Shear Stress Analysis in High-Throughput Dual-micropillar-based Microfluidic Platform

Jayant Borana[1], Jong Min Lee[2], Bong Geun Chung[2*]

[1]Department of Chemical Engineering, Indian Institute of Technology Guwahati, Guwahati, India.
[2]Department of Mechanical Engineering, Sogang University, Seoul, Korea (*bchung@sogang.ac.kr)

Abstract: We developed the dual-micropillar-based microfluidic platform to control cellular behavior. 4 × 4 dual-micropillar based platform (Figure 1) consists of 16 circular-shaped outer micropillars and 8 saddle shaped inner-micropillars. We simulated various shapes of inner micropillars to analyze the shear stress inside the inner micropillar. Therefore, this dual-micropillar-based microfluidic platform could be useful to understand cell biology.

Introduction: We simulated shear stress profiles using COMSOL Multiphysics 3.5. We simulated profiles for different depth of inner saddle-shaped micropillars and different arrangement of micropillars. We used computational fluid dynamics model to calculate shear stress at different average inlet flow rate.

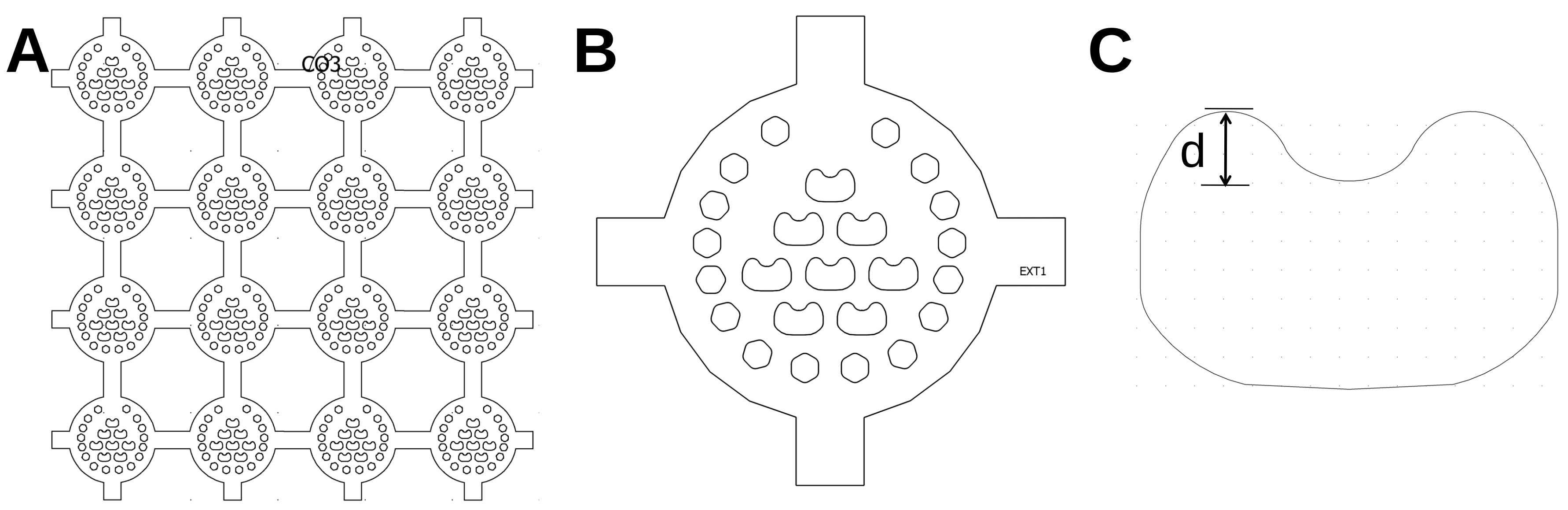

Figure 1. CAD drawing of the dual-micropillar-based microfluidic platform in COMSOL 3.5 (A) 4X4 dual-micropillar-based platform, (B) Single microchamber containing dual-micropillars, (C) Saddle shaped inner micropillar

Computational Models: The steady state Navier-Stokes Equation for incompressible Newtonian fluids was solved using COMSOL. The Perfusion medium was modeled as an incompressible, homogeneous and Newtonian fluid of properties given in Table 1 and boundary conditions are given in Table 2. Fluidic domain meshed using finer mesh.

$$\nabla \bullet \mathbf{u} = 0 \qquad (1)$$

$$\rho\, \mathbf{u}.\nabla \mathbf{u} = -\nabla p + \mu\, \nabla^2 \mathbf{u} \qquad (2)$$

Variable	Value	Units
Density	1000	Kg/m3
Dynamic Viscosity	0.001	Pa.s

Table 1. Physical Properties

Position	Boundary Condition
Wall	No-Slip
Inlet	Average Inlet Velocity
Outlet	Zero Pressure

Table 2. Boundary Conditions

Results: Shear stress increased linearly with average inlet flow rate but the rate of increase of shear stress for d = 12 µm with increasing average inlet flow rate was negligible with respect to d = 3,6 µm.

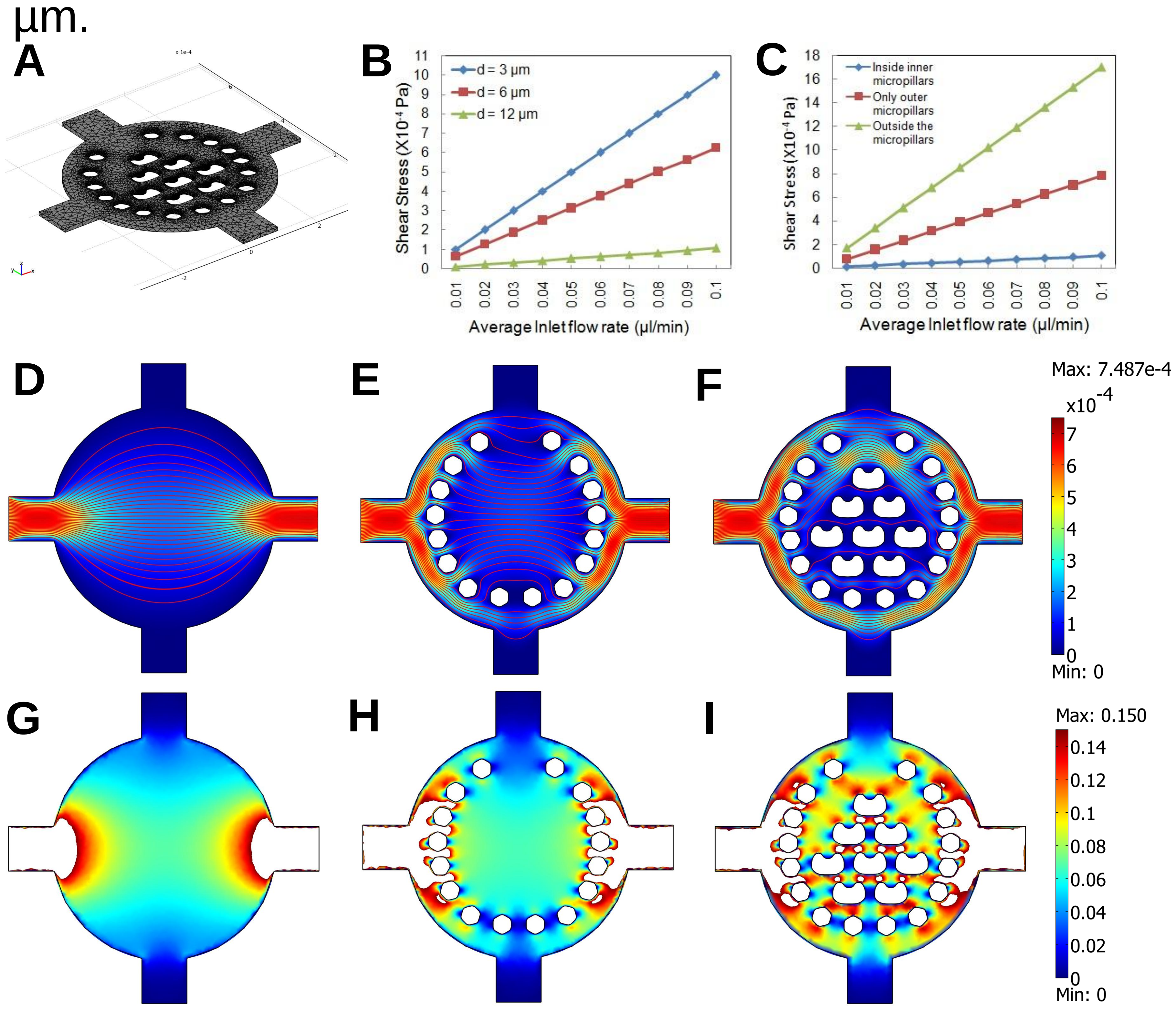

Figure 2 (A) 3D mesh in COMSOL, 2(B) Shear stress analysis inside saddle-shaped inner micropillars for different depth (d = 3, 6, 12 µm) for dual-micropillar-based platform, 2(C) Shear stress analysis inside a micro-chamber at different positions. Velocity profiles inside the chamber for perfusion medium inlet volume flow rate 0.03 µl/min from the left microchannel 2(D) when no micropillar inside the chamber, 2(E) when only outer micropillars, 2(F) when dual-micropillars are used in the chamber. Shear stress profile for single micro-chamber in response to the volume flow rate (0.03 µl/min from the left microchannel) 2(G) when no micropillars inside the chamber, 2(H) when only outer micropillarsmare used in the chamber, 2(I) when outer and saddle shaped inner micropillars (d = 12 µm) (dual micropillars) are used in the chamber.

Conclusion: We simulated shear stress at different position of platform. For different depth of saddle-shaped inner micropillars, We found that the shear stress was negligible at d = 12 µm of saddle-shaped inner micropillars. From shear stress profiles we found that outer circular shaped micropillars regulated uniform shear stress and saddle-shaped inner micropillars helped for cell docking and cell immobilization. The microfluidic platform played an important role to control cellular behaviour.

References:
1. Brian J. Kirby. *Micro- and Nanoscale Fluid Mechanics: Transport in Microfluidic Devices*, Cambridge University Press, 2010, pp. 14-19.
2. Lee, J. M., Kim, J. E., Kang, E., Lee, S. H., Chung, B. G., *Electrophoresis* 2011, *32*, 3133-3137.
3. Lee, J. M., Kim, J., Borana, J., Chung, B. H., Chung, B. G., *Electrophoresis*, 2013, 34(13), 1931-1938.

Excerpt from the Proceedings of the 2013 COMSOL Conference in Bangalore