Modelling of cancer thermal therapies with a perspective of parametric sensitivity and improved treatment planning

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**Abstract.** Cancer is the leading cause of death in the world. According to WHO in 2008 cancer was responsible for 13% of the total deaths worldwide. In America 1 out of 4 deaths is caused by cancer which constitutes the second highest mortality rate after heart disease. In Singapore it causes the highest number of deaths and is responsible for 1 out of 3 deaths. Although the 5 year survival rate has increased gradually over the past decades, there hasn’t been a drastic slump in the cancer related mortality. The gradual improvement in survival rate is attributed to early detection and better treatment modalities. From treatment point of view these factors translate to better diagnostic capabilities and enhanced therapeutic output. The scope of this talk covers the latter which relates to better prognosis owing to improved efficacy of the treatment. There are many treatment modalities that have been used to treat cancer but none of them can be qualified as soul treatment modality for all types and tumour sites. So the researchers resort to different treatments by harnessing its congruent attributes for best results against a particular cancer.

Thermal therapies are the genre of therapies which use the lethal effect of heat for treatment purpose. The presentation covers the improved efficacy of the thermal therapies of capacitive hyperthermia and radiofrequency ablation (RFA). Additionally, it deals with the simulation of bioheat transfer with a novel numerical method which makes use of its meshless characteristic to provide the optimum simulation results.

For particular therapy to be applied, it is imperative that the effect of all the parameters be known perceptively. Firstly, the factors involved in the capacitive hyperthermia were ranked which provided a broader guideline for the emphasis that needs to be cast upon each factor during the therapy.

Additionally, capacitive hyperthermia was analyzed from a physical perspective. Physical parameters like depth of tumour, size of tumour, size of electrodes and position of electrodes were considered and their effect on the maximum achieved temperature inside the biological domain was considered. Treatment index and damage index was defined which are related to achievement of treatment objective and efficiency of tumour killing respectively.

A novel meshless method known as Radial Basis Collocation Method (RBCM) has been applied to simulate the heterogeneous conduction and bioheat transfer problem. RBCM is a meshless method which uses radial basis function (RBF) interpolation to obtain the solution. RBFs hold many advantages like exponential convergence, less dependence on the dimensionality of the problem, ability to deal with complex geometries and ease of implementation, which can be harnessed to one’s benefit. RBCM was successfully applied to simulate the heterogeneous conduction and remained consistent even for extreme heterogeneities. RBCM was successfully applied to solve the bioheat transfer problem. Firstly, a homogeneous bioheat problem was simulated and comparison with the analytical solution showed that RBCM provided accurate solution. Furthermore, RBCM was extended to simulation of heterogeneous bioheat transfer problem. It was concluded that features of RBCM like accuracy, point based data dependency, ease of implementation together with meshless property make it an attractive alternative to the other numerical methods available.

Research was also carried out to analyze the efficacy of radiofrequency ablation (RFA) for varying electrothermal parameters. An attempt has been made to study the RFA for the effect of thermal conductivity, electrical conductivity and blood perfusion rate with Taguchi’s design of experiments methodology. Their combined effect was analyzed quantitatively in different tissues. It was found that ablation volume for temperature control algorithm is mostly affected by blood perfusion followed by electrical conductivity and thermal conductivity. Smallest ablation volume was observed in kidney tissue while largest lesion volume was obtained in muscle tissue. Based on the results some insightful corollaries were drawn which may be translated as qualification of RFA for the respective tissue treatment protocol. Moreover, quantification of parameter sensitivity translates to efficient design of control algorithm for power delivery. It is intended that these conclusions will help the radiologist in the treatment planning stage and would serve as broad guidelines for the application of RFA in varying biological environment.

Radiofrequency ablation (RFA) has been increasingly used in treating cancer for multitude of situations for various tissue types. In order to perform the therapy safely and obtain reliable results, the effect of the critical parameters needs to be known beforehand. We have analyzed the effect of electrical conductivity, thermal conductivity and blood perfusion rate of the tumour and surrounding normal tissue on the radiofrequency ablation under the framework of fixed temperature control. Ablation volume was chosen as the characteristic to be optimized and temperature control was achieved via PID controller. The effect of all 6 parameters each having 3 levels was quantified with minimum number of experiments harnessing the Taguchi orthogonal arrays’ fractional factorial characteristic. It was observed that as the blood perfusion increases the ablation volume decreases. Electrical conductivity of the tumour and the surrounding normal tissue has an opposite effect on the ablation volume. Increasing electrical conductivity of the tumour results in increase of ablation volume whereas increase in normal tissue conductivity tends to decrease the ablation volume and vice versa. Similarly, increasing thermal conductivity of the tumour results in enhanced ablation volume whereas an increase in thermal conductivity of the surrounding normal tissue has a debilitating effect on the ablation volume and vice versa. With increase in the size of the tumour (i.e., 2cm to 3cm) the effect of each parameter is not harmonious. Their effect changes with change in size of the tumour which is shown by the different gradient observed in ablation volume. Most important is less sensitivity of ablation volume to blood perfusion rate for smaller tumour size (2 cm) which is also in accordance with the previous results presented in literature.

Finally a research was carried out for accurate prediction of the outcome of the therapy based on the simplified models which are fast and require only very few parameters. These include spherical and ellipsoidal models. FEM simulation showed that the gradient of ablation volume for different tissue types is also different owing to varied electrical and thermal properties. The effect of maximum allowable temperature also affects the shape as well as the evolution of ablation volume. Comparison of simplified models with FEM results was carried out and it was concluded that for various tissues simplified models provide good results with an accuracy of more than 90 percent in some cases. Generally, the prediction is poor at shorter times but however becomes accurate as the treatment time progresses.