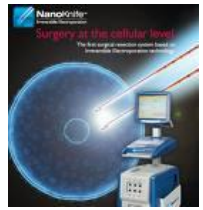
Electric Fields Distribution in Heterogeneous Tissues Under Electroporation: Numerical Modeling Using QuickField Package

Alexander Golberg, PhD
Center for Engineering in Medicine
Massachusetts General Hospital

Content

- Historic overview on pulsed electric fields in biotechnology and medicine
- Fundamentals of membrane electropermeabilization
- Applications of electroporation in biotechnology and medicine
- Application of QuickField for pulsed electric field distribution modeling in rat skin



Rubinsky and Davalos applied IRE for tissue ablation

Mir applied reversible electroporation for cancer tumor killing

Neumann first application of PEF for gene transfer

Pioneering work of Doevenspeck, followed by fundamental research by Sale and Hamilton on PEF in food

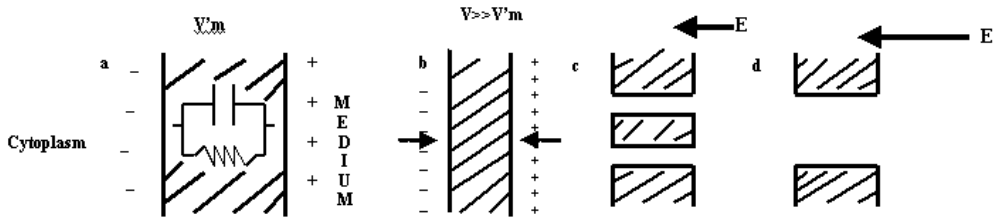
"Electropure" process for milk treatment

Nollet observed red spots on skin exposed to electric field

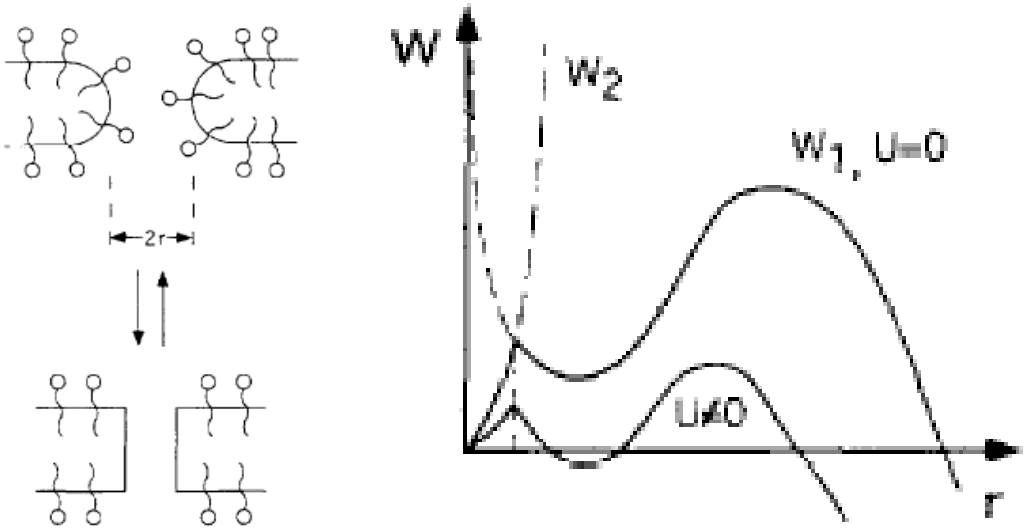
End 18th century | 1920-30 | 1960-70 | 1980-1990 | 2000-today

Fundamentals of Electroporation

$$\Delta\varphi_m = -1.5 \cdot E \cdot f(\sigma) \cdot a \cdot \cos\theta$$

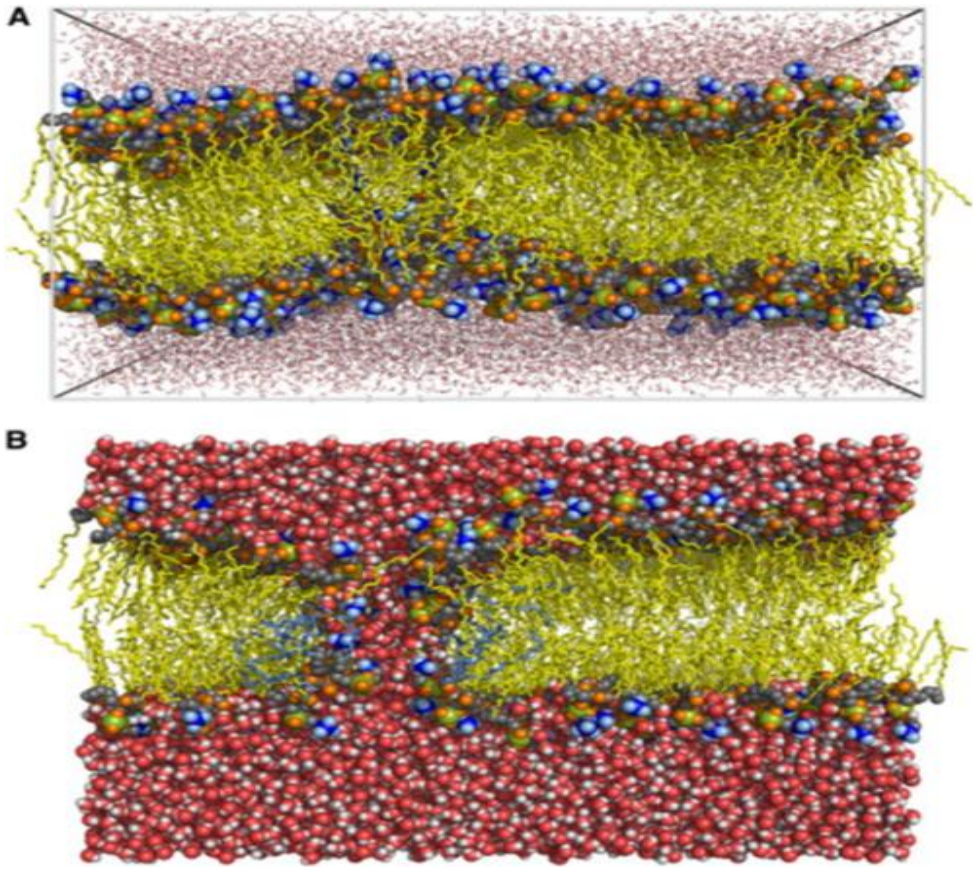


Zimmerman, 1979

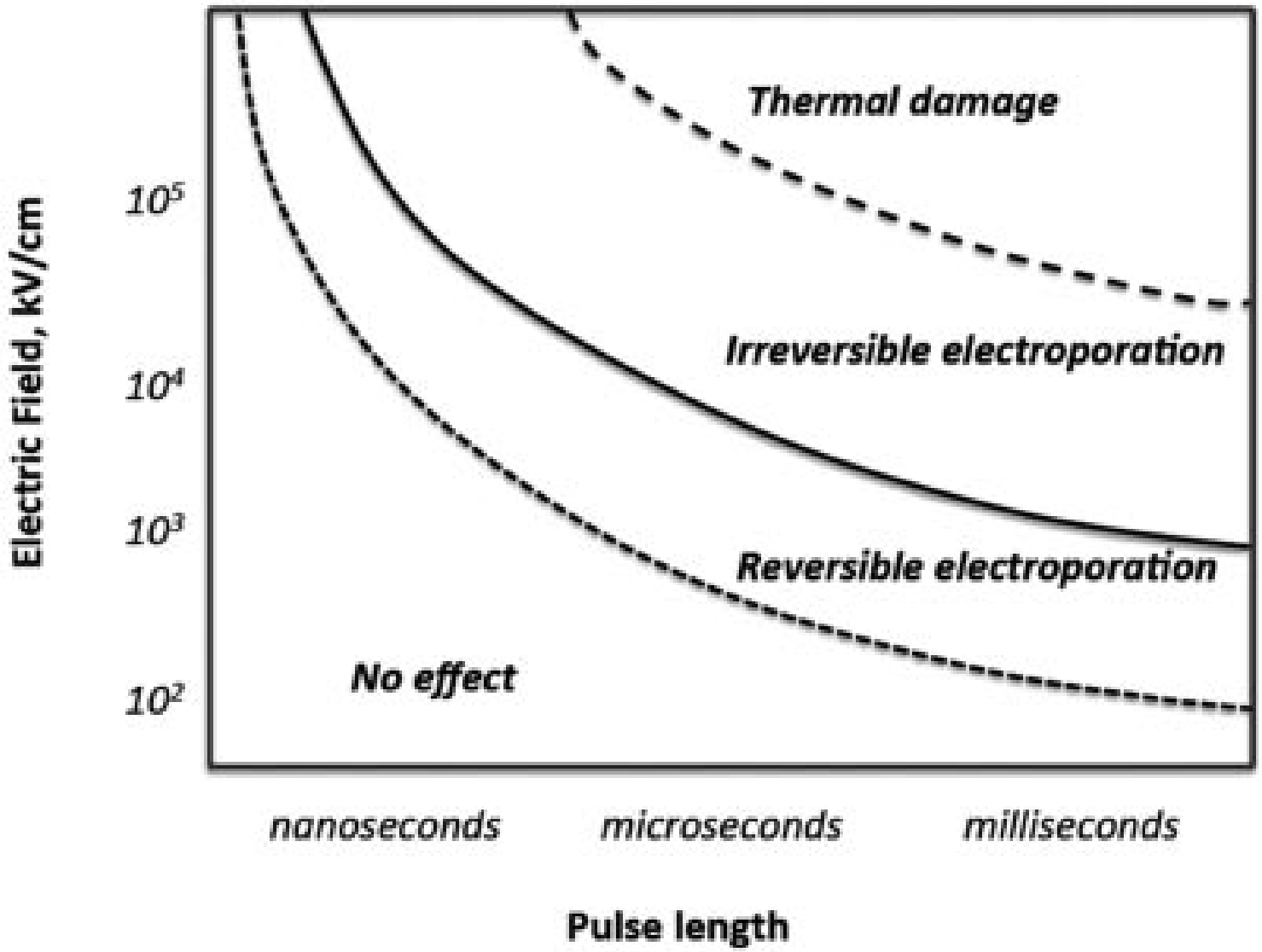


Weaver & Chizmadzhev, 1996

Multimolecular Stimulations

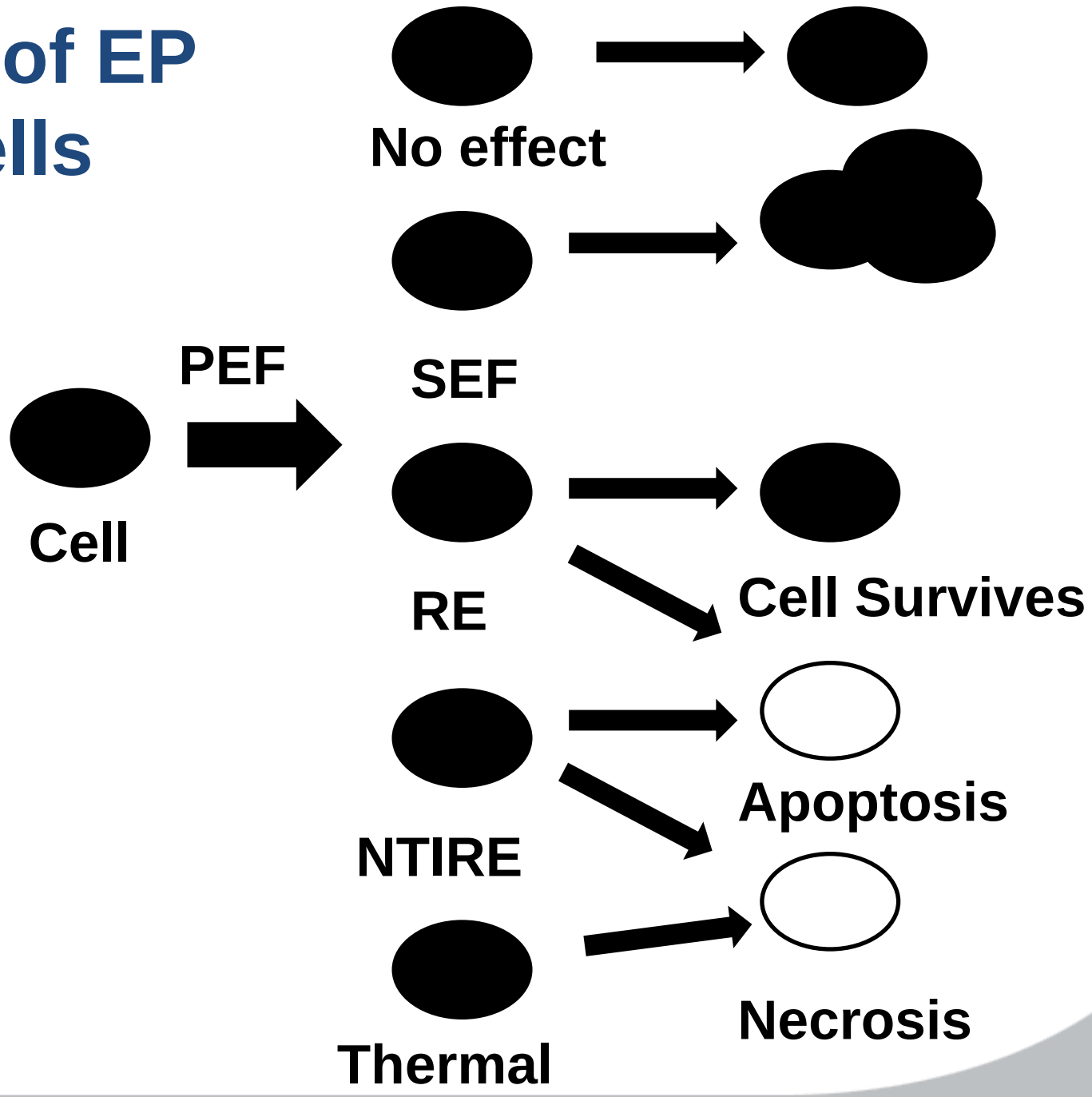


Bockman et al., 2008

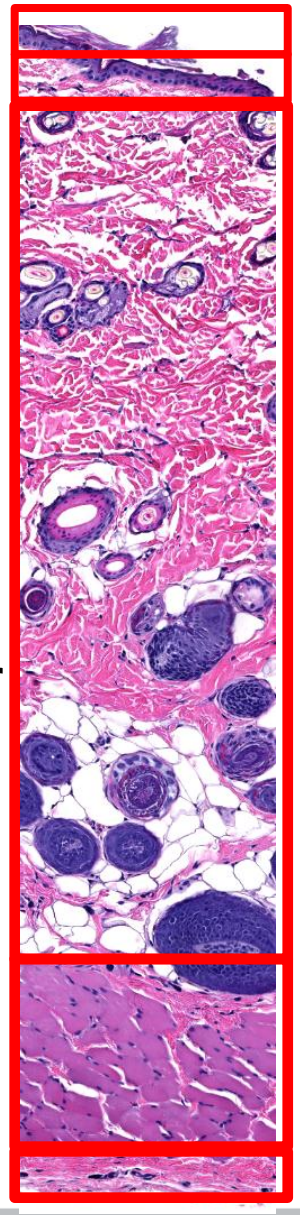


Fernand et al., 2008

Impacts of EP on Cells



Skin is a very complex tissue, even for electric fields distribution



	Before EP	After EP
Stratum Corneum	0.0000125 S/m	1 S/m
Epidermis	0.2 S/m	0.8 S/m
Dermis	0.2 S/m	0.8S/m
Muscle	0.4 S/m	1 S/m
Subcutaneous tissue	0.02 S/m	0.2S/m

Need for numerical solutions QuickField

References

Weaver J.C and Y. A. Chizmadzhev,(1996),Theory of electroporation: A review,
Bioelectrochemistry and Bioenergetics, 41(2), pp 135-160

Krassowska W and P. D. Filev,(2007),Modeling electroporation in a single cell, Biophysical Journal, 92(2), pp 404–417

Granot Y and B. Rubinsky,(2008),Mass Transfer Model for Drug Delivery in Tissue Cells with Reversible Electroporation,
International Journal of Heat and Mass Transfer, 51(23-24), pp 5610-5616

Böckmann, R.A, B. L. de Groot, S. Kakorin, E. Neumann, and H. Grubmüller,(2008),Kinetics,
Statistics, and Energetics of Lipid Membrane Electroporation Studied by Molecular Dynamics Simulations,
Biophysical journal, 95(4), pp 1837-1850

Golberg, A. and B. Rubinsky, "A statistical model for multidimensional irreversible electroporation cell death in tissue,"
BioMedical Engineering OnLine, vol. 9:13, doi:10.1186/1475-925X-9-13, 2010

Golberg, A. and B. Rubinsky," A numerical study towards electroporation based treatment planning considering muscle contraction,"
Technology in Cancer Research and Treatment, vol. 11(2):189-201, 2012.

Francois F, Rubinsky L, Golberg, A and B Rubinsky, "Variable Electric Fields for High Throughput Electroporation Protocol Design,"
Biotechnology and Bioengineering, vol. 109(8): 2168-2171, 2012.

Golberg, A and Yarmush M.L. "Nonthermal Irreversible electroporation: Fundamental, Applications, Challenges,"
IEEE Transactions on Biomedical Engineering, vol. 60 (3):707-14, 2013