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高強度聚焦超音波加熱腫瘤周圍之可行性研究

INVESTIGATION OF THE FEASIBILITY OF THE HEATING TUMOR BOUNDARY WITH HIGH INTENSITY FOCUSED ULTRASOUND THERMAL SURGERY

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一、中文摘要

本研究的目的是探討腫瘤組織周圍血液灌流對高強度聚焦超音波熱手術之可行性研究。超音波換能器所產生的壓力場是使用雷力積分式，溫度場是生醫熱傳方程式獲得。數值結果顯示高強度聚焦超音波可在腫瘤邊界上形成有效熱凝固壞死區，即使腫瘤組織血液灌流達 10 kg/㎥s。高強度聚焦熱音波加熱腫瘤周圍之熱手術可能可提一腫瘤治療的途徑。

關鍵詞：超音波、熱手術、腫瘤周圍

Abstract

The aim of this study is to investigate the feasibility of the heating on the tumor boundary using high intensity focused ultrasound (HIFU) during thermal surgery. The pressure field induced by high intensity focused ultrasound transducer was solved by the Rayleigh-Sommerfeld diffraction integral. The temperature distribution was solved by the Pennes bioheat transfer equation. Numerical results demonstrated that HIFU could produce thermal ablation lesion (*i.e.*,coagulation and necrosis for tissue) on the tumor boundary even when the blood perfusion rate on the tumor boundary reaches 10 kg/m^{3}s. The modality of heating on the tumor boundary by using high intensity focused ultrasound may provide an approach to eradication of solid tumors.

Keywords: Ultrasound, Thermal Surgery, Tumor Boundary

二、緣由與目的

Ultrasound wave beam can penetrate the body tissue and produce two effects on tissue such as non-thermal (cavitation) and thermal (heating) effects [1-7]. Cavitation, the formation and activities of bubbles (cavities) in a liquid, has been widely used to noninvasive tumor thermal treatments. A detailed investigation of bubble formation and bubble collapse is shown in the reference book of Young (1999) [8]. In general, acoustic cavitation describes the interaction of a sound field with a gas bubble. When exposed to an acoustic field, a bubble in a liquid will oscillate around an equilibrium radius [9]. The maximum response of a bubble to an acoustic field occurs when it is radiated at its resonance frequency. Furthermore, Delecki (2004) discussed that noninertial cavitation describes a repetitive oscillation of a bubble over many acoustic cycles. He also drew a conclusion that the maximum expansion of a noninertial cavity typically does not exceed twice the equilibrium radius. Cavitation occurs when the tensile strength of pure water is very large, on the order of 100 MPa, so that cavitation is almost always initiated at a preferential site for liquid rupture, that of a inhomogeneity in the liquid or tissue [10]. Crum (2004) also pointed out that because mammalian living systems circulate blood through a variety of filters (*i.e.*, lung, kidneys, liver, and so on), the cavitation threshold in blood is higher than in water, and in tissue is even higher. Typical values of the threshold are: Water- 0.5 MPa; Blood- 2.5 MPa; and Tissue- 5.0 MPa [10]. High-intensity focused ultrasound (HIFU) is a non-invasive technique for heating tumors. The principle is based on the physical effect of ultrasound beam on tissues. Furthermore, a detailed description of the physical mechanism of HIFU can be found in the reference of Bailey et al. (2003) [2]. The main goal of HIFU is to maintain a temperature between 50 to 100 °C for a few seconds (typically < 10 s), in order to cause tissue necrosis. Typically, focal peak intensity between 1000 to 10,000 W/cm^2 is used with pulse duration between 1 to 10 s and a frequency of 1 to 5 MHz [11][12].

However, according to the vascular characteristics of tumor is that the vascular supply and blood flow in tumors are markedly different from those in normal tissues. In general, the blood perfusion in tumors is poorer than that in the host's normal organs or tissues. Furthermore, blood flow is distinctly higher in the tumor periphery than in the tumor center where often tumor tissue is necrosis due to insufficient nutriment. So in this study we propose a novel boundary heating strategy by using HIFU.

三、結果與討論

Solid tumors induce tumor angiogenesis, in other words, tumor neovascularization, with extensive and rapid growth. Thus, the heating tumor boundary with HIFU may offer an approach to destruction of solid tumors. The heating parameters in this study are shown in Table I.

Table I Blood perfusion rates in core and shell domains used for simulation [13-15]

Case I		Case II		Case III		Case IV		Case V		Case VI	
Core	shell	Core	shell	Core	shell	Core	shell	Core	shell	Core	shell
0.18	1.47	0.18	5.69	0.36	2.75	0.55	3.12	0.5	5	0.5	10
Beaney et al. 1984		Beaney et al. 1984		Acker et al. 1990		Molls & Vaupel (eds) 1998					
The tumor density is 1050 kg m^{-3} (i.e., 1 ml g^{-1} min^{-1}= 18.375 kg m^{-3} s^{-1})											

And the geometry of the heating system is shown in Fig. 1. Figure 2 shows that the core and shell domains of tumors were used in the study. Figure 3 demonstrated that the maximum temperature within the tumor varies with the six different heating cases.

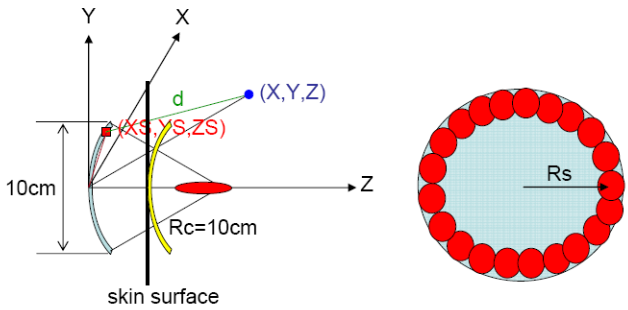

Figure 1. Schematic diagram of the geometry of the heating system. Spherically curved piezoelectric transducer with diameter 10 cm and the radius of curvature 10 cm was used for simulation. The power of the HIFU transducer is 80 Watts and the heating time is 60 seconds.

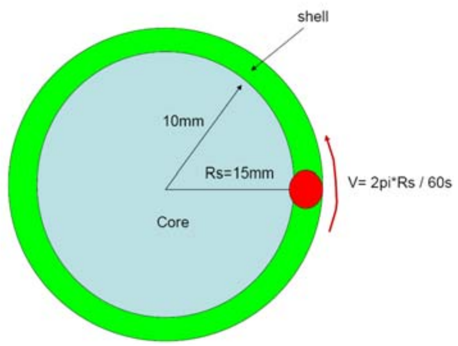

Figure 2. The two different domains (*i.e.*, core and shell) of solid tumors are represented. The light blue circle area indicates the core domain. The green ring area denotes the shell domain.

Figure 4 shows that high intensity focused ultrasound can effectively produce thermal lesion to overcome the cooling effect on the tumor boundary due to high blood perfusion. On the other hand, the use of heat by HIFU could destroy the periphery tissue of tumor.

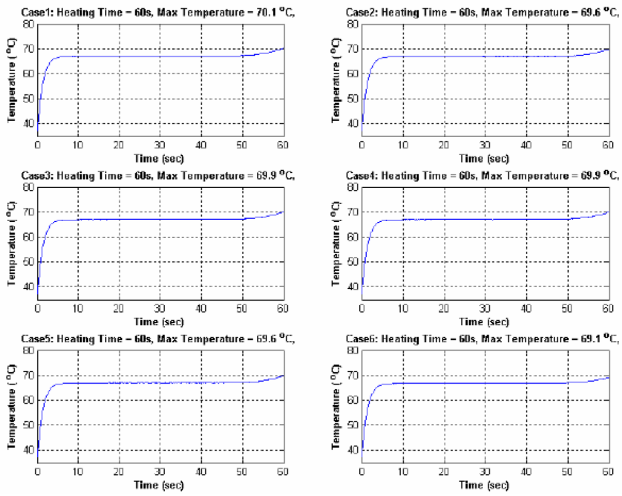

Figure 3. Peak temperature profiles of the six heating cases for HIFU treatment were presented. The power of the transducer is 80 Watts and the heating time is 60 seconds, respectively.

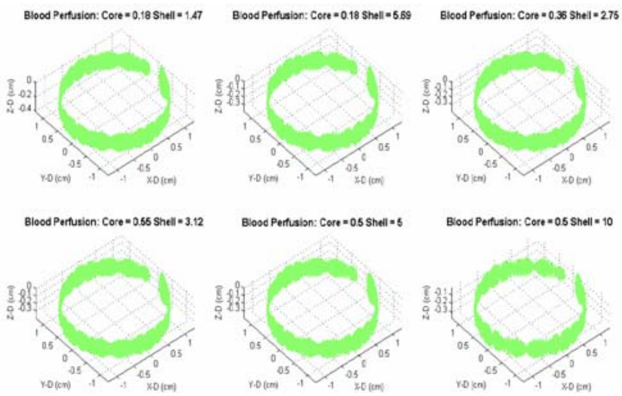

Figure 4. The thermal lesion for the six different cases

As the blood perfusion on the tumor boundary reaches 10 kg/m^3s, the thermal lesion still cover the tumor boundary (as shown in Fig. 5). Moreover, the length of thermal lesion along z-axis is about 1 cm. The diameter of thermal lesion at focal plane is about 15 mm.

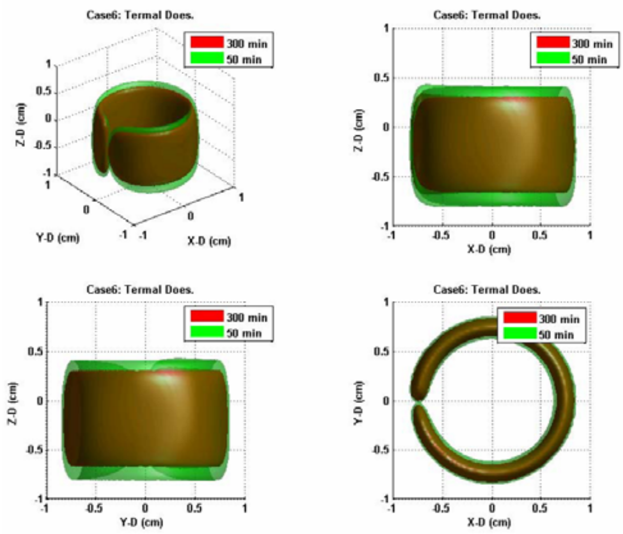

Figure 5. The thermal dose isosurface values for 50 min and 300 min for the heating case 6. The blood perfusion values for core and shell tumor region were 0.5 and 10 kg/m^3s, respectively.

四、結論

The modality of heating on the tumor boundary by using high intensity focused ultrasound may provide an approach to eradication of solid tumors.

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