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Heating Properties of the Re-Entrant Type Cavity Applicator for Brain Tumor with Several Resonant Frequencies

M. Suzuki, K. Kato, T. Hirashima, Y.Shindo, T. Uzuka, H. Takahashi and Y. Fujii

Abstract—**We have proposed the re-entrant resonant cavity applicator system for non-invasive brain tumor hyperthermia treatment. In this method, a human head is placed in the gap of the inner electrodes. A brain tumor is heated with the electromagnetic field stimulated in the cavity without contact between the human head and the applicator. We have already presented the effectiveness of the heating properties of this system with cylinder-type agar phantoms and by computer simulations.**

This paper discusses the heating properties of the developed system with the human head-type agar phantom for brain tumor hyperthermia treatment.

First, in order to heat deep brain tumors, we tried to heat the human head-type agar phantom by using several electromagnetic field patterns of the resonant frequency. We found that the temperature distributions can be controlled inside the agar phantom by changing the resonant frequencies.

Second, to heat local and deep areas of the agar phantom, we tried to achieve heating using the two different resonant frequencies. We found distinct heating properties by changing the electromagnetic field patterns of resonant frequencies.

From these results, it was found that our developed heating system can be applied to hyperthermia treatments of deep-seated brain tumors. Further, by changing resonant frequency, treatment can very correspond to the size and the position of a tumor.

I. INTRODUCTION

HYPERTHERMIA treatment is based on the clinical fact that tumors are weaker than normal tissue under the temperatures from 42 to 44℃, and they can be killed by heating repetitions of approximately 30 minutes. In the clinic, a needle type applicator has been used for targeting malignant brain tumors. However, this heating method has advantages and disadvantages. One of the advantages is that the direct and local heating of deep tumors is possible. Disadvantages are that this is an invasive heating method and ineffective for large tumors because the applicator directly inserts into the brain tumor and diameter of the needle is about 1 mm.

To overcome these problems, we propose the effectiveness of the re-entrant type resonant cavity applicator for non-invasive treatment of deep-seated tumors [1], [2]. We already confirmed the effectiveness of the experiments by heating cylinder-type agar phantoms and with computer simulations by two different electromagnetic modes called TM_{010}-like mode and TM_{012}-like mode [3]. Then, the heating area is about the cylinder-type agar phantom by using TM_{012}-like mode is approximately 50 % of the heating area of TM_{010}-like mode. From this result, the developed system is possible to heat the applied location of tumors by using the electromagnetic field patterns of the resonant frequency.

In the actual clinic, it is very important to heat deep-seated brain tumors corresponding to the size and the position where it occurred.

In this paper, we propose the heating properties of the developed system by changing several resonant frequencies and by changing the position of the agar phantom for brain tumor hyperthermia treatment. First, to heat deep brain tumors, we present the experimental heating results of the temperature distributions inside the human head-type agar phantom by changing the resonant frequencies. Second, in order to heat only a local and deep area of the agar phantom, we present the distinct heating properties by changing the electromagnetic field patterns of the resonant frequencies.

II. METHODS

Fig. 1 shows an illustration of our developed heating system. In Fig. 1, a human head is placed in the gap of the inner electrodes, and heated with an electromagnetic field stimulated in the cavity without contact between the human head and the applicator.

A photograph of the developed heating system is shown in Fig. 2. It consists of the re-entrant type resonant cavity made of an aluminum alloy, a high frequency amplifier, an impedance matching unit and a loop type antenna. The cavity

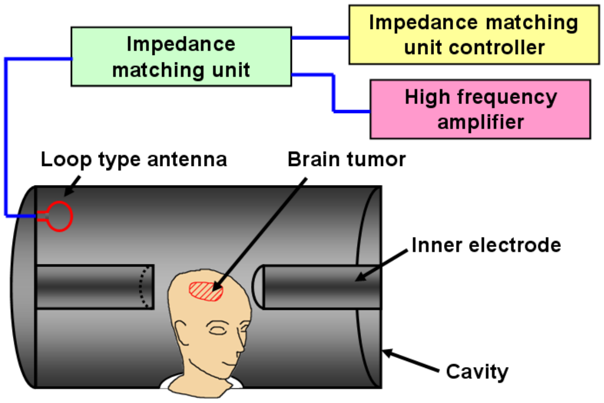

Fig. 1. Illustration of the developed heating system.

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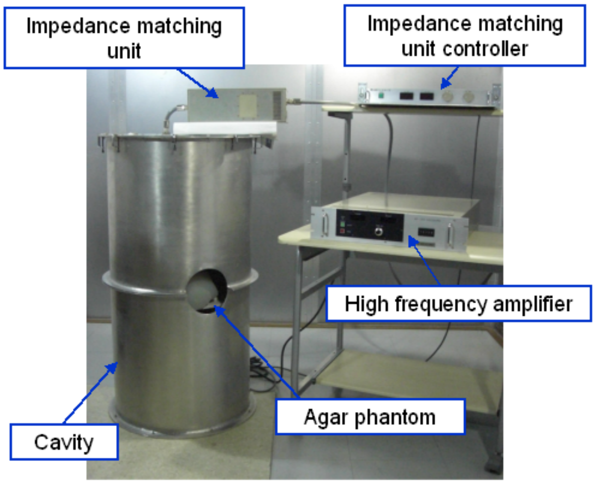


Fig. 2. Setup of the developed heating system.

is 500 mm in diameter and 1,000 mm in height. The inner electrodes inside the cavity are 100 mm in diameter and 400 mm in height. The impedance matching unit is connected to the cavity and the heating power is supplied to the cavity by the high frequency amplifier. The operating frequency is between 50 MHz and 400 MHz, and the maximum input heating power is 150 W.

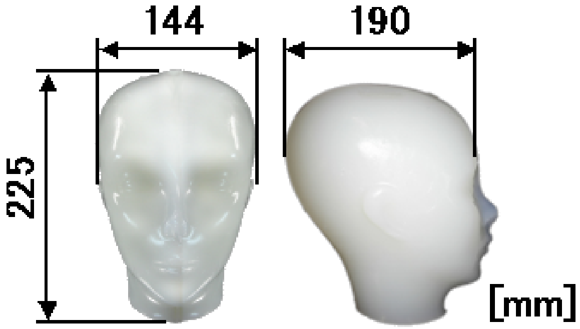
Fig. 3 shows the human head-type agar phantom used in these experiments. The human head-type agar phantom is 225 mm in height and 144 mm in width. The relative dielectric constant of the agar phantom is 80, the electrical conductivity is 0.6 S/m, and the thermal conductivity is 0.6 W/m℃. In the experiments, the human head-type agar phantom is covered with an acrylic cover representative of the skull.

A photograph of the setup of the human head-type agar phantom inside the cavity is shown in Fig. 4. In Fig. 4, α is the distance between the wall of the cavity and the top of the human head-type agar phantom, and β is the distance from the baseline, which is the position of the center in the cavity.

III. RESULTS AND DISCUSSION

First, we present the temperature distributions of the inside the agar phantom by changing electromagnetic field patterns of resonant frequency. Second, in these experimental results, to heat the local and deep regions of the agar phantom, we present the distinct heating properties by changing the electromagnetic field patterns of the resonant frequency.

Fig. 5 shows the relationship between high frequencies and normalized power consumption, which was calculated by computer simulation of the finite element method [4]. In Fig. 5, the value of distance α is 230 mm, and the peaks of the power consumption occurred at five-points of resonant frequencies. In the experiments, we tried to heat the human head-type agar phantom at resonant points from No.1 to No.5 by the developed heating system. However, heating is not achieved at resonant point No.4.



(a) (b)

Fig. 3. Human head-type agar phantom: (a) front view, (b) side view.

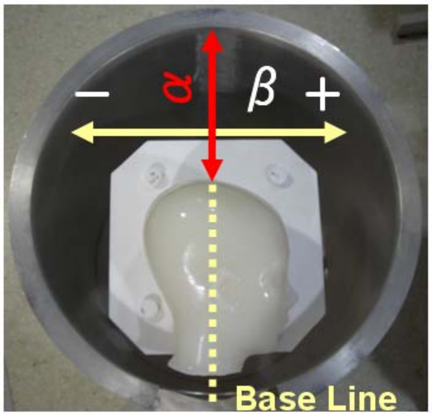


Fig. 4. Setup of the human head-type agar phantom inside the cavity.

Fig. 6 shows the thermal images of the center section of the human head-type agar phantom taken by an infrared thermal camera after 60 minutes heating by the re-entrant type resonant cavity. Experimental heating conditions are listed in Table I.

From Fig. 6, all of the thermal images show that the interior of the agar phantom is heated to maximum temperature respectively. By changing the resonant modes, the temperature distributions can be controlled.

Fig. 7 shows the measured temperature profiles along the X and Z-axes at the normalized temperature 0.8. In Fig. 7(a), the distance of the normalized temperature 0.8 is respectively shown from a_1 to a_4. Then, in Fig. 7(b), the distance of the normalized temperature 0.8 is respectively shown from b_1 to b_4. These distances are listed in Table II.

The normalized temperature T_N is given by,

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

Where T_0 is the initial temperature, $T_{\max}$ is the maximum temperature in the agar phantom.

As shown in Fig. 7, all the temperature profiles demonstrate heating of deep and local areas by changing the

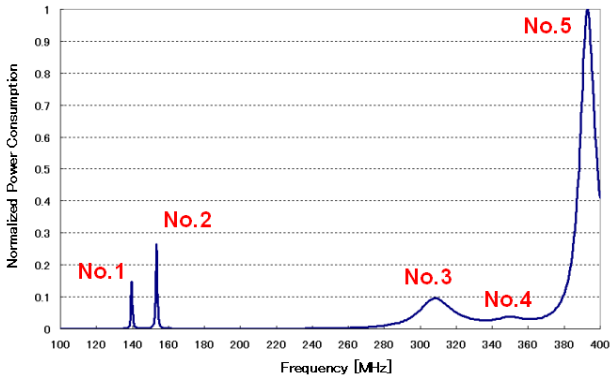
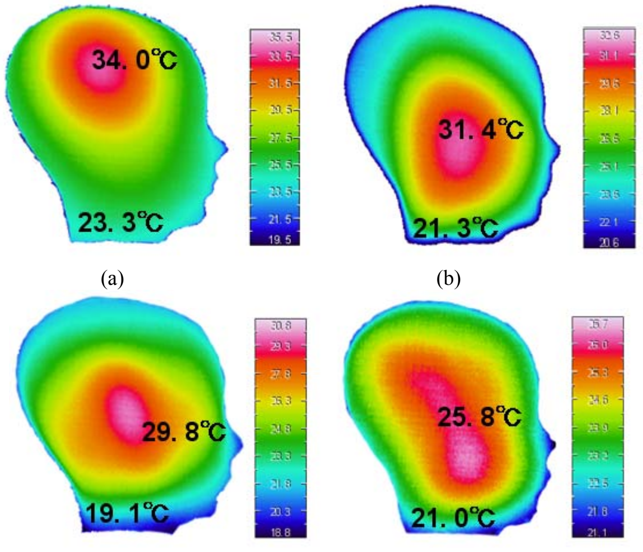


Fig. 5. Relationship between high frequencies and normalized power consumption.



(a) (b)

(c) (d)

Fig. 6. Thermal images by several resonant points:
(a) No.1, (b) No.2, (c) No.3, (d) No.5.

TABLE I
EXPERIMENTAL CONDITIONS

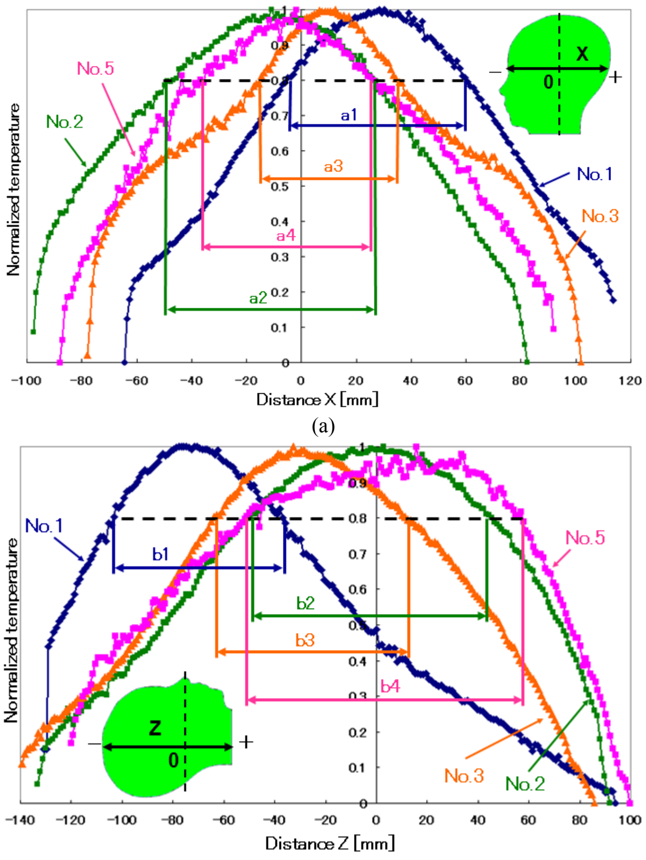
Resonant Point	Heating Power	Resonant Frequency
(a) No.1	30 W	138.20 MHz
(b) No.2		153.70 MHz
(c) No.3		305.81 MHz
(d) No.5		394.90 MHz

resonant frequencies.

Resonant point No.1 heated a local and deep area of the position of the brain. At the normalized temperature 0.8, we found that the region is approximately 32 % of the agar phantom.

Resonant point No.2 heated a deep and large area at the center of the agar phantom. At the normalized temperature 0.8, we found that the region is approximately 41 % of the agar phantom.

Resonant point No.3 heated a deep and small region at the center of the human head-type agar phantom. At the normalized temperature 0.8, the region is approximately 31 % of the agar phantom.



(a)

(b)

Fig. 7. Temperature profiles: (a) on the X-axis, (b) on the Z-axis.

TABLE II
DISTANCE OF NORMALIZED TEMPERATURE 0.8

Direction	No.1	No.2	No.3	No.5
X	a_1=65 mm	a_2=73 mm	a_3=49 mm	a_4=63 mm
Z	b_1=67 mm	b_2=95 mm	b_3=75 mm	b_4=108 mm

Resonant point No.5 heated a deep and large area of the agar phantom. We found that the region is approximately 50 % of the agar phantom at the normalized temperature 0.8.

In these experimental results, compared to resonant point No.1, the heating distance of resonant point No.3 is localized to approximately 75 % on the X-axis. The heating area of the human head-type agar phantom by using resonant point No.3 is approximately 84 % of the heating area of resonant point No.1.

The brain tumors are seated in various locations within the brain. For example, we tried to heat the same agar phantom using resonant points No.1 and No.3 by changing the position of the agar phantom. In these experiments, we examined the heating properties of the developed system corresponding to changes in the distance, as shown in Fig. 4. Experimental heating conditions are listed in Table III.

TABLE III
EXPERIMENTAL CONDITIONS

Resonant Point	Distance	Resonant Frequency
No.1	(a) α =160 mm	132.20 MHz
	(b) α =230 mm, β =-40 mm	143.10 MHz
	(c) α =270 mm	144.00 MHz
No.3	(d) α =160 mm	314.10 MHz
	(e) α =230 mm, β =-40 mm	314.50 MHz
	(f) α =270 mm	300.20 MHz

Fig. 8 and Fig. 9 show the thermal images of the central section of the agar phantom taken by an infrared thermal camera after 60 minutes of heating by the re-entrant type cavity applicator. In Fig. 8, the experimental results are heated by using resonant point No.1. Then, in Fig. 8, all thermal images show that deep areas are heated to maximum temperature and by changing the value of the distance, we can move the heating point. Each rise in temperature is approximately 8℃. When the assumed living human body temperature is 37℃, tumors will be heated to 45℃. From these results, by using resonant point No.1, it is possible that by selecting the position of the human head, our developed heating system can heat the specific location of deep-seated brain tumor.

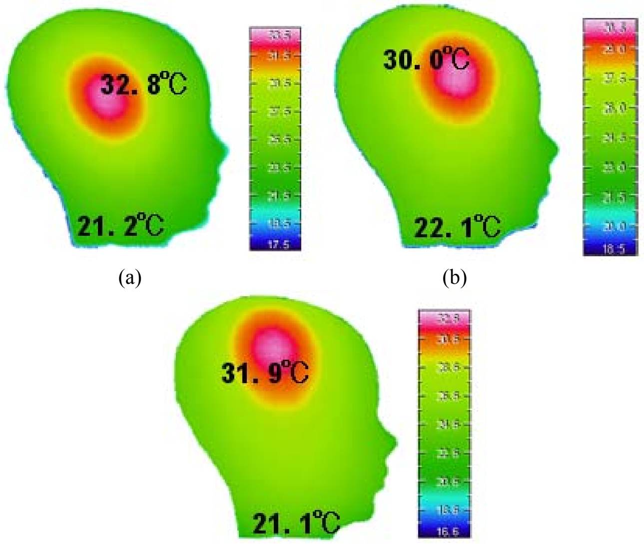
In Fig. 9, the experimental results are heated by using resonant point No.3. From Fig. 9, all thermal images show that the center of the agar phantom is heated to maximum temperature. Each rise in temperature is over 8℃, and the position of the hotspot is always at the center of the agar phantom, even if the position of the agar phantom is changed. Further, the areas heated are almost the same. From Fig. 9, by using resonant point No.3, it is possible to heat a deep region. However, in these experimental results, the heating at the position of the human brain is not accomplished. The human head has a skull in addition to a brain and the features of the brain are not uniform tissues like the agar phantom. By computer simulation using the finite element method with the anatomical model, we are now examining the effectiveness of movement of the hotspot.

From these results, we found distinct heating properties by changing electromagnetic field patterns of resonant frequencies.

IV. CONCLUSION

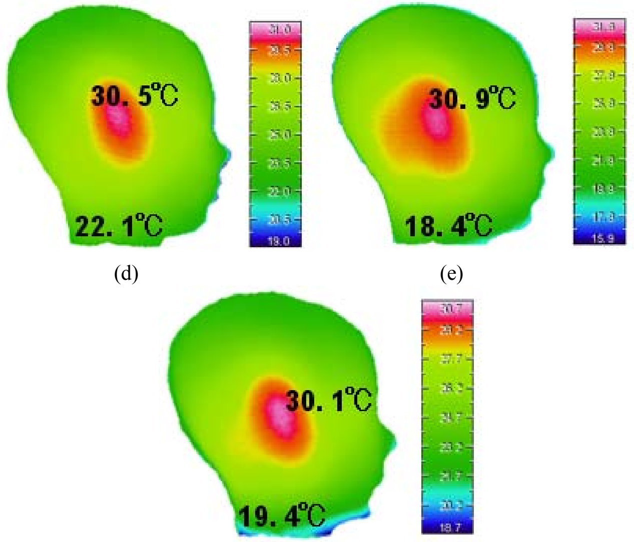
We described the hyperthermia system using the re-entrant type resonant cavity applicator for brain tumor hyperthermia treatment. According to our experimental results, the possibility of clinical heating using our developed system was confirmed by using the human head-type agar phantom for various types of deep-seated tumors by changing several resonant frequencies.

We are now planning to position the hotspot in the agar phantom with various types of resonant frequencies.



(a) (b) (c)

Fig. 8. Thermal images of resonant point No.1:
(a) α =160 mm, (b) α =230 mm, β =-40 mm, (c) α =270 mm.



(d) (e) (f)

Fig. 9. Thermal images of resonant point No.3:
(d) α =160 mm, (e) α =230 mm, β =-40 mm, (f) α =270 mm.

REFERENCES

[1] J. Matsuda, K. Kato and Y. Saito, “The application of a re-entrant type resonant cavity applicator to deep and concentrated hyperthermia” Jpn. J. Hyperthermia Oncol., Vol. 4, No. 2, pp. 111-118, 1988
[2] K. Kato, J. Matsuda and Y. Saitoh, “A re-entrant type resonant cavity applicator for deep-seated hyperthermia treatment”, Proc. of IEEE EMBS, vol. 11, pp. 1712-1713, 1989
[3] Y. Shindo, K. Kato, K. Tsuchiya, T. Yabuhara, R. Iwazaki, T. Uzuka, H. Takahashi and Y. Fujii, “Heating Properties of Re-entrant Resonant Applicator for Brain Tumor by Electromagnetic Heating Modes” Proc. of IEEE EMBS2007, pp. 3609-3612, 2007
[4] T. Yabuhara, K. Kato, K. Tsuchiya, T. Shigihara, Y. Shindo, R. Iwazaki, T. Uzuka, Y. Fujii, H. Takahashi, “Finite Element Analysis of the Re-entrant Type Resonant Cavity Applicator for Brain Tumor Hyperthermia” Proc. of IEEE EMBS2007, pp. 3540-3543, 2007