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Whole-body Averaged SAR Measurements for Small Phantom by Calorimetric Method

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1. Introduction

Wireless communication equipments are widely used. These equipments are used in the vicinity of human body. Meanwhile, a part of radiated electromagnetic waves are absorbed to human body. Biological effects of microwave exposure are depend on its frequency, and thermal effects are dominant in frequency region higher than 100kHz. In order to evaluate thermal effects, Specific Absorption Rate (SAR) is used. Especially, Whole body averaged SAR (WBA SAR) is used as a measure of thermal effects.

There are many reports about numerical analysis method such as FDTD method [2] to evaluate WBA SAR using numerical models of human, rat, etc. In contrast, measurement is quite difficult. On the other hand, some researchers have reported about WBA SAR measurement method [3]. A calorimetric method[4][5], which is one of measuring methods of WBA SAR for small animal, has been proposed.

A calorimetric method is measuring method of heat energy using a device called as a calorimeter. When this calorimeter is filled with heat transfer medium, such as water, and then warmed measurement object by microwave is put into it, the heat which the object had transited to the exterior. By measuring the amount of movements of this quantity of heat, it is possible to measure the quantity of heat which the object has been given by microwave. However, there are some problems in this method. For example, objects should be warmed enough by microwave, or measurements take long time.

In this paper, in order to develop effective calorimeter for our purpose, three kinds of heat transfer medium are compared. We measured WBA SAR using each heat transfer medium as filling substance in well and considered measurement accuracy and measuring time.

2. Whole-body averaged SAR measurements by a calorimetric method

2.1 The principle of a calorimetric method

Fig.1 shows structure of a calorimeter called as twin-well calorimeter which is used for calorimetric measurements. Twin wells are insulated from each other and exchange of heat does not occur among these. Constant temperature water circulates through the surroundings of twin wells to keep temperature in wells. Furthermore, thermocouples are connected in series to the wells, therefore difference in temperature of wells can be outputted as voltage and can be measured.

When a measurement object is into a well, its heat transits to constant temperature through heat transfer medium in the well. Amount of heat transfer (q [W]) is proportional to a difference in temperature of heat transfer medium (T_h [°C]) and constant temperature water (T_c [°C]), therefore q [W] is

$$q(t) = K(T_h - T_c) \quad (1)$$

Where K is constant of proportionality whose dimension is [W/C] and we defined it as overall heat transfer factor. It represents the ease of conduction of temperature and it depends on the thermal conductivity of heat transfer medium and containers, circulating water flow rate, etc. The total amount of heat transfer is calculated by time integration of q.

Additionally, two different temperature objects is into the twin wells respectively and take the difference of each heat by thermocouples. The difference of these quantities of heat is calculated as Equation 2 as

$$\Delta Q = K\int_0^{\infty} (T_{h1} - T_{h2})dt \quad (2)$$

Where T_{h1}, T_{h2} are temperature of heat transfer medium in each well. WBA SAR is calculated by using ΔQ [J], exposure time t_e [sec] and mass of object m [kg] as follows.

$$SAR_{WBA} = \frac{\Delta Q}{t_e \cdot m} \quad (3)$$

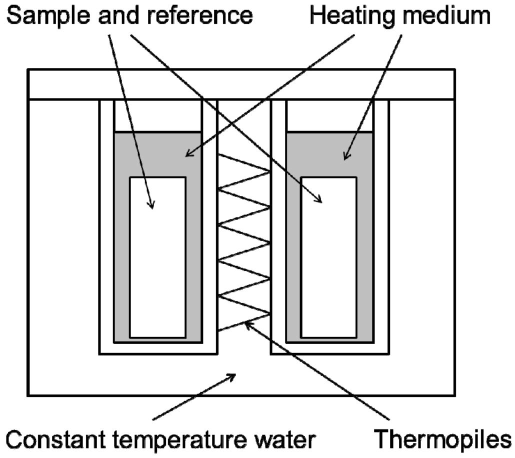

Figure 1: Structure of twin-well calorimeter

3. The effects of heat transfer medium

3.1 Medium property

In order to investigate measurement accuracy and other feature, we used air, water, and silicon oil as heat transfer medium in wells because they have different thermal constants respectively. Their thermal constants are shown in Table 1 [6].

Table 1: Thermal constant of heat transfer medium

Heat transfer medium	density [g/m^3]	specific heat [J/gK]	thermal conductivity [W/mK]
Air	1.16	1.01	0.0241
Water	997	4.18	0.561
Silicon oil	960	1.5	0.15

4. Measurements of Whole-Body Averaged SAR

4.1 Experimental apparatus for exposure

In this study, small phantom is used to evaluate accuracy and so forth experimentally. Microwave was exposed to phantom model [7] to measure WBA SAR using each heat transfer medium. The model is a 60 × 60 × 148mm rectangular parallelepiped. Shown as Fig.2, a dipole antenna is put on the position distant from phantom 10mm and it radiated 2.45-GHz sine waves with 43 W of radiation power. Exposure time is 10 seconds as short time exposure and 50 seconds as long exposure. Measurement was performed 5 times respectively in each heat transfer medium and exposure time, and averaged value was made into measured value.

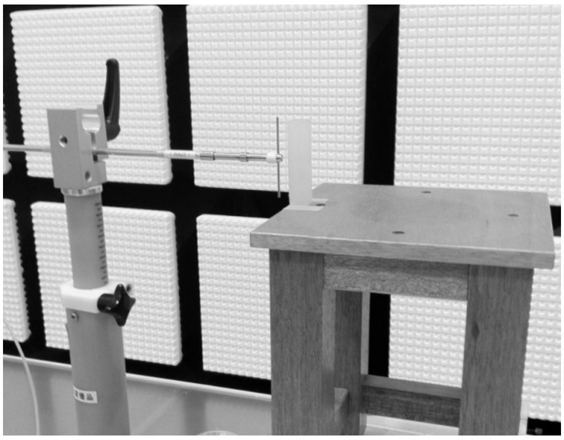

Figure 2: State of exposure experiment

4.2 FDTD simulation

In order to calculate reference value of WBA SAR, it was evaluated in numerically. Simulation was performed using the conditions shown in Table 2 and the analysis model which imitated the real environment shown as Fig.2.

Table 2 : Analysis conditions

Cell size	dx=dy=dz=0.5[mm]
Analysis domain	300×300×300
Incident wave	Sine wave (2.45GHz)
absorbing boundary condition	PML 8 layers
Electric constant	ε=53.1, σ=3.10 [S/m]
Density	1116[kg/m^3]

4.3 Experimental results

WBA SAR are evaluated experimentally and numerically, and the results are shown in Table 3. WBA SAR are normalized by the value per radiation power, and they are indicated as normalized SAR. In the measurement using water, SAR are measured with less than 10 % of error in each case of 10sec and 50sec exposure, and it can be estimated to be comparatively accurate measurement.

Table3: Results of experiment and simulation

(a) 10 sec exposure

Heat transfer medium	Normalized SAR[W/kg]		Error
	measured value	analyzed value	[%]
Air	19.5		14.1
Water	21.0	22.7	7.49
Silicon oil	20.5		9.69

(b) 50 sec exposure

Heat transfer medium	Normalized SAR[W/kg]		Error
	measured value	analyzed value	[%]
Air	18.8		17.2
Water	20.6	22.7	9.25
Silicon oil	19.9		12.3

Next, maximum voltage from thermocouples using each heat transfer medium and measuring time to transit stable temperature are shown in Fig.3 and Fig.4. At 10sec exposure, there is almost no difference of maximum voltage, but at 50sec exposure, highest maximum voltage was measured in the measurement using air.

In the measurement using air, measuring time was shortest in measurement using each medium. This is considered to be because that heat transfer is active since the difference in temperature is high as shown in Fig.3.

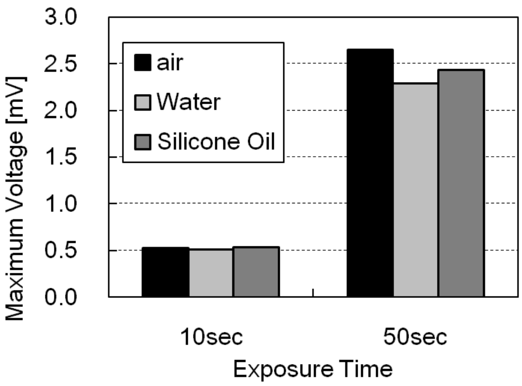

Figure 3: Maximum voltage in each medium and exposure time

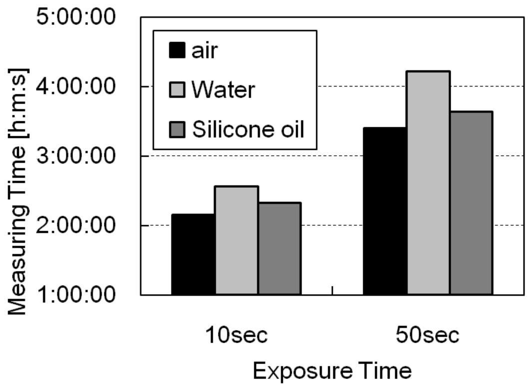

Figure4: Measuring time in each medium and exposure time

5. Conclusion

This paper has investigated on heat transfer medium for whole-body averaged SAR measurements by a calorimetric method. The microwave exposure experiment and measured WBA SAR are indicated. It turned out that measurement accuracy and measuring time change by changing heat transfer medium. Furthermore, when using water as heat transfer medium, error with measured values and simulated values of WBA SAR are less than 10% and this is the best accuracy in used three kinds of heat transfer medium.

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