Proceedings of BIO2006
2006 Summer Bioengineering Conference
June 21-25, Amelia Island Plantation, Amelia Island, Florida, USA

BIO2006-157191

STUDY ON THE ENHANCEMENT OF RF ABLATION BY INTRODUCING ADJUVANTS OF SALINE SOLUTION OR MAGNETIC MICRO/NANO PARTICLES

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INTRODUCTION

Radiofrequency (RF) ablation is a minimally invasive technique for tumor treatment. Intended benefits of RF tumor ablation include the availability of tumor treatment in nonsurgical candidate, minimal risk to patient, reduced morbidity and shorter recovery compared with those after conventional surgery, the potential for treatment on an outpatient basis, and the ability for real-time imaging guidance [1]. RF ablation, by producing heat energy that raises the temperature of the target tissue to a degree sufficient to cause thermally mediated coagulation necrosis, has been shown to be remarkably effective for thermal ablation of small tumors [2]. However, a long-term follow-up report on percutaneous RF ablation of colorectal liver metastases suggests local tumor recurrence in 35% of cases [3]. Whereas RF has been successful in ablating small neoplasms, further optimization of the ablation technique is required to induce the larger volumes of coagulation that are necessary to adequately treat larger tumors.

It is known that for a given total RF power output, the power deposition at each point in space is strongly dependent on the local electrical conductivity. Along this direction, several investigators [1, 2] have demonstrated the ability to increase RF tissue heating and coagulation volume by altering electrical conductivity in tissues through saline injection prior to or during RF ablation.

To achieve clinical benefit, optimal parameters for saline injection need to be determined for each type of RF apparatus used and for the different tumor types and tissues to be treated. In addition, considering that magnetic micro/nano particles has been used in nanomedicine fields and as a sort of material with high electrical conductivity, it is reasonable to believe that magnetic micro/nano particles can also be used as effective adjuvants to enhance the efficacy of RF ablation.

In order to better understand the mechanisms of the heating enhancement by introducing adjuvants with high electrical conductivity, we conducted a series of investigations to characterize the effects of volume and concentration of adjuvant saline or magnetic micro/nano particle pretreatment on RF ablation and to model these results to determine their applicability to in vivo systems.

METHODS

RF tumor ablation involves the application of electromagnetic energy and can produce theoretically predictable tumor destruction on the basis of well-defined variables of electrical field equation and bioheat equation.

Model for EM Field in Tissue

One can then obtain the potential φ inside the tissue through solving the source free Laplace equation:

$$\nabla \cdot \left[\varepsilon(\mathbf{X}) \cdot \nabla \varphi(\mathbf{X}) \right] = 0 \tag{1}$$

where **X** contains the Cartesian coordinates *x*, *y* and *z*, $\varepsilon(\mathbf{X})$ is the dielectric constant permittivity of tissue.

The electric field strength inside the tissue is determined by:

$$\mathbf{E}(x, y, z) = -\nabla \varphi(x, y, z) \tag{2}$$

Heat generation due to the RF dissipated power in tissue not pretreated by magnetic micro/nano particles is determined by:

$$Q_{r1}(x, y, z, t) = \sigma_1 \left| \mathbf{E}(x, y, z) \right|^2 / 2 \tag{3}$$

Heat generation due to the RF dissipated power in tissue pretreated by magnetic micro/nano particles is determined by [4]:

$$Q_{r2} = \left[\frac{3nr^3 \chi''}{4\mu_0 f R^2} + \left(1 - \frac{4}{3} n\pi r^3 \right) \frac{\sigma_2}{2} \right] \cdot \left| \mathbf{E}(x, y, z) \right|^2 \tag{4}$$

Thermal Model for Temperature Response in Tissue

The well-known Pennes equation was used to model heat transfer in biological bodies:

$$\rho c \frac{\partial T(\mathbf{X},t)}{\partial t} = k\nabla^2 T - \rho_b c_b \omega_b T + \rho_b c_b \omega_b T_a + Q_m + Q_r \qquad (5)$$

The numerical algorithm solving the above equations refers to [5].

RESULTS AND DISCUSSION

Figure 1 shows the transient temperature response of tissue at a given position (0.03 m, 0.04 m, 0.04 m) for three different cases, in which case 1 denotes the case of magnetic micro/nano particle injection, case 2 denotes the case of saline injection, and case 3 denotes the case of no adjuvant injection. Temperature distribution at t=2000s, z=0.04 m for the cases of no adjuvant injection, saline injection, and magnetic micro/nano particle injection are shown in Figs. 2-4, respectively.

The results suggest that injection of adjuvants with high electrical conductivity before RF ablation can significantly increase the target tissue heating and induced coagulation, which will likely benefit clinical RF ablation. In addition, it is indicated that injection of magnetic micro/nano particles can cause a much better RF ablation effect than saline injection.

Further results also show that temperature induced by RF heating with given volumes and concentrations of saline or magnetic micro/nano particle adjuvants can be reliably predicted using bioheat transfer simulation. Detailed description and experimental validation will be presented at the conference.

Due to the irregularly shaped tumor in clinics, the conventional RF ablation technique is hard to produce an optimal lesion in the tumor tissue. In order to obtain the optimal output, strategies to flexibly control the size and shape of the ablated zone are desired. The above results indicate that the power deposition at each point in space is strongly dependent on the local electrical conductivity. Consequently, it is also possible to flexibly control the area of RF heating and tissue coagulation by injecting adjuvants with high electrical conductivity into the tissues before or during RF application. This feature will be investigated in our future works.

ACKNOWLEDGMENTS

This work was partially supported by the National Natural Science Foundation of China under grant 50325622.

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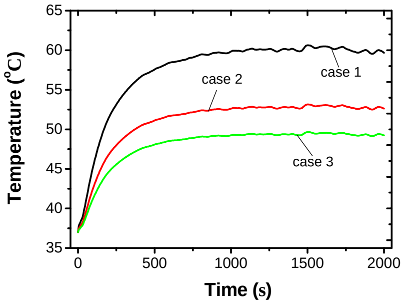

Figure 1. Transient temperature of tissue at a given position

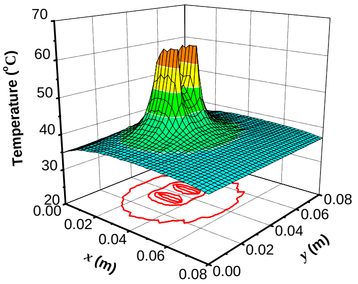

Figure 2. Temperature distribution at *t*=2000s, *z*=0.04 m for the case of no adjuvant injection

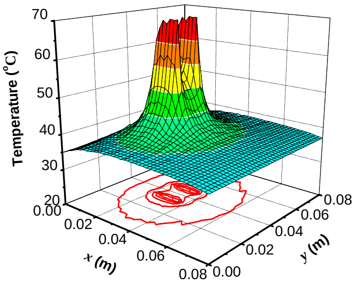

Figure 3. Temperature distribution at *t*=2000s, *z*=0.04 m for the case of saline injection

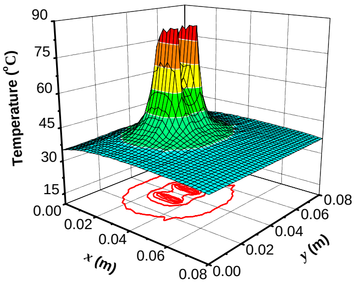

Figure 4. Temperature distribution at *t*=2000s, *z*=0.04 m for the case of magnetic micro/nano particle injection