Improvement of Heating Pattern in RF Hyperthermia -Simultaneous Application of Dielectric Heating and Induction Heating-

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ABSTRACT

Heating by RF wave is divided into dielectric heating and induction heating.
Dielectric heating and induction heating from outside the body have the compensatory heating pattern. While surface fat layer is heated by dielectric heating, it is not heated by induction heating.
While the peripheral part at the middle of the electrodes is not heated by dielectric heating, it is heated by induction heating.
By the simultaneous application both modalities, heating pattern seems to be more uniform and improved. Computer simulation of Finite Element Method (FEM) using ANSYS was conducted to dielectric heating with the results of above-mentioned feature. Theoretical considerations by the uniform RF magnetic field in a cylinder and textbooks support the feature of the above-mentioned heating pattern of induction heating.
Further computer simulation of FEM using ANSYS will be conducted to simultaneous application of dielectric heating and induction heating to verify and will be reported.

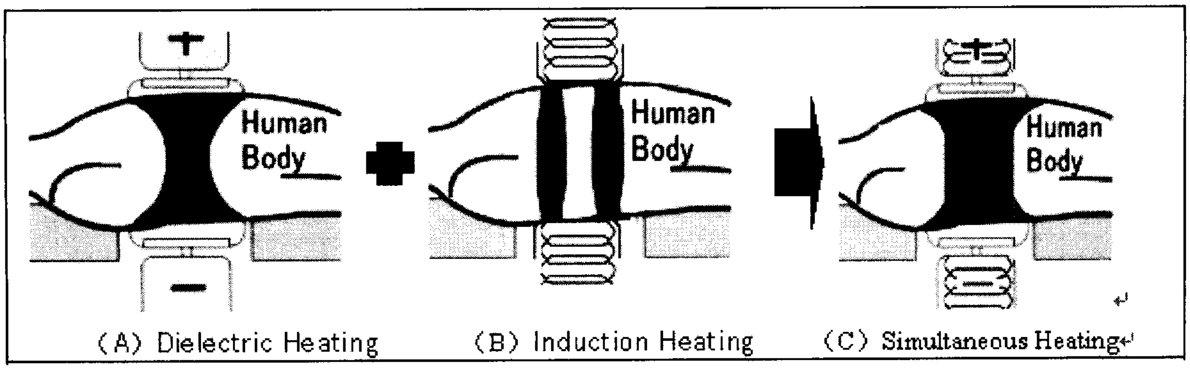
Key words: Hyperthermia, RF heating, induction heating, dielectric heating

1. INTRODUCTION

Cancer therapy are done mainly by operation, anticancer drugs, radiation, and Hyperthermia. They are achieved alone or in combination. Each modality, however, is with side effects and invasive to patients. By improving hyperthermia which seems to be lowest invasive, cancer therapy may be much improved. The aim of this study is to improve RF heating of hyperthermia to yield more uniform heating pattern. Heating pattern by RF wave is not uniform as is well known. By dielectric heating, fat layer at the surface of the body is most heated as the specific transmission σ is low in fat. And in the central region between electrodes at the surface of the body, heated area becomes smaller like a shape of a sandglass.
On the other hand, induction heating by two coils at the body surface, fat layer is not heated as the specific transmission σ is low in fat. In the vertical direction, the center of eddy currents is not heated at all, and heating rate is at most at the periphery of the magnetic field.
To some extent, they have the opposite heating pattern. More uniform heating pattern for deep-seated tumor is expected, if they are used in combination.

2.METHOD

Heating pattern is to be analyzed using computer simulation by Finite Element Method (ANSYS).
At first, heating pattern by dielectric heating alone is analyzed. On the second, heating pattern by inductive heating alone is to be analyzed. And finally, heating pattern using both modalities simultaneously is to be analyzed. Figure 1 shows schematically the expected results. Dielectric heating introduces RF currents from both electrodes in the opposite side of the body. Induction heating introduces RF magnetic field which causes eddy current in the tissue that yield heat.



(A) Dielectric Heating (B) Induction Heating (C) Simultaneous Heating

Figure 1 Expected heating pattern by dielectric heating, induction heating and simultaneous heating.

3. RESULTS

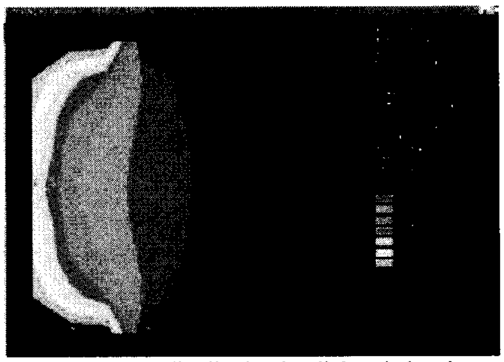


Fig. 2 Temperature distribution by dielectric heating.

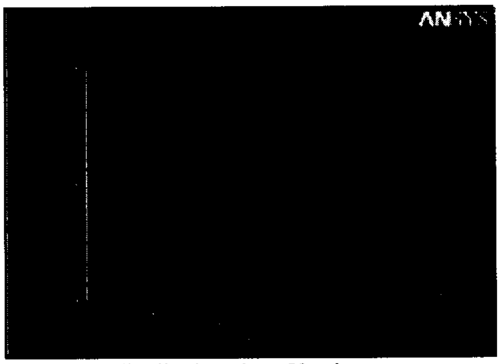


Fig.3 Temperature distribution along Y axis

Figure 2 and 3 show the temperature distribution of RF dielectric heating analyzed by ANSYS.

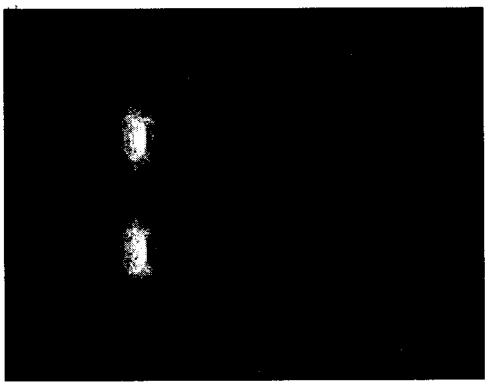


Fig.4 Magnetic flux density in induction heating

Figure 4 shows the magnetic flux density in induction heating. Temperature distribution is under calculation but will be reported at the meeting. For the moment, theoretical calculation of heat production for infinitesimal thickness is shown.

For simplicity magnetic field is uniform for $r < r_0$, while magnetic field is zero for $r > r_0$.

$$B = B_0 \sin(2\pi\nu t) \qquad (r < r_0) \text{ --------- } (1.1),$$
$$B = 0 \qquad (r > r_0) \text{ --------- } (1.2).$$

Form above equations, we obtain,

$$\mathrm{rot}\, E = 2\pi B_0 \cos(2\pi\nu t) \qquad (r < r_0) \text{ ------ } (2.1),$$
$$\mathrm{rot}\, E = 0 \qquad (r > r_0) \text{ ----- } (2.2).$$

Applying Storkes' theorem, we readily obtain,

$$E = \pi r \nu B_0 \cos(2\pi\nu t) \qquad (r < r_0) \text{ ------ } (3.1),$$
$$E = \pi (r_0^2/r)\nu B_0 \cos(2\pi\nu t) \qquad (r > r_0) \text{ ------ } (3.2).$$

Form above equations, we obtain heat generation pattern,

$$\overline{Q} = \overline{jE} = \sigma\overline{E^2} = (1/2)\sigma\{\pi r \nu B_0\}^2 \qquad (r < r_0), \text{-------- } (4.1)$$
$$\overline{Q} = \overline{jE} = \sigma\overline{E^2} = (1/2)\sigma\{\pi r_0^2/r\}^2\{B_0\}^2 \qquad (r > r_0). \text{-------- } (4.2)$$

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