Computational Strategies for Pre-Treatment Planning and Real-Time Control of Image-Guided Laser Surgery of Prostate Cancer

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ABSTRACT

Image-guided laser surgery for cancer treatment provides the benefit of precise surgical control and the promise of less post-treatment complications for patients. A successful treatment, however, involves a careful pre-treatment planning and reliable real-time control of the surgical operation. In this talk, I will present various computational strategies that are involved in pre-treatment planning and real-time control based on optimization of cellular and sub-cellular (heat shock protein) responses. Using both magnetic resonance imaging (MRI) and magnetic resonance thermal imaging (MRTI) data, we are able to construct predictive 3D numerical models that are calibrated and validated with MRTI data stream feedback every 5 seconds.

Laser surgery for cancer treatment, which is able to deliver thermal energy to specific tumor regions with very sharp precision, is a preferable minimally invasive hyperthermic modality for small and poorly defined metastases or other tumors embedded within vital organs. Utilizing the MRTI guidance of real-time treatment data while applying a laser heat source has the potential to provide unprecedented control over the treatment outcome. This presentation aims to provide a working snapshot of the current mathematical and computational framework developed to provide a real-time finite element solution of the problems of calibration, optimal heat source control, and error estimation applied the equations of bio-heat transfer and demonstrate that current finite element technology, parallel computer architecture, peer-to-peer data transfer infrastructure, and thermal imaging modalities are capable of inducing a precise computer controlled temperature field within the biological domain (tumors) embedded in vital organs (prostate). In addition, we employ nanoshells – a particular kind of spherical nano-particles with each particle consisting of a silicon core and a gold shell - to enhance to effectiveness of laser surgery.

The significance of this work is not only the real-time optimal control of surgical protocol but also that the prediction of treatment outcomes are based on biologically relevant quantities - cancer cell damage distribution and heat shock protein expression – which characterize both effectiveness of the treatment and likelihood of cancer recurrence. Although this work was developed for laser surgery of prostate cancer, it can be readily expanded to other thermal therapeutic treatments using radio-frequency, microwave, or ultrasound as energy source. Moreover, these techniques can be applicable to treat other types of cancers.

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