Electrical Response and Thermal Damage Assessment of Cutaneous and Subcutaneous Tissues to Noninvasive Radiofrequency Heating: A Computational Modeling Study

A. González-Suárez[1], J. N. Jimenez-Lozano[2], W. Franco[3]

[1]Wellman Center for Photomedicine, Massachusetts General Hospital & Harvard Medical School, Boston, MA, USA; Biomedical Synergy, Electronic Engineering Department, Universitat Politècnica de València, Valencia, Spain

[2]ZELTIQ Aesthetics, Inc., Pleasanton, CA, USA

[3]Wellman Center for Photomedicine, Massachusetts General Hospital & Harvard Medical School, Boston, MA, USA

Abstract

Introduction: Electromagnetic radiofrequency (RF) sources are widely used to heat up cutaneous and subcutaneous tissues for different applications, such as, generation of new dermal collagen and denaturation of adipocytes or fat cells. The subcutaneous morphology of tissue consists of a fine, collagenous and fibrous septa network enveloping clusters of adipocyte cells [1]; however, it is commonly regarded as a homogeneous fat layer in computational models. The anatomically correct subcutaneous tissue was modelled in a previous study in order to investigate its thermo-elastic response to RF heating [2]. In the present study the objective is to assess the effect of the presence of the septa network into the thermal damage during RF heating.

Use of COMSOL Multiphysics®: Two-dimensional electric, thermal and thermal damage models of skin, fat and muscle tissues were built and solved numerically using the Finite Element Method (FEM) with COMSOL Multiphysics® (COMSOL Inc., Burlington MA, USA). The anatomically accurate structure of the subcutaneous fat tissue was obtained by processing sagittal images of hypodermis from micro magnetic resonance imaging (MRI) [1]. We studied two different configurations of the subcutaneous fat tissue: one constituted homogenously by fat only, and another one constituted by fibrous septa and fat. The RF monopolar applicator was modelled as a voltage boundary condition. The Arrhenius integral method to assess thermal damage, Ω, was solved in COMSOL as an additional differential equation to the Laplace (steady-state electrical problem) and Pennes (time-dependent thermal problem) equations.

Results: The strength of the electric field is increased by the presence of the fibrous septa, as shown in Figure 1-2. The fibrous septa network allows conducting the electric flux to deeper subcutaneous tissue, favouring the electric field storage in the fat lobules (see Figure 2). In steady state, the temperature is ≈ 7 °C higher with fibrous septa, Figures 3-4. Most important, the

profiles of thermal damage are quite different. For tissue with fat only, the lesion is symmetrical with ellipsoidal shape, does not exceed the limits of the RF applicator and is confined to the subcutaneous fat tissue only. However, accounting for the presence of fibrous septa resulted in a region of damage that is asymmetrical and extends laterally beyond the RF applicator and 5.25 mm into the muscle.

Conclusions: Our results demonstrate the importance of including the fibrous septa when modelling RF heating of subcutaneous adipocyte tissue. The septa favours the flux of electric current and consequently, increases the bulk power absorption, which varies with the square of the electric field. Thus, the septa generates more heat and thermal damage than the lipid of adipocyte cells. The lesion volume in the case of the subcutaneous tissue constituted by fat and fibrous septa was ≈ 3 times higher than without septa. It follows that the dosimetry in treatments of subcutaneous fat related disorders with RF heating should take into account the architecture of adipocyte tissue.

Reference

[1] F. Mirrashed, J. C. Sharp, V. Krause, J. Morgan, and B. Tomanek, Pilot study of dermal and subcutaneous fat structures by MRI in individuals who differ in gender, BMI, and cellulite grading, Skin Research and Technology, 10, 161–168 (2004).
[2] J. N. Jimenez-Lozano, P. Vacas-Jaques, and W. Franco, Thermo-elastic response of cutaneous and subcutaneous tissues to noninvasive radiofrequency heating, Proceedings of the 2012 COMSOL Conference in Boston (ISBN: 978-0-9839688-9-4).

Figures used in the abstract

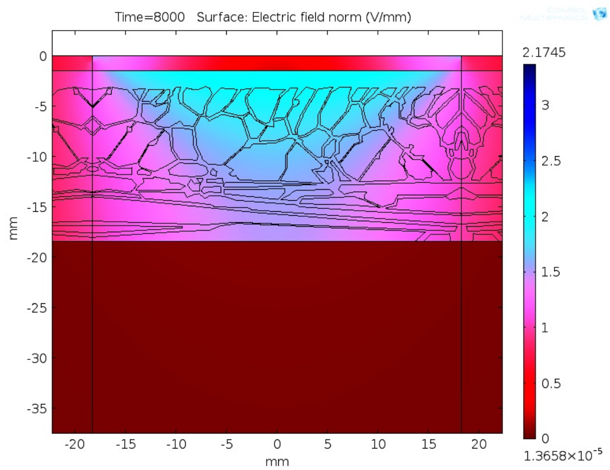

Figure 1: Electric field norm distributions in the subcutaneous tissue constituted by fat. All modelling physical and physiological properties of the fibrous septa are equal to those of the fat.

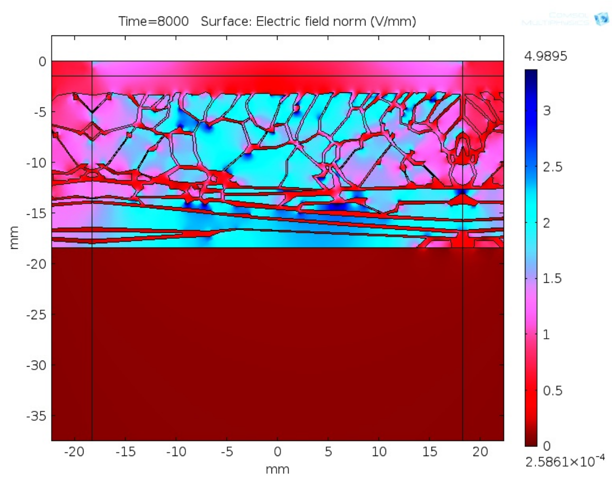

Figure 2: Electric field norm distributions in the subcutaneous tissue constituted by fat and fibrous septa.

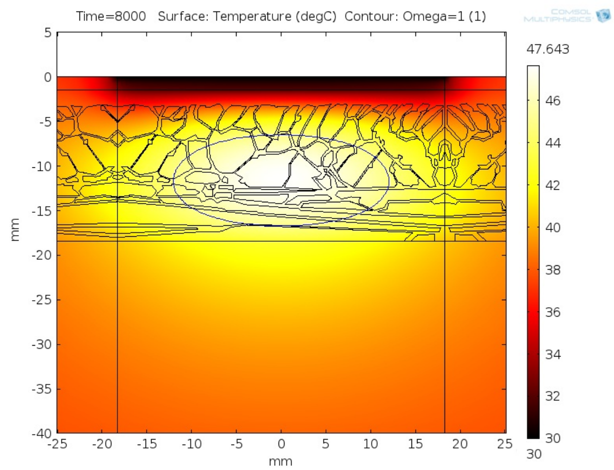

Figure 3: Temperature distribution in the subcutaneous tissue constituted by fat at steady state. Contour correspond to thermal damage $\Omega = 1$ (37% cell viability).

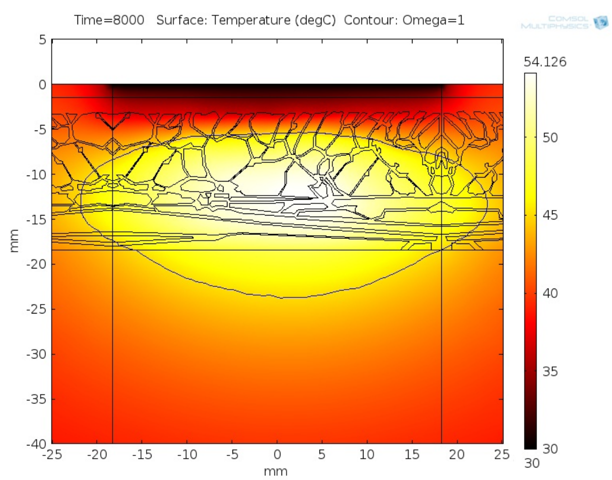

Figure 4: Temperature distribution in the subcutaneous tissue constituted by fat and fibrous septa at steady state. Contour correspond to thermal damage $\Omega = 1$ (37% cell viability).