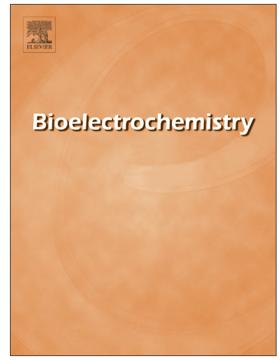
Accepted Manuscript



Numerical study of the effect of soft layer properties on bacterial electroporation

Jeffrey L. Moran, Naga Neehar Dingari, Paulo A. Garcia, Cullen R. Buie

PII: S1567-5394(17)30457-7
DOI: doi: 10.1016/j.bioelechem.2017.09.004
Reference: BIOJEC 7049

To appear in: *Bioelectrochemistry*

Received date: 2 December 2015
Revised date: 7 September 2017
Accepted date: 7 September 2017

Please cite this article as: Jeffrey L. Moran, Naga Neehar Dingari, Paulo A. Garcia, Cullen R. Buie , Numerical study of the effect of soft layer properties on bacterial electroporation, *Bioelectrochemistry* (2017), doi: 10.1016/j.bioelechem.2017.09.004

Numerical Study of the Effect of Soft Layer Properties on Bacterial Electroporation

Jeffrey L. Moran[1,2]*, Naga Neehar Dingari[1]*, Paulo A. Garcia[1]*, and Cullen R. Buie[1]§

(* denotes equal contribution)

(§ denotes corresponding author. Email: crb@mit.edu)

[1]*Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139*

[2]*Department of Nuclear Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139*

Keywords

Microorganisms; Finite-element method; Soft particle electrokinetics; Pore radius dynamics; Gram-positive bacteria.

Abstract

We present a numerical model of electroporation in a gram-positive bacterium, which accounts for the presence of a negatively charged soft polyelectrolyte layer (which may include a periplasmic space, peptidoglycan layer, cilia, flagella, and other surface appendages) surrounding its plasma membrane. We model the ion transport within and outside the soft layer using the soft layer electrokinetics-based Poisson-Nernst-Planck formalism. Additionally, we model the electroporation dynamics on the plasma membrane using the pore nucleation-based electroporation formalism developed by Krassowska and Filev [1]. We find that ion transport within the soft layer (surface conduction), which depends on the relative importance of the soft layer charged group concentration compared to the buffer concentration, significantly alters the transmembrane voltage across the plasma membrane and hence the pore characteristics. Our numerical simulations suggest that surface conduction significantly lowers the pore number in the plasma membrane. This observation is consistent with experimental studies that show that gram-positive bacteria, in general, have lower transformation efficiencies compared to gram-negative bacteria. Our studies highlight a strong dependence of bacterial electroporation on cell envelope properties and buffer conditions, which need to be taken into consideration when designing electroporation protocols.

Introduction

Electroporation subjects cells to strong (~kV/cm), short (~μs-ms) pulsed electric fields that are of sufficient strength to disrupt the plasma membrane. This disruption, which can be either transient or permanent, renders the membrane permeable to exogenous materials, and for this reason electroporation is a widely-used technique to insert molecules into the cytoplasm of cells [2–7]. The technique finds application in such diverse areas as cell transfection, drug delivery, gene and cancer therapy, synthetic biology, stem-cell research, and many others [8].