Finite Element Modeling of the Electroporation Phenomenon Using microfluidic devices

Rutgers Aresty Research Center for Undergraduates

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Abstract: Electroporation is a technique in which an electric pulse is applied to cells, which generates a membrane potential difference and induces temporal pores in the cell membrane; allowing access for molecular delivery into the intracellular space. However, the task of obtaining efficient delivery without compromising cell viability is crucial when using this technique. A microfluidic platform is a unique way to electroporate flowing cells in an automated and controlled manner while increasing cell viability. Computational models are crucial in the design process, as they can identify a microfluidic and electrical design for optimal results. My role in this ongoing project is to model a microfluidic platform that performs electroporation on blood cell types using COMSOL Multiphysics.

Introduction

- Electroporation is a commonly used non-viral method for the intracellular delivery of biomolecules and therapeutic agents.
- An electric pulse is applied to the cell and induces temporal pores in the cell membrane. Allows access for molecular delivery into the intracellular space.
- With this technique, it is crucial to obtain efficient delivery without compromising cell viability.
- A microfluidic platform allows us to electroporate flowing cells in an automated and controlled environment while maximizing cell viability.
- Computational models are crucial in the design process, as they can identify a microfluidic design for optimal results

Objective: To design a computational model of cell interactions with an electric field and the cell membrane becoming permeabilized when changing the membrane resistance.

Background

- Permeating the plasma cellular membrane for the loading of foreign substances or accessing the intracellular membrane is essential for immunoengineering and cell transfection.
- Electroporation avoids the use of viral material and the cell transaction yield is greater than chemical approaches. However, current protocols of electroporation still suffer from a low success rate when performed in bulk.
- The microfluidic platform solves these issues while enhancing the overall success rate by bringing more control in the process and using less voltage

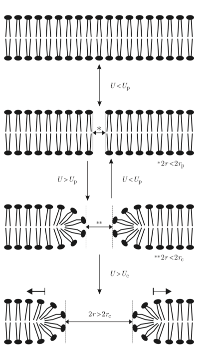

Fig. 1 showing schematic of aqueous pores forming in bi-lipid layer in cell membrane due to electroporation

Methods

- In COMSOL Multiphysics version 5.4, tutorials "Electric Field from a Charged Sphere", " Controlled Micromixer" and "Contact Impedance" allowed us to become acquainted with the functions of the software.

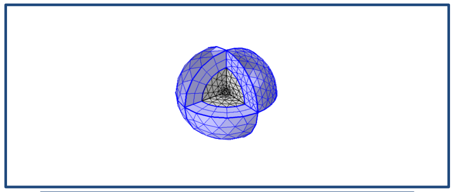

Fig2. Showing Mesh plot of Electric charged sphere done from "Electric Field From A charged Sphere Tutorial"

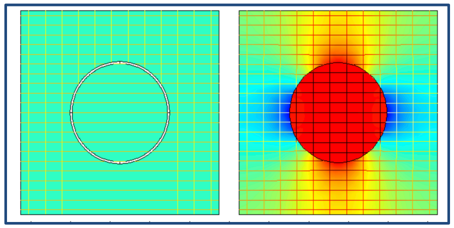

Fig3. Showing Isolines of the voltage field, electric field lines and the current density. Done using "Contact Impedance" tutorial.

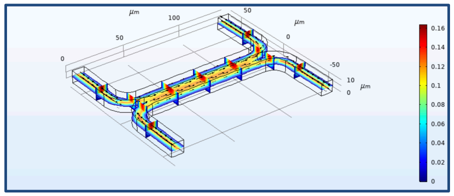

Fig.3 Showing the velocity field where viscosity is concentration independent. Done using " Controlled Micromixer" tutorial

Future Work

- Generate with a 10μm dielectric shell in diameter, and a 5nm thick membrane.
- Apply a voltage to the cell to have a uniform electric field surrounding it of 1 kV/cm. Equation used: $E = \frac{V_{app}}{L}$.
- Electrical properties of COMSOL were used to verify that transmembrane voltage, TMV was equal to the change in voltage applied.
- Equation used: $TMV = \Delta V = \frac{3}{2}ERcos\theta + TMV_{rest}$. Where E is the electric field; R is the radius of the cell (5μm)
- In the cell, the angles were calculated where the TMV was greater than 0.5V to verify that the angle on the cathodic side is greater than the angle on the anodic side.
- It was assumed that the conductivity in the electroporated portion of the membrane is: $\sigma_{m-ep} = 100\sigma_m$. Where σ_m is the conductivity for the cell membrane and σ_e is the conductivity of the external medium.

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- RISE at Rutgers

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