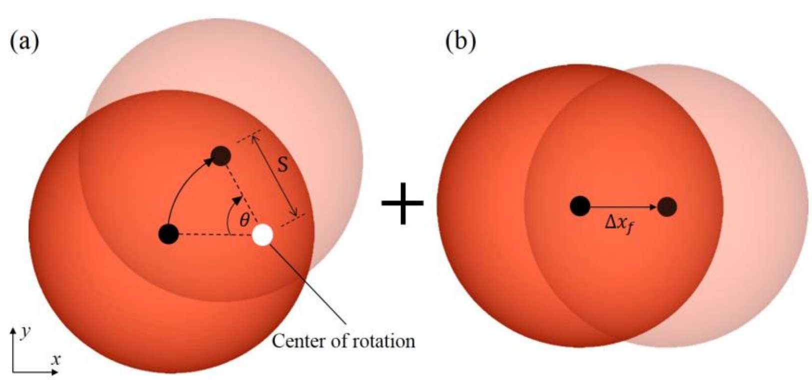

Figure a3 The motion of a cell pinball in an infinitesimal step ($\theta \to 0$). (a) Rotational motion around the contact point results in a motion in both x and y directions. (b) The fluid flow drags the cell pinball moving along x direction.

where $\Delta\theta$, Δx_R and Δy_R are the rotation angle around the contact point, the motion in *x* and *y* direction from the rotation, respectively. In addition to the rotation, the pinball is also dragged by the fluid flow in *x* direction as shown in Figure a3(b), and the overall cell motion becomes

$$\Delta x = \Delta x_R + x_f$$

$$\Delta y = \Delta y_R$$

Let *L* be the the total movement in *y* direction and *n* be the revolution times of the rotation in *k* steps. *L* and *n* can be written as

$$L = k(\Delta y) = k\, S\, \Delta\theta \qquad \text{when } \Delta\theta \to 0$$

$$n = k\left(\frac{\Delta\theta}{2\pi}\right)$$

By rearranging the above two equations, the relation between the separation *S*, the displacement *L* in *y* direction and the microbeads rotation *n* is simplified as

$$S = \frac{L}{2\pi n}$$