

Microwave and RF Heating for Medical Application under Noninvasive Temperature Measurement Using Magnetic Resonance

Yoshio Nikawa · Akira Ishikawa

Abstract

Recent development of magnetic resonance imaging (MRI) equipment enables interventional radiology (IVR) as diagnosis and treatment under MRI usage. In this paper, a new methodology for magnetic resonance (MR) scanner to apply not only diagnostic equipment but for treatment one is discussed. The temperature measuring procedure under MR is to measure phase shift of T_1 , which is the longitudinal relaxation time of proton, for the position inside a sample material with the application of pulsed RF for heating inside the sample as artificial dielectrics. The result shows the possibility to apply MR as temperature measuring equipment and as a heating equipment for applying such as hyperthermia heating modality.

Key words : Magnetic Resonance Imaging, Temperature Measurement, Artificial Dielectrics, RF Heating.

I . Introduction

The usage of MRI without using the ionizing radiation is extremely high safety compared with the diagnostic imaging apparatus such as X-ray computed tomography (CT). Moreover, the early checkup of brain infarct, brain hemorrhage and brain cancer are enabled by the practical use of these diagnostic imaging apparatus. MRI is a device that obtains the tomogram of the living body by using the nuclear magnetic resonance (NMR), and has the advantages which can obtain high resolution image for diagnosis with greatly varying contrast depending on the disease type, which is available to obtain the arbitrary cross sectional image and 3D image, which is extremely useful for diagnosing the spine and the intracranial diseases, because of no artifact with the presence of bone, and which is very safe because of no use of ionizing radiation.

The application of MRI under microwave and RF heating is promising technique for new treatment. Nevertheless, the reported heating problem for MR operation is the effects of RF magnetic field applied to the metallic materials inside human body. This problem is unintended overheat for such the metallic materials [1~3]. Also, for hyperthermia treatment, especially deep heating, it is strongly needed noninvasive temperature measuring techniques as well as deep heating methodology [4]. The newly proposed technique is to apply to measure phase shift of T_1 , for obtaining temperature in the cross-section as well as heating deep inside the body. In

addition, using phase shift method, the temperature elevation and measuring results are compared with the experimental ones and discussion is made for the new MR using technologies. Taking an image by the space widely opened not by past tunnel type MRI but open type MRI has a great potentiality.

Recent development of MRI equipment enables interventional radiology (IVR) as diagnosis and treatment under MRI [5, 6].

In this paper, a new methodology of MR scanner not only for using as diagnostic equipment but for treatment one is discussed. The temperature measuring procedure for MR is to measure phase shift of T_1 , which is the longitudinal relaxation time of proton, for the poison inside a sample material with the application of pulsed RF for heating inside the sample artificial dielectrics.

II . MR Temperature Mapping Theory

Cross-sectional image of human body can be obtained by using an equipment applying nuclear magnetic resonance (NMR). Imaging technologies for MRI have been developed magnetic field focusing, back projection method, and recent ones are mostly applying Fourier transform method. Thus, MRI applying electromagnetic (EM) waves with wavelength over 1 meter, for exciting rotating magnetic field of emitted electromagnetic waves which is excited by nuclear spin, the characteristic of going straight forward for ultra high frequency EM wave as X-ray is not available [7]. For MRI, x directed

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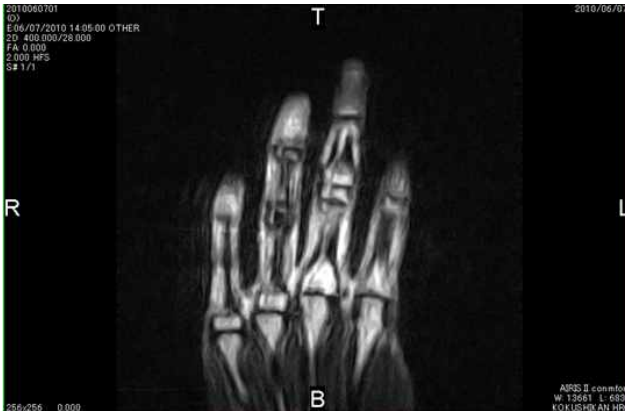


Fig. 1. Coronal image of fingers by T_1 enhanced MRI.

position, superposed magnetic field $B(x, y, z)$ can be obtained using, magnetostatic field B_0 , line shape gradient field $G_x x$ and is indicated as

$$B(x, y, z) = B_0 + G_x x \quad (1)$$

Measurement sample is put in the magnetic field shown in eq. (1), nuclear magnetism frequency $\omega(x, y, z)$ in the measuring position can be shown as eq. (2).

$$\omega(x, y, z) = \gamma(B_0 + G_x x) \quad (2)$$

Loading x-directed line shape gradient field, the proportional change of magnetic nuclear resonance can be observed and 3D identification positioning can be realized. Longitudinal relaxation time T_1 enhanced image using 0.3 Tesla MRI equipment is shown in Fig. 1. Higher T_1 signal corresponds to the area of higher amplitude of T_1 which is show white area. In this paper, temperature measuring procedure shown in eq. (3) is installed in the NMR system, temperature elevated image inside sample material is obtained by measuring phase shift of T_1 for the position of (i, j) .

$$\Delta T(i, j) = \frac{\Delta \theta(i, j)}{2\pi\gamma \cdot B_0 C \cdot TE} \quad (3)$$

Where, $\Delta T(i, j)$ is the difference in temperature, $\Delta \theta(i, j)$ the phase shift, γ (42.57×10^6 Hz/T) is the gyromagnetic ratio, B_0 (0.3T) is the magnetostatic field intensity, C (-0.01 ppm/ $^\circ\text{C}$) is the temperature coefficient, TE is the echo time. The other technique for temperature measurement is to measure enlarging T_1 and reducing signal amplitude depending on the temperature elevation. Nevertheless this technique causes errors by the amplitude of the signals which causes the other factors. For this meaning, the phase measuring procedure shown in eq. (3) will be one of the promising techniques to obtain temperature inside the sample [8].

III. Artificial Dielectrics Theory

Fig. 2 shows the regular arrangement of small spheres of which permittivity and permeability are ϵ_1, μ_1 , respectively in the medium of which permittivity and permeability are ϵ_2 and μ_2 . Fig. 3 shows the regular arrangement of small cylinders in the medium. Relative equivalent complex permittivity and permeability of the artificial material is as followings [9, 11];

$$\epsilon_r^* = \epsilon_r' - j\epsilon_r'' = \epsilon_{2r} + \frac{N\alpha_\epsilon \epsilon_{2r}}{1 - \alpha_\epsilon C} \quad (4)$$

$$\mu_r^* = \mu_{2r}' - j\mu_{2r}'' = \mu_{2r} + \frac{N\alpha_\mu \mu_{2r}}{1 - \alpha_\mu C} \quad (5)$$

where C is mutual coupling constant and $\alpha_{\epsilon\xi}$ and $\alpha_{\mu\xi}$ is shown as

$$\alpha_{\epsilon\xi} = \frac{4\pi}{3} \dot{a} \dot{b} \dot{c} \frac{\epsilon_1 - \epsilon_2}{\epsilon_2 + l_\xi (\epsilon_1 - \epsilon_2)} \quad (6)$$

$$\alpha_{\mu\xi} = \frac{4\pi}{3} \dot{a} \dot{b} \dot{c} \frac{\mu_1 - \mu_2}{\mu_2 + l_\xi (\mu_1 - \mu_2)} \quad (7)$$

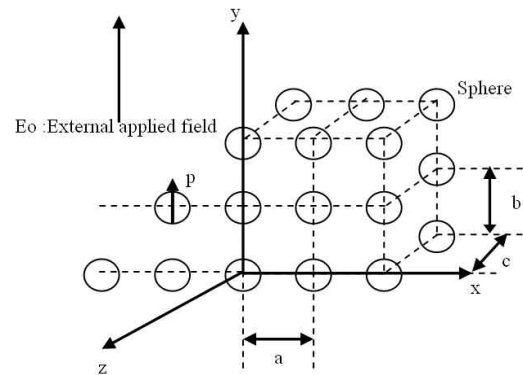


Fig. 2. Regular arrangement of small sphere in artificial dielectric material.

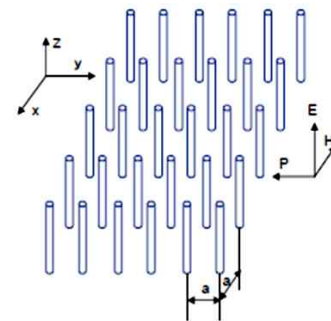


Fig. 3. Regular arrangement of small cylinder in artificial dielectric material.

In eq. (6) and (7), $\hat{a}, \hat{b}, \hat{c}$ and l_{ξ} are the normalized length in x, y, z direction and axis parameter of submicroscopic particulate which is made of artificial dielectric material.

IV. Methodology

Temperature distribution inside sample has been measured nondestructively by MRI Equipment (AIRIS II, Hitachi Medical Corporation). Water containing phantom model which is called wet phantom with the size of $\phi=100\text{ mm} \times h=100\text{ mm}$ using SAP (Super Absorbent Polymer) was applied. Inside the model, an wet phantom model was set the applicator. The applicator is shown in Fig. 4. The developed thin and light applicator, which is shown in Fig. 4 can be operated at 2.45 GHz. The square line thin applicator is directly fed by a coaxial cable. The thickness of copper meander line is $45\ \mu\text{m}$ etched on a thickness of $35\ \mu\text{m}$ polyimide substrate. The reflection coefficient of the applicator is shown in Fig. 5. Heating experiments wet phantom model is shown in Fig. 6 [12].

Additional experiments are performed for heating artificial dielectric. In this case, powdery materials capsule was prepared and inserted in the wet phantom. To measure temperature elevation under MR Scanning, an opti-

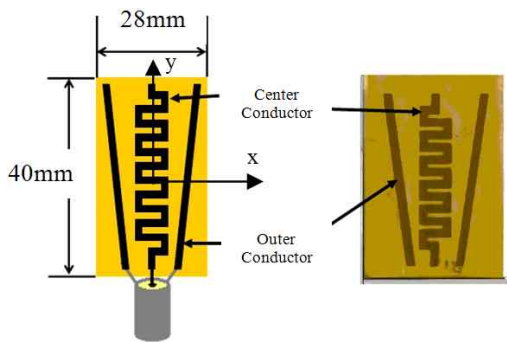


Fig. 4. Applicator model.

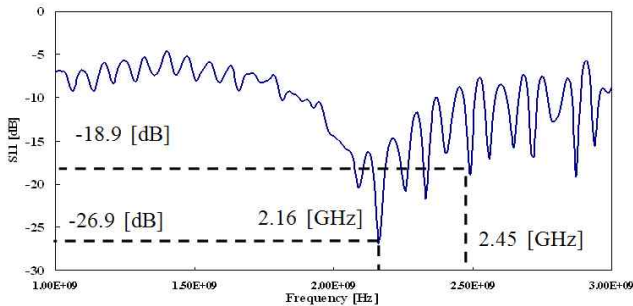


Fig. 5. Reflected power in 1.0~3.0 GHz by network analyzer.

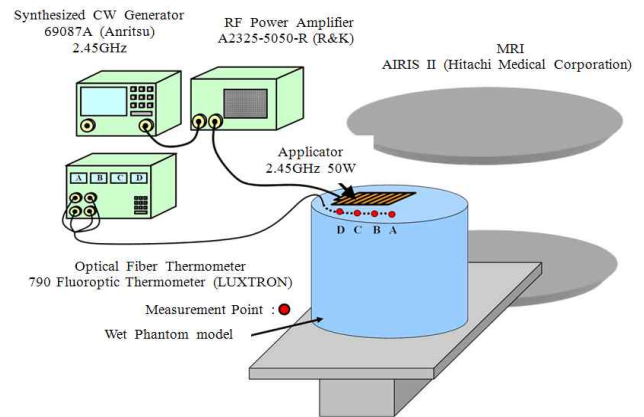


Fig. 6. Heating experiments wet phantom model.

cal fiber thermometer was set up with the fiber sensor inserting the capsule. 3D image of wet phantom model and MR cross sectional view of T_1 image is shown as Figs. 7 and 8. The schematic of the capsule is shown in Fig. 9. Characteristics of powdery materials are shown in Fig. 10 and Table 1.

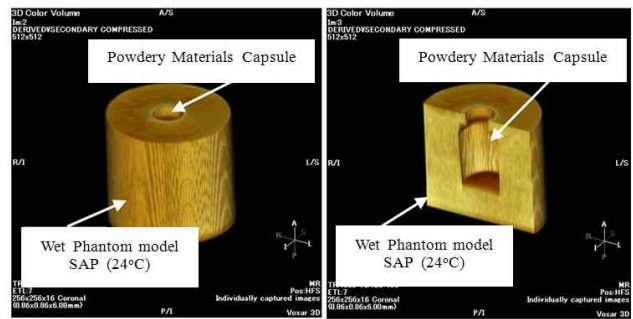


Fig. 7. 3D image of cross sectional wet phantom model ($\phi=100\text{ mm} \times h=100\text{ mm}$).



Fig. 8. MR T1 cross sectional image.

Table 1. Characteristics of powdery materials.

Sample	Grain size	Shape	Material
Aluminum	$<50\ [\mu\text{m}]$	sphere	aluminum
Carbon	$<20\ [\mu\text{m}]$	flake	graphite

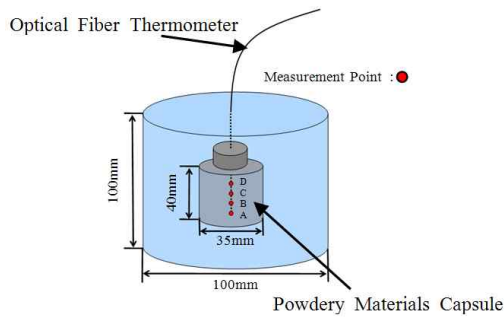


Fig. 9. Powdery materials capsule inserted the wet phantom.

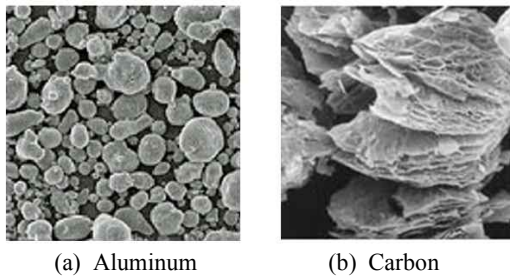


Fig. 10. SEM powdery materials.

V. Results

MR Image is shown in Fig. 11 with T_1 weighted image for the wet phantom. The results of temperature elevation in cross sections of the wet phantom are shown in Fig. 12. Fig. 13 shows simulated relative SAR distribution using TLM method. The heat conduction is relatively low and the temperature distribution almost agrees with the SAR distribution. Fig. 14 shows the results of temperature change in the applicator heating obtained by optical fiber thermometer. Fig. 15 shows the results of temperature change in the applicator heating obtained by MR scanner. From the result, it can be found that the temperature rise of maximum 4 °C can be measured nondestructively.

Results of temperature distribution in the position of aluminum and carbon powdery capsule as artificial die-

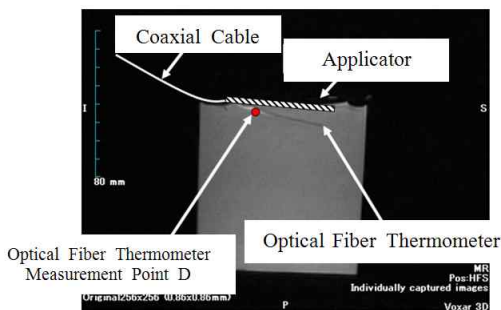


Fig. 11. Image of wet phantom model.

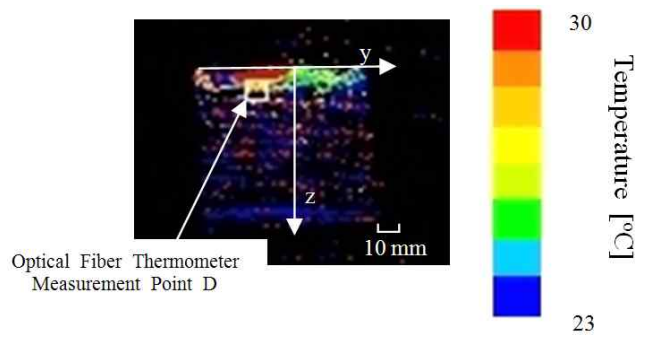


Fig. 12. Cross sectional temperature distribution (yz-plane).

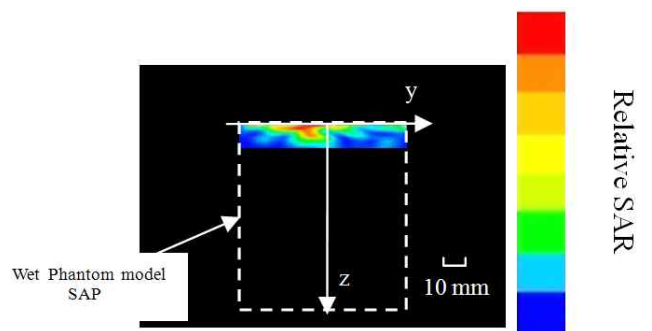


Fig. 13. Cross sectional simulated SAR distribution (yz-plane).

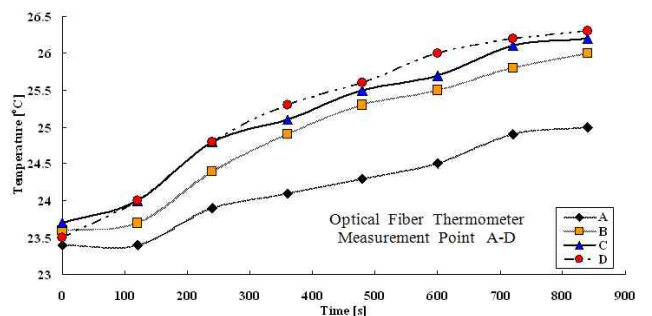


Fig. 14. Results of temperature elevation in applicator (Optical fiber thermometer).

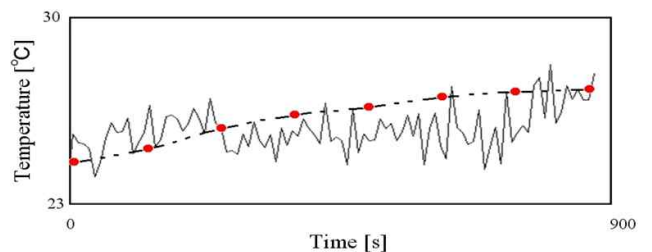


Fig. 15. Results of temperature elevation in applicator.

lectric material is shown in Figs. 16 and 17. Heat generation can be observed while taking an image using MR scanner. The peak power of 5 kW with 500 W in

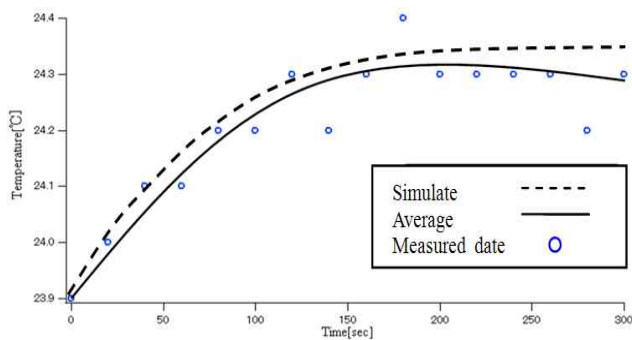


Fig. 16. Results of temperature measurement at aluminum powder capsule (optical fiber thermometer).

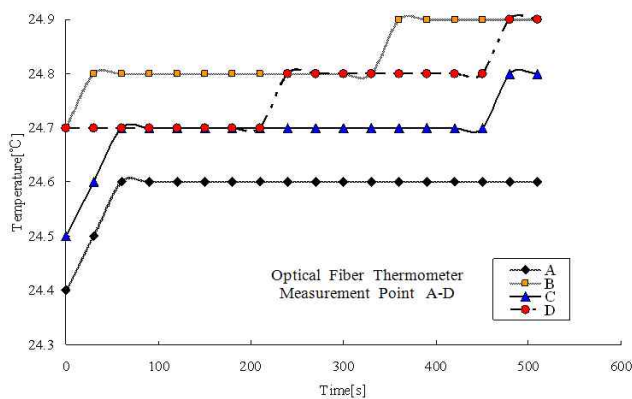


Fig. 17. Results of temperature measurement at carbon powder capsule (optical fiber thermometer).

average at 12.7 MHz is radiated from MR equipment. From the results, the elevated temperature of 0.5 °C was obtained.

VI. Conclusions

Using MR scanner, temperature inside wet phantom has been measured. The measured temperature by MR scanner was compared with that obtained by the optical fiber thermometer and found the reasonable coincident. By measuring phase shift the longitudinal relaxation time of proton obtained from MR, the temperature change inside an object could be obtained nondestructively. Furthermore, it turned out to be possible to make a dielectric heat using the RF field of MR. The measured temperature elevation shows the possibility to apply MR scanner not for the diagnostic equipment to measure temperature but also for the treatment equipment to heat up the temperature inside body to realize such as hyperthermia to heat up the cell temperature. Further study is

to enhance the accuracy of the temperature measurement and develop the technique of measuring temperature rise using MR scanner.

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