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Mass transfer modeling of solid tumor growth for therapy evaluation and prognosis

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ABSTRACT

Simulation of tumor evolution at the macroscopic, tissue scale can be applied to cancer treatment optimization. This paper aims to gain deeper insight into the dynamics of tumor growth at this scale and to develop predictive, quantitative mathematical models which can be used as a decision tool supporting oncologists and surgeons.

This preliminary model describes tumor progression as mass transfer governed by partial differential equations, incorporating a multi-species logistic growth/decay law to account for the production of necrosis and the interaction with therapy. The set of governing equations is integrated by a commercial platform of Finite Element Method.

After a validation study with literature data on a hepatocellular carcinoma, a sensitivity analysis was conducted by including the driving source terms (growth rates, drug efficiency and its delivery/availability). Results suggest that, in the first two months of therapy, tumor volume progress is related nonlinearly so that a mere 10% of stronger/weaker cancer malignancy lead to doubling/halving the tumor volume, the increment of drug efficiency by 25% lead to a 60% decrease of the volume, while a smaller efficiency by 25% lead to a sudden runaway of the disease. Finally, the optimal administration pattern for chemoembolization was found with a 4-points therapy delivery on the same side with respect to the Region of Interest.

1. Introduction

Oncology is the branch of medicine dealing with prevention, diagnosis, treatment and prognosis of cancer. Cancer deeply involves with the physical, social, psychological, emotional and financial status of patients and our society as a whole. Development of engineering models, to address the complex framework of personalized and precision cancer prognosis, would help optimize patient's treatment and minimizing its cost for the health administrations.

Numerical simulations of heat and mass transfer have been performed in three main areas. In the first one, a variety of interventional procedures have been described by applying treatments such as heat (Kuznetsov [1]), ultrasound (Shih et al. [2]), microwaves (Keangin, Rattanadecho and Wessapan [3]) and radio frequency (Macchi et al. [4]). In the second area, numerical modeling have helped improving diagnosis and measurement, as reviewed by Gonzalez-Hernandez et al. [5].

In the third area tumor proliferation at the macroscale has been modeled. From a materials science perspective, cancer is a multiscaled substrate, bearing nonlinear couplings between the nanoscale (genomics), the microscale (cell signals/molecular biology) and the macroscale (tumor mass dynamics). This variety of scales has been attacked so far in a vast body of literature, as reviewed by Deisbock et al. [6], Barbolosi et al. [7], Yankeelov et al. [8], the most promising so far being the ACGT project (summarized by Stamatakos et al. [9]). Among the proposed cancer mechanisms, the continuum mechanics approach exploiting a set of partial differential equations (PDEs) holds the promise to encompass and embody some of said couplings. PDE formal platforms and related computation were initiated by Gatenby and Gawlinski [10] by using reaction-diffusion modeling paradigms, and were more recently employed in a variety of ways, as for examples in the works co-authored by M.A.J. Chaplain [12], K.R. Swanson [11] and V. Cristini [13].

In this paper, a mass transfer approach has been exploited for an occurrence of solid cancer (no significant transport of chemical/biological species within the tissues by a macroscopic flow). By its nature,

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