Project Title:

Quantitative cross-scale analysis of bond dynamics properties on the characteristics of cell rolling adhesion velocity distribution in microvessels.

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1. Background and purpose of the project, relationship of the project with other projects

When the adhesion force of cells is not enough to balance the inertial force on the cells, the cells will detach from the wall and migrate laterally in the tube under the action of wall-induced lift force and shear-induced lift force, which is called lateral migration. Revealing the mechanism of lateral migration is crucial for flow cytometry, cell diagnostics and cell separation techniques, which allows the development lab-on-a-chip devices to precisely manipulate particles. Using a straight circular tube, the free rolling migration behaviors of two cells with different axial distances were studied. The axial and lateral migration of two cells under different axial spacing, Re and stiffness was demonstrated, and this study will further guide the design of inertial microfluidic devices.

2. Specific usage status of the system and calculation method

The dynamic features of free rolling of two identical cells in a straight tube of length 240 μm are reproduced using an immersed boundary method. The particles are initially placed close to the bottom of the tube. The initial lateral distance of the centre of the cell from the bottom of the tube is r^0. The initial axial distance between the cells is δ_{x_0}. Besides, the particle initially located downstream is called leading cell; the other particle is called lagging cell. The flow field is discretized with a fixed Eulerian grid and the cell membrane is discretized with a movable and deformable Lagrangian grid, ignoring the thickness of the cell membrane. The constitutive relationship of the cell membrane was adopted from the hyper-elastic model proposed by Skalak. The bending model was adopted from the model proposed by Porzikidis. The fluid inside the cell has the same density as the outside fluid and the viscosity is five times the outside fluid. The membrane is discretized using triangular mesh and the elastic forces on the membrane are calculated using a finite-element method. Then the elastic forces are spread to the surrounding fluid meshes using a smooth delta function. Periodic boundary conditions are applied and the fluids are driven by a fixed pressure gradient.

3. Result

Fig. 1 shows the variation of axial distance δ_x between two cells when they migrate from the bottom of the tube. As shown in the figure, When the initial distance δ_{x_0} is relatively large, the axial distance δ_x is essentially stable, while both cells have the same lateral migration trajectory. When δ_{x_0} is relatively small, the axial distance δ_x gradually increases and stabilizes and lateral migration velocity of downstream cells is greater than that of upstream cells.

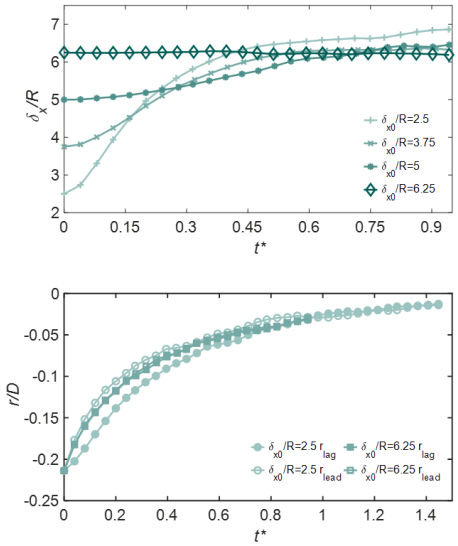

Fig. 1 (a)Variation of axial distance between the centres of two cells at different initial axial distances; (b) Variation of lateral position of two cells at different initial axial distances

We also explored the migration patterns of cells under different Reynolds numbers. As shown in Fig. 2, for larger Re, when cell migration reaches a stable state, the lateral spacing between cells is smaller. In lateral migration, larger Re causes cells to reach a lateral stable position faster. Comprehensive comparison of changes in lateral migration and cell spacing, the more the cell spacing has not reached a stable value after reaching the lateral stabilization position, for large Re.

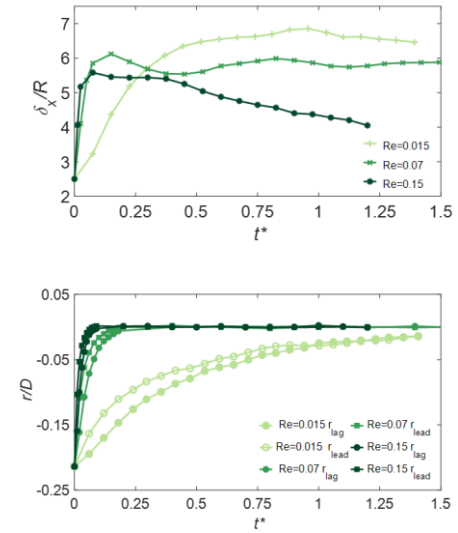

Fig. 2 (a)Variation of axial distance between the centres of two cells at different Re; (b) Variation of lateral position of two cells at different Re.

In order to further analyze the mechanism behind cell migration under different Re, we also analyzed the smoothness when migration reached a stable state. As shown in Fig. 3, after cell migration reaches stability, when Re is small, the cells are close to the centre of the pipe, and two stable vortices of different sizes are formed between the cells. When Re gradually increases, the cell is located in the centre of the tube, and two stable vortices of equal size are formed between the cells; the larger the Re, the smaller the vortex strength is.

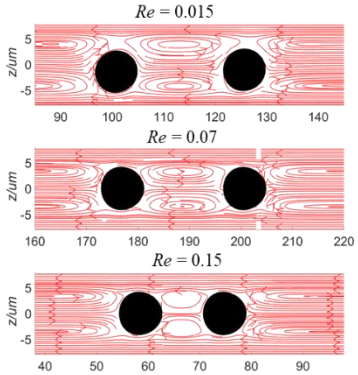

Fig. 3 Streamlines in the formation of stable cell pairs

We also explored the migration of cell pairs under different hardnesses, as shown in Fig. 4, the velocity of lateral migration of initially upstream cells is greater than that of downstream cells when cell stiffness increased. When cells are stiffer, cells cross the centre of the tube in the lateral position, eventually forming stable cell pairs. With greater cell stiffness, oscillating cell pairs form on both sides of the pipe.

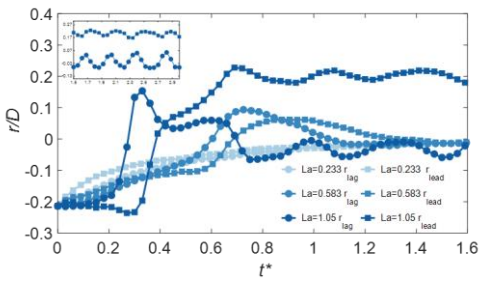

Fig. 4 Variation of lateral position of two cells at different La

4. Schedule and prospect for the future

The above study was conducted only on cells of the same size. If the cell sizes are different, how the migration trajectories of the two cells will be different is worth exploring. In addition, in the real physiological environment, there are a large number of red blood cells, and the cell migration trajectory under the influence of red blood cells is also a problem worth exploring.