A Rhesus Monkey Model and WBA SAR

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Abstract

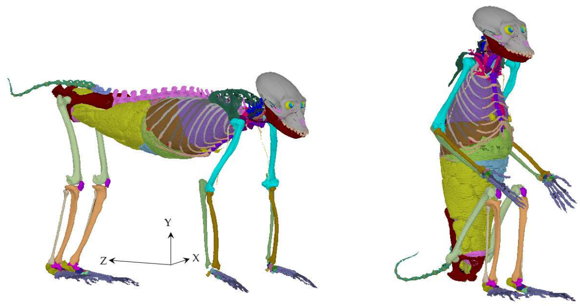
The surface model of a rhesus monkey in the Visible Monkey project of Korea had been implemented. However, the posture of the monkey model is very different from that of a live monkey because the original images were obtained in a supine position. Therefore, the monkey models in walking and sitting postures, close to those of a live monkey were realized. This paper presents the SAR results calculated for the monkey model in a walking posture exposed to electromagnetic fields in a reverberation chamber.

1. Introduction

For established adverse effects in IEEE Std. C95.1[1] and ICNIRP Guidelines[2], the threshold for whole-body average (WBA) SAR of 4 W/kg is based on that for disruption of ongoing behavior in laboratory animals including nonhuman primates. In particular, the primates are very useful animal models because they are more than 95% identical to the human gene. From IEEE Std. C95.1 (2019), it can be seen that behavioral performance experiments for nonhuman primates were mainly conducted before 1990s and they were exposed to electromagnetic fields (EMF) with a specific polarization below 6 GHz. The 4 W/kg averaged over the entire body mass is regarded as the exposure level corresponding to the adverse health effect threshold for an increase in body core temperature of 1 °C. A reduction factor or a safety factor of 10 and 50 is applied to this threshold for occupational exposure and general public, respectively. The ICNIRP guidelines (2020) extended the WBA SAR limits for frequencies up to 300 GHz. Scientific knowledge of the behavioral performance for primates exposed to randomly-polarized EMF such as in a reverberation chamber (RC) or EMF in the frequency range higher than 6 GHz seems necessary.

For dosimetry prior to behavioral performance study, the authors try to employ a virtual rhesus monkey model in a walking posture under the assumption of whole-body exposure in an RC.

2. Model and Methods



(a) walking (b) sitting

Figure 1. Surface models of a rhesus monkey (skin, fat and muscle were excluded in the figure.)

Chung et al. previously produced the sectioned images of a rhesus monkey (female, head-to-feet length 758 mm, weight 4.3 kg, age at sacrifice 93 months, color depth 48-bit color, intervals 0.05 mm (head) and 0.5 mm (remainder of the body), pixel size 0.024 mm) in the Visible Monkey project [3] and then the images were segmented and the surface models of 167 structures were implemented [4]. The model data was publicly disclosed on the data portal (https://www.data.go.kr/en/data/15074162/fileData.do) of Ministry of the Interior and Safety of Korea. Since the posture affects the whole-body resonance frequency and the SAR distribution of the organs, two postures close to those of a live monkey were realized; walking (quadrupedal) and sitting postures [5].

Previous studies for nonhuman primates had been conducted with radiation from a dipole or a horn antenna in an anechoic chamber [6]-[8]. The animals under test were fixed using restraint devices in the form of a chair or a box. The SAR was calculated or measured in a saline-filled phantom.

In this paper, total 24 plane waves with different incident directions and polarizations were used to simulate spatially uniform plane waves in an RC. The number of incident directions is twelve and the directions accord with those to the vertices from the origin of an icosahedron. The number of polarizations for each vertex is two. To find out the whole-body resonant frequency range, the whole-body simulations were conducted with a voxel size of 2 × 2 × 2 mm^3 in the range between 50 MHz and 2.45 GHz using the finite-difference time-domain (FDTD) technique.

3. Results

First, the time-averaged SAR was calculated at each voxel for each plane wave incidence at each frequency and then the SAR values of each voxel for 24 plane waves at each frequency were averaged. The power dissipated in each voxel shall be calculated by multiplying the voxel SAR by the voxel mass density. The power dissipated in the whole body shall be calculated by summing up the power in all voxels of the whole body. The WBA SAR was calculated as the ratio of the power dissipated in all voxels consisting of tissues divided by the total mass of the whole body.

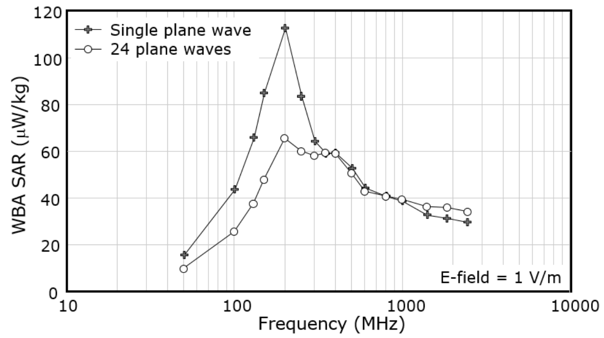
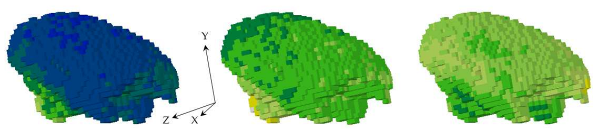


Figure 2. WBA SAR of the monkey model in walking posture.

Figure 2 shows WBA-SAR of the monkey model in the walking posture in the frequency range of 50 MHz–2.45 GHz. The single plane wave is incident from the direction of θ=63.4° and ϕ=288° with the vertical polarization. While the single wave incidence shows a clear and sharp resonance, the averaged result for the 24-wave incidences provides a relatively weak and dull resonance over a frequency range of 200–400 MHz. The WBA-SAR for the single plane wave was obtained by averaging SARs of all voxels.

Because specific animal models showed higher or lower WBA-SARs than 4 and 5 W/kg at the behavioral disruption threshold, de Lorge suggested that WBA SAR may not be the best indicant of behavioral effects across frequencies and other aspects such as local SAR might be preferable [7].

Therefore, not only the WBA SAR and changes in core temperature should be evaluated in the study of the behavioral effects of EMF, but also the local SAR of specific regions in the brain related to body temperature regulation needs be observed. Figure 3 shows the SAR distribution of the monkey brain. The whole-brain average SAR is 5.4, 30.1, and 53.1 μW/kg at 100, 350, and 2450 MHz, respectively. They show a very different change from the WBA-SAR of Figure 2 with frequency.



100 MHz 350 MHz 2.45 GHz

Figure 3. Brain SAR.

4. Conclusions

In this paper, SAR of a rhesus monkey model in a walking posture in an RC was calculated. Other postures should be considered because an RC allows free movement of the animal inside the chamber. In order to properly estimate the time-average SAR of a specific body organ in this exposure situation, after individual calculations for representative postures are made, time weights should be given to the results for each posture in a future study.

6. Acknowledgements

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