Thermal Distribution in a Phantom Using 8MHz RF Capacitive Type Hyperthermia

Jong Young Lee, M.D., Kyung Ran Park, M.D., Kye Jun Kim, B.S. and Ki Joon Sung, M.D.*

Department of Radiation Oncology, and Radiology Yonsei University, Wonju College of Medicine, Wonju, Korea*

To evaluate the temperature distribution according to the size of the electorde and the thickness of the phantom using 8MHz radiofrequency capacitive heating device, various sized electrodes and phantoms were used in combination. The radii of the electrodes are 10, 15, 20, 25, and 30 cm and the thickness of cylindrical phantoms with diameter 30 cm were 10, 15, 20, 25, 30, and 35 cm.

When the thickness of the phantom was 25 cm or 30 cm, homogenous heating was achieved by using the electrode which diameter was equal to or greater than the thickness of the phantom. When the thickness of the phantom was 20 cm or less. homogenous heating was not achieved by using the electrode which diameter was equal to the thickness of the phantom, but achieved by the larger diameter of the electorode. When the sizes of paired electrodes were not equal, the smaller electrode side was preferentially heated.

Key Words: Hyperthermia, radiofreguency, Thermal distribution

INTRODUCTION

Many biologic studies of the hyperthermia with the radiation or with some anticancer agents have demonstrated the remarkable effects of heat on tumor control[1,2,3]. And the hyperthermia combined with the irradiation as an adjuvant modality in the cancer treatment has been used in many institutes.

In general, the three types of local heating devices-microwave, ultrasound, and radiofrequency are the most popular.

Microwave can heat the superfical site, but cannot heat the deep region effectively. Although ultrasound can heat the deep tissue, the main disadvantage is that its penetration in air and bone is very poor. Radiofrequency type is effective to heat some deep tissue sites at the sacrifice of localization, together with the risk of heating superficial tissues excessively[4].

This study reports the characteristics of the temperature distribution according to the size of the electrode and the thickness of the phantoms using an 8 MHz radiofrequency (RF) capacitive heating device.

MATERIALS AND METHODS

1. Heating Device

The unit consisted of 4 basic components: (1) cabinet which has a radiofreguency generator and heat exchange system, (2) a C-type rotational gantry for a pair of electrodes, (3) treatment couch, and (4) computorized control console. The RF energy is transmitted from a generator via two coaxial cables to two electrocdes. RF is opplied with a pair of electrodes placed on apposite side of the gantry. The gantry is able to be rotated 90 degrees with the electrodes which can be moved independently moved in or out.

The unit has a thermometry system with five Teflon-coated probes of copper-constantan (Sensortek, Inc., Type IT-18, New Jersey).

2. The Electrodes with cooling System

The radii of the electrodes are 10, 15, 20, 25, and 30 cm. The surface of the metal plate of the electrodes is closed by soft vinyl membrane. The interior of the electrodes are filled with 0.4% saline solution, which is circulated between the electrodes and the heat exchanger. This bolus makes it possible to attach the electrodes to the phantom or body surface smoothly. The circulating saline solution cools the surface of the phantom.

3. The Phantoms

Cylindrical phantoms with diameter 30 cm were made of 4% agar gel containing 0.2% Sodium Chloride, which thicknesses were 10, 15, 20, 25, and 30 cm.

Several 18 gauge angiocatheters were inserted into the phantoms from the lateral side with a 1 cm spacing and thermocouples were placed in the catheter. For keeping the accurate spacing and the parallel, the acryl template was used.

4. Heating and Temperature Measurement

The temperature of the circulating saline bolus was maintained at 20°C for this study. Heating was continued until temperature was reached to 42°C at any point of the phantom. Immediately after heating, the temperature distributions in the phantoms at the different horizontal planes were determined by retracting the thermocouple probes outward at 1 cm intervals through angiocatheters. The temperature of the phantom was also measured by the thermalvideo system (TVS-3300 ME, Nippon Avionics Co, Ltd) after the phantom was cutted.

For evaulation of thermal distribution according to the size of the electrode and the thickness of the phantom, each size of electrodes and variable thickness of phantoms were used in combination.

RESULTS

1. 10 cm Thickness Phantom

Using 15×15 cm or above sized electrode, thermal distribution showed a maximal heat area in the center of the phantom. Using 10×10 cm sized electrode, thermal distribution showed a cold area in the center and a relatively hot spot underneath the electrodes (Fig. 1).

2. 15 cm Thickness Phantom

Twenty by twenty centimeter or above sized electrode was able to heat the midplane of the phantom homogenously. 15×15 cm or 10×10 cm sized electrode made a cold area in the center of phantom (Fig. 2).

3. 20 cm and 25 cm Thickness Phantom

In combination with 25×25 cm or above sized electrode, thermal distribution showed a central

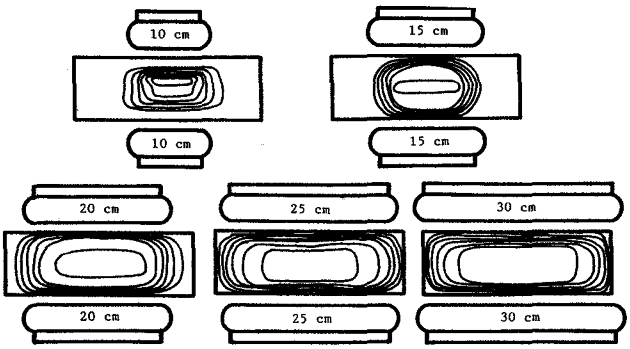

Fig. 1. Thermal distribution in 10 cm thickness phantoms.

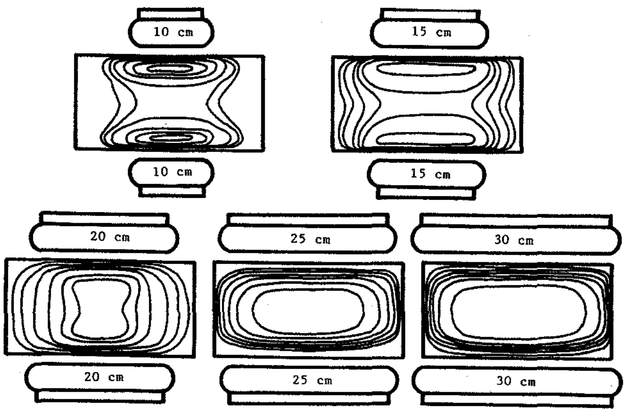

Fig. 2. Thermal distribution in 15 cm thickness phantoms.

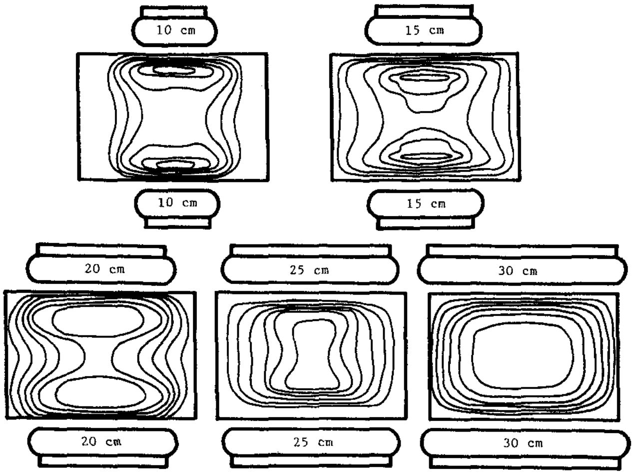

Fig. 3. Thermal distribution in 20 cm thickness phantoms.

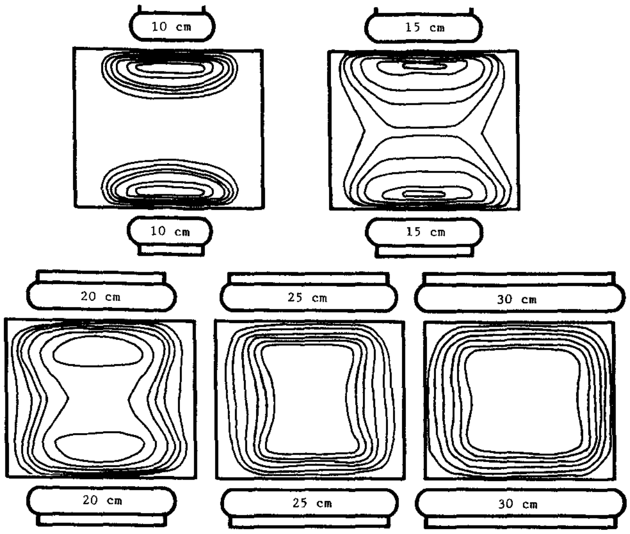

Fig. 4. Thermal distribution in 25 cm thickness phantoms.

heating, but 20×20 cm or below sized electrode, it showed a cold area in the center of the phantom (Fig. 3, 4).

4. 30 cm Thickness Phantom

Only 30×30 cm sized electrode was able to heat the center of the phantom homogenousiy. Below 30×30 cm sized electrede were not able to heat the center of the phantom homogenously. Below 30×30 cm sized electrode were not able to heat the center of the phantom without peripheral hot spot (Fig. 5).

5. Pair of Different Sized Electrode(10×30 cm, 20×30 cm)

When the sizes of paired electrodes were not equal, the smaller electrode side was preferentially heated. Thicker and thicker the phantom is, more and more the maximal heating zone shifted toward smaller electrode side (Fig. 6, 7).

DISCUSSION

Hyperthermia has been used for cancer therapy

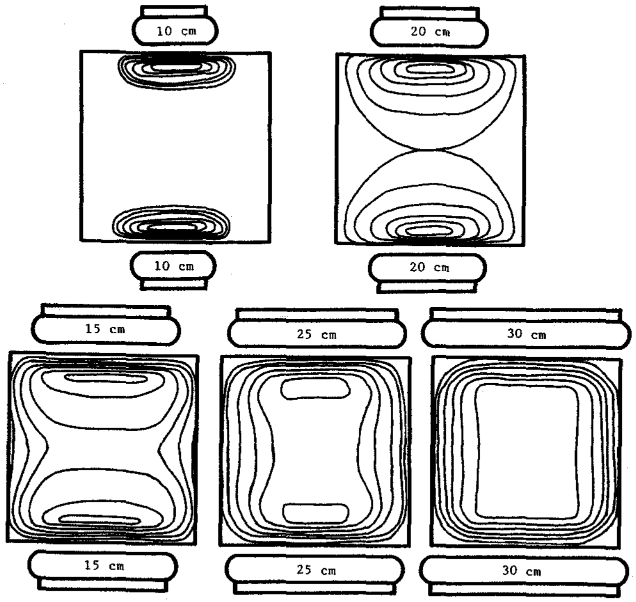

Fig. 5. Thermal distribution in 30 cm thickness phantoms.

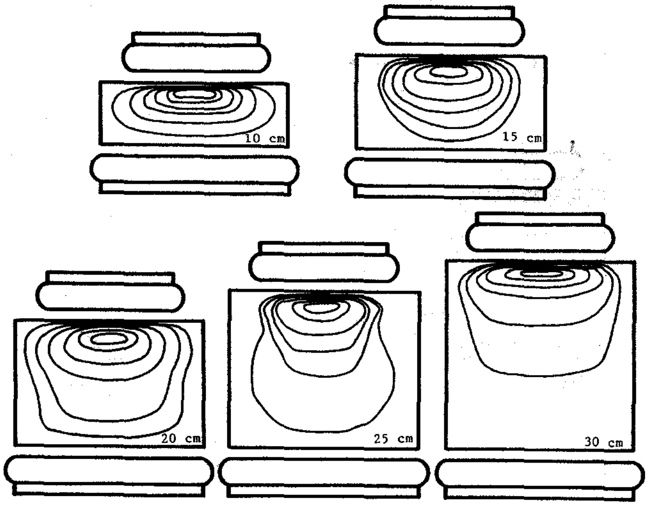

Fig. 6. Thermal distribution in various thickness phantoms with 20 and 30 cm electrode combination.

since the late 1800's. There is increasing evidence that heat alone or in combination with radiation or chemotherapy is effective in inducing objective tumor regression[5].

Clinical application of hyperthermia falls into two broad categories-whole body and localized hyperthermia. Methods of inducing whole body hyperthermia include wax baths, hot air cabinets, water blankets, and space suits[4].

Local hyperthermia offers a wider range of therapeutic possibilites. Methods of inducing localized heating include immersion in hot water, and irrigation of body cavity with hot liquids. The methods with the greatest potential for inducing localized hyperthermia in patients are those involving microwave, ultrasound, or radiofrequency-capacitive coupling and inductive coupling.

Microwave has some advantages: quite good

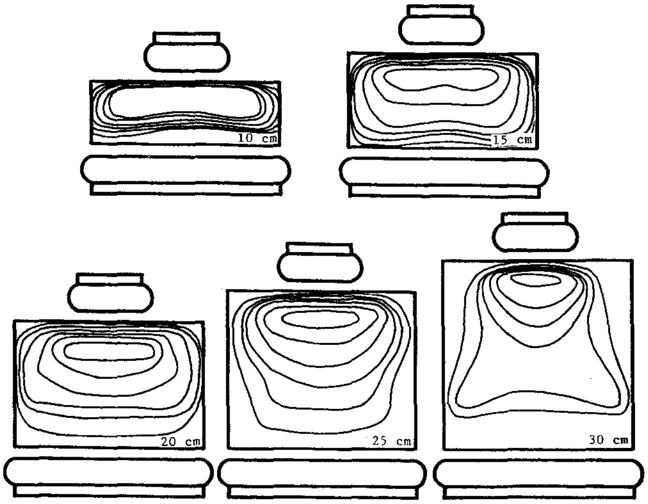

Fig. 7. Thermal distribution in various thickness phantoms with 10 and 30 cm electrode combination.

penetration due to near field of radiating sources at 300~400 MHz, resonant absorption that may occur at some sites, small heating of fat relatively, coaxial applicator useful, and development of multiapplicator systems and microwave thermography. Microwave has some disadvantages: difficulty in predicting heating pattern, large temperature gradients associated with coaxial applicators, and poor penetration for frequencies greater than 1 GHz[5,6].

Ultrasound has advantages: good depth dose relationship available with focusing, good penetration in soft tissues, possibility of enhancement of biological effects of temperature by nonthermal mechanism, and technology available for multitransducer systems and phased array. It has disadvantages: requiring coupling medium, large reflections at gas/tissue and bone/soft tissue interfaces, and rapid attenuation in bone[5,6].

RF heating can be delivered by either inductive or capacitive heating methods. Using radiofrequency inductive heating, maximum heating is deep in tissue with very little heating of skin or fat tissue, but heatng pattern is non-uniform. Capacitive heating has an adavantage-ability to heat large volumes at depth, and has a disadvantage-excessive heating of superficial and fat tissues[5,6]. Radiofrequency capative heating has been used by several investigators for the treatment of various human tumors, and it has a demonstrated efficacy for large and deep-seated tumors[2,7,8]. It has been demonstrated that electrode size in relation to the diameter and thicikness of the phantom markedly affects the thermal distribution[2,7,8,9]. To achieve homogenous heating, it has been recommended that the diameter of the electrod should be equal to or larger than the thickness of the phantom or the patient[9].

This study showed that 25 cm or 30 cm thickness of the phantom required electrode which size was same or larger than the thickness of the phantom. In 20 cm or less thickness of the phantom, same size electrode as the thickness of the phantom did not show homogenenous heating pattern, but the electrode which size was larger than the thickness of the phantom showed homogenous heat distribution.

Tissue of the human body is inhomogenous, so the conductivity of each tissue is different. And there is great variation in the organization of the microcirculation in different tissues. Because blood flow is the primary mode of heat dissipation during local hyperthermia, any changes in blood flow induced during heating would have a significant impact on the temperature distribution[10,11].

Because the phantom is homogenous and not vascularized, heat distribution and electrophysical properties of the phantom are different from the human body, this study shows how to deliver heat to human body and how to select a suitable electrode size according to the thickness of a human body.

CONCLUSION

The thermal distrubution was investigated in variable size of electrodes and variable thickness of phantoms using 8 MHz radiofrequency capacitive type hyperthermia. We have measured the thermal distribution in agar phantom as follows.

1) When the thickness of the phantom was 25 cm or 30 cm, homogenous heating was achieved by using the electrode which diameter was equal to or greater than the thickness of the phantom.

2) When the thickness of the phantom was 20 cm or less, homonegenous heating was not achieved by using the electrode which diameter was equal to the thickness of the phantom, but achieved by the larger diameter of the electorde.

3) When the sizes of paired electrodes were not equal, the smaller electrode side was preferentially heated.

REFERENCES

1. **Hiraoka M, Jo S, Dodo Y, et al:** Clinical results of radiofrequency hyperthermia combined with radiation in the treatment of radioresistant cancers. Cancer 54:2829-2904, 1984
2. **Abe M, Hiraoka M, Takahashi M, et al:** Multi-institutional studies on hyperthermia using an 8-MHz radiofrequency capacitive heating device (Thermotron RF-8) in combination with radiation for cancer therapy. Cancer 58:1589-1595, 1986
3. **Hiraoka M, Jo S, Akuta K, et al:** Radiofrequency capacitive hyperthermia for deep-seated tumors. Cancer 60:128-135, 1987
4. **Hand JW, Haar G:** Heating techniques in hyperthermia. Brit J Radiol, 54:443-466, 1981
5. **Brezovich IA, Lilly MB, Durant JR, et al:** A practical system for clinical radiofrequency hyperthermia. Int J Rad Onc Biol Phys 7:423-430, 1981
6. **Hahn GM, Kernahan P, Martinez A, et al:** Soma heat transfer problems associated with heating by ultraasound, microwaves, or radio frequency. Ann New York Acad Sci. 335:327-346, 1980
7. **Song CW, Rhee JG, Lee CKK, et al:** Capacitive heating of phantom and human tumors with an 8 MHz radiofrequency applicator (Thermotron RF-8). Int J Rad Oncol Biol Phys 12:365-372, 1986
8. **Chu SS, Suh CO, Kim GE, et al:** Development and thermal distribution of an RF capacitive heating device. Kor Soc Therap Radiol 5:49-57, 1987
9. **Lee Ckk, Song CW, Rhee JG, et al:** Clinical experience with thermotron RF-8 Capacitive heating for bulky tumors: University of Minnesota experience. Radiol Clin North Am 27:543-558, 1989
10. **Emami B, Song CW:** Physiological mechanisms in hyperthermia: A review. Int J Radiol Oncol Biol Phys 10:289-295, 1984
11. **Waterman FM, Nerlinger RE, Moylan III DJ, et al:** Response of human tumor blood flow to local hyperthermia. Int J Radio Biol Phys 13:75-82, 1987

= 국문초록 =

8 MHz 고주파 유전형 가열장치로 가열한 모형에서의 열분포

연세대학교 원주의과대학 치료방사선과학교실, 방사선과학교실*

이종영 · 박경란 · 김계준 · 성기준*

8 MHz 고주파 유전형 가열장치로 모형을 가열할 때에 전극의 크기와 모형의 두께에 따른 온도 분포를 알아보기 위하여 다양한 크기의 전극과 다양한 두께의 모형을 조합하여 실험하였다.

전극은 10, 15, 20, 25, 그리고 30 cm 크기를 사용하였고 모형은 10, 15, 20, 25, 그리고 30 cm 두께를 사용하였다.

모형의 두께가 25 cm 이상일 경우에는 전극의 크기가 모형의 두께보다 크거나 혹은 같을때에 중심부에 균일한 온도 분포를 얻을 수 있었으나, 모형의 두께가 20 cm 이하일 경우에는 전극의 크기가 모형의 두께와 같을 때는 균일한 온도 분포를 얻을 수 없었고 전극의 크기가 모형의 두께보다 클 때만 균일한 온도 분포를 얻을 수 있었다. 크기가 다른 한쌍의 전극을 사용하여 가열시에는 작은 전극 쪽으로 가열 부분이 집중되었고 그 현상은 전극크기의 차가 클 수록 심하였다.