Development of Inductive Regional Heating System for Breast Hyperthermia

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***Abstract*—In response to demand for clinical use, a simple noninvasive regional heating applicator system for breast hyperthermia has been developed using ferrite cores. Since the breast is positioned between a pair of ferrite cores, it is possible to regionally heat it without considering the dimension of the breast. To find a method of controlling the heating position horizontally and vertically, magnetic-field distributions are analyzed using the three-dimensional finite-element method. Theoretical analyses suggest that a conductive thin plate and a novel eddy current absorber are effective for controlling the maximum heating position. A new applicator system operates at a frequency of 4 MHz and a maximum output power of 600 W. Heating tests using an agar phantom and rabbits show a temperature rise of more than 8 °C at a depth of 8 cm after heating for 10 min without heating fatty tissue.**

***Index Terms*—Applicator, breast cancer, ferrite, hyperthermia, inductive heating.**

I. INTRODUCTION

BREAST cancer has been increasing worldwide in recent years [1]. Surgical excision, chemotherapy, and radiotherapy including hyperthermia have usually been offered as effective treatments. Recently, to preserve the breast, the concept of quadrantectomy (QUART) or tumorectomy (TURT) has been introduced as a promising therapy for breast cancer. This treatment is a partial excision therapy for breast cancer and includes auxiliary dissection and radiotherapy.

In these treatments, hyperthermia has often been applied as a combination therapy based upon the fundamental principle of hyperthermia [2], [3]. As is well known, in combination therapy of X-ray radiation and hyperthermia, hyperthermia can complement the regulation of the allotted dose of X-rays to the human body during the treatment period. Further, for a small tumor, local heating can be achieved with X-ray radiation. However, for a large tumor of more than 6 cm in diameter, hyperthermia is required, particularly for a recurrent tumor. It is, however, difficult to realize a noninvasive regional and deep-heating method using electromagnetic waves because the heating depth is restricted by the skin-depth principle at microwave frequencies. Conversely, to achieve deep heating at a low frequency such as RF, regional heating is impossible; generally, because a large applicator is needed. As a result, the heating region cannot be localized. This paper presents a noninvasive regional heating applicator for breast hyperthermia on the basis of the clinical demands mentioned above. The principle of this applicator is based upon inductive heating. Many kinds of applicators for inductive heating have been proposed in the long history of hyperthermia [4]–[14].

In this paper, paying attention to the heating characteristic that a ferrite core with a pair of magnetic poles can efficiently heat the inside of a protuberance on a human body, a simple applicator system using the ferrite cores has been developed. To find a method of controlling heating position vertically or horizontally, magnetic-field distribution was analyzed using the three-dimensional (3-D) finite-element method (FEM) taking eddy current into consideration. From this theoretical investigation, it is suggested that a conductive thin plate is effective for controlling magnetic-field distribution or eddy current. Applying this simple method, a simple inductive applicator using ferrite cores was constructed and heating tests were conducted at a frequency of 4 MHz with an output power of 600 W. The heating position can be well controlled horizontally and vertically by moving the ferrite core applicator with the conductive shielding plate and the eddy current absorber. Theoretical and experimental investigations were carried out using an agar phantom and rabbits. A temperature rise from the initial value of more than 8 °C has been obtained after 10 min of heating at a depth of 8 cm using an agar phantom and rabbits without heating fatty tissue.

II. CONSTRUCTION OF APPLICATOR

A ferrite core applicator system for hyperthermia was first proposed by one of the authors to achieve effective heating and to solve irradiation problems [15]. Since then, several kinds of ferrite core applicators have been studied and developed [16]–[19]. By introducing a ferrite core for the inductive applicator, a magnetic field can be concentrated between a pair of poles. Accordingly, local or regional heating becomes possible with a relatively low input power, and irradiation around the applicator is decreased, compared to the same kind of inductive applicator, which is also agreeable from the viewpoint of electromagnetic compatibility (EMC).

Fig. 1(a) shows a schematic view of the fundamental construction of the applicator system. A pair of cylindrical ferrite cores with length and diameter of 20 and 7 cm, respectively, is used for the applicator. The distance between a pair of ferrite cores is adjustable depending on the size of the breast. This applicator consists of a separated pair of ferrite cores. Generally,

Manuscript received August 12, 1999; revised November 11, 1999.

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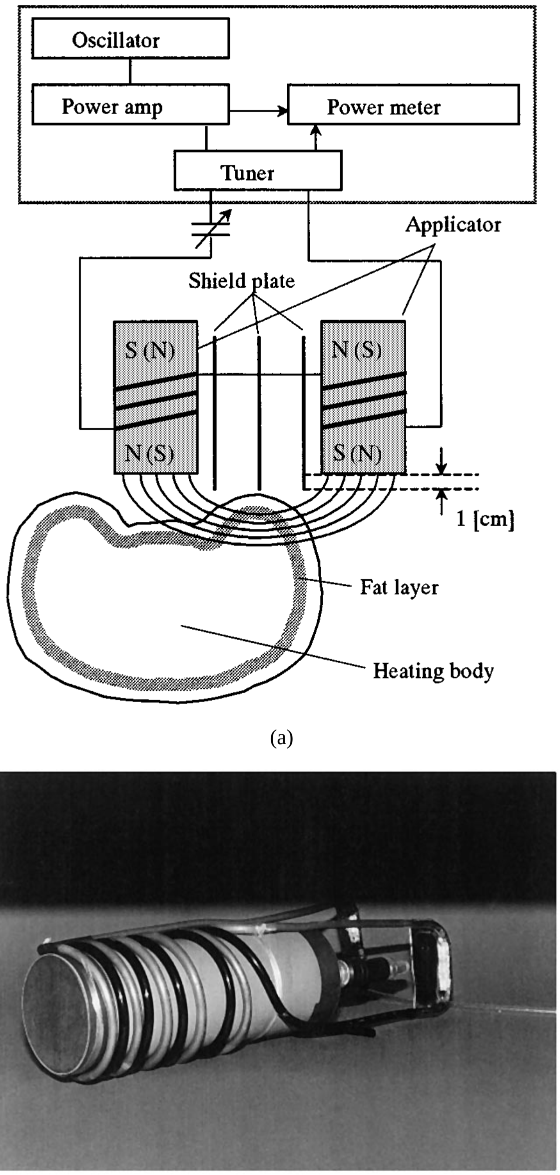
Publisher Item Identifier S 0018-9480(00)09532-6.



(a)

(b)

Fig. 1. Construction of applicator system. (a) Construction of applicator system. (b) Ferrite core applicator.

magnetic cores have been constituted with a closed magnetic path, e.g., a horseshoe magnet. However, to easily operate an applicator at any angle and any location, a hyperthermia applicator with an open magnetic path has been proposed by one of the authors, as shown in Fig. 1(a) [20]. Introducing this structure allows mobile operation of the applicator. To reduce heat generation at the ferrite core, a copper pipe for cooling water is used as a coil together with a flexible cooling hose. A cooling duct is also buried inside the ferrite core, as shown in Fig. 1(b).

The heating principle is as follows. The RF current for the coil is fed to make a different magnetic pole and couple a magnetic field at the chip of a separated pair of ferrite cores, as shown in Fig. 1(a). The breast we want to heat is placed between or under the separated pair of ferrite cores. The magnetic field penetrating the breast causes an eddy current. As a result, Joule's heat arises.

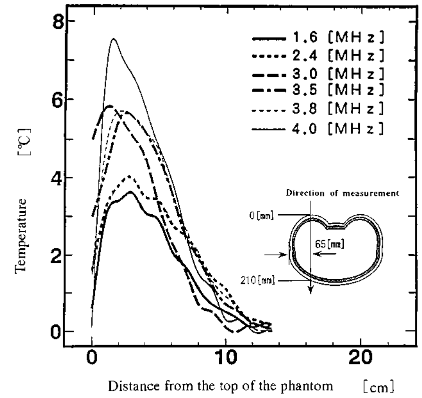


Fig. 2. Temperature characteristics in the phantom against operating frequency.

To effectively control the heating position vertically or horizontally, conductive plates to shield the magnetic field are introduced. Two conductive plates are attached to the ferrite cores and one conductive plate is placed between a pair of ferrite cores. The actions of each conductive shield plate are as follows. When the magnetic field generated by a pair of magnetic poles is applied to a conductive plate, an eddy current is generated. The eddy current that flows at the lower edge of the conductive plate acts to enforce a magnetic field against the magnetic field generating between a pair of magnetic poles. As a result, magnetic flux density increases under the lower part of the conductive plate and causes the magnetic fields to make a detour. This conductive shield plate also has an action that the leakage magnetic field from the side of the ferrite cores is reduced, and it assures a strong coupling of the magnetic field only between poles.

In Fig. 1(a), an operating frequency of 4 MHz is adopted. This frequency was determined, based upon the following reason. Heating efficiency for the phantom increases as the frequency becomes higher. However, if the higher frequency of more than 4 MHz is taken, heat generation of the ferrite core itself increases. As the result, it becomes difficult to cool the ferrite core and disadvantageous to achieve deep heating, as shown in Fig. 2. Taking these into consideration, a Ni–Zn-type ferrite with a good performance around this frequency is selected. This heating test was conducted using an agar phantom and a pair of ferrite cores without shield plates.

However, it is found that deep regions of the phantom cannot be heated well.

III. Analysis

To find a method of achieving deep heating and controlling the heating position, the magnetic field and eddy current distribution were analyzed using the FEM. In this analysis, the following 3-D fundamental equation for vector potential A, which takes the eddy current into consideration, is used:

$$\nabla \times (\nu \nabla \times A) = J_0 - \sigma \frac{\partial A}{\partial t} - \sigma \nabla \phi \tag{1}$$

where ν is the magnetic reluctance, J_0 is the forced current density, σ is the conductivity, and ϕ is the electric potential.

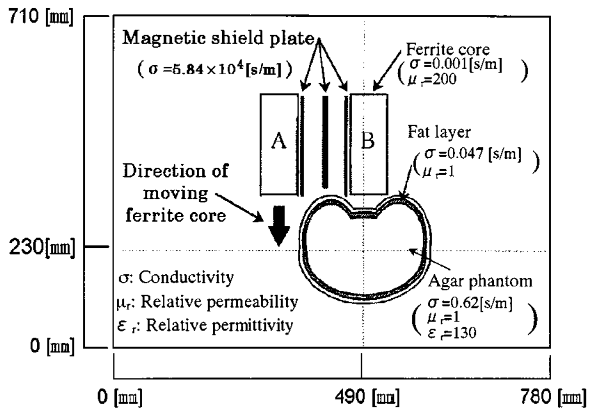


Fig. 3. Analytical model.

Solving the above equation for A by means of the Galerkin method, the magnetic field and eddy current distribution are calculated [19]. The numbers of elements and nodes in the 3-D case are 61 236 and 11 704, respectively. Fig. 3 shows the present model used for the analysis.

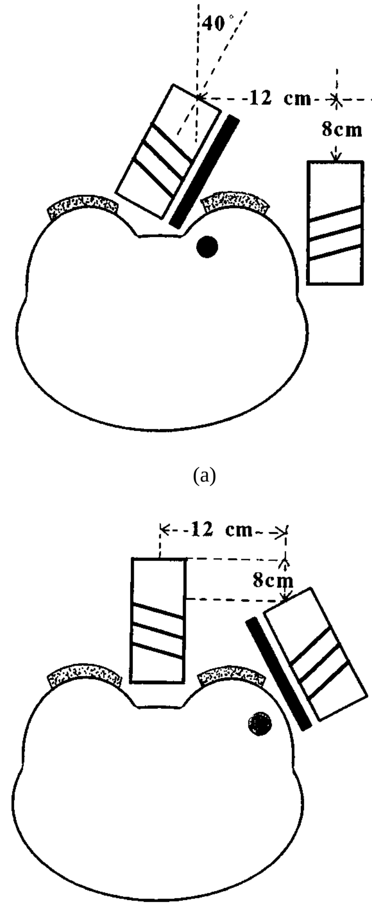
A two dimensional cross section of the analytic region is represented to be able to easily understand the configuration of the present analysis. In this figure, A and B represent the ferrite cores. Magnetic shield plates made of copper are set up to control the magnetic field. A phantom simulating a human breast is placed between a pair of ferrite cores with the shield plate. This phantom has a shape like an elliptic cylinder with a pair of protuberances for the breasts. The dimensions of the longer and shorter axes of the elliptic cylinder are 30 and 20 cm, respectively. A portion of the protuberance has a height of 3.0 cm. Material constants of each part are shown in Fig. 3. Frequency is assumed to be 4.0 MHz. An agar phantom subject to the guideline assigned by the Quality Assurance Committee, Japanese Society of Hyperthermia Oncology (QAC, JASHO) was used. During the inductive heating, it is clear from the heating principle that only a conductive material with a loss is well heated, but fat and mammary tissue belonging to a high insulating materials are not readily heated [19]. To demonstrate this fact, an agar phantom with a pig fat layer as a model of a subcutaneous one is used in this study.

IV. Numerical Results and Heating Experiment

A. Method for Controlling Heating Position Horizontally

To find out how to control the heating position in the horizontal direction, many analyses were conducted taking the positions of magnetic shield plates, their number, the angle and position of ferrite cores, etc. into consideration. From these theoretical investigations, one effective method to horizontally shift a heating position in the breast was found.

Fig. 4(a) and (b) shows a method to shift the heating position horizontally. For this purpose, only one magnetic shield plate is attached to a ferrite core, as shown in Fig. 4(a) and (b). That is, a magnetic shield plate is attached to a ferrite core at the side where we want to shift a heating position. The ferrite core is inclined at an angle of about 40° to the vertical axis. By introducing these arrangements of the shield plate and ferrite core,



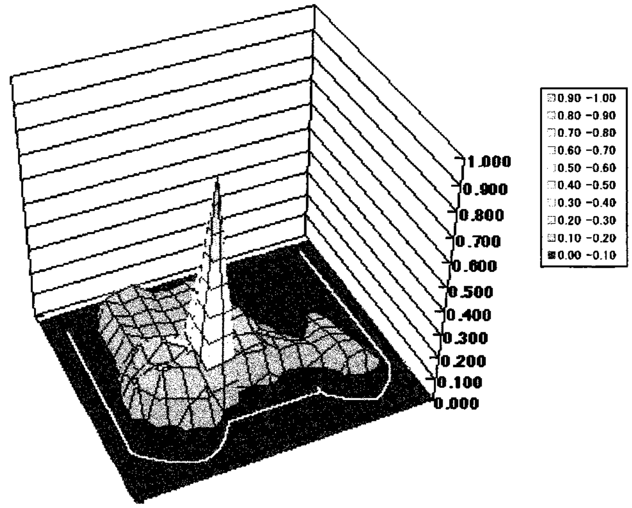
(b)

Fig. 4. Method of controlling heating position horizontally. (a) The case of shifting heating region to the left-hand side in the breast. (b) The case of shifting heating region to right-hand side in the breast.

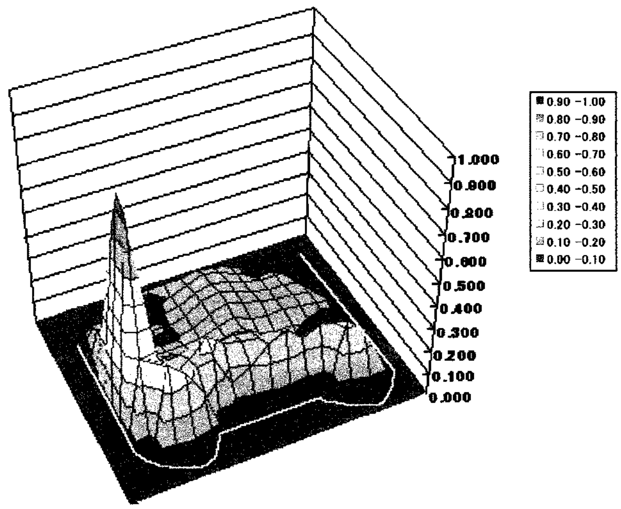
it is possible to control the heating position horizontally and to control it vertically by sliding the outside ferrite core while keeping the angle stationary.

Fig. 5(a) and (b) shows the eddy current distribution based on the 3-D FEM, taking the eddy current absorber into consideration. These figures show a bird's eye view of the eddy current distribution normalized by its maximum value. In these figures, it is found that the heating position is shifted toward the right- and left-hand sides in the breast without being generated at unexpected positions.

The principle of the eddy current absorber is as follows. Generally, eddy current distribution in inductive heating has a tendency to be concentrated on a higher conductive part of heating material and distributed on the surface of it. Therefore, if a material with a higher conductivity than that of the surface of the heating material is put on the surface of it, an eddy current can flow into the material with higher conductivity. In addition, if this conductive material also has ohmic loss, eddy current flow in the material with a higher conductivity can be absorbed due to an ohmic loss and converted into Joule's heat. To satisfy this condition, silicone rubber containing fine carbon powder was designed. Three prototype silicone rubber eddy current absorbers with different conductivities were made. Conductivity is optimized experimentally to efficiently absorb



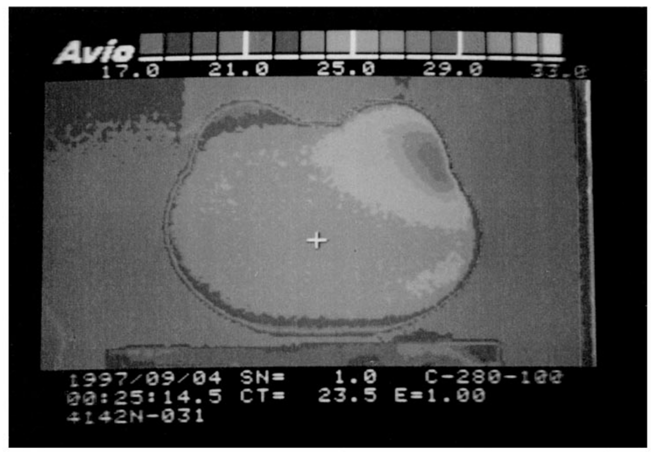
(a)



(b)

Fig. 5. Bird's eye view of heating position. (a) Bird's eye view of heating position corresponding to Fig. 4(a). (b) Bird's eye view of heating position corresponding to Fig. 4(b).

(a)



(b)

Fig. 6. Thermographic view of phantom. (a) Thermographic view of phantom corresponding to Fig. 4(a). (b) Thermographic view of phantom corresponding to Fig. 4(b).

the eddy current. As a result, an eddy current absorber with a conductivity of 1.25×10^2 S/m has been selected. The eddy current absorber has an oblong shape with a cavity to circulate cooling water.

Fig. 6(a) and (b) shows a thermographic view of the experiment after 15 min of heating using an agar phantom with a fat layer. The output power is 600 W and the operating frequency is 4 MHz. The agar phantom is subject to the guideline assigned by the QAC, JASHO. The size of the phantom along longer and shorter axes of the elliptic cylinder are 30 and 20 cm, respectively. A portion of the protuberance has a height of 3.0 cm. In the experiment, the eddy current absorber achieves effective heating characteristics without generating hot spots at other sites in the phantom.

B. Method for Controlling Heating Position Vertically

To control the heating position vertically, the magnetic-field distributions near the breast were analyzed using the FEM. Magnetic shield plates were introduced to control the magnetic field and examine its shield effect.

Figs. 7(a) and 8(a) show visualized magnetic flux density distributions without and with the conductive shield plates. That is, Fig. 7(a) has only one shield plate at a central position between ferrite cores. Fig. 8(a) shows magnetic flux density distribution when the conductive shield plates are attached to the ferrite cores. Figs. 7(b) and 8(b) shows normalized magnetic flux density versus the distance from the surface of the breast. In Fig. 7(b), in the absence of conductive shield plates with the ferrite cores, the maximum value of the magnetic flux density occurred at a depth of around 5 cm in the phantom when the left-hand-side ferrite core is 8 cm below the surface of the breast. This case is shown by blank squares in Fig. 7(b).

In Fig. 8(b), blank squares shows that the maximum value of the normalized magnetic-field distribution occurs around eight when the left-hand-side ferrite core is 8 cm from the surface of the breast, as shown in Fig. 8(a). By comparing the results in Figs. 7 and 8, it was found that the magnetic field can penetrate a deep region when the magnetic shield plates were attached to the near ferrite cores.

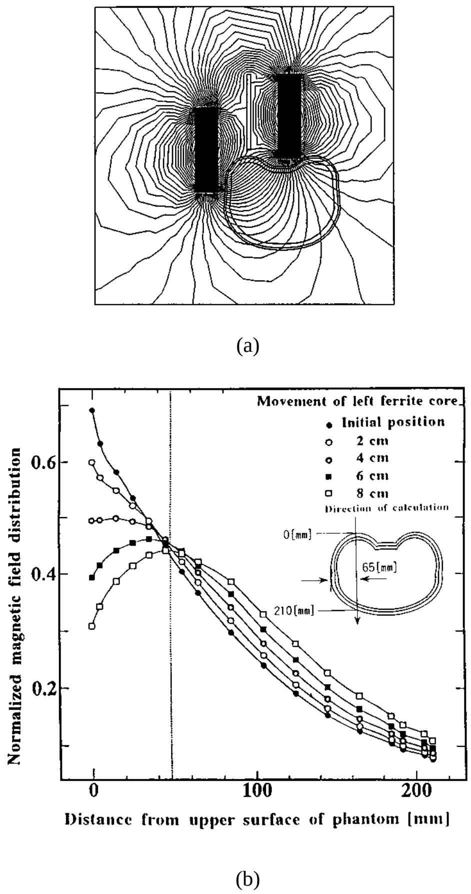


Fig. 7. Magnetic-field distribution without shield plates near both ferrite core. (a) Visualized magnetic-field distribution. (b) Magnetic-field distribution inside phantom.

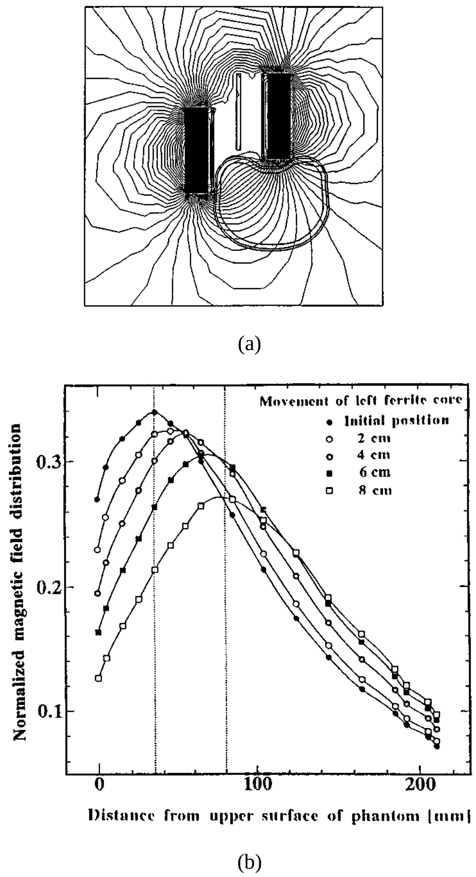


Fig. 8. Magnetic-field distribution with shield plates near both ferrite cores. (a) Visualized magnetic-field distribution. (b) Magnetic-field distribution inside phantom.

To examine these theoretical results, heating tests were conducted. The output power is 600 W and the operating frequency is 4 MHz. The same phantom as that described in Section IV-A was used. Temperatures were measured using thermography after 15 min of heating. Fig. 9 shows an experimental result of the temperature characteristics depth-wise against the distance from the initial positions of the ferrite cores. Crosses show the case when the left-hand-side ferrite core with a shield plates is lowered, as shown in Fig. 9.

Further, Fig. 10(a) and (b) shows the result of a theoretical analysis of the heating position in both cases when the right-hand-side ferrite core with a shield plate is near the surface of the breast and it is lowered at 8 cm, keeping the left-hand-side ferrite core with a shield plate stationary.

It is suggested that the magnetic shield plate plays an important role in controlling the heating position deeply.

To examine these heating characteristics, a heating experiment was conducted. Fig. 11(a) and (b) shows thermographic views after a heating experiment. The experimental method is the same as the case mentioned above. Fig. 11(a) shows the case when a right ferrite core is not lowered or is at the same level to the left-hand side. Fig. 11(b) corresponds to the case in Fig. 10(b). The white portion near the breast in these figures represents the highest temperature. It was found that these heating characteristics demonstrate the theoretical results.

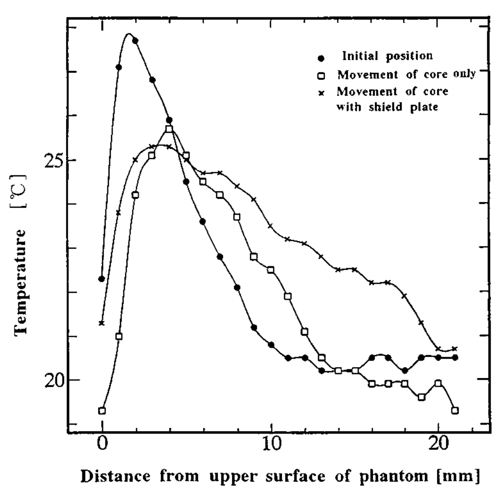


Fig. 9. Experimental results of temperature distribution without and with shield plates near ferrite cores.

V. Development of Applicator System

On the basis of the theoretical and empirical investigations, a new applicator system for breast cancer has been developed. A heating test using an agar phantom with a layer of fat and an animal was conducted. The operating frequency is 4.0 MHz and, normally, the output power is 600 W. A rabbit was used as the

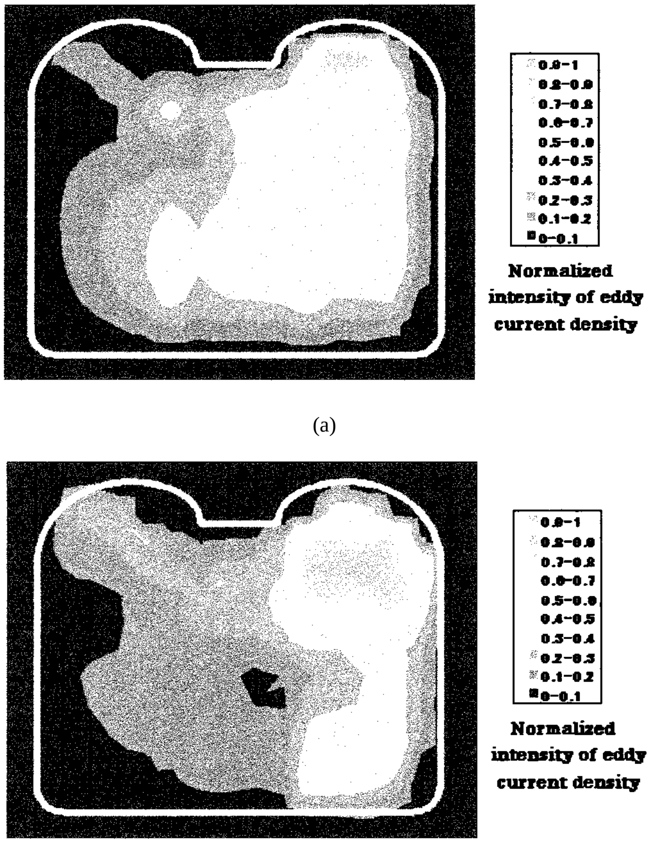


Fig. 10. Theoretical analysis of eddy current distribution by the 3-D FEM. (a) The case when both ferrite cores are in their initial positions. (b) The case when a right ferrite core is lowered at 8 cm.

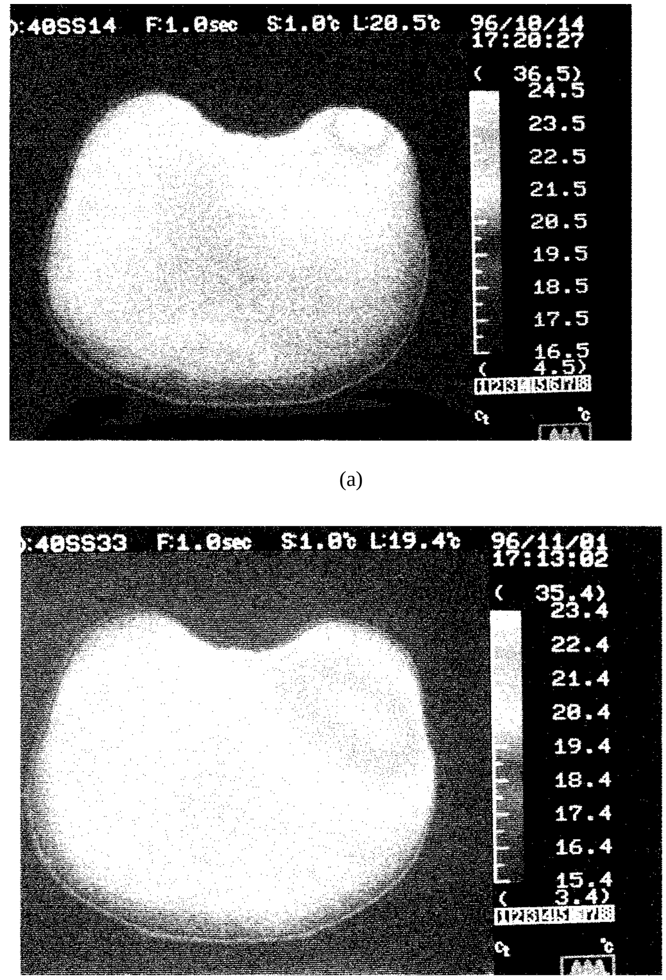


Fig. 11. Thermographic view of the phantom. (a) The case when both ferrite cores are in the same level near the surface of a breast. (b) The case when the right ferrite core is lowered 8 cm.

animal. Four thermosensors consisting of an optical fiber is inserted into the rabbit. The sensors are inserted into and around the liver. The average temperatures were measured. In this animal experiment, a temperature rise of more than 8 °C from the initial value was obtained after 10 min of heating. It became clear that heating efficiency in an animal is superior to a phantom or an agar phantom subject to the QAC, JASHO.

Fig. 12 shows the appearance of the applicator system developed. The ferrite cores are covered with an acrylic resin. The magnetic shield plates are integrated with the acrylic case of the ferrite cores. This applicator system has a special feature in that a patient is treated while sitting on a chair and putting a breast between both applicators on a table. It can also be applied to a patient lying on a bed. In addition, it is possible to perform noninvasive heating without heating the fat layer under the skin. For this reason, this applicator system is expected to be available not only for hyperthermia, but also for general thermal therapy [21].

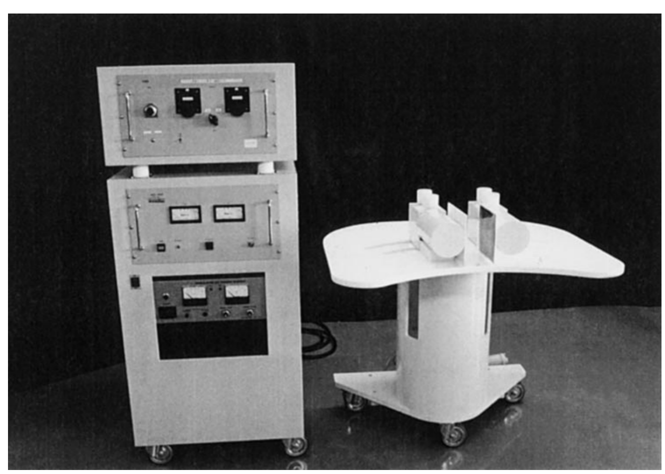


Fig. 12. Appearance of applicator system developed.

VI. Conclusion

A simple ferrite core applicator system for the treatment of breast cancer has been developed, paying attention to the fact that a protuberance on a human body is heated well by a ferrite core applicator with a pair of poles. To control heating position, magnetic-field distributions were investigated based on a theoretical analysis using the FEM. It was clarified that the method for controlling the heating position horizontally and vertically can be achieved by introducing a thin conductive shield plate and a eddy current absorber. Consequently, heating tests using agar phantoms and rabbits showed that the heating position is easily controlled with a high efficiency.

A summary of the main results is as follows.

1) The 3-D FEM analyses for the magnetic-field distribution and the experiments suggest that a deep region up to 8 cm for the present phantom size can be heated using ferrite cores with thin copper shield plates. The horizontal heating position can be controlled at a position to the left- and right-hand sides inside the breast, which satisfies clinical needs.
2) For the design of the ferrite core applicator, the operating frequency, method of cooling ferrite core, size of magnetic shield plate, and eddy current absorber have been optimized. Consequently, an applicator with thin copper plates of 15 $\times$ 10 cm operated with a relatively low power of 600 W compared to a conventional inductive applicator that could be designed at 4 MHz.
3) Using this noninvasive applicator, heating tests were conducted with agar phantoms and rabbits. A temperature rise of more than 8 °C from the initial level at a depth of 8 cm was obtained after heating for 10 min without heating the fatty layer. It was clarified that animal heating using a rabbit is superior to heating an agar phantom assigned by the QAC, JASHO. Heating tests for clinical use must be the subject of further study.

ACKNOWLEDGMENT

The authors would like to thank Director I. Yokoyama, TDK Inc., Yuri-gun, Akita, Japan, and Director S. Watabe, TDK Inc., Yuri-gun, Akita, Japan, for supplying ferrite materials, and also Prof. A. Rosen, Drexel University, Philadelphia, PA, for his kind suggestions regarding this paper.

REFERENCES

[1] A. Rosen and H. D. Rosen, *New Frontiers in Medical Device Technology*: Wiley, 1995, pp. 312–337.
[2] A. Westra and W. C. Dewey, "Variations in sensitivity to heat shock during the cell-cycle of Chinese hamster cell in nitro," *Int. J. Radiat. Biol.*, vol. 19, pp. 467–477, 1971.
[3] E. Ben-Hur *et al.*, "Thermal enhanced radio-response of cultured Chinese hamster cell-inhabitation of repair of sub lethal damage and enhancement of lethal damage," *Radial Res.*, vol. 58, pp. 38–51, 1974.
[4] P. P. Antichi *et al.*, "Selective heating of coetaneous human tumors at 27.12 MHz," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-26, pp. 569–572, Aug. 1978.
[5] F. K. Storm *et al.*, "Clinical RF hyperthermia by magnetic-loop induction: A new approach to human cancer therapy," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-30, pp. 1149–1157, Aug. 1982.
[6] R. S. Elliott *et al.*, "Electromagnetic heating of deep seated tumors," *IEEE Trans. Biomed. Eng.*, vol. BEM-29, pp. 61–64, Jan. 1982.
[7] J. R. Oleson, "A review of magnetic induction methods for hyperthermia treatment of cancer," *IEEE Trans. Biomed. Eng.*, vol. BME-31, pp. 91–97, Jan. 1984.
[8] P. S. Ruggera *et al.*, "Development of RF helical coil applicator which produce transversely uniform axially distributed heating in cylindrical fat-muscle phantoms," *IEEE Trans. Biomed. Eng.*, vol. BME-31, pp. 98–105, Jan. 1984.
[9] M. J. Hagman *et al.*, "Coupling efficiency of helical coil hyperthermia applications," *IEEE Trans. Biomed. Eng.*, vol. 32, pp. 539–540, July 1985.
[10] I. Kimura *et al.*, "VLF induction heating for clinical hyperthermia," *IEEE Trans. Magn.*, vol. Mag-22, pp. 1897–1900, June 1986.
[11] J. G. Kern *et al.*, "Experimental characterization of helical coil as hyperthermia applicators," *IEEE Trans. Biomed. Eng.*, vol. 35, pp. 46–52, Jan. 1998.
[12] H. Kanai, "Magnetic induction hyperthermia," *IEEE Trans. Magn.*, vol. MAG-88, no. 41, pp. 42–52, Jan. 1988.
[13] A. L. Albert *et al.*, "The RF troidal transformer as a heat delivery system for regional, and focused hyperthermia," *IEEE Trans. Biomed. Eng.*, vol. 35, pp. 1077–1085, Dec. 1988.
[14] J. B. Anderson *et al.*, "A hyperthermia system using a new type of inductive applicator," *IEEE Trans., Biomed. Eng.*, vol. BEM-31, pp. 212–227, Jan. 1984.
[15] Y. Kotsuka, "A new construction method on induction heating material for hyperthermia," IEICE, Tokyo, Japan, Tech. Rep. 85-78, 1985.
[16] Y. Kotsuka and E. Hankui, "Investigation on two types of applicators for local hyperthermia of induction and capacitive heating," *Proc. Int. EMC. Symp Dig.*, vol. 2, pp. 722–725, Sept. 1989.
[17] ——, "Development of ferrite core applicator with variable gap," *Nat. Conv. IEICE*, vol. B-292, 1990.
[18] Y. Kotsuka *et al.*, "Development of a new ferrite core applicator system for inductive deep hyperthermia," in *Proc. 6th Int. Congr. Hypertherm. Oncol.*, Tucson, AZ, Apr. 1992, p. 339.
[19] Y. Kotsuka, E. Hankui, and Y. Shigematsu, "Development of ferrite core applicator system for deep-induction hyperthermia," *IEEE Trans. Microwave Theory Tech.*, vol. 44, pp. 1803–1810, Oct. 1996.
[20] Y. Kotsuka *et al.*, "Development of ferrite core applicator for local induction heating," IEICE, Tokyo, Japan, Tech. Rep. EMCJ90-38, Sept. 1990.
[21] A. Rosen and H. D. Rosen, "RF/Microwaves in thermal therapies," IEICE, Tokyo, Japan, Tech. Rep. MW98-21, May 1998.

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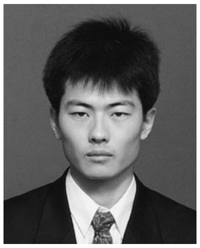

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