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Experimental heating properties of re-entrant type resonant cavity applicator for deep tumor hyperthermia

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Abstract - This paper discusses the heating properties of a new type hyperthermia system composed of a re-entrant type resonant cavity applicator for a deep tumor of the abdominal region. In this heating method, a human body is placed between the two inner electrodes, and is heated with electromagnetic fields stimulated in the cavity without contact between the surface of the human body and the applicator. First, the experimental heating results of an agar-muscle equivalent phantom were presented. Second, we performed a experiment with a lard-agar phantom. The center region of the agar phantom could be heated selectively without generating hot spots in the lard layers. From these results, it was found that our newly developed heating method is useful for a deep-seated tumor hyperthermia treatment.

I. Introduction

Several heating methods have been proposed to heat deep tumors, for example, RF capacitive heating applicators [1], microwave heating applicators [2], and some of them have been in practical use. But they have advantages and disadvantages, and successful heating has not yet been realized.

We have proposed a new type of applicator using the re-entrant type resonant cavity developed especially for deep tumors, and tested them experimentally using a prototype applicator with an agar phantom. This paper presents the heating properties of developed applicator for deep tumor hyperthermia treatment.

Here, first, experimental heating results of an agar-muscle equivalent phantom, of which size is the same as the human body, are presented. Second, the results of heating lard-agar phantom are also presented.

From these results, it is shown that our newly developed heating method is useful for heating a deep-seated tumor.

II. Methods

Fig. 1 shows an illustration of our heating system [2], [3]. In Fig. 1, a human head is placed in the gap of inner electrodes and heated by the enclosed electromagnetic fields inside the cavity.

Fig. 2 shows a diagram of the developed heating system.

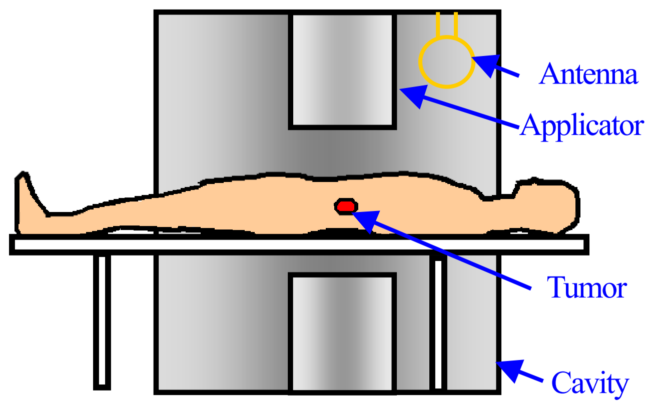


Fig. 1 Illustration of heating system.

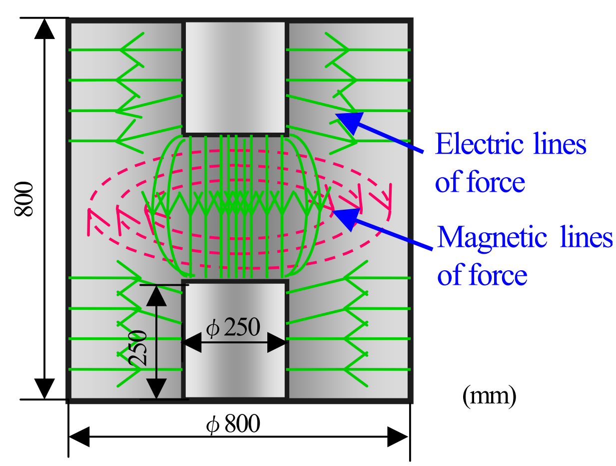


Fig. 2 Electric and magnetic field patterns.

Fig. 2 shows the electric and magnetic field patterns for a TM-like mode inside the cavity and size of the cavity [4]-[6].

The cavity used in these experiments was 800 mm in diameter, and 800 mm in height. Inside the cavity, the inner electrode was 250 mm in diameter and 250 mm in height.

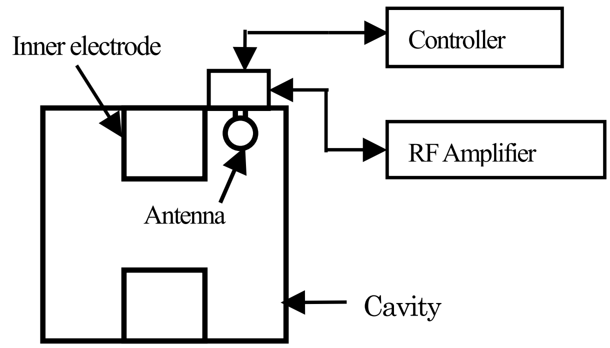
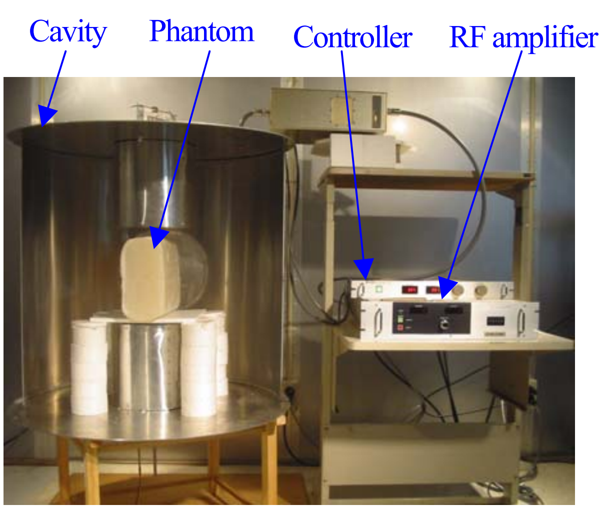


Fig. 3 Diagram of heating system

(a)



(b)

Fig. 4 Setup of heating system.
(a) antenna, (b) heating system.

Fig. 3 shows the diagram of the developed heating system. It consists of an RF amplifier, a cavity, an antenna and a controller. A photograph of the prototype heating system is shown in Fig. 4. Fig. 4(a) shows the antenna made of copper plate used in these experiments. We used the loop type antenna that is 100 mm in diameter, 10 mm in width, and 1mm in thickness. Electric and magnetic fields inside the cavity are excited by the antenna. Fig. 4(b) shows the heating system used in these experiments. The maximum input power is 150 W, and the operating frequency can be changed from 50 to 200 MHz. The controller works to control impedance matching. The amplifier and controller are connected to the cavity with the coaxial cables.

III. RESULTS

A. Agar phantom experiments

The configuration of the agar phantom, 345 mm in width, 230 mm in length and 120 mm in height, used in these experiments is shown in Fig. 5. Fig. 6 shows a thermal image of the sagittal slice of the agar phantom taken by an infrared thermal camera after 60 minutes heating by the developed heating system. The heating power was 20 W, and the resonant frequency was 145.2 MHz. In Fig. 6, before heating, an initial temperature inside the agar phantom is 24.3 ℃, and after heating, the center of the agar phantom is heated to the maximum temperature 25.2 ℃ concentrically.

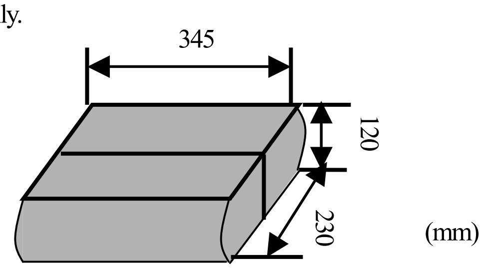


Fig. 5 Agar phantom.

Fig. 7 shows the temperature profile along the r and z-axes shown in Fig. 6. In Fig. 7, normalized temperature T_N can be calculated by equation (1)

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

Where T_0 is initial temperature, T_{max} is maximum temperature inside the agar phantom.

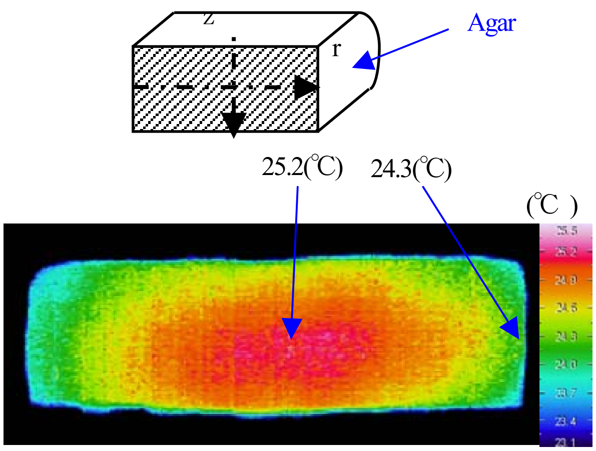
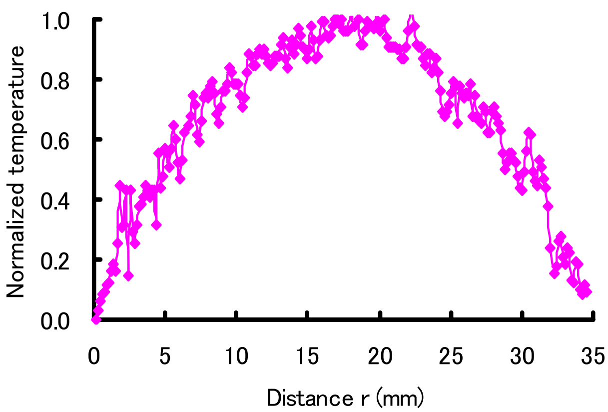
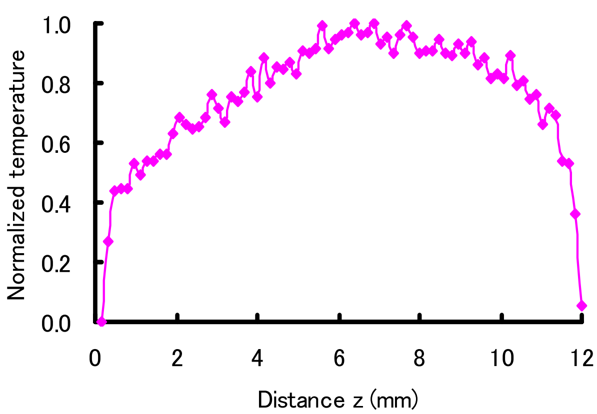


Fig.6 Thermal image of agar phantom just after heating.



(a)



(b)

Fig. 7 Temperature profile, (a) on the r-axis, (b) on the z-axis.

In Fig. 7, from along both the r and z-axes, the hot spot appears at the deep region of the agar phantom.

B. Lard-agar phantom experiments

Fig. 8 shows the configuration of the lard-agar phantom used in these experiments. The photograph is shown in Fig. 9. As shown in Figs. 8 and 9, the lard on the top of the agar phantom is 10 mm in thickness, while, the lard around the sides is in 5 mm in thickness. Fig. 10 shows the thermal image of the sagittal slice of the lard-agar phantom taken by the infrared thermal camera after 60 minutes heating by the re-entrant resonant cavity. The heating power was 20 W, and the resonant frequency was 152.2 MHz. In Fig. 10, before heating, an initial temperature inside the agar phantom is 29.8 ℃, and after heating, the center of the agar phantom is heated to the maximum temperature 31.4 ℃ concentrically without generating hot spot in the lard layer. Fig. 11 shows the temperature profile along the r and z-axes shown in Fig. 10. In Fig. 11, from along both the r and z-axes, the hot spot also appears at the deep region of the lard-agar phantom

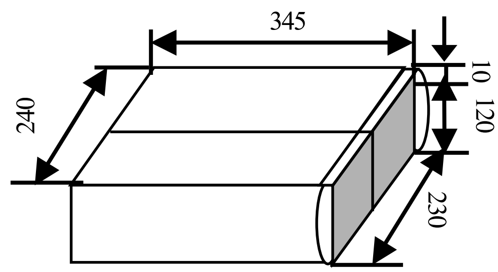


Fig. 8 Configuration of lard-agar phantom.

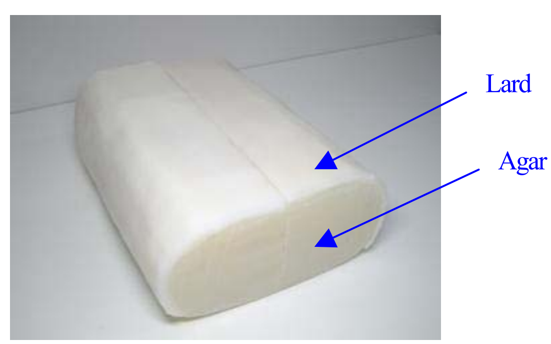


Fig. 9 Lard-agar phantom.

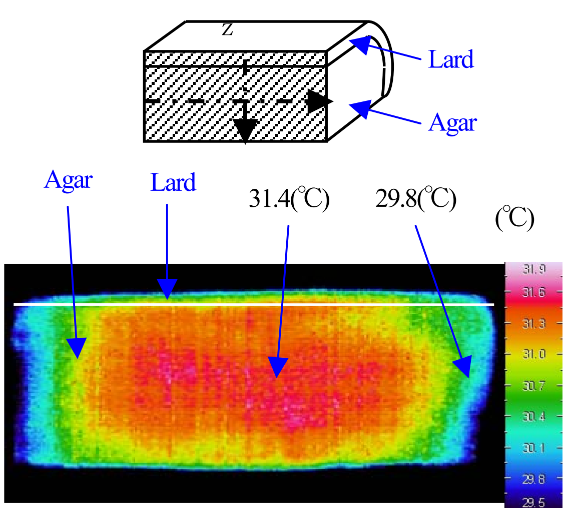


Fig. 10 Thermal image of lard-agar phantom just after heating.

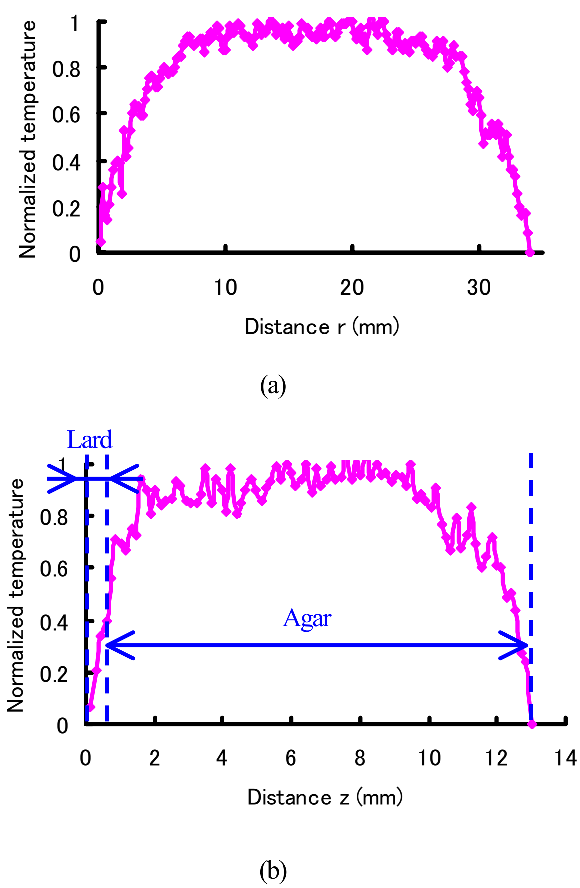


Fig. 11 Temperature profile, (a) on the r-axis, (b) on the z-axis.

IV. Conclusion

The hyperthermia system using a re-entrant resonant type applicator for deep tumor hyperthermia treatment has been described. According to our experimental heating results with the agar phantom and the lard-agar phantom, the proposed heating methods are expected to apply to deep and localized hyperthermia treatment of the abdominal region.

We are now trying to heat the abdominal region of an animal using the proposed heating system.

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