Optimizing Performance of Equipment for Thermostimulation of Muscle Tissue Using COMSOL Multiphysics

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Abstract

Thermostimulation is a combination therapy which involves the use of heat therapy and electrical stimulation simultaneously. In thermostimulation, electrical stimulation is typically done by applying a current at the surface of the body. This leads to stimulation of nerves and/or muscles when the electric field at the nerve/muscle cell location inside the muscles is above a certain threshold. The stimulation is combined with heating, typically applied to the muscle tissue by using heat pads or heat wires at the skin surface. The design challenge for thermostimulation equipment is to get a combination of high enough electric field strength and temperature within the muscle tissue without causing pain or skin burns. In the present work, COMSOL Multiphysics is used to simulate the temperature distribution and electric field distribution within body tissue for varying body composition and varying design parameters of the thermostimulation equipment. Use of COMSOL Multiphysics: The AC/DC Module is used for the electromagnetic (EM) simulations and the Heat Transfer Module is applied for the heat simulations. The body tissue in the COMSOL models is modelled as a layered structure, consisting of a bone layer, a muscle layer, a fat layer and a skin layer. Electrodes, heat pads and conductive gel are modeled as separate layers on top of the skin layer. Both 3D and axisymmetric models are considered. COMSOL LiveLink™ for MATLAB® is used in order to do script based parametric analysis, sensitivity analysis and iterative optimization from MATLAB®. Results: Heating simulations have been done for varying fat layer thicknesses in order to investigate how the body composition influences the final muscle temperature and the heating time. The simulations show significant variation of both heating time and final temperature with fat layer thickness (Figure 1). This shows how one must adjust the time needed for preheating of a patient before starting muscle stimulation according to the patient's body composition. It was also found that in order to get even temperature distribution in the muscle tissue, the heat wire separation is more critical than expected (Figure 2), and thus the heat wire separation should be held as small as possible. Regarding the electrical stimulation part of thermostimulation equipment, one interesting question is the conductivity of the stimulation electrodes. From a production point of view, low conductivity electrodes are advantageous. However, low conductivity of the stimulation electrodes has significant negative effect on the distribution of the electric field within the muscles (Figure 3). In the present work a minimum recommended electrode conductivity is found from doing a series of simulations with varying electrode conductivity. Another topic of interest is how

leakage of stimulation gel influences the stimulation effect in the muscle tissue. The present simulation results show how small amounts of gel leakage can lead to significant focusing of the electric field in certain regions (Figure 4). Conclusions: The present work has shown how the multiphysics approach gives information regarding design choices for thermostimulation equipment, and relative effectiveness of thermostimulation equipment for patients with different body composition.

Figures used in the abstract

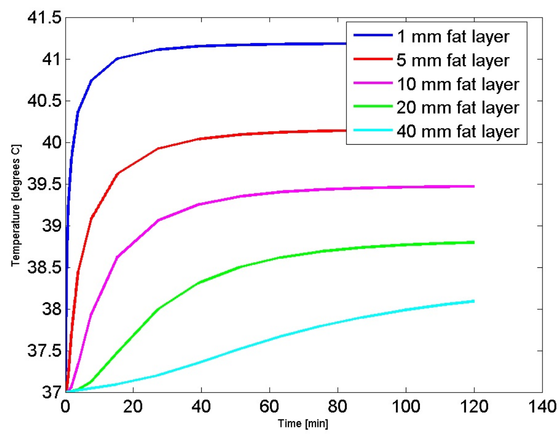

Figure 1: Temperature variation as a function of time at muscle/fat layer interface as a function of time for fat thicknesses of 1- 40 mm.

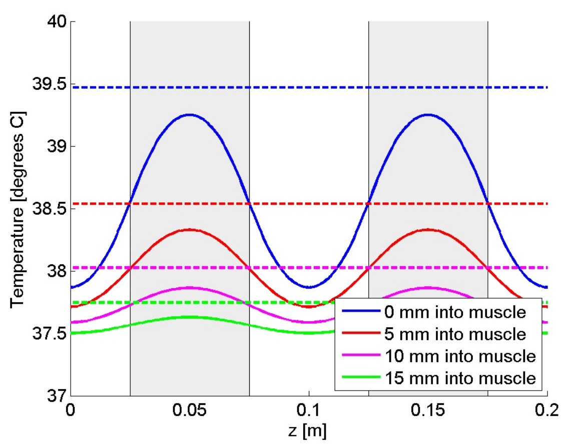

Figure 2: Heat distribution along the length of model at the fat layer/muscle layer interface and at three different positions in the muscle tissue. Solid lines is for the case with heat wire spacing of 10 mm. Dotted lines are for uniform electrodes.

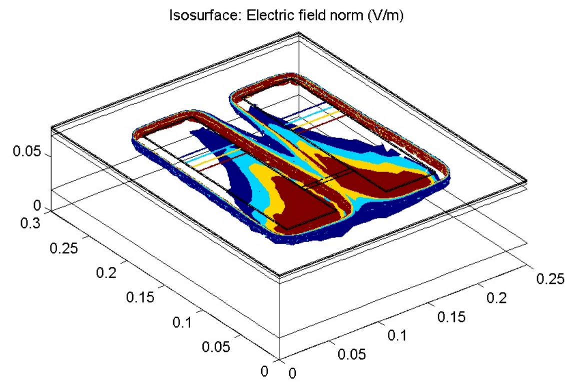

Figure 3: 3D isosurface plot of the electric field in the tissue for the case of electrode conductivity of 10 S/m. Isosurfaces are plotted for electric field values of 10, 12, 14, and 16 V/m.

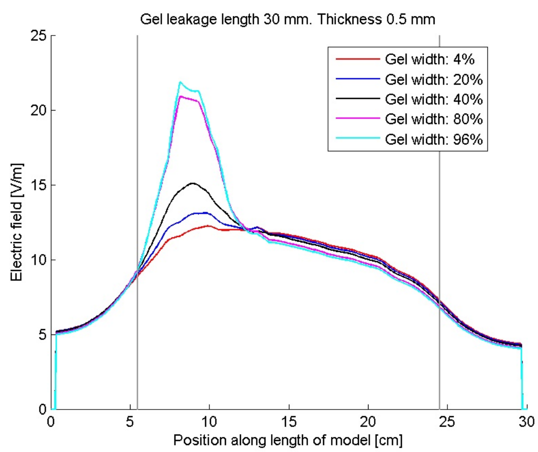

Figure 4: Variation of electric field in the muscle tissue with amount of gel leakage.