Heating Performance of Loop Antenna for Microwave Thermal Therapy by Combination of HIFU Treatment System

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1. Introduction

In recent years, tumour treatment systems which employ high-intensity focused ultrasound (HIFU) technology have been studied [1], [2]. One of those systems has transducers in the water tank installed in the center of the bed. Then it radiates ultrasound focusing on the cancer cells and heats them. This system can generate precise heated region, but has difficulty in generating large one. On the other hand, external heating system using microwave techniques can make large heated region around the surface of skin. Therefore we propose a new treatment system combining two methods mentioned above. Figure 1 shows the combined system. It can treat wide superficial tumor such as skin tumour. The HIFU heats marginal part of tumour and electromagnetic (EM) wave heats large part near surface at the same time. Even if two treatment systems are not simultaneously used, one device having two treatment systems will be beneficial in cost and place to set up devices on.

In order to realize this system, we have been developing microwave antenna which can be used with transducers in the water tank. The antenna is required to work in the water and not to interfere the HIFU treatment. Therefore we adopt circular loop antenna, which is intended to be set over the transducers so that ultrasound can travel through the hole of the antenna.

In this study, specific absorption rate (SAR) and temperature distributions of muscle due to circular loop antenna with model based on a real therapeutic situation except transducer were numerically calculated.

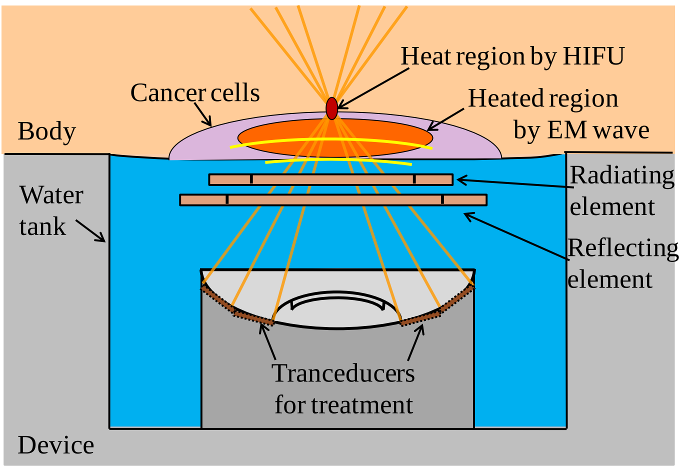

Figure 1: The combined system.

2. Procedure for Calculations

In the numerical calculation, the electric field is calculated at both muscle and water by using the finite-difference time-domain (FDTD) method. Then the SAR distributions inside the muscle are calculated from following equation.

$$\mathrm{SAR} = \frac{\sigma}{\rho} E^2 \quad [\mathrm{W/kg}] \qquad (1)$$

where σ is the conductivity of the tissue [S/m], ρ is the density of the tissue [kg/m^3], E is the electric-field strength [V/m]. The SAR takes a proportional value to the square of the electric field and is equivalent to the heating source generated by the electric field in the tissue. Finally, in order to calculate temperature distributions, following bioheat transfer equation is solved by using the FDM (finite-difference method) [3].

$$\rho c \frac{\partial T}{\partial t} = \kappa \nabla^2 T - \rho \rho_b c_b F (T - T_b) + \rho \mathrm{SAR} \qquad (2)$$

where c is the specific heat [J/kg·K], T is the temperature [°C], κ is the thermal conductivity [W/m·K], ρ_b is the density of blood [kg/m^3], c_b is the specific heat of blood [J/kg·K], F is the blood flow rate [m^3/kg·s], and T_b is the temperature of the blood [°C]. Table 1 shows parameters for the calculations [4]. The temperature distributions are calculated at muscle, and the bottom of the muscle where the muscle meets the water is kept at 25 °C so that the surface of the muscle can be cooled by the water.

Table 1: Parameters for calculation

	Muscle	Water
ε_r	56.9	77.4
σ [S/m]	0.8	0.03
ρ [kg/m^3]	1020	1000
c [J/kg·K]	3500	
κ [W/m·K]	0.6	
F [m^3/kg·s]	8.15×10^{-7}	

	Blood
ρ_b [kg/m^3]	1060
c_b [J/kg·K]	3960
T_b [°C]	37

3. Calculation model

Figure 2 shows calculation model. A loop antenna operating at 430 MHz, which is designated the industrial, scientific and medical (ISM) band in some country, is set in water, and muscle is set above them. Distance between muscle and antenna is 30 mm, and that between antenna and bottom is 100 mm. Top boundary matched with muscle is 8-layer PML. Side and bottom boundary is set up with PEC. A reflecting element is placed beneath the antenna so that the antenna can radiate the EM wave efficiently toward the muscle.

Figure 3 shows the antenna configurations. Both are circular, and covered by dielectrics to separate the antenna from the water. Respective external radiuses are 50 and 60 mm. The reflecting elements were kept away 12 mm from the antenna. The net input power is assumed to be 25 W, the muscle initial temperature is 37 °C, the water temperature is kept at 25 °C, and the heating time is 90 minutes.

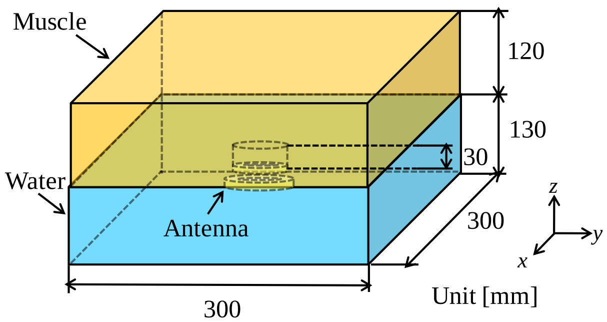

Figure2: Calculation model.

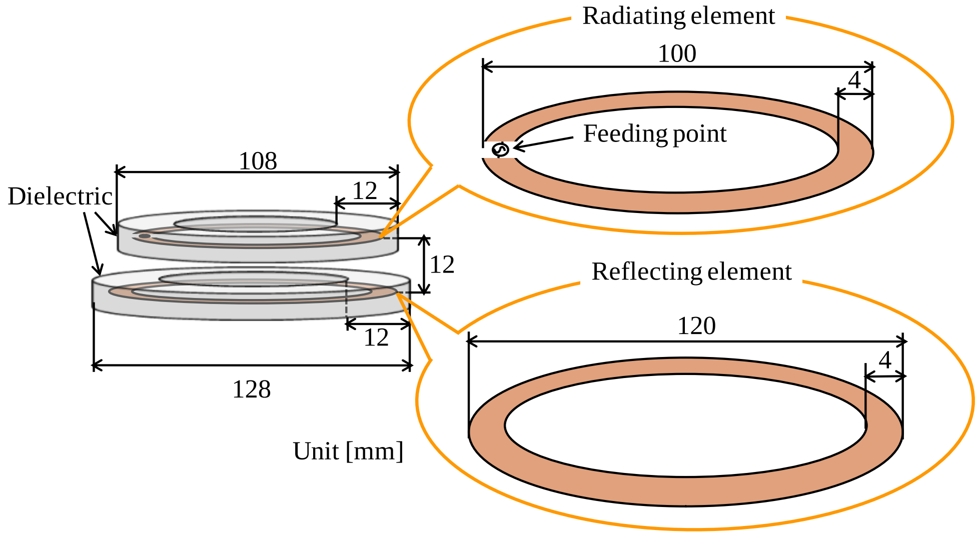

Figure 3: Antenna configuration.

4. Calculated results

Figure4 shows the SAR distributions of muscle on the *y*-*z* plane which divide muscle into two equal parts and the *x*-*y* plane of muscle surface close to the antenna. The circle drawn by white broken line indicates the location of antenna just beneath this plane.

Figure 5 shows the temperature distributions on the *y*-*z* plane which is the same position as the SAR distributions and the *x*-*y* plane which is 16 mm from surface close to the antenna (white broken line on the *y*-*z* plane indicates the position). Black broken line means 42 °C border line, which is effective temperature in hyperthermia. As the figure shows, the heated region of which temperature rises above 42 °C was confirmed at 14 mm inside from bottom surface of muscle.

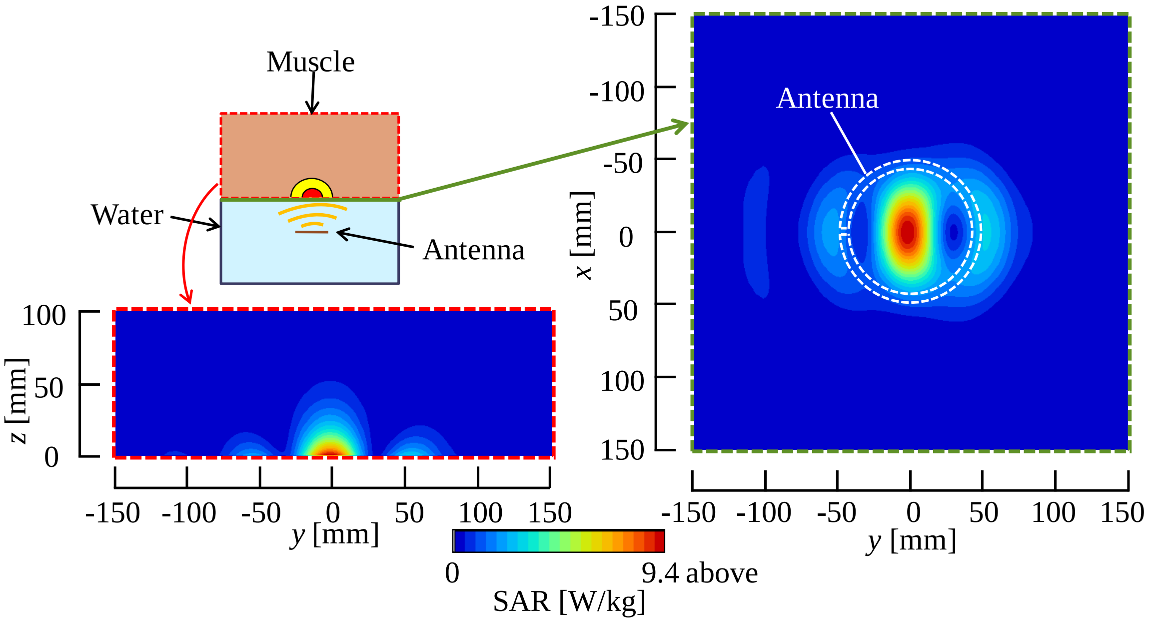

Figure 4: SAR distributions.

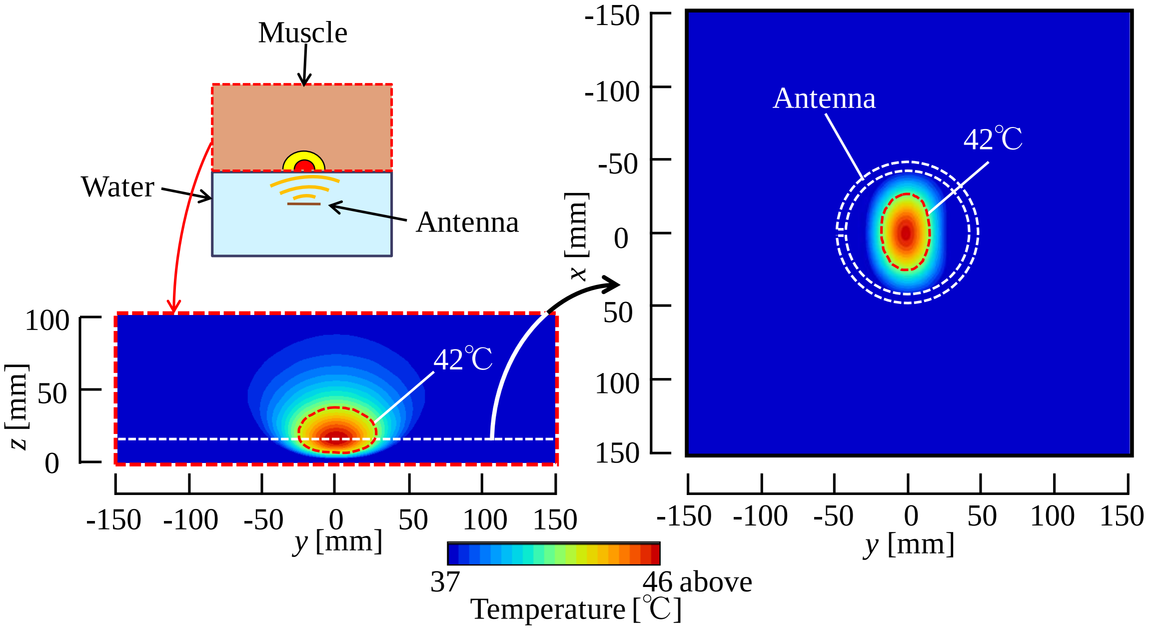

Figure 5: Temperature distributions.

5. Conclusion

In this study, the SAR and temperature distributions due to a loop antenna for the microwave thermal therapy were numerically calculated. According to the results, the circular loop antenna can heat muscle tissue above 42 °C. We have suggested the possibility of realizing a new treatment system combined with HIFU and EM energy.

As a further study, temperature distributions will be measured by experiment.

References

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