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# Theoretical and Experimental Investigation of the Relationship among SAR, Tissues and Resonant Frequencies in MRI

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## Introduction:

The major bio-effects associated with the RF radiation during MRI are directly related to the thermal effects of the electromagnetic field. SAR is one of the most important parameters related to thermal effect and acts as a guideline for MRI safety. Generally, there are two methods to measure SAR by experiment: using E-field probe to measure the electrical field strength [1] and using thermometer to measure the temperature change directly [2]. Simulation is another important method to investigate SAR theoretically [3]. If both methods of simulation and experiment can be used it may help us to better understand the SAR relationships between different tissues and different RF frequencies.

## Methods:

The FDTD (finite difference time domain) method [4] was used to find the RF electromagnetic field distribution in samples through time-dependent Maxwell's equations. A region of interest (ROI), 102×102×118 mm was divided into a mesh of 1,227,672 Yee cells, where the basic element of 3D meshes in FDTD method is 1 mm/cell in each dimension. An 8-leg birdcage coil was chosen as RF coil in the simulation, in which the conductivity of copper ($5.95 \times 10^7$ S/m) was only assigned to the coil cells. The sample inside of the coil was chosen as a cylinder with height of 40mm and radius of 18mm.

To verify the simulation results, an experiment was carried at a 1.5T MRI system (Signa, GE Medical System, Milwaukee, USA). Compared with the method of using electric field probe, the temperature measurement is more direct and accurate because temperature change is the final outcome of the RF deposition. The phantoms for experiments were designed and built to simulate dielectric characteristics (permittivity and conductivity) of human tissues (muscle, brain and bone) [5]. A GE standard transmit-receive knee coil was used for phantom experiments. SAR can be calculated by the equation:

$$SAR = C_i \frac{dT}{dt} \quad (1)$$

where $C_i$ , T and t are heat capacity, temperature of tissues and time respectively. The *Ci* is $3.0 \times 10^3$, $2.8 \times 10^3$ and $2.3 \times 10^3$ J/kg.°C for individual muscle, brain and bone.

A vacuum quartz vessel was designed and fabricated as the container for phantoms. Another thermal fiber insulation (Ceramic Fiber) was wrapped on the vessel shown in Fig.1. One of the most RF-power-intensive pulse sequences, Sagittal 3D Fast Spin Echo (FSE) sequence (TE: 85ms, TR: 480ms, Echo Train: 32), was chosen in our experiment. In all the experiments, the image field of view (FOV) was set to 18cm×18cm and the slice thickness was chosen as 5mm. To obtain enough absorbed RF energy, NEX = 8 (the number of averaging time) was chosen.

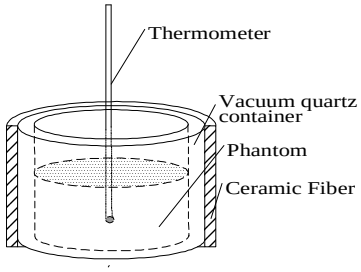


Fig. 1. Installation for experiment, Ceramic Fiber was wrapped on the vacuum quartz vessel

## Results and Discussion:

The SARs of three tissues (muscle, brain, bone) were simulated at frequencies of 21.28MHz (0.5T), 63.85MHz (1.5T) and 128 MHz (3T) respectively. All the final data have been normalized in Table 1. The experiment results at 1.5T were illustrated in Fig 2.

As shown in Table 1, the SAR of muscle is much higher than brain and bone at all three RF frequencies. When the magnetic field strength increases from 0.5T to 3T, the SAR(s) of muscle, brain and bone increase differently and are 7.49 folds, 10.87 folds and 12.92 folds respectively. The SAR of muscle is 1.72 folds higher than brain and 8.74 folds higher than bone at 63.85MHz (1.5T). Considering the difference of heat capacity in equation (1), the slope of muscle in Fig 2 should be slightly higher than brain (1.61-fold) and much higher than bone (6.7-fold). The temperature slope of muscle is 1.7-fold over that of brain in the experiment, which is only 5% difference compared with the theoretical result. Because of the resolution limitation of the thermometer used (the scale is 0.1°C), the temperature change of the phantom to simulate bone is too low (less than 0.1 °C theoretically) to be measured. The SAR experiment results based on the phantom may be different from human body because human can automatically adjust his own temperature by his or her metabolism system. The SAR simulation and experiment based on human subjects would be much more complicated and were not discussed here. However, these quantitative SAR experiments on phantoms could be a reference for us to better understand SAR characteristics of different tissues at different frequencies, and can also be extended to other field strength.

| | 21.28MHz | 63.85MHz | 127.7MHz |
|---|---|---|---|
| Muscle | 1.3434 | 5.1288 | 10.059 |
| Brain | 0.60140 | 2.9772 | 6.5352 |
| Bone | 0.10427 | 0.58705 | 1.3474 |

Table 1. Average SAR (W/kg) of three tissues at three RF frequencies by calculation.

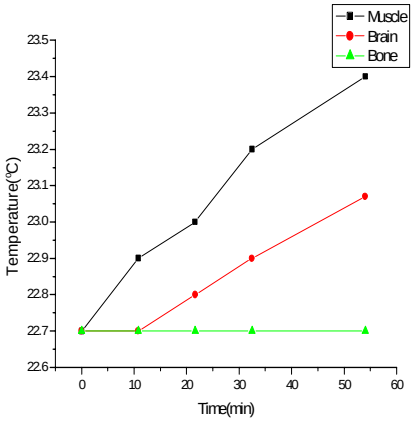


Fig. 2.The temperature increase vs. time for muscle, brain, and bone phantoms by 1.5T experiment

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