A Finite Element Heat Transfer Model for Cryosurgery Applications

M.C. Hsieh and T. S. Ravigururajan

Department of Mechanical Engineering, College of Engineering

1. Introduction

Cancer is the second leading cause of death in American, with lung cancer having the greatest occurrence. Last year, more than 175000 cases [1] diagnosed in United States. As a result, more effective methods of treatment are needed. Cryosurgery or the destruction of undesired biologic tissues by freezing becomes an important invasive surgical technique. The technique use low temperature for treatment of tumor was introduced by James Arnott, and English physician, for the treatment of an advanced uterine carcinoma in 1865[2]. Since Arnott's first report, numerous of cryosurgery devices and techniques have been suggested.

The application of minimally invasive cryosurgery requires the development of a procedure that minimizes the damage to the surrounding tissues during the freezing process. These include accurate localization of the cryoprobe, precise monitoring of the frozen region, and proper freezing time. In this study, the prediction of the probe's optimal application time to effective freeze and kill the tumor and prevent excessive damage to the surrounding health tissues will be presented by using 2-D model in Ansys.

2. Mathematical Model

The conduction heat transfer in tissue can be described by Pennes bioheat equation

$$(\rho c)\frac{\partial T}{\partial t} = \nabla(k\nabla T) + \rho_b c_b w_b (T_b - T) + q_m \qquad (1)$$

Where T is the tissue temperature, t is the time, k is the conductivity, Tb is the blood temperature, wb is the blood perfusion rate, qm is the metabolic heat generation.

Assume that no heat generation of the tissues and no effect of blood perfusion, the energy equation can be used to model tissue temperature as a function of both position and time throughout the tumor and healthy lung tissues.

$$(\rho c)\frac{\partial T}{\partial t} = K\left(\frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial Y^2}\right) \qquad (2)$$

3. Problem Description and Setup

Cryosurgery for treating lung cancer will be simulated in Ansys. A diameter 1.0mm cryoprobe is inserted into 1cm tumor surrounded by the normal tissues. Compressed gaseous nitrogen with temperature -190℃ flows through the instrument, making the probe's front metal cold enough to freeze and destroy the tumor. The tumor is assumed to be completed surrounded by a continuous cylinder of healthy tissues. The dimensional model is shown in Figure1. The thermal characteristics of tumor and normal tissues are listed in the Table 1[3]. The initial temperature is set to 37℃ for both tumor and normal tissues. Temperature is destroy tumor tissue is assumed to be -40℃.

The goal is to determine the cryoprobe optimal application time to effectively destroy tumor in the lung, while minimizing the damage to the surrounding healthy tissues.

4. Results and Discussion

The simulation was performed at probe temperature of -190℃ over an extend period of time up to 300 seconds. The results show the change of temperature within the lung tissues with increasing the probe application time. The temperature history plots of nodes located at the tumor, edge between tumor and normal tissues, and normal tissues have been obtained. The optimal probe application time in this simulation shown in figure 2 is determined to be 150 seconds where the tumor was totally frozen to desired temperature and no significant damage to the surrounding health tissues.

Next step, an analysis was performed by changing the density of surrounding tissues. The results were observed that the lower density of surrounding tissues will result a shorter freezing time within the tumor.

5. Conclusion

Cryosurgery for treating lung cancer has been modeling in Ansys. The results obtained from various test conditions. It was determined that the optimal cryoprobe application time in this lung tumor model is 150 seconds. This simulation results in large percentage of tumor death, while minimizing the damage to surrounding normal tissues. The density of surrounding tissues has significant effect of freezing temperature transfer inside the tumor. Further design recommendations include using multiple cryoprobes simultaneously to both decrease application time and increase effective tumor cell death while preserving the surrounding normal tissues. Furthermore, different shape and size of tumor should be considered as well as different geometry of cryoprobes.

6. References

[1] Maiwand MO. Cryosurgery for lung cancer: clinical result and technical aspects. Technology in cancer research and treatment, 2004;3:143-150.

[2] Arnott, J. On the treatment of cancer by regulated application of an anesthetic temperature. J Churchill, London (1851).

[3] Rabin Y,Lung DC, and Stahovich T.F. Computerized planning for multiprobe cryosurgery using a force-field analogy. Computer Methods in Biomechanics and Biomedical Engineering, 2004; 7: 101-110.

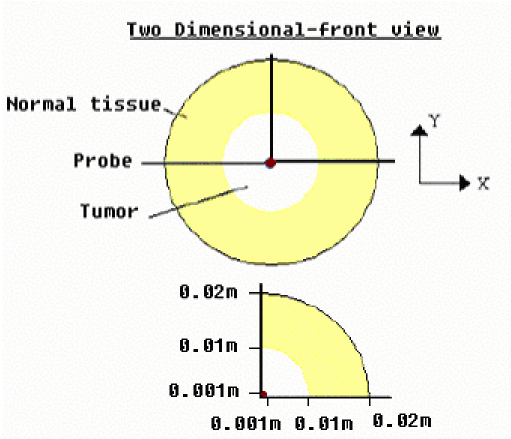

Figure 1. Tumor model with dimensions used in analysis and modeling

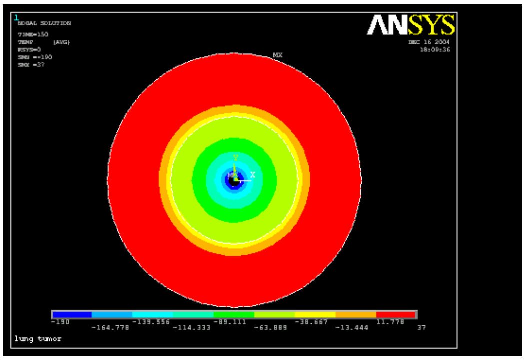

Figure 2. Temperature Contour after application of probe for 150 seconds

Tissue Type	Radius(m)	Thermal Conductivity(W/mK)	Density(kg/m³)
Tumor	0.01	1.40	200
Normal	0.02	0.245	960

Specific Heat (J/kgK)	Temperature
3600	T>273K
15440	251K<T<273K
2300	T<251K

Table 1. Thermal characteristics of tissue