Analysis of PhotoThermal Ablation

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Outline

• Motivation
• Implementation
• Verification
• Application
Tumor ablation

• Cancer tumors

• Tissue necrosis
  – Cancer cells irreversibly damaged at 42°C
  – Normal cells can survive up to 47°C

• Tumors have limited vascularity
  – Inability to disperse heat

• Minimally invasive ablation
  – Radiofrequency
  – Microwave
  – Laser
PhotoThermal Ablation

- Improved localization of treatment
- Laser interaction with photothermal sensitizers
- Gold nanoparticles
- Near IR laser radiation for tissue penetration
- Localized generation of heat
COMSOL Multiphysics® model

- Light diffusion in tissue
  - Irradiance distribution
- Layered tissue structure
- Heat transfer due to absorption of light
- Heat dissipation
  - Perfusion
  - Convection from outer surface

Radiation source
Tumor
Radiation diffusion
Governing equations

• Time dependent diffusion:

\[ \frac{1}{c} \frac{\partial}{\partial t} \Phi + \nabla \cdot (D \nabla \Phi) = -\mu_a \Phi + S \]

\( \Phi \): photon fluence (number of photons per unit area per unit time), \([1/(m^2 \cdot s)]\)
\( D = 1/3(\mu_a + \mu_s') \): optical diffusion coefficient, \([m]\)
\( \mu_a \): absorption coefficient \([1/m]\)
\( \mu_s' \): reduced scattering coefficient \([1/m]\)
\( c \): speed of light in tissue \([m/s]\)
\( S \): source, other than that due to absorption \([1/(m^3 \cdot s)]\)

• Fluence flux:

\[ \Gamma = -D \nabla \Phi, \]
COMSOL Multiphysics® implementation

- General form PDE interface
- Tissue properties defined in the Parameters node

\[ \frac{\partial}{\partial t} \left( \phi + \nabla \cdot (-\nabla \phi) \right) = -\mu_a \phi + S \]

\[ \phi \text{ Flux} \quad \text{Sink term} \]

\[ a \text{ Damping or Mass Coefficient} \]

\[ s \text{ Mass Coefficient} \]
Model validation

- Light pulse in an infinite homogeneous medium

\[ \Phi = c (4\pi Dc t)^{-3/2} \exp(-\mu_c c t) \exp \left( -\frac{r^2}{4Dc t} \right) \]
Light diffusion: Tissue

- Simplified layer structure
- Boundary conditions

Symmetry
Zero flux

Fluence continuity
Interior boundaries
Heat transfer: Tissue

- Time dependent tissue temperature due to photon absorption
  \[ \rho C_p \frac{\partial}{\partial t} T + \nabla \cdot (-k \nabla T) = Q_{light} + Q_{bio} \]

- Heat source due to light
  \[ Q_{light} = \mu_a \Phi \cdot h(v) \]

- Heat transfer due to perfusion
  \[ Q_{bio} = \rho_b C_{p,b} \omega_b (T - T_b) \]

- Boundary conditions
Tissue heating

• Transient and steady state temperature distribution as a function of laser light parameters
Summary

• Model developed to predict transient temperature response of human tissue when subject to laser radiation

• Thermal history:
  – Laser power
  – Thermal dissipation due to human body

• Optimization of therapeutic patient treatment profiles