2013 Taste of Research Summer Scholarship Program

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Laser Induced Hyperthermia of Superficial Tumors: Thermal Damage Model With Regeneration of Healthy Tissue

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Research Theme: Fundamental and Enabling Research

Background and Motivation

Laser induced hyperthermia at mild temperature is a promising therapy that used to fight cancer especially melanoma or carcinoma. It is used to destroy cancerous cells while minimizing the adverse effects of it on the surrounding healthy tissue.

In previous studies, a mathematical model was developed to study the thermal effects leading to destruction of the superficial tumours using computational analysis. This model considers both radiative and transient heat transfer in the human body. It takes into account the metabolic heat generation, blood perfusion through capillaries and heat exchange between a human body and ambient medium. Fig 1. shows the skin tissue with melanoma on the left side and the finite element method (FEM) triangulation of an axisymmetric computational region on the right side.

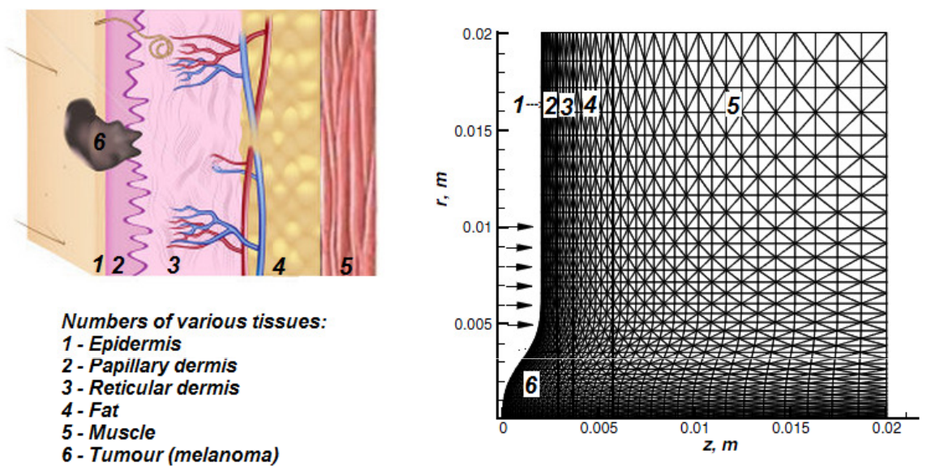

Fig. 1: Skin tissue and FEM model for computation (the arrows represent the laser irradiation for thermal treatment).

However, in previous studies, the regeneration of healthy tissue after the hyperthermia treatment was not taken into account.

Aims and Objectives

- To improve the existing mathematical model by introducing the regeneration term for healthy skin tissue.
- To use the modified thermal damage model to study the thermal conversions of the tumour and healthy tissue.

Method

The methodology for the modified thermal damage model is shown below:

- The traditional Arrhenius kinetic equation in the mathematical model is modified with considering a term proportional to the local blood perfusion for healthy tissues only. This term is responsible for the cell regeneration. The modification of Arrhenius kinetic equation with the perfusion term is shown in below.

$$\frac{\partial \xi}{\partial t} = (1-\xi) A \exp\left(-\frac{E}{RT}\right) \quad \textbf{Modification} \quad \frac{\partial \xi}{\partial t} = (1-\xi) A \exp\left(-\frac{E}{RT}\right) - B\xi\omega$$

Equation 1: Modified Arrhenius kinetic equation.

Where ξ is the degree of tissue degeneration, E is the activation energy, A is the Arrhenius constant, R is the universal gas constant, T is temperature in unit Kelvin, B is the dimensionless coefficient and ω is the blood perfusion rate measured in unit /s .

- A suitable choice of Arrhenius kinetic parameters are obtained from literature. The B coefficient was chosen to make a realistic prediction for thermal destruction of the tissue.
- The existing Fortran code for the computational analysis was modified based on Equation 1 .
- The heating method is periodic laser irradiation for 60 minutes. Fig. 2 shows the fragments of periodic heating of the skin using incident radiative flux, q for the time in seconds.

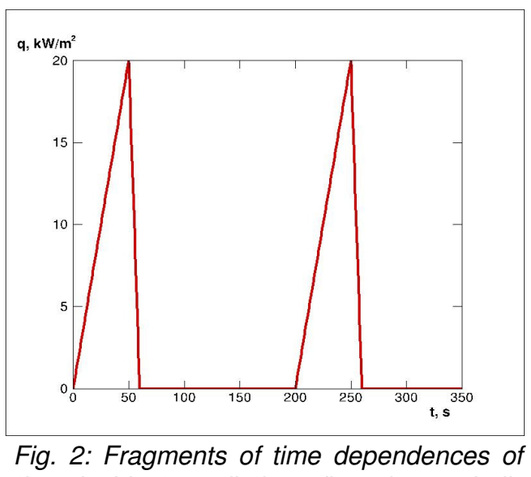

Fig. 2: Fragments of time dependences of the incident radiative flux in periodic heating.

Results

Temperature

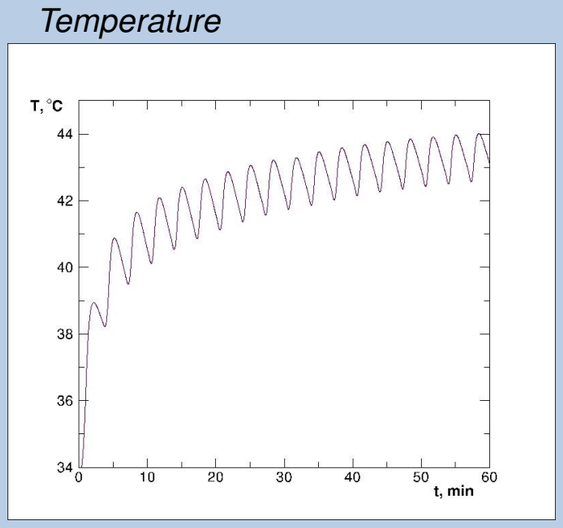

Fig. 3: Time variation of tissue temperature in the tumour centre.

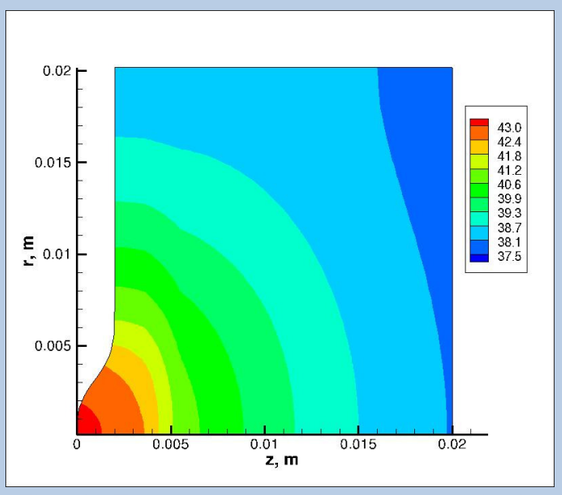

Fig. 4: Temperature field at the end of thermal treatment by periodic laser irradiation

Fig. 3 shows the oscillation of the tissue temperature in the centre of tumour as the result of the periodic laser irradiation. The temperature never exceed 44˚C since the treatment is designed to be in the mild temperature range. Fig. 4 shows the temperature field in the end the thermal treatment. It is observed that the tumour region has highest temperature comparing to the healthy tissue.

Thermal Destruction

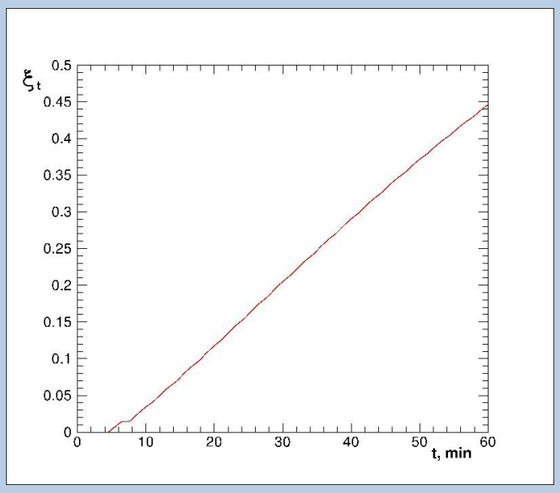

Fig. 5: Degree of thermal destruction of the tissue cells in tumour centre.

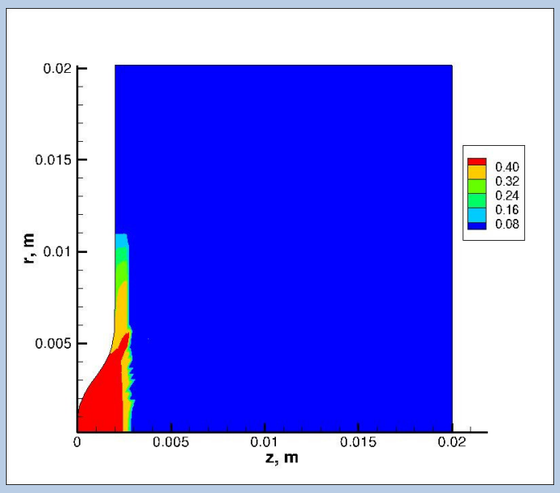

Fig. 6: Thermal destruction contour of the tissue.

Fig. 5 shows the degree of thermal destruction of the tissue cells in the tumour centre during the periodic heating. The observation is the destruction of the tissue cells gradually increases while the temperature goes through oscillations due to periodic heating.

Fig. 6 shows the thermal destruction contour for the tissue at the end of treatment. It is observed that the tumour region has the highest destruction whilst the irradiated region also exhibits increased thermal destruction.

Conclusion

Regeneration of healthy tissues based on the blood perfusion rate was introduced into the Arrhenius kinetic equation to improve the estimation of thermal conversions during laser induced hyperthermia of superficial tumour.

Numerical simulations showed that the model is capable for the prediction of different rates of thermal conversions in tumour and healthy tissues.

Plan for the Future

- The thermal destruction and regeneration of arterial blood should be considered.
- Different heating regimes can be used to investigate its effect on the degree of thermal destruction of the tumour and healthy tissue.
- The model should be validated by comparison with experimental data.