Simulation of Interstitial Nanoparticle Flow for Development of Tumor-on-a-Chip Device

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Introduction: A numerical simulation using COMSOL Multiphysics® was performed to study the flow behaviors of nanoparticles in a microfluidic device, which mimics a drug delivery system in tumor tissues. This microfluidic device, a tumor-on-a-chip, is under development for the efficient study of drug delivery to tumor cells, and to also avoid complicated and costly animal studies [1,2].

Computational Methods: The fluid field, **u**, was solved using 2D steady state Navier-Stokes equation and continuity equation:

$$\rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot[-p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T)] \quad (1)$$

$$\rho\nabla\cdot(\mathbf{u}) = 0 \quad (2)$$

No slip boundary condition and no particle flux condition were imposed on all the solid boundaries. Nanoparticle concentration *c* was then solved using the time-dependent convection-diffusion equation:

$$\frac{\partial c}{\partial t} + \mathbf{u}\cdot\nabla c = D\nabla^2 c \quad (3)$$

D is a diffusion coefficient of a nanoparticle with its radius *r*:

$$D = \frac{k_B T}{6\pi\mu r} \quad (4)$$

The number of particles diffused into the tumor chamber , N_{leak}, was measured to evaluate and the flux:

$$Flux = \frac{1}{2r_{tumor}\pi}\frac{dN_{leak}}{dt} \quad (5)$$

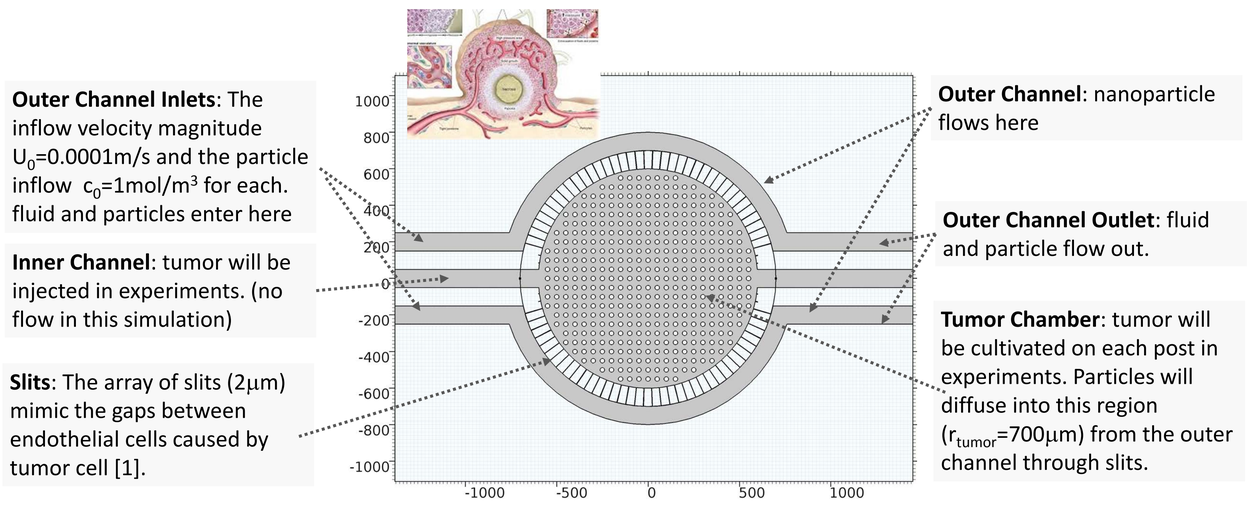

Figure 1. The tumor-on-a-chip device (scale in μm) and the tumor structure

Results: Steady state flow field

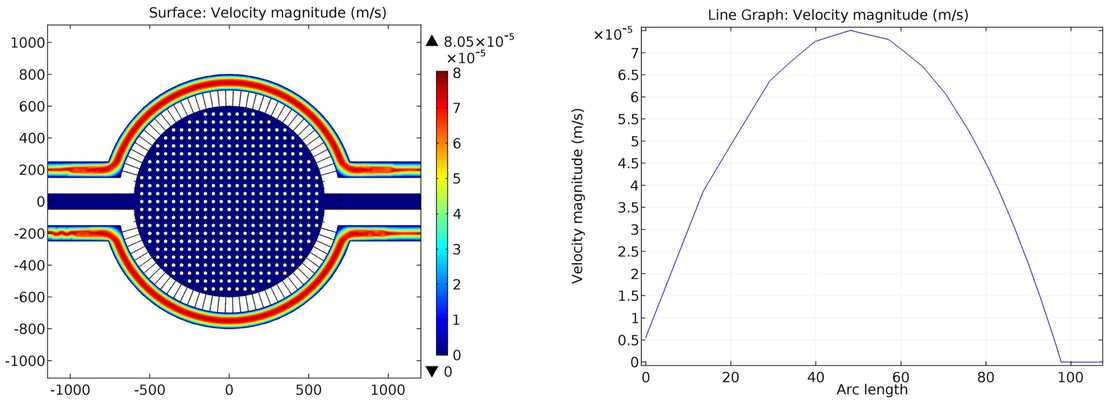

Figure 2. (a) 2D map and (b) 1D velocity profile of the stationary fluid velocity magnitude in the outer channel show that the effect of slit on the velocity profile is little and the particle transport into the chamber is possible by diffusion through each slit.

Results: Time-dependent concentration distribution

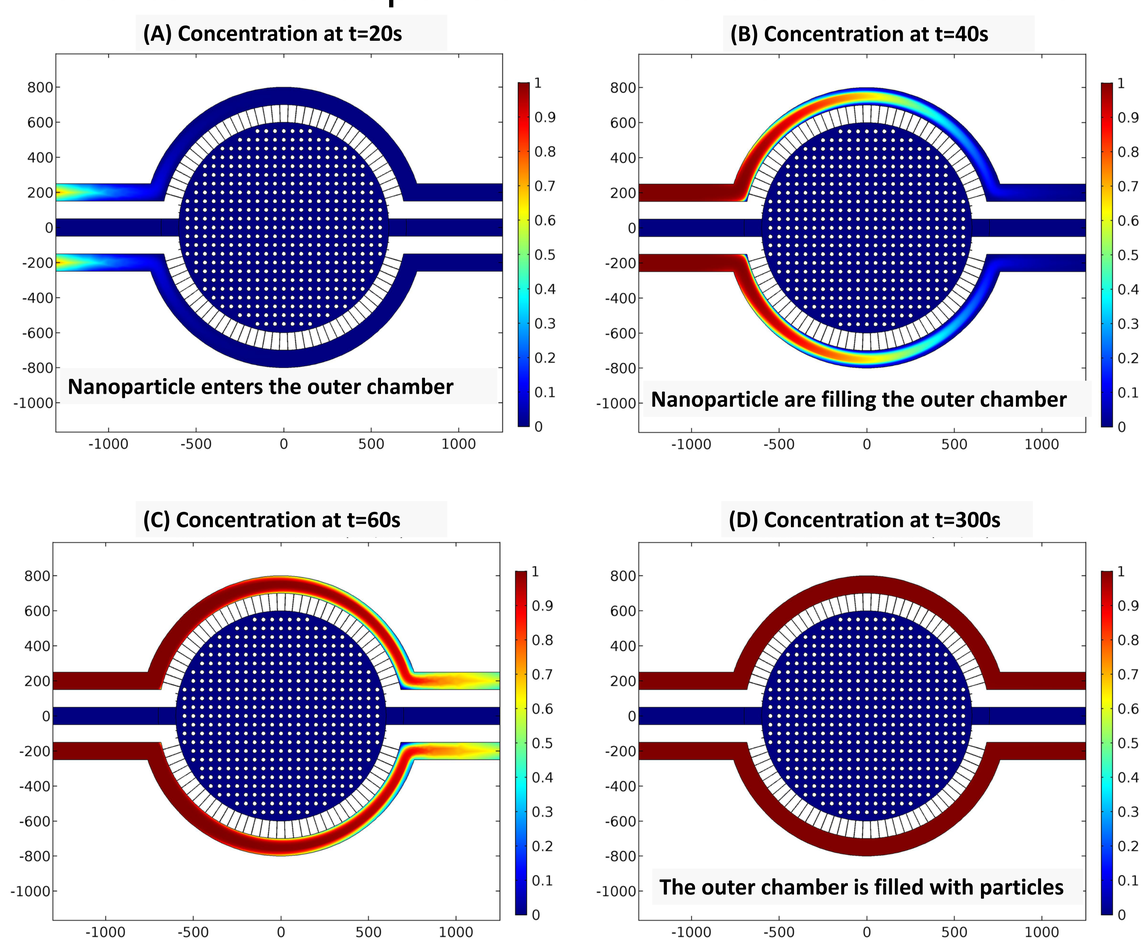

Figure 3. 2D maps of time-dependent concentration distributions for r=100nm: The number of particles which diffused into the tumor chamber is found to be very small for this geometry.

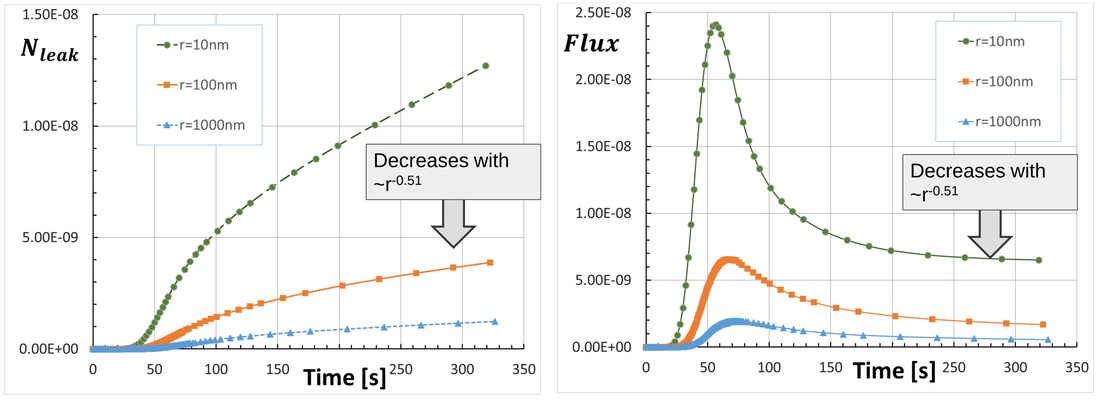

Figure 4. Time-dependent behaviors of (A) N_{leak} and (B) the *Flux* with different particle sizes r=10nm, 100nm, and 1000nm. Flux gradually decreases as the concentration in the slit and the chamber increases. The effect of particle size was found to reduce the particle transport with ~$r^{-0.51}$

Conclusions: This simulation was performed to understand the flow behaviors in the tumor-on-a chip device. The particle flux into the tumor region was found to be very low which indicates the difficulty of drug delivery. All the particle transport behaviors decreased with ~$r^{-0.51}$. Particle geometry (shape) effect in the tumor-cultivated chamber will be investigated in the future.

Acknowledgements: Financial support by the Center for Biomedical Science & Engineering of Missouri S&T

References:

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