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Heating properties of a new hyperthermia system for deep tumors without contact

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***Abstract*— In this paper, heating properties of the proposed hyperthermia system for non-invasive treatment of deep tumors are discussed. Our heating system is composed of a large size resonant cavity applicator. In this heating method, a human body is placed between the two inner electrodes. It is heated by electromagnetic fields stimulated in the cavity without contact between the surface of the human body and the applicator.**

First, we presented the experimental results of heating a cylindrical agar phantom and a cylindrical fat-agar phantom using the proposed system. From the thermal images of the heated phantoms, the center of the agar was locally heated to maximum temperature.

Second, we presented the experimental results of heating a mini pig. In the heating experiment, temperature measurements were performed by using fiber-optical thermometers inserted in four locations inside the mini pig. From the results, the deepest region of the liver was heated to the highest temperature 43.3°C.

I. Introduction

HYPERTHERMIA is based on the clinical fact that cancer cells are more sensitive than normal tissue in the temperature range of 42-43°C [1]. Various types of heating systems for heating deep tumors have been proposed [2] , [3]. However, these systems have advantages and disadvantages, with regard that deep-seated tumors can not be sufficiently heated.

In order to mitigate these disadvantages, a new heating system using a large size resonant cavity for heating the deep region of human body was developed [4]. In this heating method, a human body is placed in the gap of two inner electrodes and is heated by electromagnetic fields excited in the resonant cavity.

In this paper, first, we presented the experimental results of heating a cylindrical agar phantom and a cylindrical fat-agar phantom using the developed applicator at various resonant frequencies. The center of the agar was locally heated to maximum temperature and the temperature rise was approximately 4℃.

Second, we performed heating experiments on mini pig. In the heating experiment, temperature measurements were performed by using fiber-optical thermometers inserted in four locations inside the mini pig.

From these results, it was found that the deepest region of the liver is heated at a relatively higher temperature than other non-distant surrounding tissue.

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II. Methods

Figure 1 shows an illustration of the developed heating system [4]. In the heating method, a human body is placed in the gap between two inner electrodes inside the cavity. The deep abdominal tumor is heated by electromagnetic fields stimulated in the cavity without contact between the surface of the human body and the electrode.

Figure 2 shows the developed heating system used in the experiments. It consists of an amplifier, an impedance matching controller, a matching box, an antenna, a cavity and a computer to control the heating system. The cavity used in the experiments is 1,400mm in diameter and 1,000mm in height. To concentrate the heating energy in the center of the cavity, the inner electrodes are 50mm in diameter and 350mm in height, respectively [4]. The cavity is constructed of 8 sections made of aluminum. The maximum input power is 150W, and the operating frequency is between 50MHz and 400MHz. The amplifier and matching controller are connected to the cavity shown in Fig. 2(a). The high frequency current flows from the amplifier to the antenna. The impedance matching unit is directly attached to the cavity wall to reduce the loss of electrical current shown in Fig. 2(b). In order to excite electromagnetic fields inside the cavity, the loop antenna is made of a copper plate which is about 350mm in length, 20mm in width, and 1mm in thickness, respectively.

Figure 3 shows photographs of the agar phantoms used in the experiments. In Fig. 3(a), the cylindrical agar phantom is 180mm in diameter and 130mm in height. In Fig. 3(b), the cylindrical fat-agar phantom is 180mm in diameter and 160mm in height, and the upper and lower fat layers are respectively 20mm and 10mm in thickness, respectively. The fat layers represent the abdomen and dorsal region of the human body. The components of the agar phantom used in the experiments are listed in Table I.

Figure 4 shows the setup of the mini pig heating experiment. The mini pig is 60cm in length and 10kg in weight, respectively. We medicated the mini pig with the anesthetic drug in accordance with the rule of the experimental facility. The mini pig was sleeping during the heating experiment of two hours. In order to measure tissue temperatures during heating, four fiber-optical thermometers were inserted into the mini pig as shown in Fig. 4.

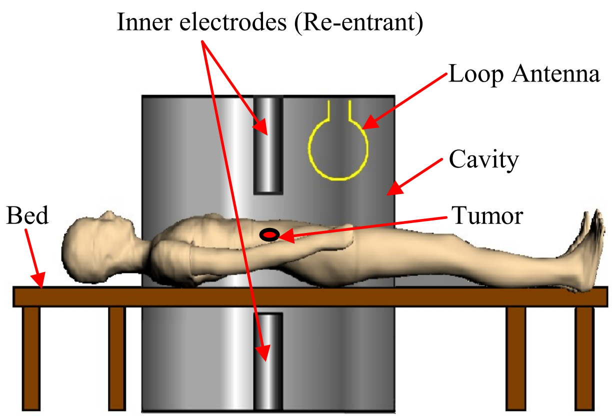
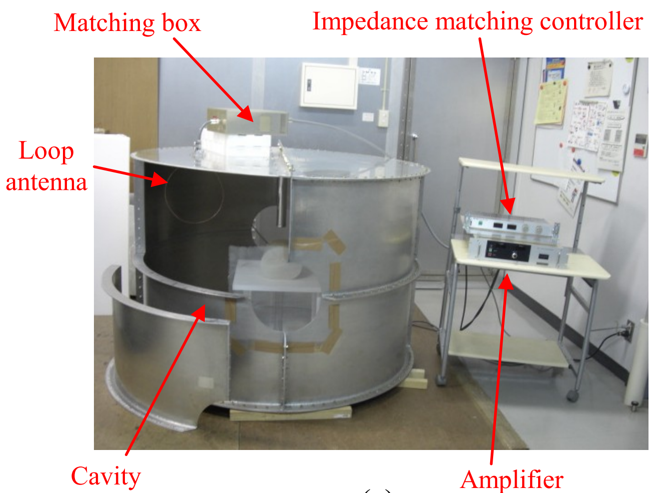
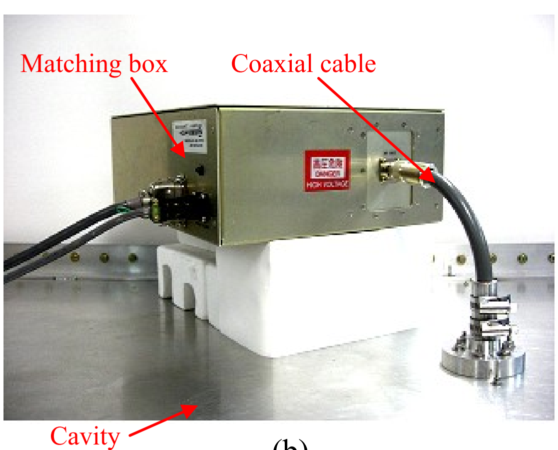


Fig. 1 Illustration of developed heating system.

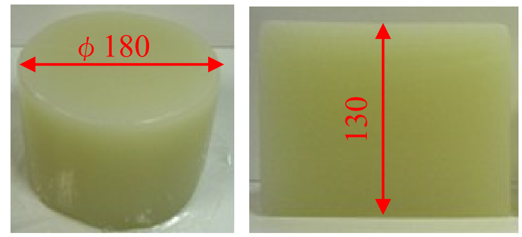


(a)

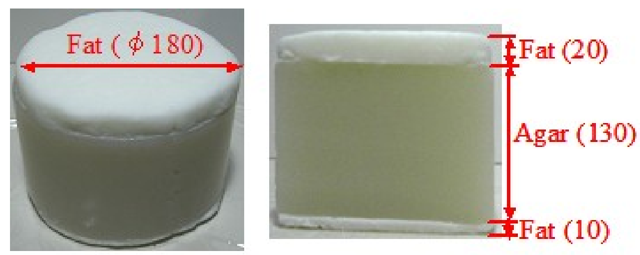


(b)

Fig. 2 Setup of heating system :
(a) heating system, (b) impedance matching box.



(a) [mm]



(b) [mm]

Fig. 3 Cylindrical phantoms used in the heating experiments:
(a) agar phantom, (b) fat-agar phantom.

TABLE I
AGAR PHANTOM USED IN THE EXPERIMENTS

Conponents 【%】	
Agar	4.0
Salt	0.24
Sodium azide	0.1
Water	95.66

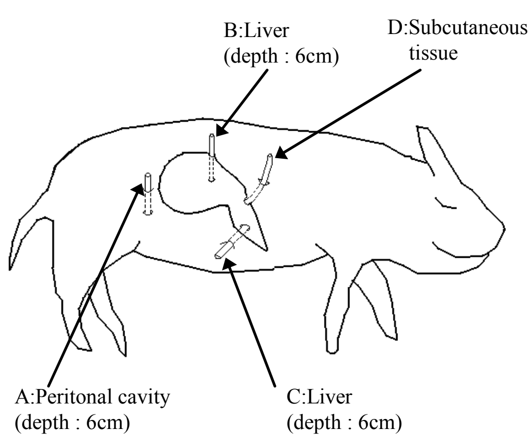


Fig. 4 Setup of the mini pig heating experiment.

III. RESULTS AND DISCUSSION

A. Heating experiments of agar phantoms

Here, first, we performed heating experiments on agar phantoms as shown in Fig. 3.

Figure 6 shows the thermal image of a sagittal slice of the agar phantom taken by an infrared thermal camera after 30minutes of heating with our heating system. The heating power was 15W and the resonant frequency was 128.00MHz. In Fig. 5, the center of the agar phantom was heated to 30.9°C and the temperature rise was approximately 4°C. when the assumed living human body temperature in 37°C, tumor will be heated to 41°C or more.

Figure 6 shows the normalized temperature profiles along the x and z-axes. Here the normalized temperature T_N is calculated by equation (1):

$$T_N = \frac{(T - T_0)}{(T_{\max} - T_0)} \qquad (1)$$

Where T_0 is the initial temperature and T_{max} is the maximum temperature inside the agar phantom. From Fig. 6, the hot spot was locally generated at the center of the phantom without contact. From (α_2/α_1)=0.51 and (α_4/α_3)=0.57 as shown in Fig. 6, the inside of the cylindrical agar phantom was heated about 60% on both the x and z-axes at the normalized temperature 0.8. Next, we performed the experiments using the cylindrical agar phantom with fat layers.

Figure 7 shows the thermal image of the sagittal slice of the fat-agar phantom taken by an infrared thermal camera after 30minutes of heating. The heating power was 15W and the resonant frequency was 126.85MHz. In Fig. 8, the center of the fat-agar phantom was heated to 23.7°C and the temperature rise was approximately 3°C. The center of the agar was heated to maximum temperature. Since the thickness of the upper fat layer was thicker than that of the human fat layer as shown in Fig. 3, the upper layer was heated more than the human layer.

Figure 8 shows the normalized temperature profiles along the x and z-axes. In Fig. 8, the center of the phantom is the hottest location inside the phantom. From (β_2/β_1)=0.50 and (β_4/β_3)=0.72, the inside of the cylindrical fat-agar phantom was heated about 70% on both the x and z-axes at the normalized temperature 0.8.

From these results, it was found that the developed heating system could heat the deep region of the agar phantom non-invasively.

B. Mini pig heating experiments

Next, we performed heating experiments on a mini pig as shown in Fig. 4. Figure 9(b) shows the results of measuring temperature changes at four locations A, B, C and D as shown in Fig. 9(a). In Fig. 9(b), the measured temperature B at the center of the liver was heated to 43.3°C which is the highest

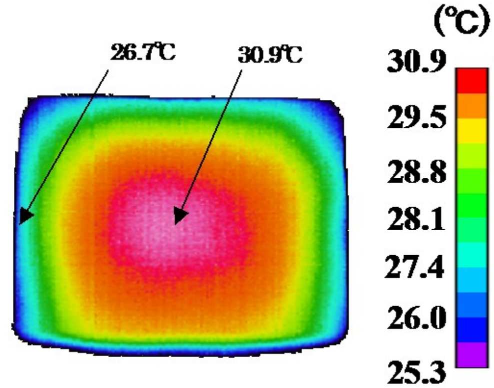
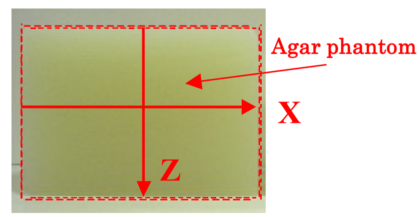
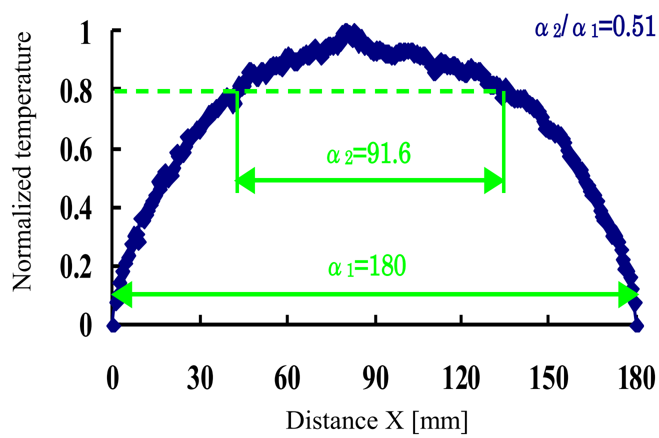
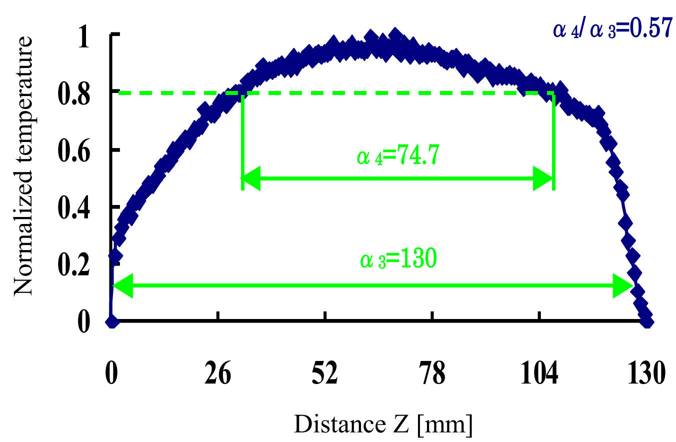


Fig. 5 Thermal image of cylindrical agar phantom just after heating.





(a)



(b)

Fig. 6 Normalized temperature profiles:
(a) on the x-axis, (b) on the z-axis.

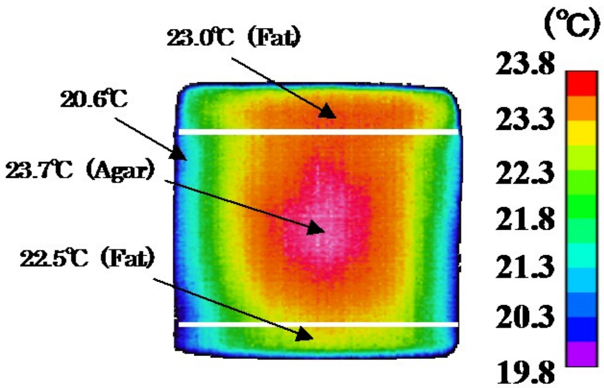
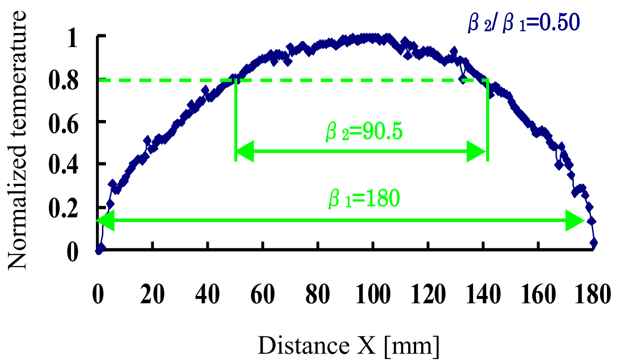
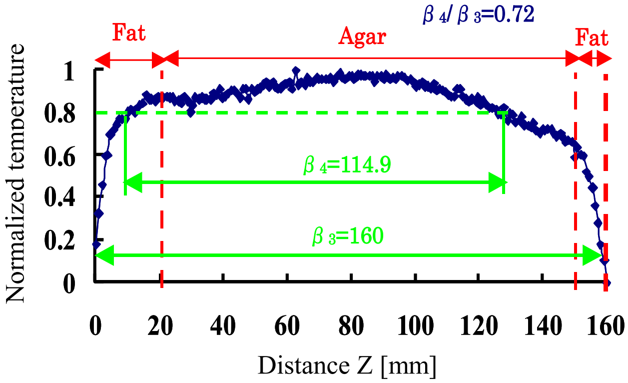


Fig. 7 Thermal image of cylindrical fat-agar phantom just after heating.

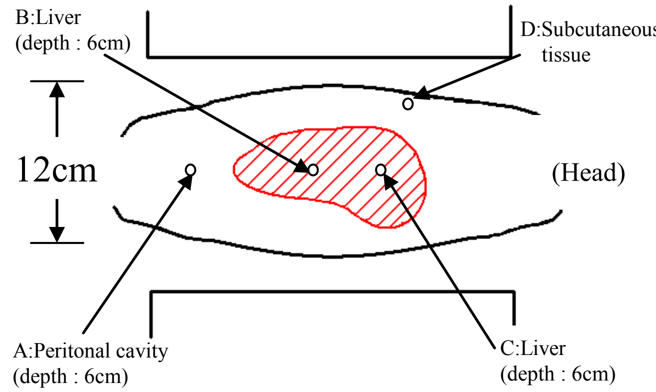


(a)

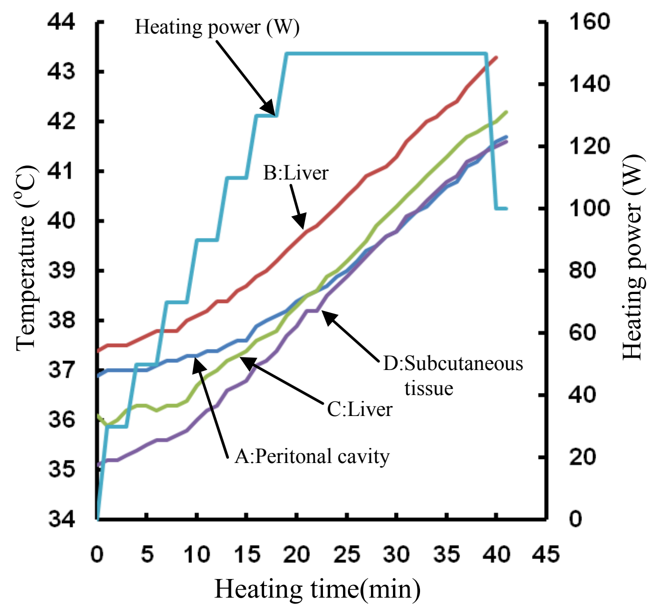


(b)

Fig. 8 Normalized temperature profiles:
(a) on the x-axis, (b) on the z-axis.



(a)



(b)

Fig.9 Result of pig heating experiment:
(a) locations of measuring temperatures, (b) measured temperature changes.

temperature. The temperature of both side A and C is heated to 41.4°C and 41.6°C, respectively. Furthermore, the fat layer location D was heated to 41.8°C. It was found that the temperature at the center of the liver was higher than the temperatures at the other locations by 1.5°C or more. In Fig. 9(b), the resonant frequency was 98.7MHz.

IV. Conclusion

We proposed a new method using a large size resonant cavity applicator for heating deep tumors in abdominal regions. According to our experimental heating results with the agar phantoms and the mini pig, our heating system is expected to non-invasively perform deep and localized hyperthermia treatments.

We are trying to control the heating area by changing electromagnetic heating modes occurring at several resonant frequencies with the developed heating system.

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