NEW APPLICATORS FOR MICROWAVE HYPERTHERMIA

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ABSTRACT

Two types of applicators using microstrip for microwave hyperthermia are proposed. One is a microstrip patch applicator using a dielectric substrate made of silicone rubber with flowing water (Type I). The other is a microstrip array applicator using flowing water substrate (Type II). The applicators are flexible and can avoid the surface overheat of the heating medium. The heating experiments at 430 MHz show that the applicator can be in contact well with the uneven surface of the body and can heat relatively wide and deep portion inside simulated human muscle.

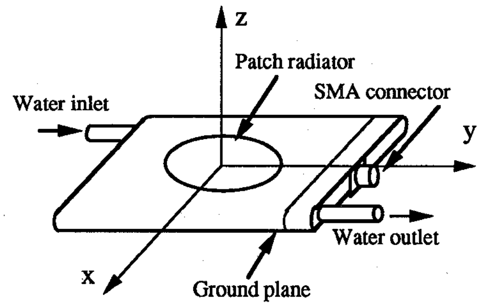


Fig. 1. Schematic view of Type I applicator.

I. INTRODUCTION

Recent EM energy application for medicine, such as for hyperthermia treatment of cancer, demands the reliable and easy coupling method of the EM energy to the human body [1]-[3]. Conventional applicator design for such application basically consists of the rectangular waveguide techniques. To minimize the size and to improve coupling efficiency of the applicators, they are usually loaded by water or other dielectric materials, therefore such applicators become heavy in weight and large in size when using frequency becomes lower than several hundred megahertz. These problems sometimes makes such waveguide applicators difficult to apply for the clinical treatment.

Using microstrip applicator may solve these problems, because it is possible to design small in size, flexible and light in weight. The flexibility has a merit that the applicator fits on the parts of uneven surface of the human body. The authors formerly presented applicators using microstrip [4], [5]. These applicators still have some problems for the clinical usage.

In this paper, we will show two types of light, thin and flexible microstrip applicator which can be used for clinical treatment. One is a new microstrip patch applicator using dielectric substrate made of silicone rubber with flowing water (Type I). The other is microstrip array applicator using flowing water substrate (Type II). Type I applicator applies a electro-magnetic (EM) coupling method to make it more flexible. Type II applicator consists of integration of a dielectric substrate and a cooling device. Heating abilities of the two types of the applicators are examined by measuring its electric field distributions and by heating experiments.

II. DESIGN OF MICROSTRIP APPLICATOR

A. Type I Applicator

Type I applicator applies microstrip patch antenna design method and its schematic view is shown in Fig. 1. Silicone rubber flat bag made of 0.5 mm thickness silicone rubber sheet constructs the applicator. The patch and the ground plane are attached on each side of the silicone rubber flat bag. To keep the length between the patch and the ground plane, the insulator made by silicone rubber is set inside the bag. The patch and the ground plane on the silicone rubber are fed by EM coupling method through the APC-7 connector which is attached at one side of the applicator (see Fig. 2). The connector is firmly fixed by a 1.0 mm thickness silicone rubber flame placed on the edge of the applicator. The thickness of the applicator, that is the length between the ground plane and the patch, is sustained 4.0 mm by the silicone rubber insulator shown in Fig. 2. Water flowed in the space between the patch and the ground plane acts as the dielectric substrate and also acts to avoid the surface overheat of the medium directly contacted to the microstrip patch applicator.

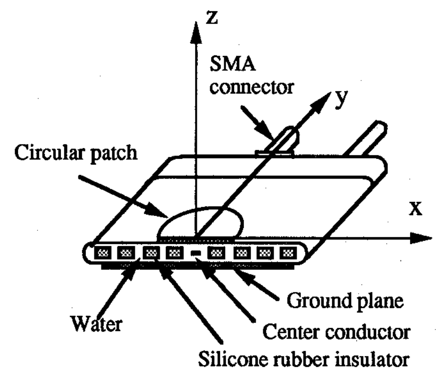


Fig. 2. Cross sectional view of Type II applicator.

X

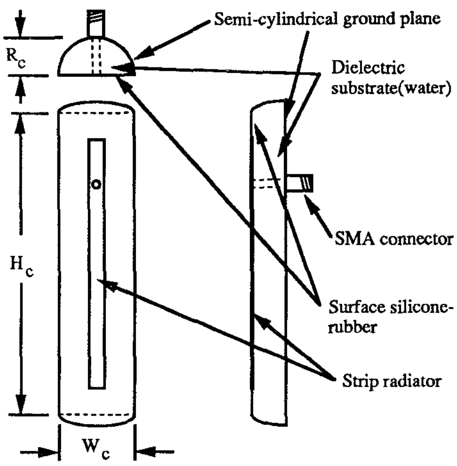


Fig. 3. Schematic view of the element of Type II applicator.

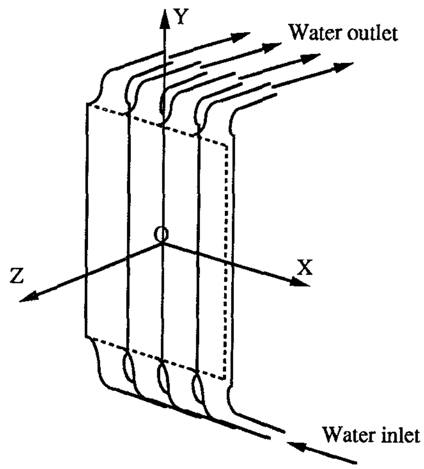


Fig. 4. Set-up of the Type II applicator.

Here, ε is the relative dielectric constant of the substrate and can be given by

$$\log \varepsilon = V_1 \log \varepsilon_1 + V_2 \log \varepsilon_2 \qquad (1)$$

where V_1 and V_2 are the volume ratio of water and silicone, ε_1 and ε_2 are the relative dielectric constants of water and silicone, respectively. The diameter of the patch D can be obtained by

$$D = \frac{\lambda_0}{2\sqrt{\varepsilon}} \qquad (2)$$

where λ_0 is the wavelength in the free space. From (1) and (2), D=60 mm is obtained.

B. Type II Applicator

Fig. 3 shows the construction of the element of Type II applicator. The dimensions are as follows; R_c=7.5 mm, W_c=15.0 mm and H_c=60.0 mm. The elements are directly contacted to the surface of the heating materials. The general set-up of the element is shown in Fig. 4. Each element consists of a thin rectangular strip radiator and semi-cylindrical ground plane. Thin plastic tube, inside which flows cooling water, enclosed the applicator. The space between the surface of the applicator and ground plane is filled with flowing deionized water as a dielectric substrate. Since the dielectric constant of deionized water is very high (ε_r=78 at 430 MHz, 20^{o}C) the following advantages are expected; the wave length is reduced and the element is designed smaller accordingly, and the applicator has better impedance matching with the human body.

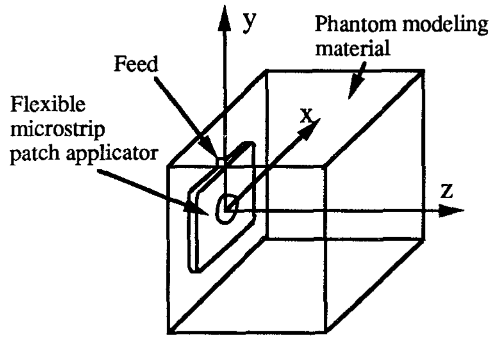


Fig. 5. Type I applicator set-up with axis (set A).

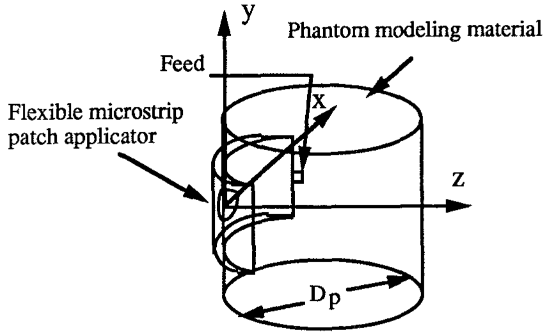


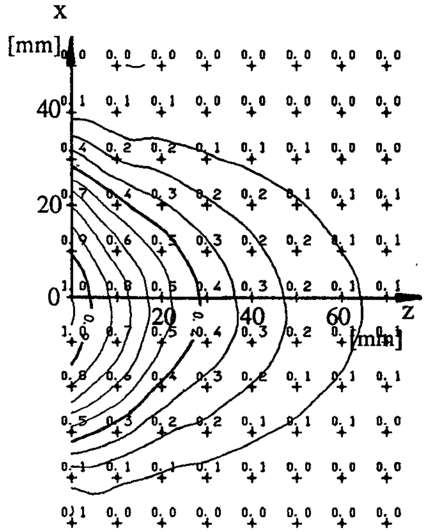
Fig. 6. Type I applicator set-up with axis (set B).

III. EXPERIMENTAL RESULTS

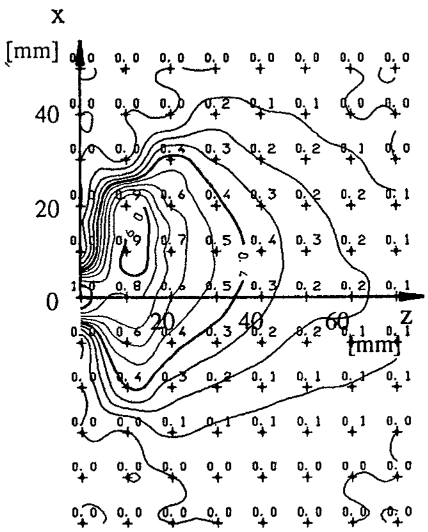
A. Applicator Set-up

Experimental set-up of the Type I applicator are shown in Figs. 5 and 6 with the coordinates. Applicator is set in the two way which is called as set A and B. Set A is a normal setting which the applicator is in contacted with the plane phantom model (see Fig. 5). Set B is a setting which the applicator is in contacted with the cylindrical shaped phantom model with feed line at right angles to the central axis of the cylinder (see Fig. 6). Here, the diameter of the cylinder D_p is 150 mm. Reflection coefficient of the applicator is changed when the applicator setting changes. The reflection coefficient was the minimum (-17dB) in the case of the set A. In the case of the set B, the reflection coefficient was increased, but it was still less than -12 dB and this means that the applicator can be used for the 430 MHz heating.

As for the experimental set-up for the Type II applicator, set A' which is a normal setting as set A (see Figs. 4 and 5), and set B' which is in contact with the cylindrical shaped phantom model of D_p =150 mm with strip line in parallel to the central axis of the cylinder are prepared.



(a) Set A

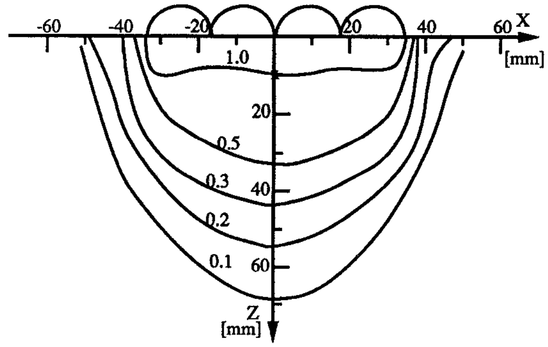


(b) Set B

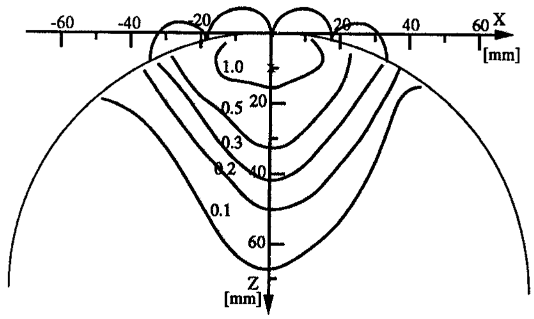
Fig. 7. SAR distributions in the 0.4 % NaCl solution using Type I applicator.

B. Electric Field Distribution

Electric field was measured in the lossy liquid medium of 0.4% saline solution as a electrically equivalent phantom model of human muscle. In this case, the saline solution was put inside a cube or a cylinder made of 2.0 mm thickness acrylic resin. Results of electric field distribution in the x-z plane in the case of set A and set A' are indicated as SAR distribution and are shown in Figs. 7(a) and 8(a), respectively. From Figs. 7(a) and 8(a), it is found that the electric field distribution along the x-z plane is almost symmetry. The depth where SAR becomes 50% is around 20 mm in the case of set A and around 30 mm in the case of set A'. On the other hand, as is shown in Fig. 7(b) in the case of set B, while the electric field distribution along x-z plane is a little asymmetry, the depth where SAR becomes 50% increases up to 30 mm. In the case of set B' which is shown in Fig. 8(b), the depth where SAR becomes 50% is not so



(a) Set A'



(b) Set B'

Fig. 8. SAR distributions in the 0.4 % NaCl solution using Type II applicator.

changed. By bending Type I applicator as Fig. 6, the applicator generates a kind of focussing effect, hence the depth of penetration becomes increased.

C. Temperature Distribution

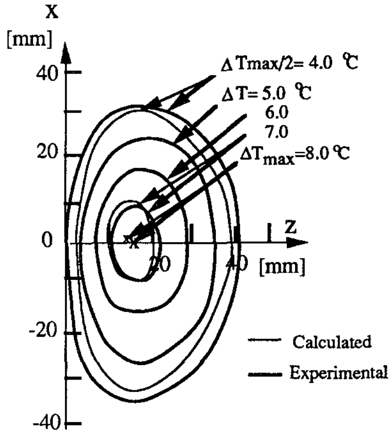
The simulation of temperature distribution inside static phantom model of muscle was performed in the x-z plane using experimental results of the electric field distribution and heat transfer equation which is shown below,

$$\frac{\partial}{\partial t}\rho c T = q + \gamma \nabla^2 T \qquad (3)$$

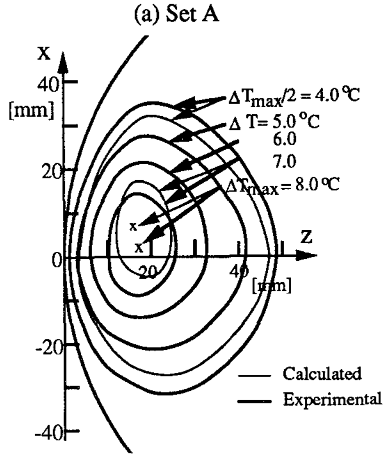
where

- ρ density of tissue (g/cc),
- c specific heat of tissue (cal/g^{o}C),
- γ coefficient of heat conduction (cal/cm.s ^{o}C),
- T temperature in the medium (^{o}C),
- q heat input due to EM fields obtaining by SAR.

The heating experiment was also performed using cylindrical shaped phantom modeling material of human muscle which is made of 0.35% of NaCl, 0.05% of NaN_3, 4.0% of agar and 95.6% of H_2O. Initial temperature of the model was kept at 20^{o}C and the input microwave power was controlled so that the temperature elevation rate at the maximum temperature point became 1^{o}C per minute. The temperature of cooling water was 20^{o}C. Figs. 9(a) and 10(a) show the temperature elevation in the cubic phantom modeling material of the human muscle. The result of simulation is also shown in Fig. 9 (a) by thin lines. The experimental results

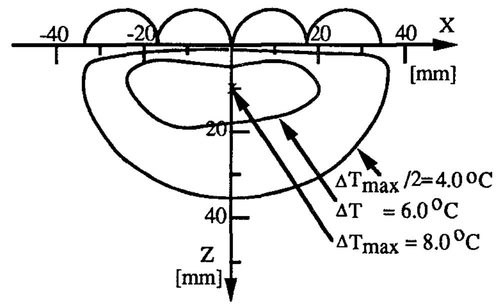


(a) Set A

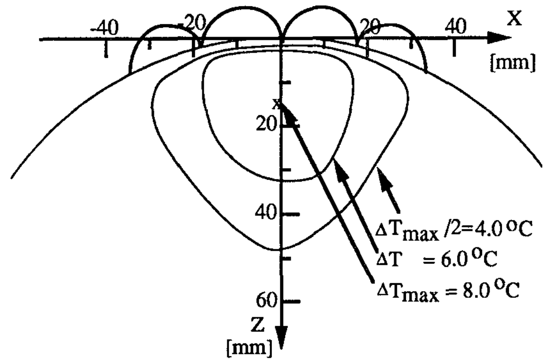


(b) Set B

Fig. 9. Temperature distributions in the simulated muscle using Type I applicator.



(a) Set A'



(b) Set B'

Fig. 10. Temperature distributions in the simulated muscle using Type II applicator.

agree well with the simulated ones. The results show that the effective heating depth (i.e. where the temperature of $(T_{max}-T_{min})/2 = 4^oC$) reached around 40 mm, and the width of the effective heating reached over 60 mm in the x-z plane. Figs. 9 (b) and 10(b) show the temperature elevation in the cylindrical phantom modeling material. The result of simulation is also shown in Fig. 9 (b) by thin lines. The experimental results agree well with the simulated ones. The results show that the effective heating depth reached almost 50 mm, and the width of the effective heating reached to 60 mm in the x-z plane.

IV. CONCLUSIONS

A small, light and flexible microstrip patch applicators were presented and tested. Type I applicator which is applied EM-field coupling method can fit on the uneven surface human body and can avoid the overheat of the surface which is directly contacted to the applicator by the cooling water flowed inside the applicator. The applicator, whose total size of 120 mm x 120 mm and thickness of 4.0 mm, operates at 430 MHz. Type II applicator which is microstrip array, each element is compact enough to fit to the uneven surface configuration of the human body. The surface cooling function provides another important advantage with respect to this applicator. The measurement of the electric field distribution from the applicator and the heating experiment shows that the effective heating width of around 60 mm and the maximum effective heating depth of 50 mm could be realized. The measurements of the electric field distribution from the applicator and the heating experiments at 430 MHz show that the applicator can be used for the human tissue heating such as hyperthermia application.

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