Simulation of Molecular Transport of an Electroporated Cell using COMSOL Multiphysics®

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Introduction: Electroporation is a highly efficient transfection method which is used to inject molecules into cells by creating temporary pores in cell membranes using an electrical field. It has been successfully utilized in applications such as tumor treatments, gene therapy, and cell-based therapy. Here we have used COMSOL Multiphysics® to simulate the molecular transport into a cell during the electroporation. In this calculation, the concentration variation with time was analyzed in- detail using COMSOL.

Computational Methods:

Geometry : Cell was drawn to scale using AutoCAD. Then imported to COMSOL and the rest of the geometry was drawn using COMSOL geometry tools. The geometry was meshed densely with a custom mesh.

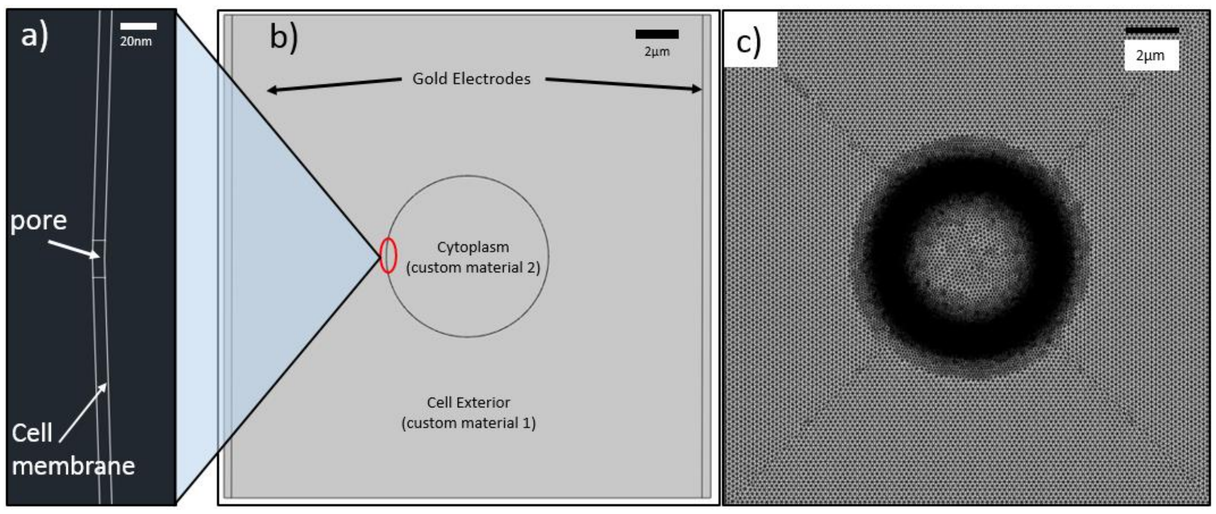


Figure 2. (a) A zoomed view of the geometry near the pore (b) The geometry of the the model in COMSOL (c) User defined Highly dense mesh of the system

Physics and Governing Equations :

Electric currents physics in AC/DC module and the Transport of diluted species physics in Chemical species transport module were used in calculations. Ficks' law combined with molecular migration in electric fields and porous media was used to calculate molecular transport(equation 1).

$$\boldsymbol{R_i} = \frac{\partial \boldsymbol{c_i}}{\partial \mathrm{t}} + \nabla.(-\boldsymbol{D_i}.\nabla \boldsymbol{c_i} - \boldsymbol{z_i}.\boldsymbol{u_{m,i}}.\boldsymbol{F c_i}.\nabla \boldsymbol{V}) \quad (1)$$

$\boldsymbol{R_i}$: Reaction rate expression, $\boldsymbol{c_i}$: Concentration of the solution, $\boldsymbol{D_i}$: Diffusion coefficient, $\boldsymbol{z_i}$: Charge number, $\boldsymbol{u_{m,i}}$: Mobility of molecules, $\nabla \boldsymbol{V}$: Electric field.

Results: The concentration inside the cell was calculated over the time and export in to an animation

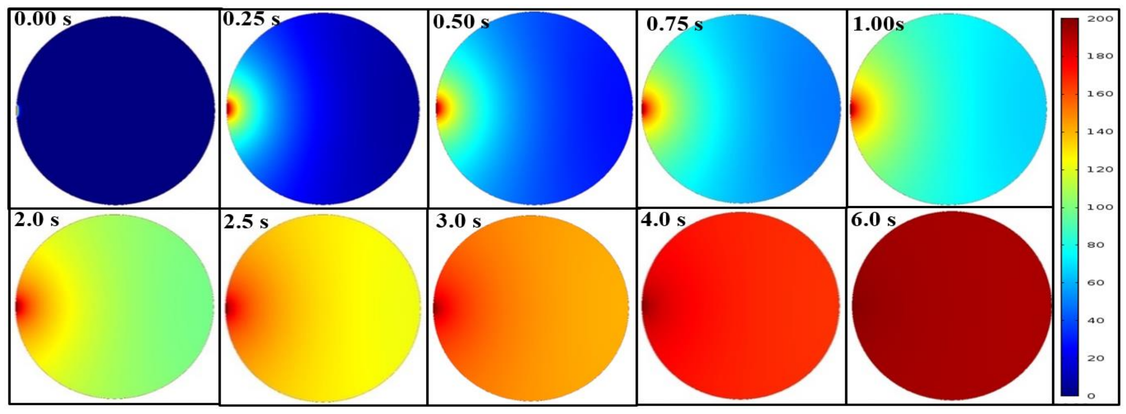
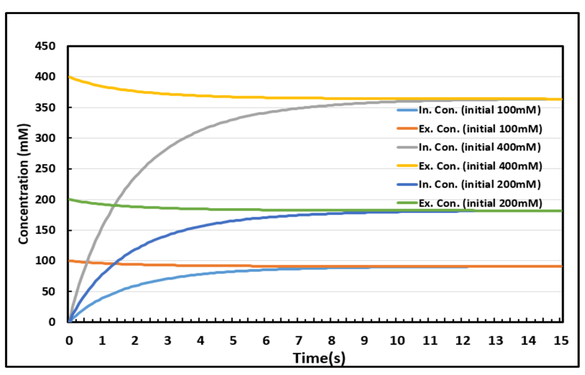


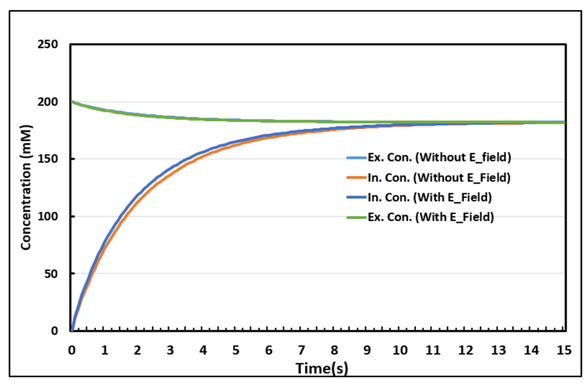
Figure 3. Calculated molecular concentration (mol/cm^3) variation inside the cell with the time (With the initial outside concentration of 200 mol/cm^3)

Then the molecular uptake with different initial concentrations and different electric fields were calculated.



Molecular intake can be controlled by changing the cell exterior concentration or the electroporation pulse width(time)

Figure 4. Concentration variation inside and outside of the cell with different initial extracellular molecular concentrations plot with time)



Molecular intake can be supported by an electric field on top of the diffusion.

Figure 5. Concentration variation inside and outside of the cell with electric filed applied and without applying electric field plot with time

Conclusions: We have designed a simulation model which successfully analyze the molecular uptake in an electroporated cell, with different conditions in electroporation.

References:

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