Numerical modeling of coupled physical phenomena C2

Nataša Pavšelj
University of Ljubljana, Faculty of Electrical Engineering

Duration of experiment: appr. 45 min
Maximal number of participants: 4
Location: Laboratory of Biocybernetics
Level: advanced

PREREQUISITES

Basic to advanced knowledge of finite element modeling is required.

THEORETICAL BACKGROUND

The effects of various physical phenomena can be investigated by separately analyzing each individual phenomenon, with no respect to interaction between them. However, often we are dealing with two or more interacting, simultaneously occurring phenomena, such as heat transfer in tissue due to resistive heating. This coupling may give rise to tissue conductivity changes (due to temperature increase), which in turn changes the magnitude of electric current. When constructing a model, we have to estimate such interactions and, if needed to obtain accurate results, include mutual dependencies. To do so, we need data on how the material properties significant for one field (such as the electric field) vary with the value of another field (such as temperature) and vice versa.

Conduction heating of a material is described by the following equation:

$$\rho c \frac{\partial T}{\partial t} - \nabla(k \nabla T) = Q , \qquad \text{where}$$

T is the temperature, ρ is the material (tissue) density, c is the specific heat capacity of the tissue, k is its thermal conductivity, and Q is the heat source, in our case the resistive heating of the material:

$$Q = \sigma \left|\nabla V\right|^2 , \quad \text{where}$$

σ is electrical conductivity of the material and V is electric potential.

The aim of the experiment is to become familiar with multiphysics modeling and to evaluate the rise in tissue temperature during the application of different electric pulses. Also, we would like to demonstrate the usefulness and necessity of such numerical models for the planning of experiments and treatments as well as the analysis of the results.

EXPERIMENT

Current trends show increased interest in the field of intra- and transdermal drug delivery. However, physical or chemical methods to enhance transdermal drug delivery have to be used in order to temporarily increase skin permeability. One of the possibilities to temporarily breach the barrier function of skin is using high voltage direct current electric pulses (electroporation) to create aqueous pathways across lipid-based structures. It has been shown that molecular transport, following skin electroporation is generally localized to small areas, termed local transport regions (LTRs).

The application of electric pulses on skin will be investigated on a finite element numerical model of a local transport region and its surroundings, constructed in COMSOL Multiphysics (COMSOL AB, Sweden). The LTR will be modeled as a conductive structure in the otherwise highly resistive *stratum corneum*. Local transport regions are formed as a result of the application of electric pulses on skin and are expanded by resistive heating caused by high local current density occurring because of the drop in the resistivity of the *stratum corneum* inside the LTRs. The thermal origin of LTR formation also raises concerns regarding skin recovery issues after being exposed to electric pulses. Namely, when the temperature of around 70˚C is exceeded, structural changes occur.

Protocol: Evaluate this temperature increase by coupling the electrical and the thermal quantities, for different parameters of electrical pulses.

In the first part of our work, experiment with different amplitudes and lengths of a single electric pulse to estimate the temperature increase within the duration of one pulse.

In the second part, use trains of pulses, with intervals between them when there is no current flow. During these periods, the cooling of the tissue takes place, which should be taken into account during the simulation. Evaluate different pulse parameters, together with pulse repetition frequency.

FURTHER READING:

Vanbever R, Pliquett UF, Préat V and Weaver JC. Comparison of the effects of short, high-voltage and long, medium-voltage pulses on skin electrical and transport properties. *Journal of Controlled Release* 69: 35-47, 1999.

Pliquett U and Gusbeth C. Surface area involved in transdermal transport of charged species due to skin electroporation. *Bioelectrochemistry* 65: 27-32, 2004.

Pliquett U, Gallo S, Hui SW, Gusbeth C and Neumann E. Local and transient structural changes in stratum corneum at high electric fields: Contribution of joule heating. *Bioelectrochemistry* 67(1): 37-46, 2005.

Pavšelj N and Miklavčič D. Numerical models of skin electropermeabilization taking into account conductivity changes and the presence of local transport regions. *IEEE T. Plasma Sci.* 36: 1650-1658, 2008

Becker SM and Kuznetsov AV. Thermal in vivo skin electroporation pore development and charged macromolecule transdermal delivery: A numerical study of the influence of chemically enhanced lower lipid phase transition temperatures. *International Journal of Heat and Mass Transfer* 51: 2060-2074, 2008

NOTES & RESULTS