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One-way Coupled Benchmark for Combined-Hyperthermia-Radiotherapy Treatment in Slab Geometry

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Radiation dosimetry has traditionally been treated as single physics [1]. However, several applications could benefit from the coupling of dose deposition with other physics to synchronously model the underlying system. One such application is the modeling of tumor response to combined-hyperthermia-radiotherapy (CHR) treatment. Several different tumor microenvironments undergo constitutive changes upon exposure to heat [2]. These changes result in increased radiosensitivity in tumor tissue making tumors more susceptible to treatment via radiation [3]. CHR treatments combine heat and radiation to maximize tumor cell kill while reducing damage to the surrounding normal tissue.

We developed a multiphysics-based one-way coupled model to predict the response of localized tumors to CHR in [4]. It combines radiation transport (dosimetry) with heat transfer (hyperthermia) and cell population dynamics (tumor dynamics) to model a highly simplified slab-geometry system. We used the following mono-energetic, slab geometry transport equation with isotropic scattering to model transport [5]:

$$\frac{1}{v}\frac{\partial \psi}{\partial t} + \mu\frac{\partial \psi}{\partial x} + \sigma_t \psi = \frac{\sigma_s}{2}\phi + \frac{Q}{2}, \qquad (1)$$

where, $\psi = \psi(x, \mu, t)$ is the angular flux at position x, along angular cosine μ, at time t; σ_t and σ_s are the macroscopic total and scattering cross-sections; Q is an isotropic internal source; v is the particle speed; and $\phi = \int_{-1}^{1} \psi d\mu$ is the scalar flux. The cell survival probability was calculated using the following set of equations [6]:

$$D = \left(\frac{\mu_{en}}{\rho}\right)\phi\Delta t E, \quad (2a)$$

$$D_E = \alpha D + \beta D^2, \quad (2b)$$

$$S = \exp(-\mathrm{D_E}), \quad (2c)$$

where, D, D_E, and S are the dose, effective dose, and the cell survival probability at position x and time t, respectively. Moreover, α and β are radiobiology parameters. Hyperthermia is modeled using the following heat conduction equation [7]:

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial \mathrm{x}} \kappa \frac{\partial T}{\partial x} + q, \quad (3)$$

where ρ, c_p, and κ are the specific heat capacity, the material density, and the thermal conductivity of tissue, respectively; q is the volumetric heat source; and T is the temperature at position x and time t. The tumor dynamics is modeled as a diffusion process using the following equation [8]:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial \mathrm{x}} I \frac{\partial c}{\partial x} + pc - Rc, \quad (4)$$

where c is the tumor cell concentration at position x and time t; I is the coefficient representing motility of tumor cells; and p is the proliferation rate. Here, R represents the effect of therapy on tumor cell kill:

$$\mathrm{R_{RT}} = 1 - \mathrm{S}, \quad (5a)$$

$$R_{CHR} = \xi(1 - \mathrm{S}), \quad (5b)$$

where $\mathrm{R_{RT}}$ and R_{CHR} quantify the effect of stand-alone radiotherapy and CHR treatments respectively, and ξ is a radiosensitivity parameter at position x and time t [4]. The above set of equations returns a one-way coupled system that can be solved sequentially.

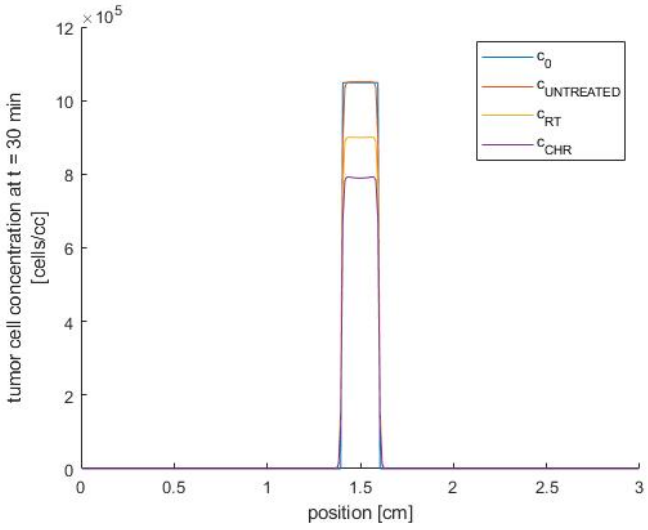

Figure 1: Cell Concentration Comparison

We will develop a highly precise benchmark set of solutions for the coupled equations (Eqs. 1 to 5) presented above. Our preliminary result presents a comparison of tumor response to different treatment scenarios in Fig. 1. This result is precise up to five digits. We will employ sophisticated convergence acceleration techniques including the Wynn-epsilon algorithm [9] to develop our benchmark for the full presentation and subsequent paper.

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REFERENCES

[1] F. Attix, *Introduction to Radiological Physics and Radiation Dosimetry*, Wiley-VCH Verlag GmbH and Co. KGaA, Weinheim, Germany (2004).
[2] P. Kaur, M. Hurwitz, S. Krishnan, A. Asea, Cancers **3**, 3799-3823 (2011).
[3] E.J. Hall, A.J. Giaccia, *Radiobiology for the Radiologist*, Lippincott Williams and Wilkins, Philadelphia, USA (2012).
[4] OUR M&C PAPER – idk how to cite it yet MAYBE PUT IT ON ARXIV?
[5] E.E. Lewis, W.F. Miller, *Computational Methods of Neutron Transport*, American Nuclear Society, La Grange Park, USA (1993).
[6] R. Rockne et al., Phys. Med. Biol. **55**, 3271-3285 (2010).
[7] J.R. Cannon, *Encyclopedia of Mathematics and Its Applications*, Addison-Wesley Publishing Company/Cambridge University Press, Boston, USA (1984).
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