Thermo-elastic Response of Cutaneous and Subcutaneous Tissues to Noninvasive Radiofrequency Heating

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Abstract

Radiofrequency (RF) energy exposure is a well-established method for generating heat in tissue to incise, excise, ablate or coagulate the targeted tissue. RF technology offers unique advantages for noninvasive selective heating of relatively large volumes of tissue. Cutaneous and subcutaneous tissues are commonly considered layered structures in terms of RF energy deposition. This is a valid assumption for cutaneous tissues, namely epidermis and dermis. However, the subcutaneous structure of tissue consists of a fine collagen fiber mesh (interlaced fiber septa) with clusters of adipocytes, as shown in Figure 1. Hence, there is a lack of understanding about the thermo-elastic response of subcutaneous tissues to internal electric heating by the presence of fiber septa interlaced between fat lobules and its qualitative and quantitative features. Using COMSOL, we have modeled the problem of two-dimensional electro-thermo-elasticity of a three-layer tissue (skin, fat and muscle) including the fiber septa structure within fat. We have studied two different geometries, one with cellulite and one without. Fiber septa architecture was obtained by processing sagittal images of skin from MR [1]. We have selected constant electrical, thermal, elastic and perfusion properties for the tissues as well as interface boundary conditions. At the skin surface, we defined a constant voltage, convective and affixed boundary condition. Electric propagation is assumed time independent since it is very fast compared to heat diffusion and the mechanical response of the tissue. Models are one way coupled. Our analysis shows that the presence of the fiber septa architecture contributes to change of the static electric field within fat, as shown in Figure 2 for an individual with cellulite. There is greater electric power absorption in fat lobules than in the fiber septa filaments. However, fiber septa favors the flux of electric current density, as shown in Figure 2. When reaching the thermal steady-state, fiber septa has a higher temperature than fat, bringing selective heating of the fibers, as shown in Figure 3. Due to the selective heating, fiber septa has a greater volumetric strain than the other tissues, as shown in Figure 4. We have illustrated the physical principles of the thermo-elastic response in tissue due to selective RF energy deposition in fat with fiber septa structures. When RF energy is delivered to the skin surface, electric current flux is favored through the fiber septa and therefore, there is selective heating. Preference heating of fiber septa will contribute to collagen denaturation and contraction of the local lobules of the subcutaneous fat tissue. Findings can be used for the design and development of RF heating devices.

Reference

Mirrashed, F., et al., 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, p. 161–168 (2004).

Figures used in the abstract

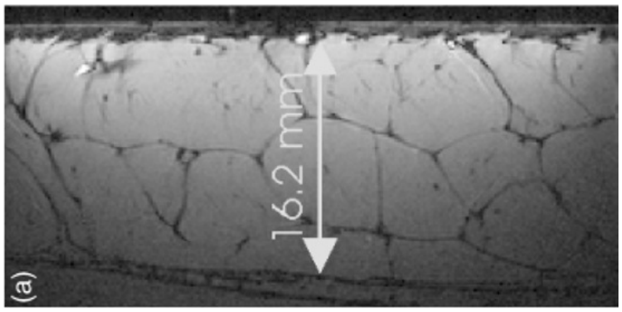

Figure 1: Magnetic Resonance (MR) image of the skin of a female with a cellulite Grade 52.5, hypodermis 16.2 mm. Dark filaments correspond to fiber septa [1].

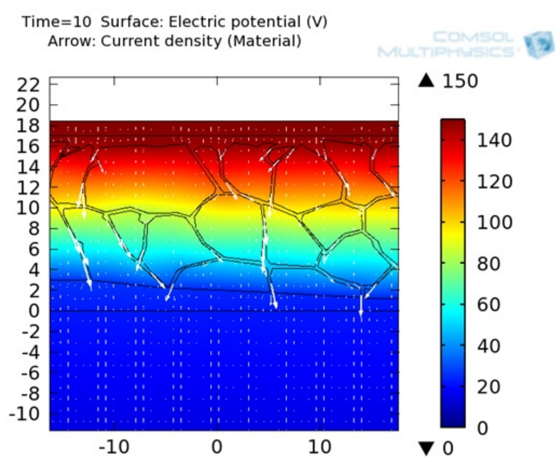

Figure 2: Results in a representative geometry for an individual with cellulite, constant voltage at the outer surface 150 V and physical properties at 1 MHz. Electric potential distribution and current density (arrows).

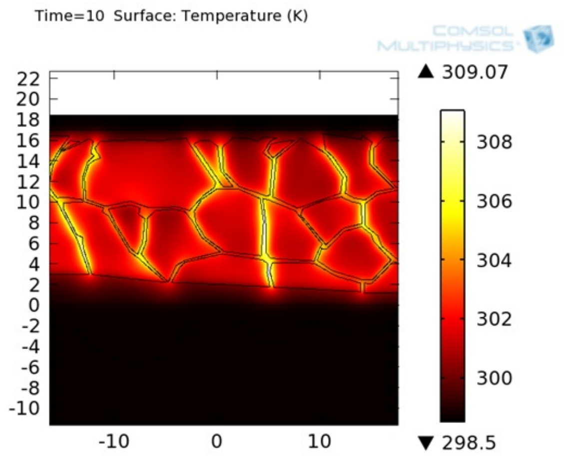

Figure 3: Temperature distribution at 10 seconds.

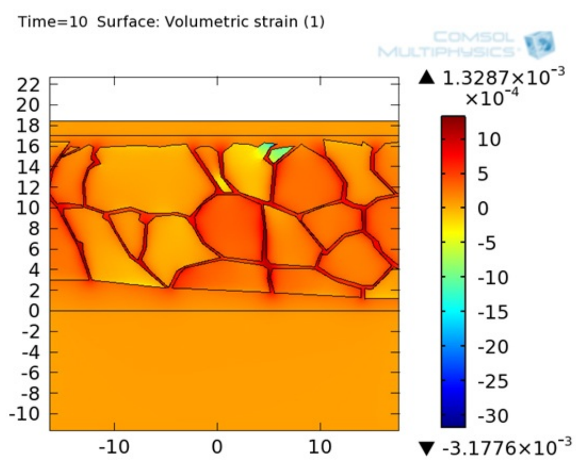

Figure 4: Volumetric strain at 10 seconds.