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

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Abstract

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 photosensitizer (PS) by a therapeutic light dose. This results in the production of a highly reactive oxygen species, singlet oxygen, and ultimately leads to tumor cell death. In I-PDT, light is delivered interstitially to the tumor volume via catheter embedded fiber optics. Due to the complex anatomy of LA-HNSCC, careful planning of light delivery and fiber insertion is necessary. In this study, we tested the feasibility of using COMSOL Multiphysics® software to simulate light propagation during I-PDT of LA-HNSCC. We have developed an image-based approach, using finite element analysis (FEA), to suggest the number and location of treatment fibers needed for I-PDT and to calculate the delivered light dose.
Methods: De-identified computed tomography scans of patients with LA-HNSCC were obtained and analyzed using a data visualization and model generation software (Simpleware Ltd., Exeter, UK). Three-dimensional geometries, representing the tumor and surrounding anatomical features such as bone, tissue, and major blood vessels, were created from the segmentation of the CT scans. These geometries were exported to COMSOL Multiphysics. In COMSOL® software, cylindrical representations of optical fibers were inserted throughout the tumor geometry. FEA was used to solve the time-dependent diffusion approximation to the equation for radiative transport.

Use of COMSOL Multiphysics® Software: A diffusion model was set up using the Chemical Reaction Engineering Module. This model was used to compute the resulting photon distribution throughout a three-dimensional geometry when exposed to laser light.

Results: Figs. 1 - 3 depict the meshes generated in COMSOL Multiphysics and the simulation results obtained for a patient with LA-HNSCC (Note: This patient had two tumors of the head and neck). Overall, for a treatment time of 250 seconds, the average light dose throughout the tumor volume and along the surface of the tumor were, respectively, 46.2 J/cm² and 21.5 J/cm² for tumor 1 and 44.9 J/cm² and 26.9 J/cm² for tumor 2.

Conclusion: Using COMSOL® software, we were able to model light propagation in tissue and display the resulting light dose in both two-dimensional and three-dimensional plots. Our developed finite element model for computing light propagation has the potential to aid in the pretreatment planning and real-time monitoring of I-PDT of LA-HNSCC.

Reference

1. P.J. Lou, et al., Interstitial photodynamic therapy as salvage treatment for recurrent head and neck cancer, Br J Cancer, 91(3), p. 441-6 (2004).

2. B. Karakullukcu, 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).

Figures used in the abstract

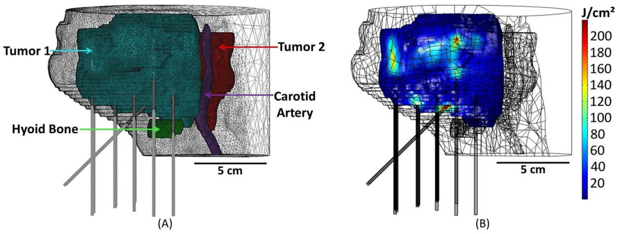

Figure 1: (A) Mesh created in COMSOL and (B) resulting fluence (J/cm²) throughout the tumor volume for a treatment time of 250 seconds for tumor 1.

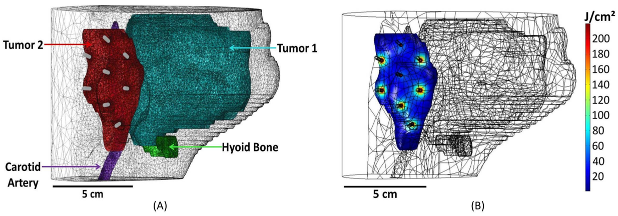

Figure 2: (A) Mesh created in COMSOL and (B) resulting fluence (J/cm²) throughout the tumor volume for a treatment time of 250 seconds for tumor 2.

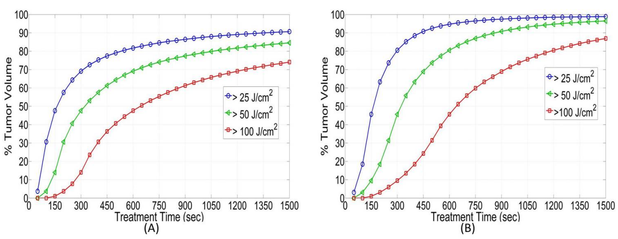

Figure 3: Dose volume histograms representing the percent of the tumor volume that will receive greater than 25, 50 and 100 J/cm² as a function of time for (A) tumor 1 and (B) tumor 2.