Modeling Hyperthermia Effects on a Spherical-Shaped Tumor: A Proposed Computational-Modeling Approach

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Introduction

Hyperthermia is a more advanced technique to treat cancer cells. It is composed of high temperature heating on the area of the tumor. Due to its localization, hyperthermia treatment is considered to be safer and kills cancer cells with minimal damage to surrounding tissues.[1] The hyperthermia treatment depends on several factors, such as the tumor shape, size, and location.

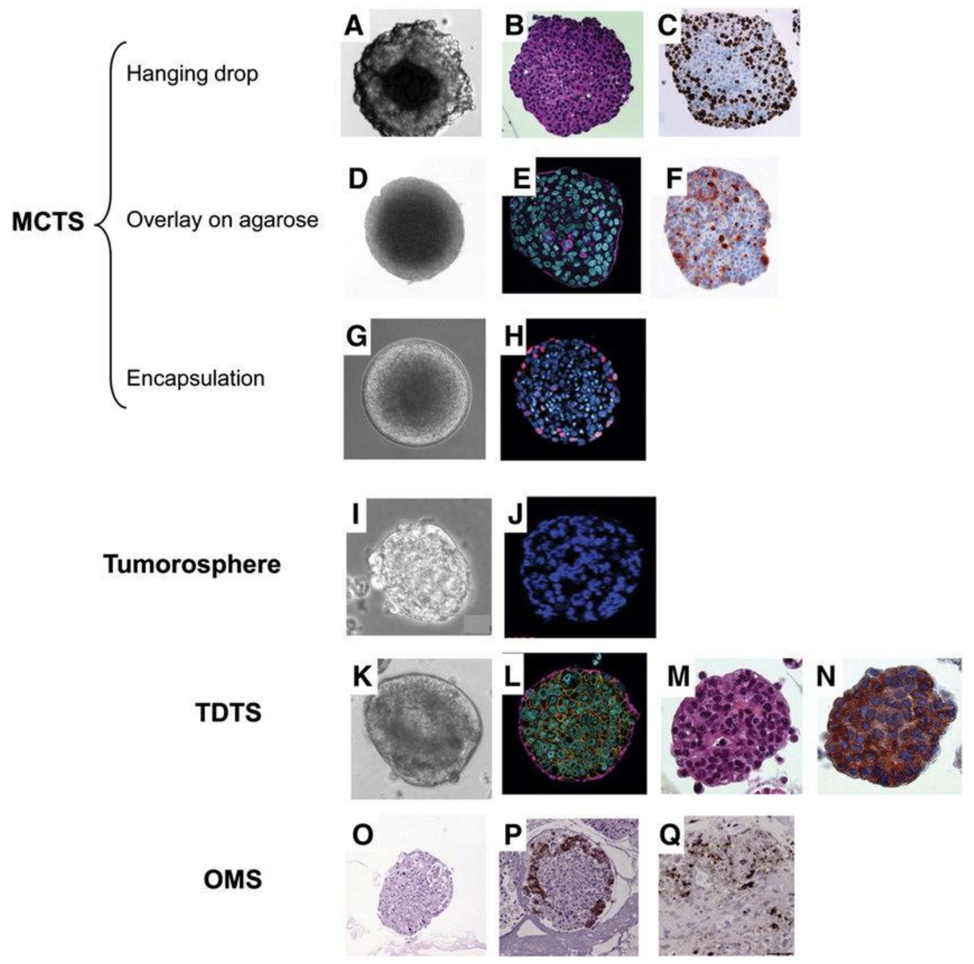

Figure 1: Spherical Cancer Models[2]

In this project, spherical tumors have been chosen due to their symmetry.[2] This facilitates the formulation of the heat transfer equation in spherical coordinates, because only the radius of the tumor varies. The heat transfer equation is the basis for any heat transfer problem, and in the case of the hyperthermia treatment on a tumor, there is the conduction term, the accumulation term, and the generation term (see Incropera and De Witt, 2013).[3] Hyperthermia treatment will be considered as the heat generation term and will be considered as constant for the first part of the project. In the second part, it will be considered as variable, i.e. as a function either of time and/or space.

Research Questions

- How can hyperthermia treatment on a spherical cancer tumor be modeled?
  - •Under a constant heat generation
  - •And under a variable heat generation
- How can the model be structured to be easily accessible to medical doctors in treatment of cancer tumors?

Proposed Design & Methods

This project is aimed at modeling the heat transfer process for hyperthermia treatment of a spherical-shaped tumor in order to predict both the temperature profiles as well as the rate of cancer cell killing inside the tumor domain. The model will be based upon the conservation equation for heat conduction with "bulk" heat sources. By assuming limiting cases of the heat sources (such as uniform and constant), a solution will be first proposed for the model by using a separation of variables approach for differential equations coupled with particular solutions.

After this has been completed, a mathematical and computational approach, based on the use of integral equations for engineering problems, will be developed to address cases with a general heat sources, i.e., sources that are not necessarily constant or uniform.

After the heat transfer equation solution approach is reviewed and understood, the model for hyperthermia treatment of the spherical tumor will be proposed and solved. The goal of this model is to make the hyperthermia treatment more "tunable" for patients with different sized spherical tumors and potential physiological conditions.

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Research Plan Implementation

The plan is centered on building the research on courses and introductory research conducted in Dr. Arce's research group and it will follow a systematic integration of the applied mathematics to the cancer tumor domain. One key aspect is to identify the proper geometrical domain (i.e. spherical geometry) to relevant tumor cases (see Weiswald et. Al., 2015)[2] and then formulating the differential thermo problem with the proper boundary conditions. This can be accomplished with information already available in Dr. Arce's research group. The next step is building the knowledge and understanding to implement suitable solutions for the model. Both the Green Function coupled with integral equation approaches have led to successful results in other tumor geometries (Allred et al, 2018).[4,5]

Anticipated Results

The research done in this project will be used to obtain a temperature profile for hyperthermia treatment under varying conditions. Then, this model will be used to obtain the rate of shrinking cancer cells inside the spherical tumor.

The model will use physiological parameters that can be tuned up for individual patients making the prediction potentially useful to guide MD in the cancer treatment strategy

Discussion

The potential benefits of this hyperthermia treatment model will improve the specificity of the medical doctor in applying hyperthermia treatment to cure spherical cancer tumors in the patient.

The study will allow for a more "personalized" approach to treat patients more efficiently. By increasing the availability of accurate information about how the treatment works for a given hyperthermia range and treatment conditions, medical doctors will hopefully be able to more effectively use hyperthermia treatment based on patient information.

References

1. van der Zee J. Heating the patient: a promising approach? Ann Oncol. 2002 Aug;13(8):1173-84.
2. Weiswald, Louis-Bastien et al. "Spherical cancer models in tumor biology" *Neoplasia (New York, N.Y.)* vol. 17,1 (2015): 1-15.
3. Incropera, Frank P. *Principles of Heat and Mass Transfer*. 7th Ed., International Student Version. ed. Hoboken, NJ: Wiley, 2013. Print.
4. Arce, Pedro E., A. Nastasia Allred, Yung-Way Liu, J. Robby Sanders, Pedro E. Arce. "Integral-Spectral Methods with Healthcare Applications: Cancerous Tumor Treatment, Hemodialysis, and Kidney Malfunction- Some Exciting Opportunities." 2018 AIChE Annual Meeting, Pittsburgh, PA, October 2018. Invited talk.
5. Allred, A. Nastasia, Yung-Way Liu, J. Robby Sanders, Pedro E. Arce. "Modeling Heat Transfer Using an Integral Equation Approach via Green's Function: Application to Cancerous Tumor Undergoing Hyperthermia Treatment." 2018 AIChE Annual Meeting, Pittsburgh, PA, October 2018. Poster Presentation.

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