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

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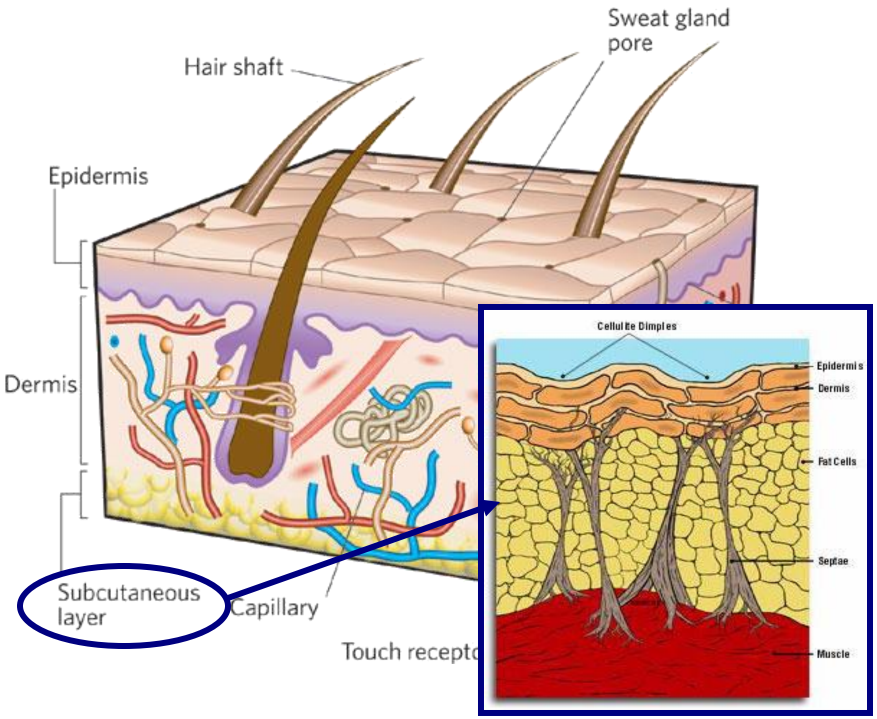
Contents

Content

❑ Skin-fat structure



❑ **Epidermis**: outer cellular layer (~0.1 mm)

❑ **Dermis**: A dense connective tissue layer perfused with micro-vessels (~1 mm)

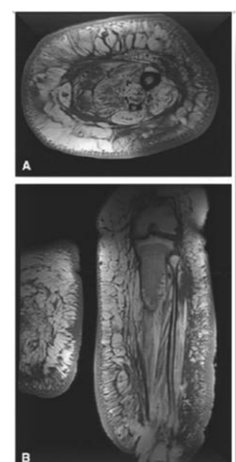
❑ **Hypodermis** (or **subcutaneous tissue**): a fine, collagenous and fibrous septa network with clusters of fat cells (1 cm to 10 cm)

❑ Radiofrequency (RF) heating

A **non-invasive** technique can be used to produce **selective heating** of subcutaneous tissue

❑ Clinical applications

Subcutaneous fat diseases:
Lipomatosis, Madelung's disease, lipedema or cellulite



❑ Objectives

- ❑ Model a real structure of subcutaneous tissue
- ❑ Assess the electrical and thermal effect of fibrous septa within subcutaneous tissue during RF hyperthermic heating (< 55ºC)
- ❑ Quantify and compare the thermal damage occurred in two subcutaneous tissue structures (one composed by fat only and another by fat and fibrous septa)

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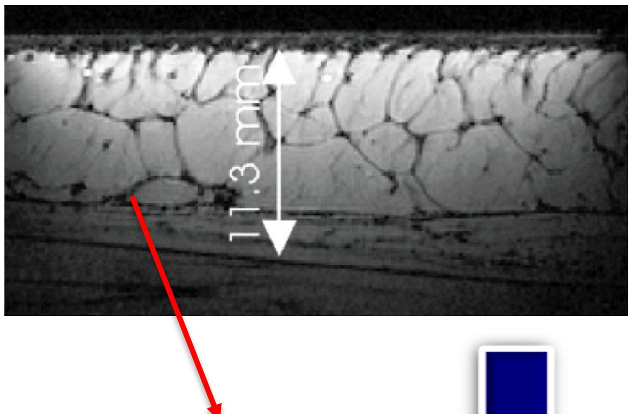
COMSOL Multiphysics 4.3b

Content

❑ Domain Geometry

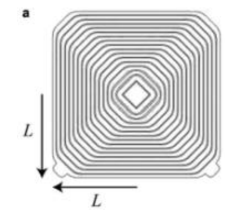
MRI skin of a female *(Mirrashed, F., et al., Skin Research and Technology, 10, 2004).*

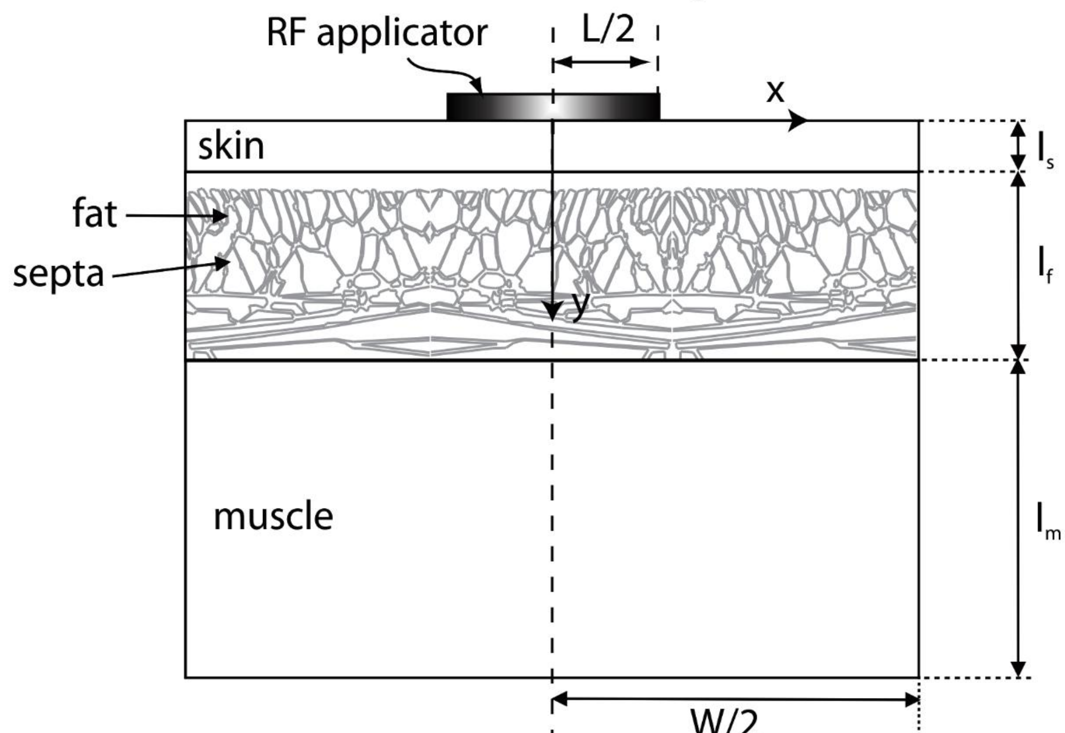


Fibrous septa

RF monopolar applicator (*Franco, W. et al. LSM 42, 2010*)

Upper view





❑ Governing Equations

❑ Coupled electric-thermal problem

1 **Thermal problem**: Heat Transfer

$$\rho c \frac{\partial T}{\partial t} = \nabla(k\nabla T) + Q_m + c_b \omega (T_b - T) + Q$$

$$Q = \sigma |E|^2$$

2 **Electric problem**: Electric Currents

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

❑ Thermal damage problem

3 **Arrhenius Equation:** Domain ODEs and DAEs

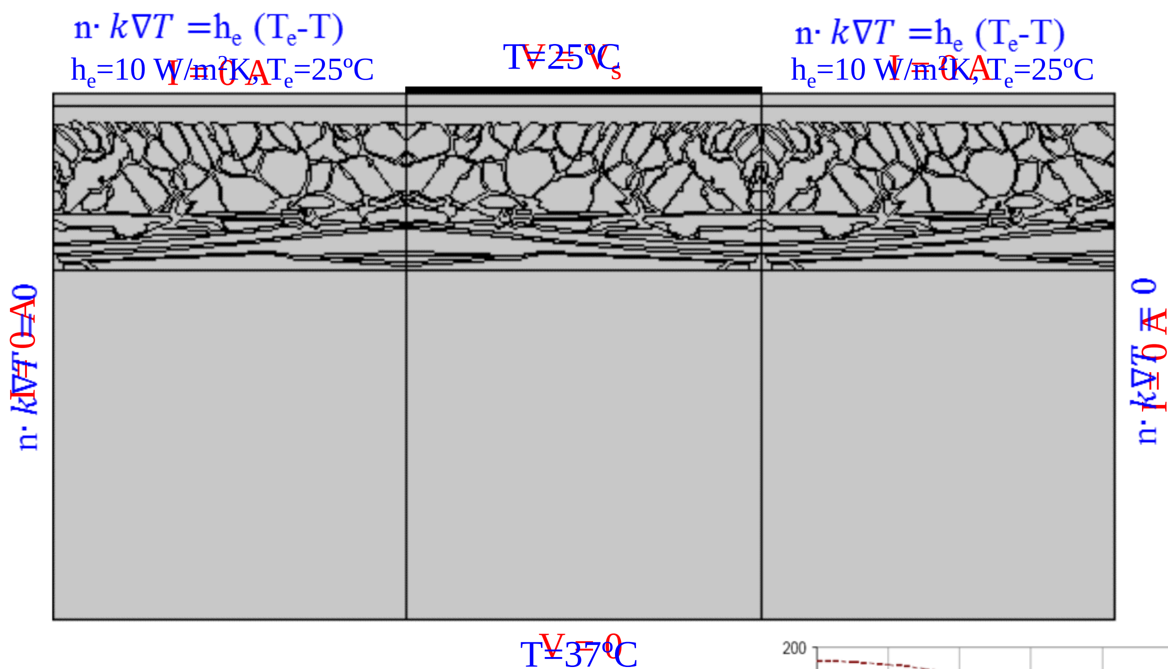
$$\Omega(t) = \int_0^t A \cdot e^{\frac{-\Delta E}{RT}} dt$$

- A and ΔE for skin (Weaver and Stoll 1969)
- **Ω = 1→** lesion contour (transepidermal necrosis, 63% reduction in cell viability)

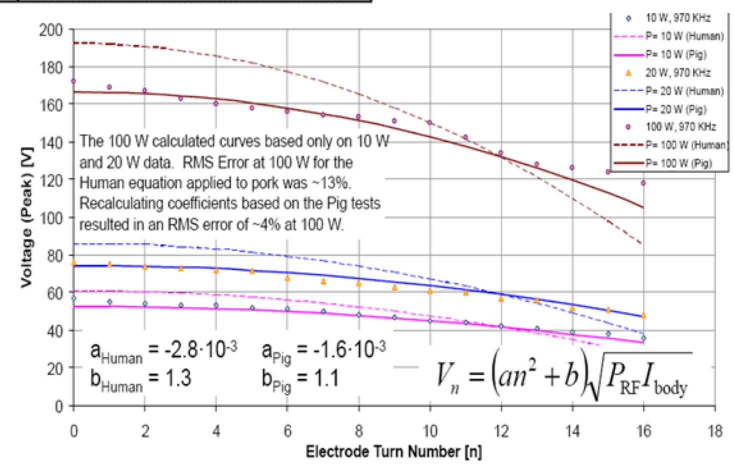
Boundary conditions

Thermal conditions

Electrical conditions



$$V_s(-L \le y \le L, 0) = \left(a \left(1 \frac{y}{L} \right)^2 + b \right) \sqrt{PI}$$



❑ Thermal and electrical characteristics of the model elements

Element	ε_r	σ (S/m)	k (W/m·K)	ρ (kg/m^3)	c (J/kg·K)	ω (kg/m^3·s)
Skin	1832.8	0.22	0.53	1200	3800	2
Fat	27.22	0.025	0.16	850	2300	0.6
Muscle	1836.4	0.5	0.53	1270	3800	0.5
Septa	1832.8	0.22	0.53	1200*	3800	0

❑ Main Physical assumptions

- Homogeneous tissues
- Tissues have isotropic electric and thermal properties
- Constant k, c and ω → variations are not significant within the 35-50°C range
- Properties of the fibrous septa similar to those of the dermis
- The perfusion term in the septa is neglected (i.e. fibrous septa as solid)

Content

1. Introduction
2. Mathematical modeling
3. **Results**
4. Conclusions

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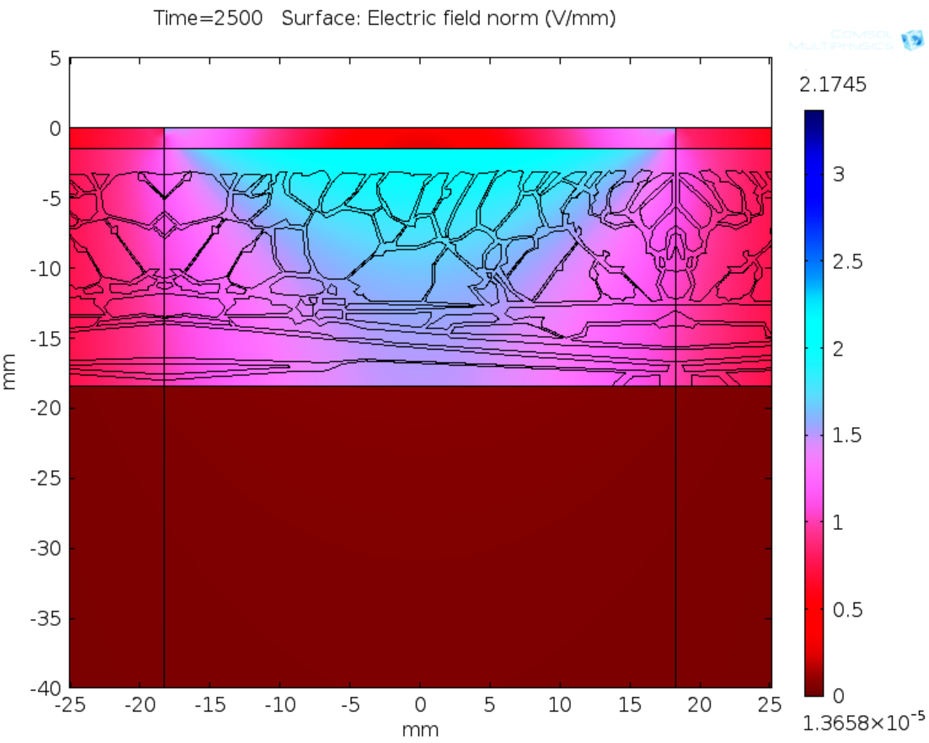
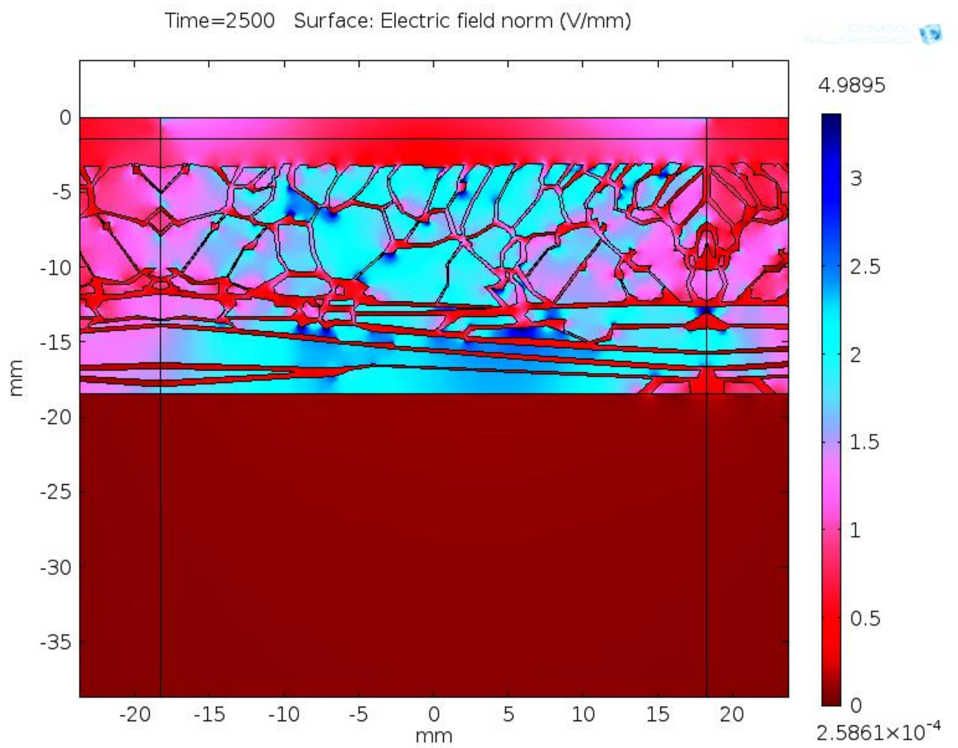
❑ Electric field

Subcutaneous tissue with fat only (no fibrous septa)

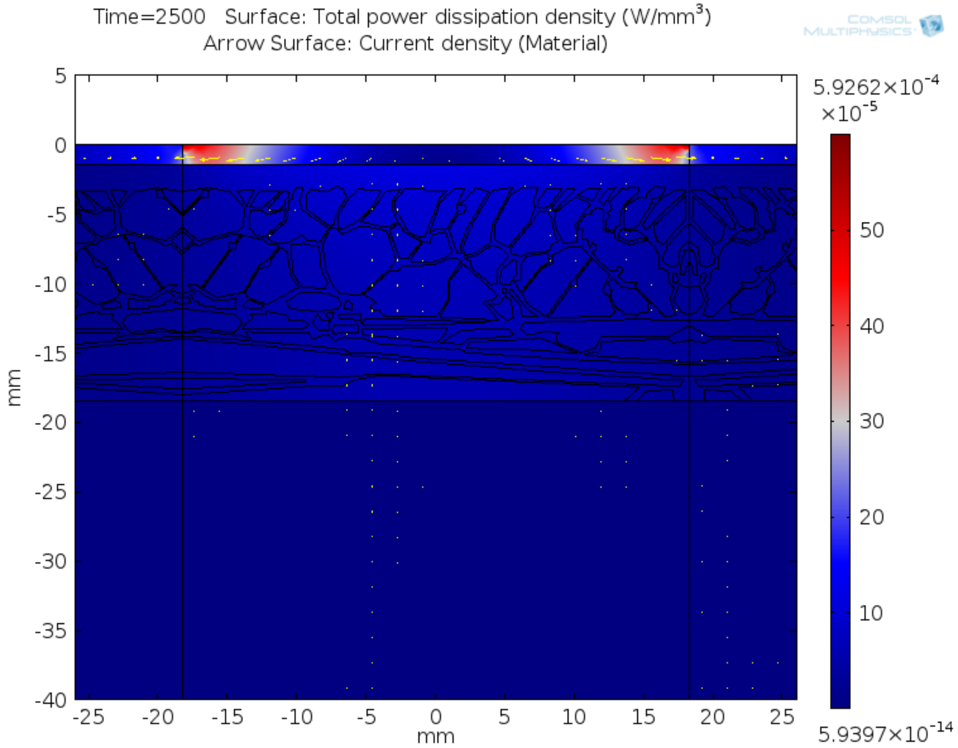


Subcutaneous tissue with fat and fibrous septa

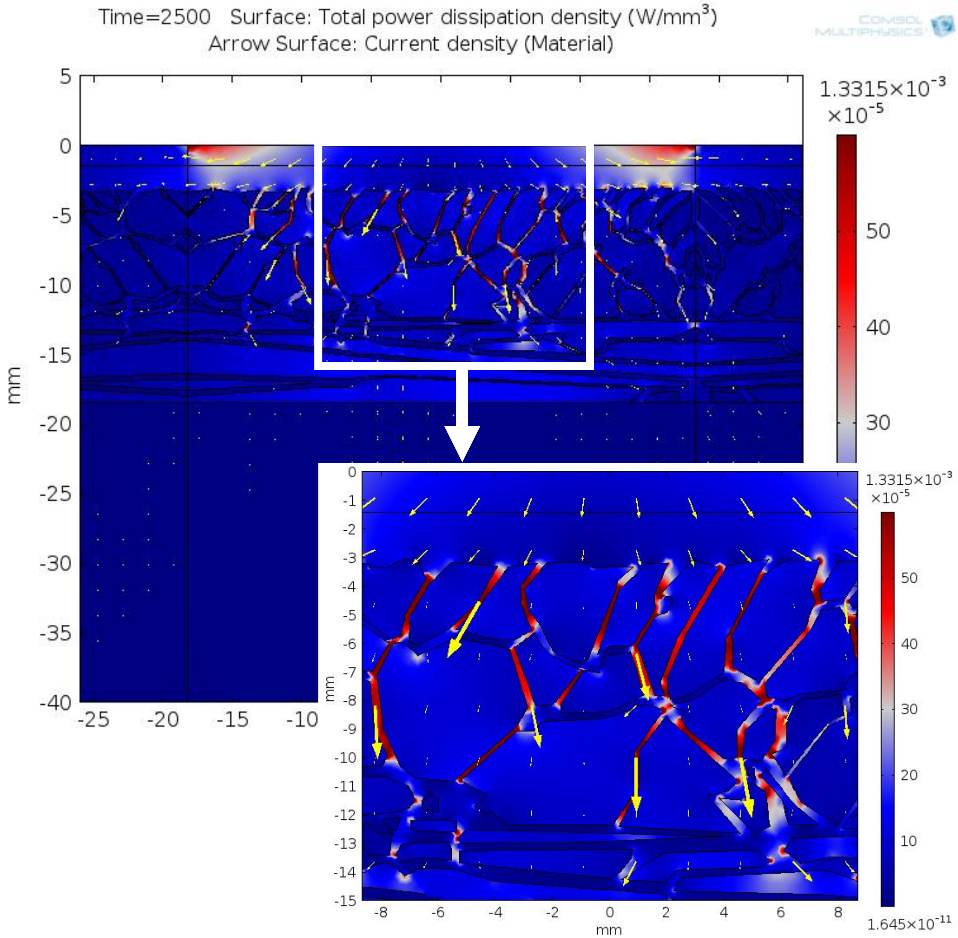


- Total electric power absorption (Q) and Electric currents (arrows)

Subcutaneous tissue with fat only (no fibrous septa)

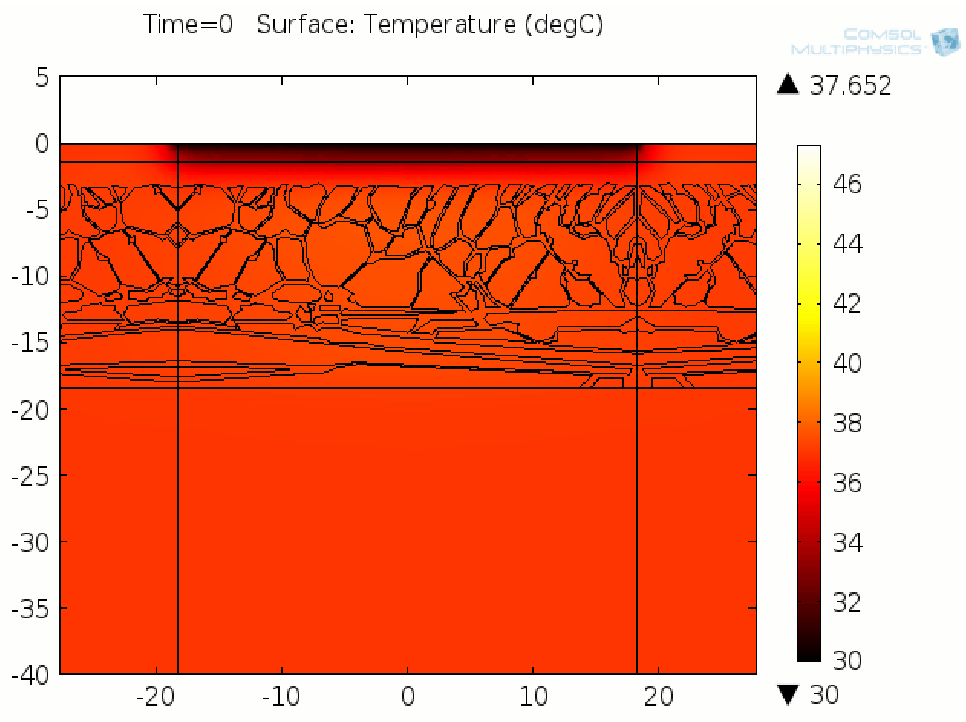


Subcutaneous tissue with fat and fibrous septa

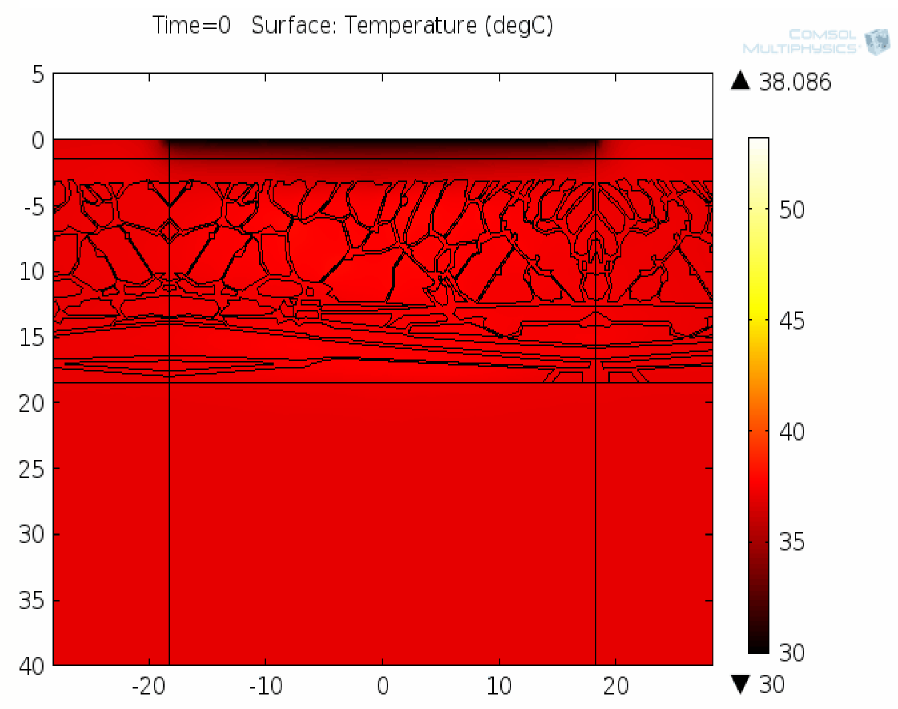


❑ Temperature distribution and thermal damage

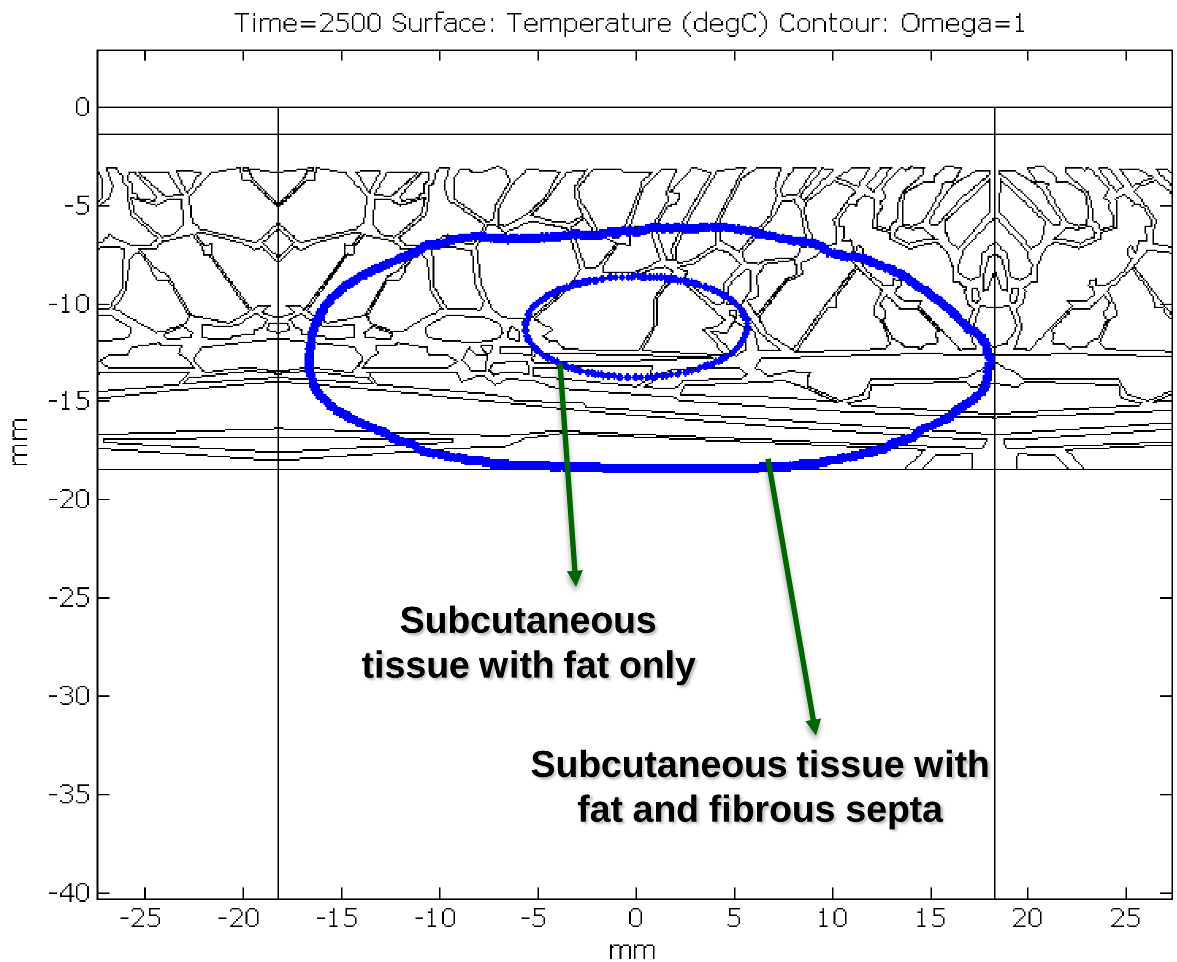
Subcutaneous tissue with fat only (no fibrous septa)



Subcutaneous tissue with fat and fibrous septa



❑ Thermal damage quantification



The lesion volume is ~ 7 times higher considering fibrous septa

Content

- Our results demonstrate the **importance** of including the fibrous septa when modeling RF heating of subcutaneous tissue:
  - The intensity and extent of the electric field in the subcutaneous tissue is increased considering fibrous septa network
  - Fibrous septa favors the flux of electric current → increasing the intensity of the electric field, which in turn increases power absorption within subcutaneous tissue
  - Neglecting the electric and thermal energy contributions of the fibrous septa results in underestimating thermal damage

- Our findings would be **useful** to design and develop novel devices and treatments to subcutaneous fat diseases during RF hyperthermic heating

→ **Knowledge of correct dosimetry**

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