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Characterization and Manipulation of Complex Biological/Nano Molecules

***Wing Kam Liu[1]**

[1] Department of Mechanical Engineering
Northwestern University
Evanston, IL 60208, USA
http:// www.tam.northwestern.edu/wkl/**liu**.html

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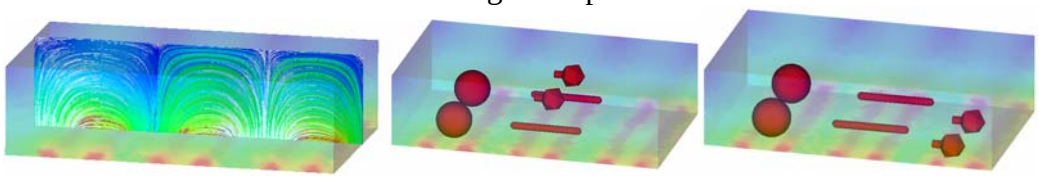
ABSTRACT

The characterization and manipulation of complex biological systems has reached a stage to resolve various levels of details. We briefly outline the immersed electrohydrodynamics finite element method (IEFEM) coupled with multiphysics features for solving a class of bio-nano-fluidics problems. We then apply the multiphysics of the composite electric field for the guided alignment of the nanowires, viruses, and DNA. Preliminary results demonstrate that the proposed IEFEM provides an ideal modeling platform for the modeling of electric field guided assembly of nanowires and multi-physics biological systems, including cell-extra cellular matrix interaction and its application to molecular regenerative engineering.

Cell adhesion to extracellular matrix is a process involved in developmental morphogenesis and pathogenic disorders. The modulation of cell adhesion represents an engineering approach that can be used for scientific research as well as therapeutic treatment of pathogenic disorders. In collaboration with Professor Shu Q. Liu of Northwestern University and Dr. Yan Chun Li of the University of Chicago, we intend to enhance the retention of bone marrow-derived endothelial cell (EC)-like cells by molecular modulation in a matrix-based arterial reconstruction model for preventing thrombosis and intimal hyperplasia, develop an integrated experimentation-computational model to analyze the adhesion properties of the EC-like cells and assess alterations in the adhesion properties in response to molecular modulation, and use the arterial reconstruction model as an example to demonstrate the significance of "molecular modulation of cell adhesion" for improving vascular function.

We are currently using the same simulation-based software to design and fabricate a novel nano-electromechanical sensor for cellular force measurements and selective deposition of viruses and stretching of a DNA molecule. For the first time, three-dimensional assembly of nano/biomaterials of various geometries and electrical properties has been comprehensively studied using the new method. Simulation of the dynamic process of electro-manipulation of individual and multiple cells agrees well with experimental data. The measurements of traction forces and the simultaneous imaging of the fibrous structure of the cell will provide critical input to the simulation of cell motility. We will also describe another IEFEM potential application, the comprehensive understanding of the specific captive mechanism, which is used to predict the appropriate electric field strength, frequency, and flow velocity to screen, separate, and trap a specific virus among several different kinds of viruses. Suppose we know that the sample solution contains the three types of viruses and their electrical properties have already been determined from our experiments. The viruses can be

selectively trapped according to different gap sizes. The below figure shows the trapping process according to the electrical properties and the sizes and shapes, which demonstrates the fundamental working concept of the IEFEM.



(a) (b) (c)

Schematic of capturing of three viruses according to size and electric properties (a) electric field formation (b) trapping process (c) capturing of three viruses (ball, rod, and tailed icosahedral).

The ability to manipulate deformable particles, especially virus particles, is essential to biological and medical applications. Via numerical simulation using IEFEM, the electro-deformation of viral particles and the underlying physics are explored. Furthermore, the virus trapping in complex biological fluid conditions is investigated. For example, virus detection within blood is highly influenced by the complex multiscale and multiphysics factors including the effects of the shear rate dependent blood viscosity, the influence of cell rigidity on blood rheology and the Fahraeus-Lindqvist effect. Bioparticle interaction is an important issue in various physiological phenomena including the recognition of foreign bacteria. It has been found that surface structure and membrane proteins are the key factors in producing adhesive/repulsive forces. Such complex intermolecular forces and protein dynamics can be modeled as a potential, akin to an intermolecular potential. This approach is extended to model both virus interactions and virus substrate interaction. Within the multiscale approach, bioparticle interaction may also be modeled via bonds which form and break according to an empirical statistical law based on molecular dynamic simulation: $P_f=1-exp(-k_{on}\Delta t)$, $P_r=1-exp(-k_{off}\Delta t)$, where P_f is bond formation probability and Pr is bond breaking probability and k_{on} and k_{off} are functions of bond length and temperature. Such ligand-receptor bond forces can be accumulated on the FEM element surface through integration over the virus surface.

REFERENCES

[1] W. K. Liu, E. Karpov, S. Zhang, and H. Park, “An Introduction to Computational Nano Mechanics and Materials,” *Computer Method in Applied Mechanics and Engineering (CMAME)*, 193 (17-20): 1529-1578 2004.

[2] W. K. Liu, Y. Liu, D. Farrell, L. Zhang, X. S. Wang, Y. Fukui, N. Patankar, Y. Zhang et al., "Immersed Finite Element Method and its Applications to Biological Systems," CMAME, 195, 1722-1749, 2006.

[3] Liu, W. K., Karpov, E., and Park, H. S., *Nano Mechanics and Materials: Theory, Multiscale Methods and Applications*, Wiley, 2006.

[4] Y. Liu and W.K. Liu, “Rheology of Red Blood Cell Aggregation in Capillary by Computer Simulation”, *Journal of Computational Physics*, 220 (1), pp 139-154, 2006.

[5] Y. Liu, J. Chung, W.K. Liu, and R. Ruoff, “Dielectrophoretic Assembly of Nanowires”, *Journal of Physical Chemistry B*, 110 (29), pp 14098-14106, 2006.

[6] Y. Liu, W.K. Liu, N. Patankar, and T. Belytschko, “Immersed Electrokinetic Finite Element Method”, *International Journal for Numerical Methods in Engineering,* 71, 379-405, 2007.