Proceedings of IMECE2007
2007 ASME International Mechanical Engineering Congress and Exposition
November 11-15, 2007, Seattle, Washington, USA

IMECE2007-43920

CONFORMAL TUMOR TREATMENT BY THE COMBINED CRYOSURGICAL AND HYPERTHERMIC SYSTEM: OPTIMAL CONFIGURATION OF THE MULTIPLE PROBES

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ABSTRACT

Recently, a minimally invasive probe system capable of performing both cryosurgery and hyperthermia treatment for deep tumor was developed. With the increasing applications of such combined system, it becomes apparent that without optimal configuration of the multiple probes during multiple freeze/heat cycles, it is difficult produce a conformal lesion in the tumor tissue, which may lead to either insufficient or excessive freezing/heating and consequently, to tumor recurrence or to destruction of healthy tissue. In this study, a comprehensive three-dimensional numerical investigation is performed to design optimal configurations of the multiple probes used in the combined cryosurgical and hyperthermic treatment. The results presented in this study will be useful for treatment planning of the combined cryosurgical and hyperthermic treatment.

INTRODUCTION

Since the beginnings of modern cryosurgery, the need for repetitive freezing in the cryosurgical treatment of cancer has been recognized. Many investigations have suggested that multiple freeze/thaw cycles can result in significantly more damage to the tumor and better outcome than a single cycle [1]. The repeated cycle can produce faster and more extensive tissue cooling, so that the volume of frozen tissue is enlarged and the border of certain tissue destruction can be moved closer to the outer limit of the frozen volume [2]. For this reason, repetition of the freeze-thaw cycle is important for the tumor treatment.

Recently, a new tumor ablation modality based on the freezing immediately followed by a strong heating has been developed [3]. Similar to freeze/thaw cycle of cryosurgery, the freezing/heating process during the combined cryosurgery and hyperthermia can be termed as freeze/heat cycle. Because the combined cryosurgery and hyperthermia system is a new modality for tumor treatment, the freeze/heat behaviors of biological tissue subject to it have received few attentions up to now, and the complex three dimensional (3-D) heat transfer characteristics involved in multiple freeze/heat cycles remain unknown up to now.

Tumor treatment with this combined cryosurgical and hyperthermic system has been proved to be more effective and flexible than the conventional cryosurgical therapy. To obtain optimal clinical output for both cryosurgery and hyperthermia, total and exact destruction of tumor tissues is very important. Failure to do so can lead to either insufficient or excessive freezing/heating, and consequently result in tumor recurrence or destruction of healthy tissue. It is also accepted that without careful configuration of the multiple probes during multiple freeze/heat cycles, it is difficult to tell whether the target tissue has been frozen/burned adequately and irreversibly damaged, and it is also difficult to produce an expected conformal lesion (to maximize the tumor killing effect while minimizing thermal injury on healthy tissues). The aim of this study is to design optimal configurations of the multiple probes to perform conformal tumor treatment with the combined cryosurgical and hyperthermic system.

METHODS

Using the effective heat capacity method, the energy equation simultaneously describing for frozen, partially frozen and unfrozen tissues during freezing/heating process can be written as:

$$\tilde{C}\frac{\partial T(\mathbf{X},t)}{\partial t}=\nabla\cdot\tilde{k}\nabla T(\mathbf{X},t)-\tilde{\omega}_b C_b T(\mathbf{X},t)+\tilde{Q}_m+\tilde{\omega}_b C_b T_a\,,\ \ \mathbf{X}\in\Omega \quad (1)$$

where $\tilde{C}$ is the effective heat capacity; $\tilde{k}$ is the effective thermal conductivity; $\tilde{Q}_m$ is the effective metabolic heat generation; and $\tilde{\omega}_b$ is the effective blood perfusion.

The numerical algorithm and computer code used in this study is revised from that developed in our previous work [4].The description and derivation of the algorithm is omitted here for brevity. Readers are referred to [4] for more details.

RESULTS AND DISCUSSION

In cryosurgical clinics, complex-shaped iceballs which conformally enwrap the tumor with complex geometry are usually obtained by combined use of multiple cryoprobes. In this study, numerical investigations were also performed for the cases using multiple probes. Figures 1-3 shows part of results, in which 3 probes with different configurations are applied (the freeze/heat cycle includes 10 min freezing and succedent 10 min heating). Results in Figs. 1 and 2 indicate that either insufficient or excessive freezing/heating have been resulted with the corresponding probes' configuration. It is shown in Fig. 3 that lethal area produced by freezing has totally encompassed the whole tumor with similar shape, and that parameters of probes under configuration 3 have been optimal. The current results also suggest that the combined cryosurgery and hyperthermia system has strong freezing and heating capability, and that it may improve the treatment effect by providing double chances to possibly kill tissues. Detailed description and more results will be presented at the conference.

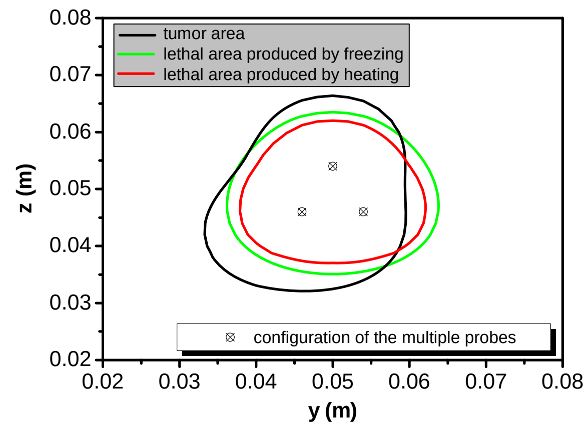

Fig. 1. Lethal areas produced by 3 probes under configuration 1

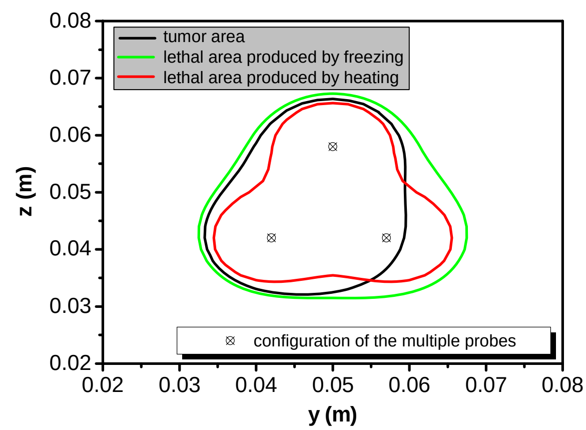

Fig. 2. Lethal areas produced by 3 probes under configuration 2

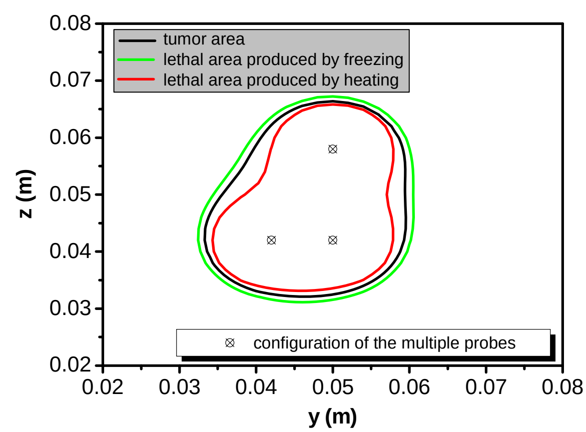

Fig. 3. Lethal areas produced by 3 probes under configuration 3

ACKNOWLEDGMENTS

This work was partially supported by the National Natural Science Foundation of China (under Grants 50576104 & 50325622) and the Initial Funding for the Gainer of Excellent Doctoral Dissertation of CAS.

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