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Development of the re-entrant type resonant cavity applicator for brain tumor hyperthermia - Experimental heating results -

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Abstract - A re-entrant type resonant cavity applicator for brain tumor hyperthermia treatment is presented. In this method, a human head is placed between the gap of the inner re-entrant cylinders, and is heated with electromagnetic fields stimulated in the cavity without contact between the surface of the human head and the applicator. First, the comparison of the computer simulation and experimental results were presented. The estimated temperature agrees with the measured temperature with an error of 10% or better. Second, a method to control the heating pattern was presented. In the method, a human head was moved towards the electrode. The controllable range of heating pattern was about 70% of the distance from the center of the agar phantom in the direction of depth.

I. Introduction

It is important to transfer heating energy deep into a human head for successful hyperthermia treatments. The radio frequency hyperthermia system with a needle type applicator for heating brain tumors was proposed [1]. Generally, the needle type heating systems have advantages and disadvantages. One of the advantages is that the direct and local heating of deep tumors are possible. Disadvantages are that they have an invasive heating method and a small heating area. Therefore, successful heating has not yet been realized.

We have proposed a new type of applicator using a re-entrant type resonant cavity developed especially for deep and surface tumors, and tested them experimentally using a prototype applicator with an agar phantom.

Here, first, the experiment of heating an agar-muscle equivalent phantom by the developed system was performed. Second, the phantom was moved towards the electrode to control the heating pattern.

This paper discusses the heating properties of the developed applicator for deep and surface brain tumors hyperthermia treatment. From these results, it is shown that our newly developed heating method is useful for heating a deep-seated tumor and a surface tumor of the human brain.

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.

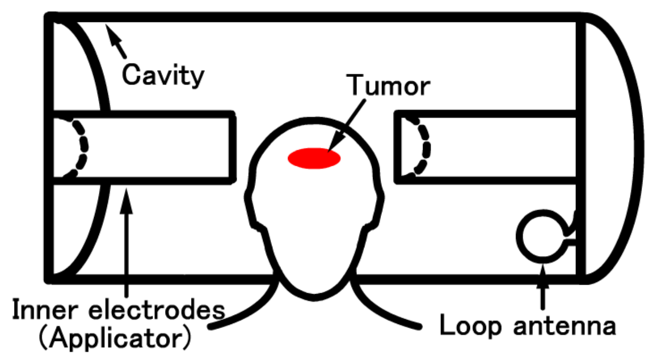


Fig. 1 Illustration of heating system.

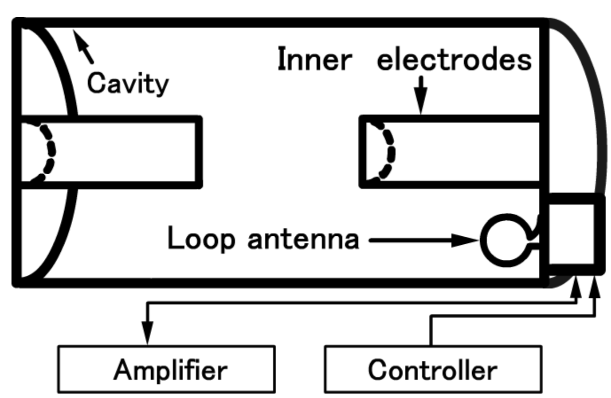
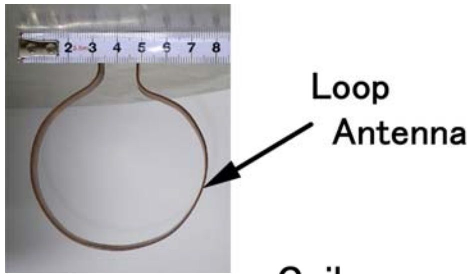
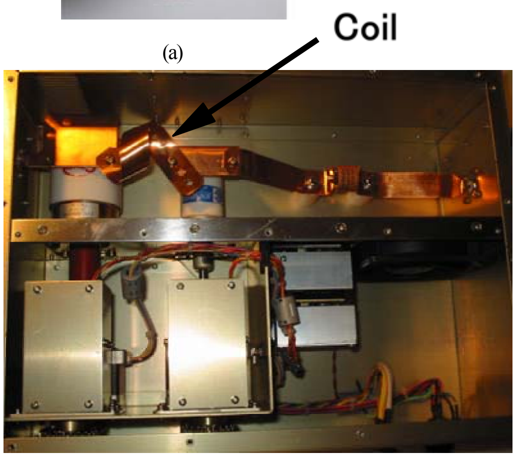


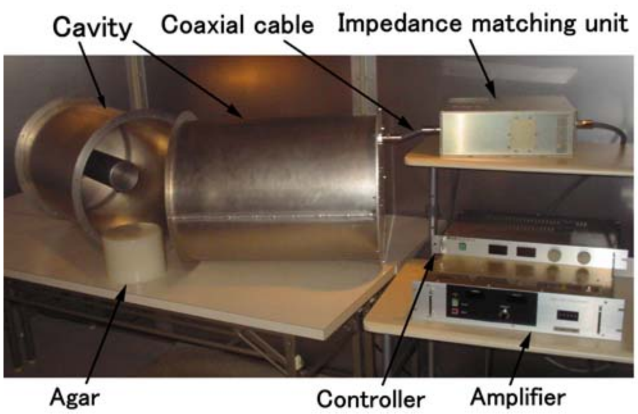
Fig. 2 Diagram of heating system.



(a)



(b)



(c)

Fig. 3 Setup of heating system,
(a) antenna, (b) impedance matching unit,
(c) heating system.

It consists of an amplifier, a cavity, a loop type antenna and a controller. The maximum input power is 150W, and the operating frequency can be changed from 50 to 200MHz. The controller works to control impedance matching. A photograph of the prototype heating system is shown in Fig. 3. Fig. 3 (a) shows the loop type antenna made of copper plate, which is 70mm in diameter, 9mm in width, and 1mm in thickness. Fig. 3 (b) shows

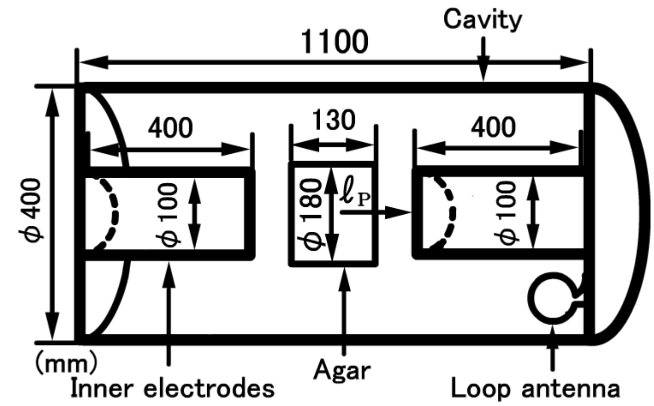


Fig. 4 Cross-sectional view of the cavity.

the impedance matching unit used in these experiments. The coil is made of copper plate, which is 65mm in length, 20mm in width, and 0.3mm in thickness. Fig. 3 (c) shows the heating system used in these experiments. The impedance matching unit is connected to the cavity by the coaxial cables.

Fig. 4 shows the cross-sectional view of the cavity. The cavity made of aluminum plate is cylindrical, 400mm in diameter and 1100mm in height. On both sides of the cavity, inner electrodes of 100mm in diameter and 400mm in height were used. In Fig. 4, ℓ_p shows the moved length of the agar phantom from the center of cavity to the inner electrode. Electric and magnetic fields are excited by the loop antenna inside the cavity. We made cylindrical agar phantoms of 130mm in height and 180mm in diameter for the experiments.

III. Results

A. Comparison between heating Measurement and Estimation

Fig. 5 shows a thermal image of the sagittal slice of the agar phantom taken by an infrared thermal camera after 30 minutes heating by the re-entrant resonant cavity. Experimental heating conditions are listed in Table I. From Fig. 5 (a), the center of the agar phantom is heated to maximum temperature. On the other hand, from Fig. 5 (b), it can be seen that the hot spot moved significantly to the right side of the agar phantom.

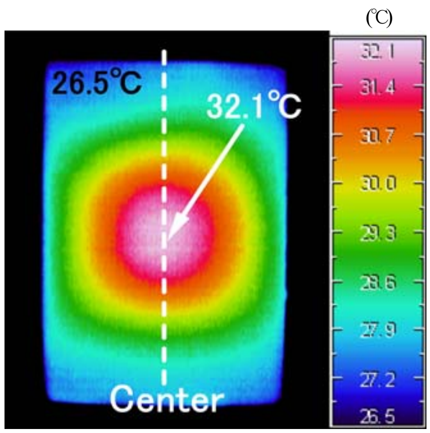
Fig. 6 shows the measured and estimated temperature profiles along the x and z-axes, when ℓ_p is 0mm. From Fig. 6, the estimated temperature agrees with the measured temperature with an error of 10% or better.

The normalized temperature T_N is given by

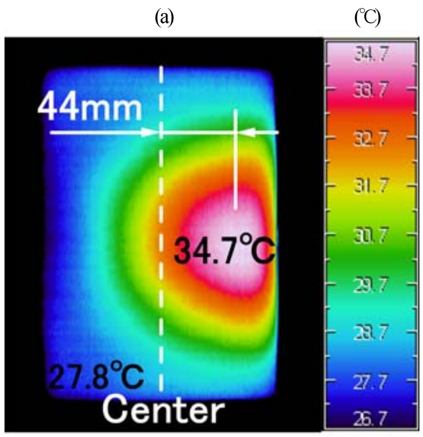
$$T_N = \frac{(T - T_0)}{(T_{max} - T_0)}. \qquad (1)$$

Table I Experimental condition.

	heating power	moved distance ℓ_p	resonant frequency
(a)	30W	0mm	156.4MHz
(b)	30W	65mm	149.0MHz



(a)



(b)

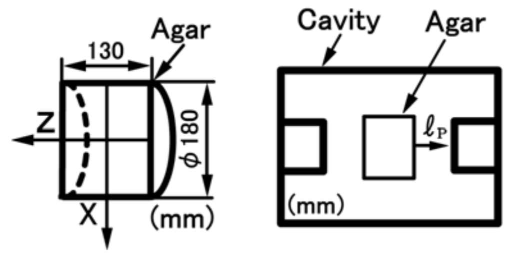
Fig. 5 Thermal images of heated agar phantom,
(a) ℓ_p=0 mm, f=156.4 MHz, (b) ℓ_p=65 mm, f=149.0MHz.

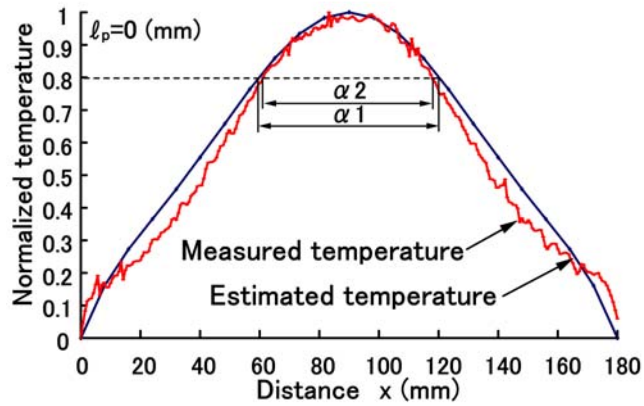
Where T_0 is the initial temperature, T_{max} is the maximum temperature inside the agar phantom.

B. Control Method of the Hot Spot

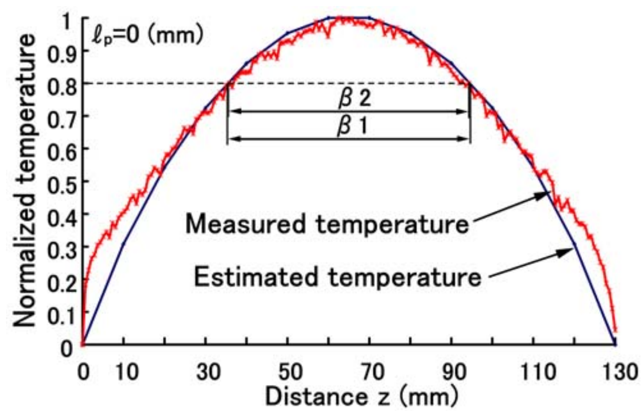
Fig. 7 shows the temperature profiles along the z-axis. In Fig. 7, when ℓ_p were 35mm, 55mm and 65mm, the position of maximum temperature inside the agar phantom moved 21mm, 32mm and 44mm, respectively.

Fig. 8 shows the relationship between the position of the agar phantom and the position of maximum temperature inside the agar phantom. In Fig. 8, the distance L_c and L_p are normalized as in following equations,





(a)



(b)

Fig.6 Temperature profiles,
(a) on the x-axis, (b) on the z-axis.

$$L_c = \frac{\lambda_c}{(\lambda_c)_{max}} \quad (2)$$

$$L_p = \frac{\lambda_p}{(\lambda_p)_{max}} \quad (3)$$

where ℓ_c is the distance from the center of the agar phantom to the

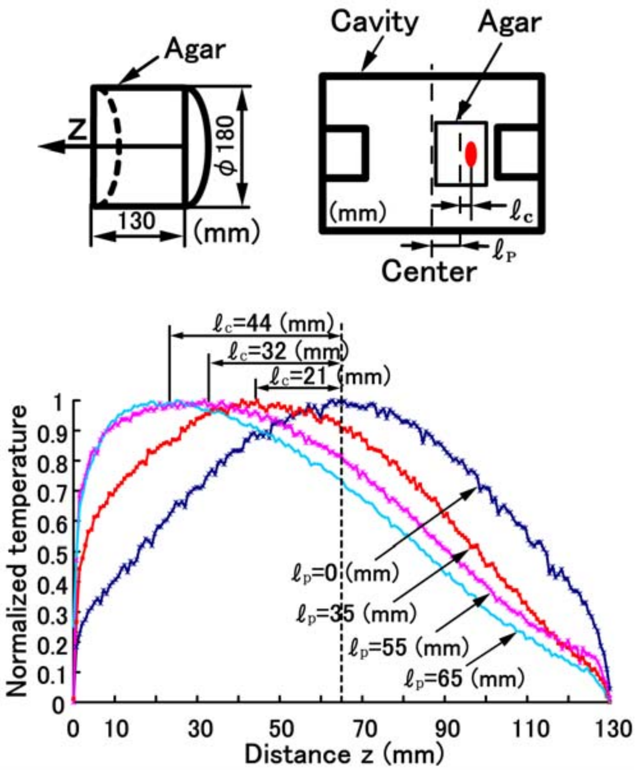


Fig. 7 Temperature profile on the z-axis.

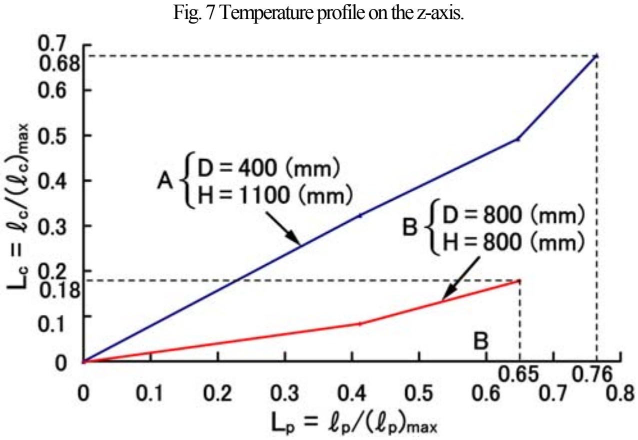


Fig. 8 Relationship between position of agar phantom and position of maximum temperature inside the phantom.

position of the maximum temperature, ℓ_p is the distance from the center of the cavity to the agar phantom. In Fig. 8, the lines A and B are experimental results with the different resonant cavity applicator [4], [5]. These resonant cavity applicators were 400mm in diameter and 1100mm in height, and 800mm in diameter and 800mm in height, respectively. From Fig. 8, it is found that using the resonant cavity applicator A, the movement of the position of the maximum temperature inside the agar phantom is larger than that of B.

IV. Discussion

The first purpose of this study was to show the comparison between the experimental heating results and the results of its computer simulation. As shown in Fig. 6, comparing normalized temperature value of 0.8, the estimated temperature agrees with the measured temperature with an error of 10% or better.

The second purpose of this study was to show that the position of maximum temperature can be controlled with the proposed methods. As shown in Fig. 8, the controllable range of the heating pattern was about 70% of the distance from the center of the agar phantom in the direction of depth.

V. Conclusion

We proposed the hyperthermia system using a re-entrant resonant type applicator for deep and surface seated brain tumors. From our computer simulation and experimental results, it is confirmed that the proposed system can be applicable to hyperthermia treatment of deep and surface brain tumors.

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