Modeling Electrical and Thermal Conductivities of Biological Tissue in Radiofrequency Ablation

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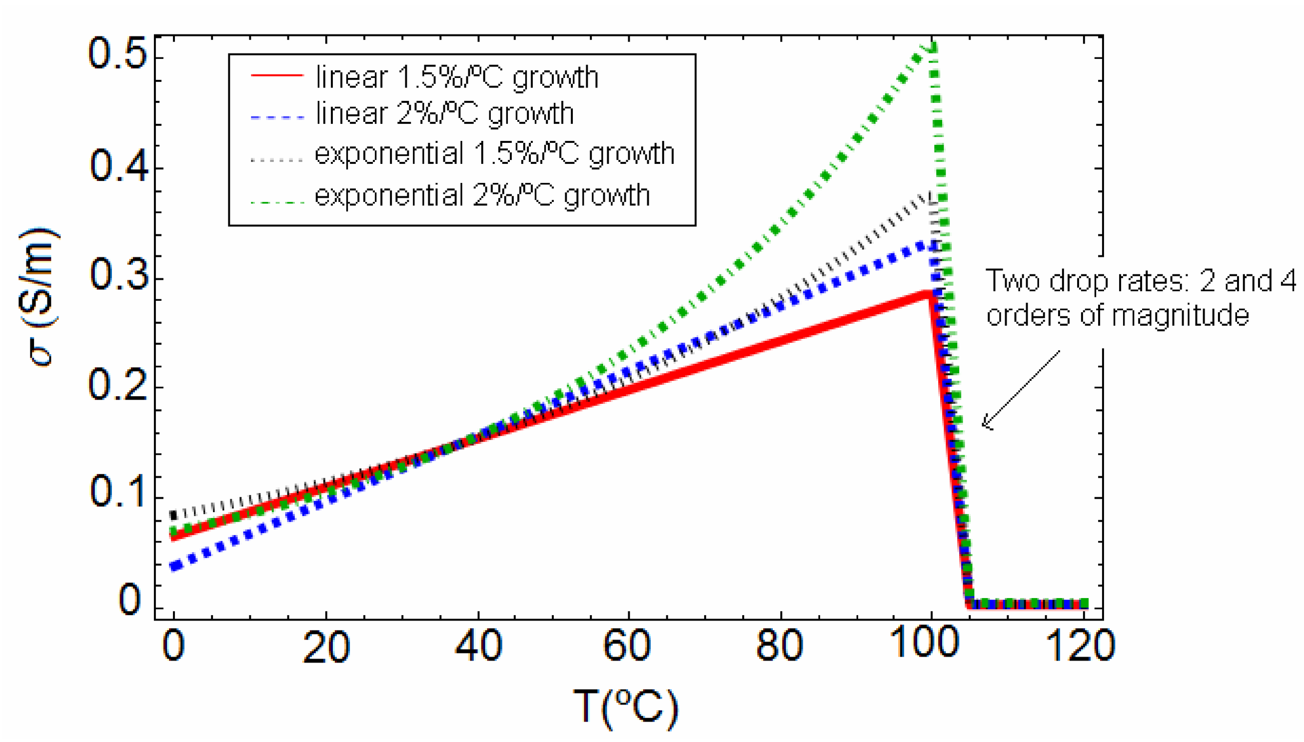
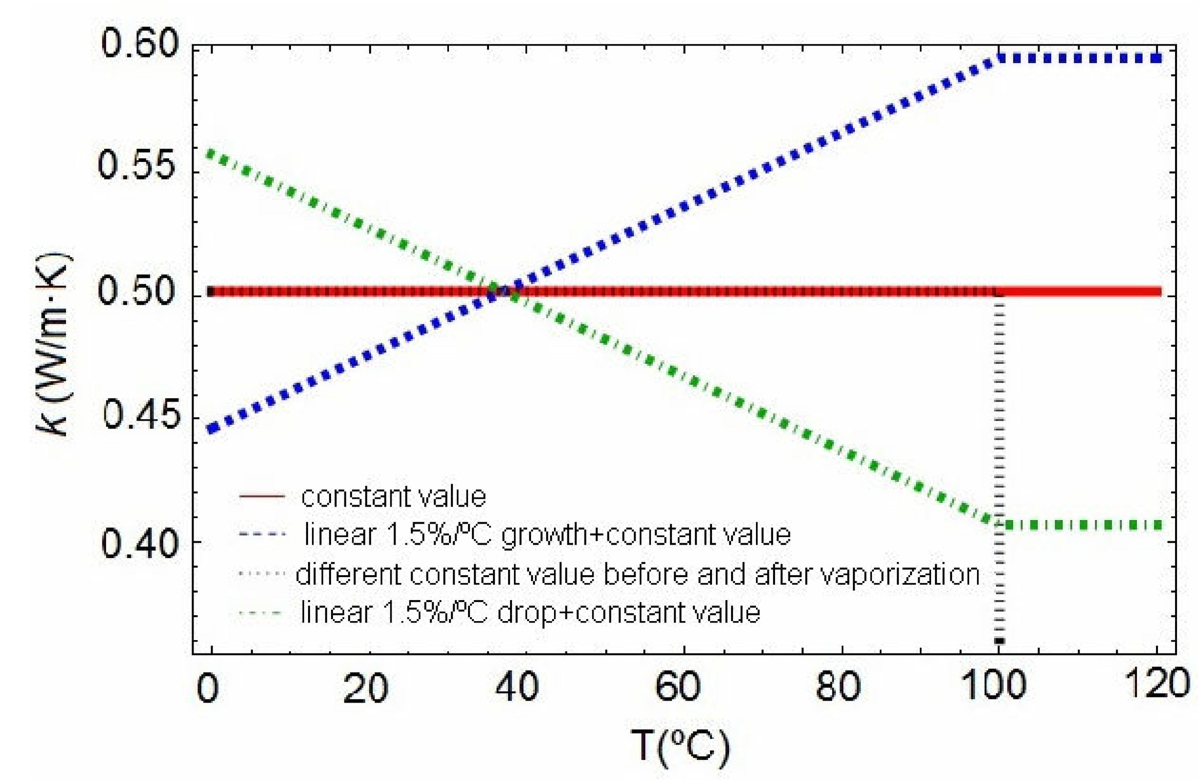
INTRODUCTION

Radiofrequency ablation (RFA) is a minimally invasive technique used to treat some kinds of cancer. In RFA electrical currents (≈500 kHz) are employed to heat the target biological tissue over 50ºC. Theoretical modeling is a usual method to study the biophysics of RFA. However, it is necessary that models are realistic to obtain meaningful results. The mathematical functions used to model the temperature-dependence of electrical (σ) and thermal (k) conductivities are one of the most important factors which influence the realism. At the literature we found different ways to model this dependence. The question was: The use of different mathematical functions to model the temperature dependence of σ and k produce great variations in results? Our objective was to answer this question.

FUNCTIONS TO MODEL THE TEMPERATURE DEPENDENCE OF ELECTRICAL AND THERMAL CONDUCTIVITIES

We focused our attention in the most usual piecewise mathematical functions employed to model the temperature dependence of σ and k. These figures represent the kind of functions used to model σ and k.

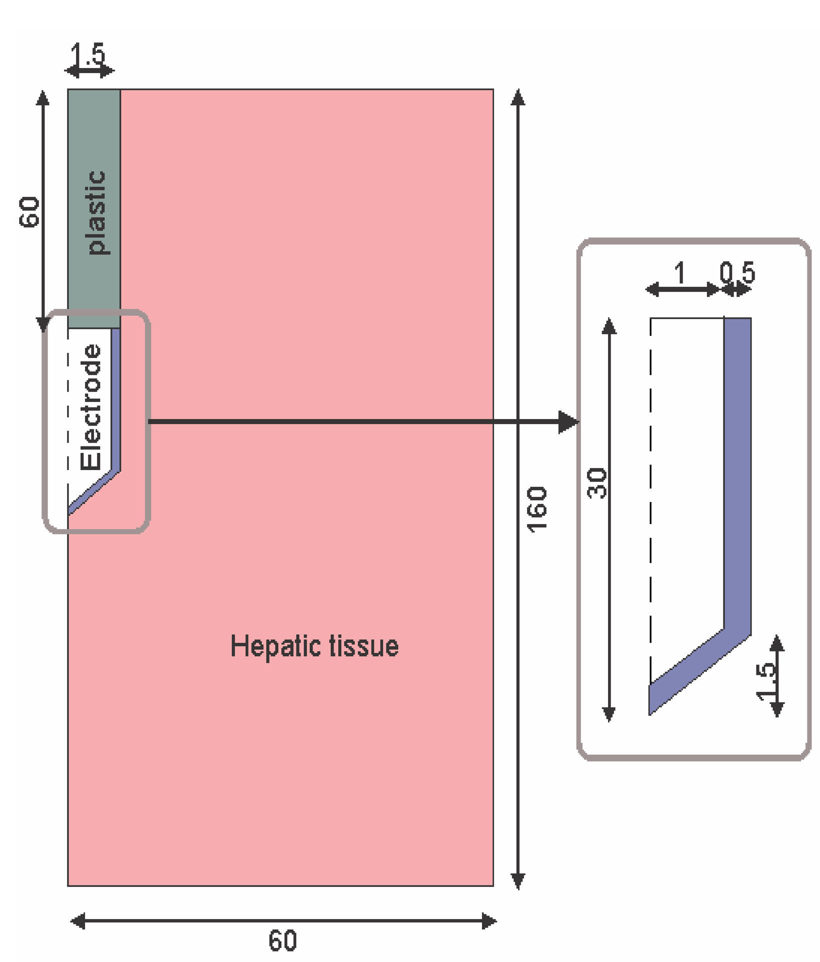




RFA MODELING WITH COMSOL MULTIPHYSICS

To compare the effect of the different combinations of the mathematical functions, we considered a theoretical radiofrequency hepatic ablation model which consisted of a fragment of hepatic tissue and an internally cooled electrode. The model was based on a coupled electric-thermal problem, which was solved numerically using COMSOL Multiphysics.

GEOMETRY



GOVERNING EQUATIONS

Laplace Equation

$$\nabla \cdot \sigma \nabla V = 0$$

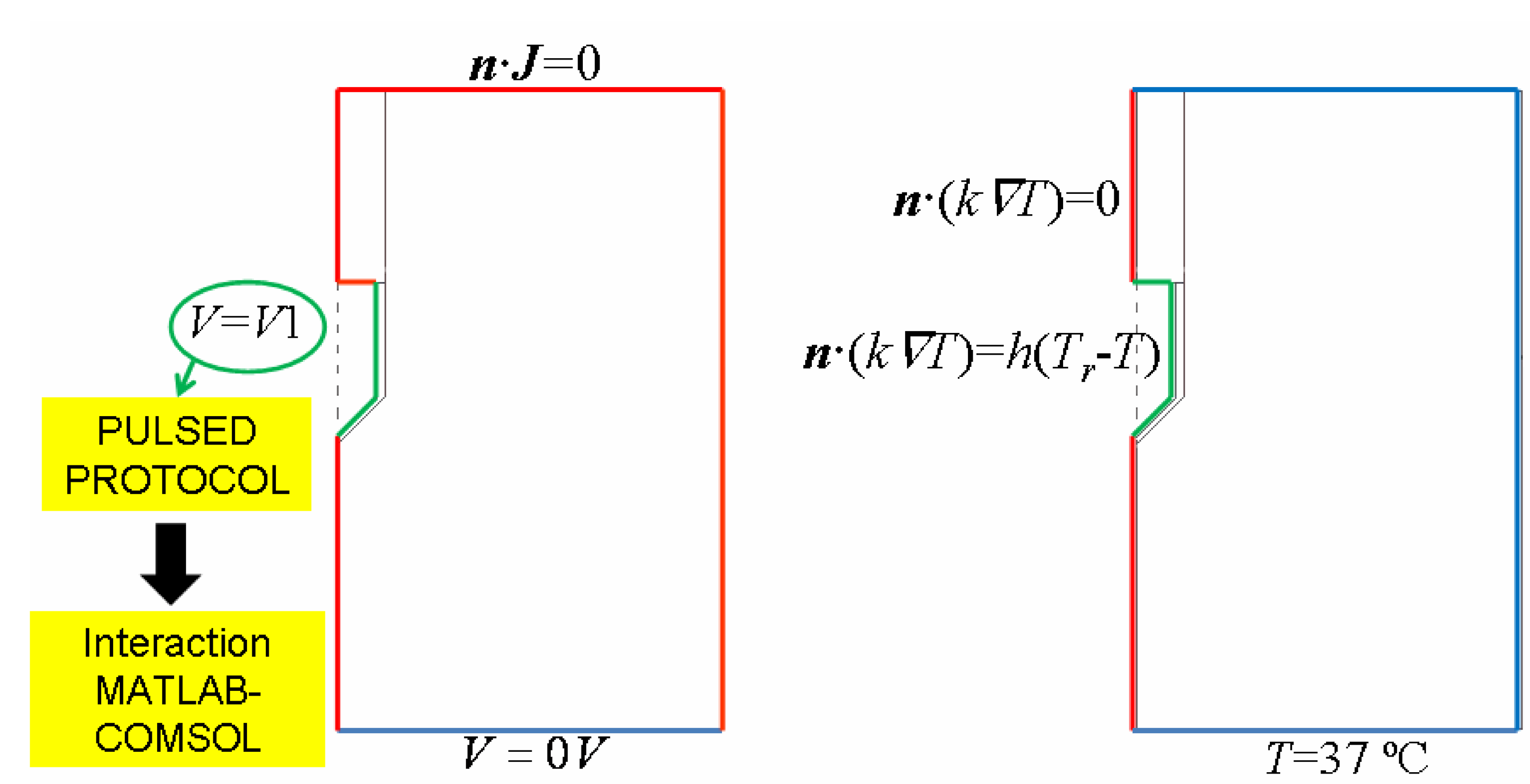
Bioheat Equation & Enthalpy Method

$$\frac{\partial(\rho h)}{\partial t} = \nabla(k\nabla T) + q + Q_p$$

$$Q_p = \beta \rho_b c_b \omega_b (T_b - T)$$

$$\beta = \begin{cases} 0 & \Omega \geq 1 \\ 1 & \Omega < 1 \end{cases} \qquad \Omega(t) = \int_0^t A e^{\frac{-\Delta E}{RT}} dt$$

BOUNDARY CONDITIONS



RESULTS

We obtained the lesion size evolution for the 32 cases considered. More specifically, we are interested in the value of the lesion short diameter a (transverse diameter). For cases in which only σ varied the maximum difference found in all cases was 6% between cases at ≈220 s and only 3.5% at 6 minutes. We show in figure 1 the results for cases 1-4, in which k was constant, σ growth was modeled according to all cases considered and a σ drop of 2 orders. Differences are negligible between all the cases considered for k.

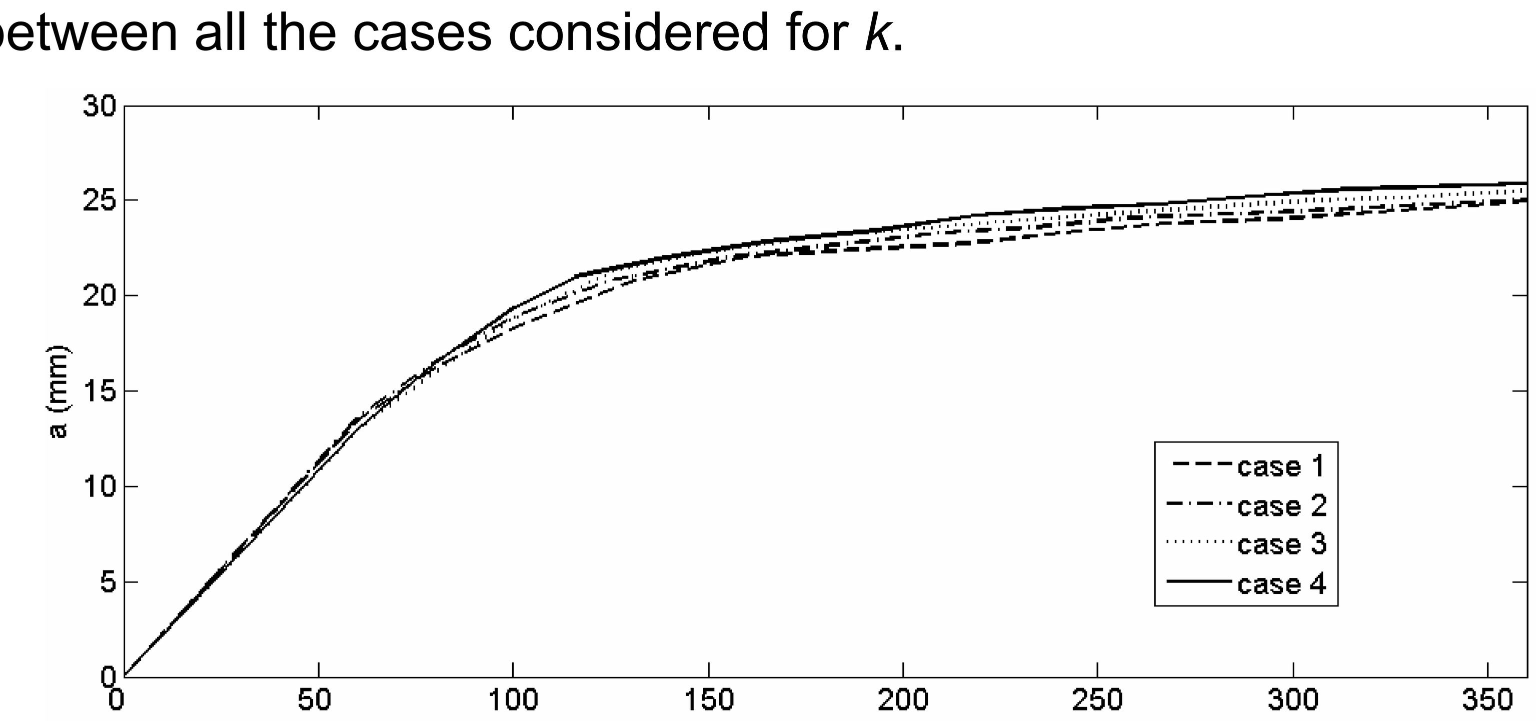


Figure 1. Evolution of the lesion short diameter (a) throughout 360 s for cases 1 to 4.

CONCLUSIONS

In RFA the temperature dependence of σ below 100°C can be modeled equally well either by using a linear or exponential increase or an increase rate of between +1.5%/°C and +2%/°C and above 100°C can be modeled equally well by using an abrupt drop of either 2 or 4 orders of magnitude between 100°C and 105°C. In the context of this study, the term "equally" means that the computed lesion short diameter after 6 minutes ablation differs by less than 3.5%.

The temperature dependence of k can be ignored and hence a constant value can be used.

Our aim was not to choose the most suitable function to represent the temperature-dependence of σ and k, which would need additional experimental studies outside the scope of this work.

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