Simulation Of Molecular Transport Of An Electroporated Cell Using COMSOL Multiphysics®

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Abstract

Electroporation is a highly efficient cellular transfection method which is used to inject molecules into living cells. The electroporation involves creating temporary pores in cell membranes using an electrical field. It has been successfully utilized in medicine and biology for producing knockout mice, gene therapy, and cell-based therapy. As electroporation is an easy and rapid method, it is able to transfect large number of cells in a short time, once optimum electroporation conditions are determined. Major drawbacks in the current state-of-art electroporation techniques are substantial cell death caused by high voltage pulses and not having control over the molecular intake per pulse. To address those issues, we are proposing a method to control/monitor the exact molecular intake by controlling the concentration of the molecules suspended in the electroporation solution and manipulating the electric field, while keeping the cells viable.

As a first step, we have used COMSOL software to calculate the variation in molecular intake with time. Here, we modeled a cell with a diameter of 7µm and 5nm thick cell membrane with a pore of 20nm radius (represent average area of all the pores) in the membrane and the cell was placed in between two parallel electrodes producing an electric field of 3kV/cm. First, the simulation model was drawn to scale using AutoCAD software and imported into COMSOL software. Both AC/DC module and the Electrochemistry module were used as physics and the time domain analysis was conducted. Transport mechanisms including convection, migration in electric field, and migration through porous media were considered and two physics equations were linked to take the applied electric field into calculations in transport mechanisms. Then the geometry was meshed using a custom mesh size with minimum element size of 0.5nm to obtain accurate results as the minimum geometry size is 5nm. After setting all the required parameters and boundary conditions, the COMSOL simulation was performed and the molecular concentration of the cell interior was calculated and plotted with the time. "Figure 1" indicate the results.

From the simulation results, it is concluded that, with the initial concentration of 200 mol/cm3 in the molecular suspension it takes about 7 seconds to come to an equilibrium concentration in cell interior and exterior. As we have an interval around 15~20s before pores reseal completely in electroporation maintaining the above concentration will ensure that the interior of the cell will come to the same concentration of the respected molecule compared to the exterior solution.

Figures used in the abstract

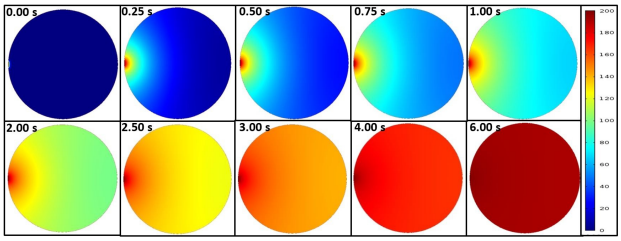

Figure 1 : Fig. 1. Simulation results of Molecular concentration (mol/cm3) variation inside the cell with the time using COMSOL software (With the initial outside concentration of 200 mol/cm3.)