Radio Frequency Tissue Ablation Simulation with COMSOL Multiphysics® Software

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Abstract

Radiofrequency (RF) tissue ablation is commonly used to treat medical conditions involving dysfunctional tissue especially in the heart, kidneys, lungs, bones, or liver. An electrode at the tip of a catheter delivers high frequency current (350-500 kHz) to the targeted tissue causing it to heat and then ablate without disturbing the electrical signals of the nervous system or heart, and with minimal impact to neighboring healthy tissue.

We developed a COMSOL Multiphysics® software model of a monopolar RF ablation procedure where tissue is close to a blood vessel (see Figure 1). The model includes electric and heat transfer physics and fluid flow in the blood vessel. The geometry and loading in this model are altered from actual values used in products but the simulation approach, challenges and sensitivities discussed below are not affected by this change.

The thermal and electric fields are coupled due to the thermal dependence of the electric conductivity and the contact impedance between electrode and tissue. The electric field problem is a frequency domain harmonic analysis, and the heat transfer problem is a transient time-domain analysis. We set up the fluid flow analysis to be decoupled from the thermal-electric physics. We applied a constant voltage for a 20 second duration and continue the simulation for an additional 10 seconds to simulate the initial part of the cooling stage. We used the built-in scalar evolution equation in COMSOL to track the damage evolution throughout the tissue. We selected thermal and electric properties of muscle tissue, including their variation with time based on Ref. [1] and references therein.

Figure 2 shows the blood flow and blood and tissue temperatures 15 seconds into the simulation. The non-symmetric temperature field in the blood and to a lesser extent the tissue shows the importance of explicitly modeling the blood fluid flow in this problem. Figure 2 also shows that the maximum temperature is inside the tissue, 0.13 mm below the tissue surface. Figure 3 shows the maximum temperature reached in the tissue and the maximum value of the damage scalar vs. time. Note that the damage scalar continues to increase beyond the end of RF heating.

Accurate modeling of tissue ablation poses many challenges including proper load application, accurate evaluation of material properties including their variation with temperature, and accurate application of boundary conditions [2]. We use this model to illustrate the sensitivity of the thermal ablation behavior to the following parameters: (i) electrical impedance between the modeled region and the second electrode, typically

placed on the body of the patient, and between electrode and tissue, and (ii) temperature dependence of tissue electrical and thermal conductivities. Figure 4 shows the predicted maximum tissue temperature and size of the heat affected zone. The variations in properties selected for this sensitivity analysis are within a reasonable level of uncertainty for the respective parameters. The results highlight the importance of model validation for RF tissue ablation simulations, and how COMSOL software is a useful tool for that purpose.

Reference

1. C. Rossmann and D. Haemmeric, Review of temperature dependence of thermal properties, dielectric properties, and perfusion of biological tissues at hyperthermic and ablation temperatures, Crit Rev Biomed Eng., 42(6), 467-492 (2014).

2. J. Segui and N. Elabbasi, Multiphysics Analysis for Medical Devices [Webinar]. COMSOL webinar series. Retrieved from https://www.comsol.com/events/10421/multiphysics-analysis-for-medical-devices/. Feb. 25 2016.

Figures used in the abstract

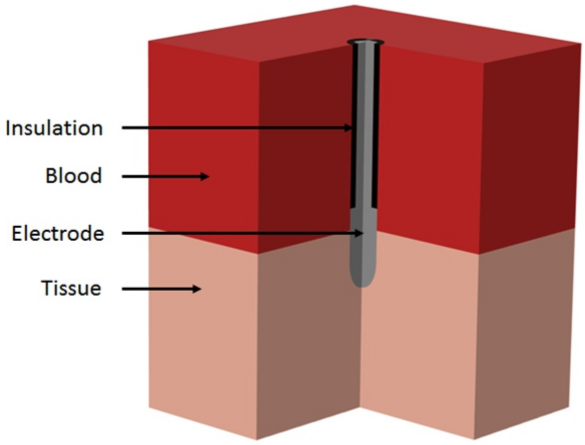


Figure 1: Schematic of the RF ablation model.

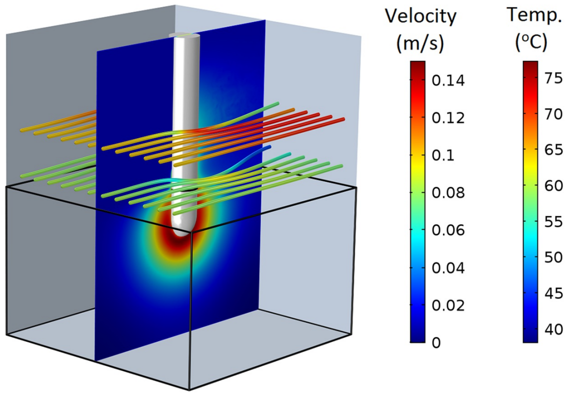


Figure 2: Temperature in the tissue and blood, and flow streamlines, 15 s into the simulation.

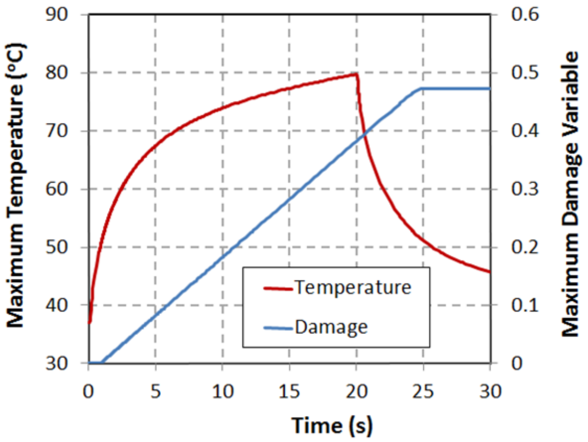
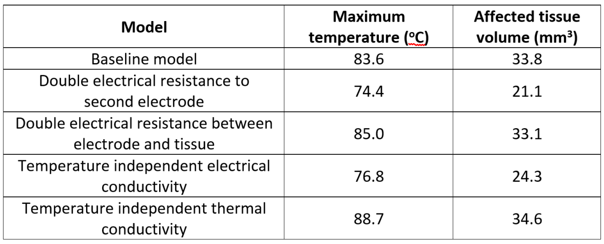


Figure 3: Maximum temperature and damage scalar in the tissue vs. time.



Model	Maximum temperature (ºC)	Affected tissue volume (mm³)
Baseline model	83.6	33.8
Double electrical resistance to second electrode	74.4	21.1
Double electrical resistance between electrode and tissue	85.0	33.1
Temperature independent electrical conductivity	76.8	24.3
Temperature independent thermal conductivity	88.7	34.6

Figure 4: Sensitivity of maximum temperature and size of heat affected zone to changes in properties.