Simulating Light Propagation During I-PDT of Locally Advanced Head and Neck Cancer

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Introduction: Interstitial Photodynamic Therapy (I-PDT) is a promising palliative treatment option for refractory, locally advanced head and neck squamous cell carcinoma (LA-HNSCC) [1, 2]. I-PDT involves the activation of a photosensitizing drug by a therapeutic light dose, which results in damage to the cancerous tissue. In I-PDT, light is provided via catheter embedded fiber optics. Due to the complex anatomy of LA-HNSCC, careful planning of light delivery and optical fiber insertion is necessary. The objective of this work was to test the feasibility of using COMSOL Multiphysics® Software to simulate light propagation during I-PDT of LA-HNSCC.

Computational Methods: In COMSOL, a diffusion model was set up to compute the photon distribution throughout three-dimensional (3-D) geometries, representative of LA-HNSCC, when exposed to laser light. Our finite element model for computing the light dose was described previously in Oakley *et al* [3]. In this approach, the 3-D, time-dependent diffusion equation is derived from the equation for radiative transfer, and is given by:

$$\frac{1}{c_n}\left(\frac{\partial}{\partial t}\Phi(x,y,z,t) - \nabla(\alpha^n \nabla\Phi(x,y,z,t))\right) = -\mu_a^n \Phi(x,y,z,t)$$

$$\text{where } \alpha^n = c_n \cdot [3(\mu_a^n + (1-g)\mu_s^n)]^{-1}$$

$\Phi(x,y,z,t)$ is the photon flux (Photons/m²/sec), α^n is the optical diffusion coefficient (m²/sec) of tissue n, μ_a^n and μ_s^n are the linear absorption and scattering coefficients (1/m) of tissue n, g is the optical anisotropy factor, and c_n is the speed of light in tissue n. The source laser light is represented by a flux of diffused photons emitted from the inside surface of the catheter, and is given by (Neumann boundary conditions):

$$\frac{P_{laser} c_o}{(h_p v_l)} = -\alpha^n \nabla\Phi(x,y,z,t)$$

P_{laser} is the laser irradiance (W/m²), c_o is the speed of light in a vacuum (3×10^8 m/sec), h_p is the Planck's constant (6.626×10^{-34} J/second), and v_l is the laser light frequency (1/sec).
In our previously published work, we were able to optimize the mesh size of the LA-HNSCC models [3]. This allowed us to reduce the simulation computation time to within 5 minutes.

Results:

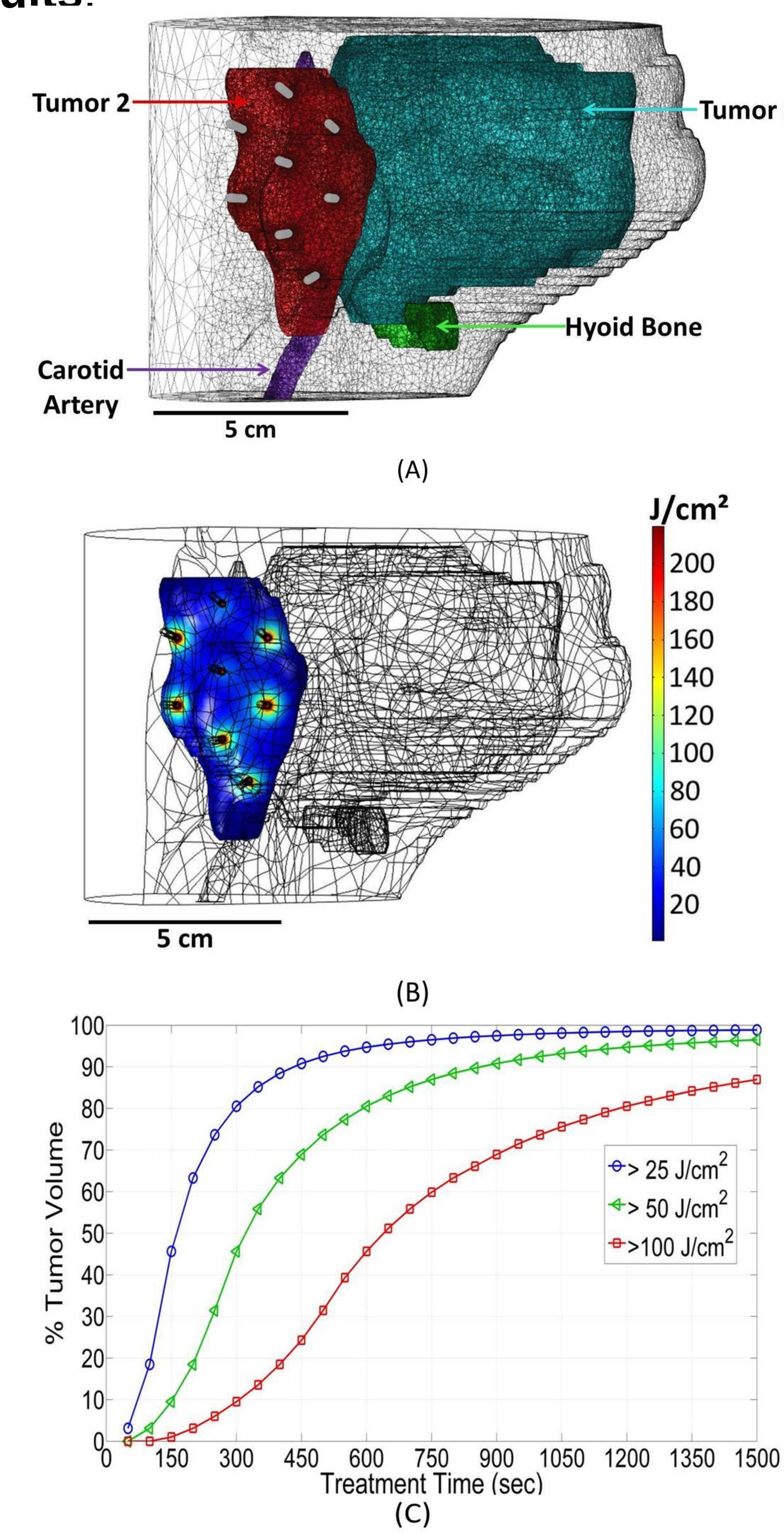

Figure 2. (A) Mesh created in COMSOL, (B) resulting fluence (J/cm²) throughout the tumor volume for a treatment time of 250 seconds for tumor 2, and (C) dose volume histogram representing the percent of the tumor volume that will receive a prescribed light dose as a function of treatment time (sec).

Conclusions: The light propagation during I-PDT can be simulated using COMSOL and can be displayed in both two-dimensional and three-dimensional plots. Our developed finite element model has the potential to aid in the pretreatment planning and real-time monitoring of I-PDT of LA-HNSCC.

References:

1. Lou, P.J., et al., *Interstitial photodynamic therapy as salvage treatment for recurrent head and neck cancer,* Br J Cancer, 91(3), p.441-6 (2004).
2. Karakullukcu, B., et al., *mTHPC mediated interstitial photodynamic therapy of recurrent nonmetastatic base of tongue cancers: Development of a new method,* Head Neck, 34(11), p.1597-606 (2012).
3. Oakley, E., et al., *A new finite element approach for near real-time simulation of light propagation in locally advanced head and neck tumors,* Lasers Surg Med., 47(1), p.60-67 (2015).

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