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Statistical analysis of RF exposures depending on body surface area

Yuwei Jiang[(1)], Tongning Wu* [(1)]
(1) China Academy of Information and Communications Technology, Beijing, China

Abstract

With the wide application of 5G networks, the population's exposure levels to RF-EMFs has also changed. The present work aimed to study the evaluation model of Chinese human body surface area (BSA) and electromagnetic dosimetry in the second generation to the fifth-generation wireless communication frequency band. Whole-body-averaged specific absorption rate (WBSAR) from 900 MHz to 3.5 GHz was calculated with the finite-difference time-domain method for front RF exposure configurations. This study highlights the importance of body surface area (BSA) in WBSAR characterization. The regression model was improved with human body models of different sizes, and the estimation error of WBSAR was about 5%. This study is suitable for establishing the statistical distribution of the WBSAR for Chinese population characterized by its morphology.

1. Introduction

Over the past 20 years, great efforts have been made to digitally assess exposure to radiofrequency electromagnetic fields. To protect people from EMF overexposure, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronic Engineers (IEEE) have defined limits[1]. However, the rapid development of 5G wireless communications induces public concern about possible health effects.

Nowadays, computing resources have increased, and large and complex problems can be analyzed in few hours. Numerical dosimetry is intensively used to analyze the SAR distribution in tissues and design exposure setup. Numerical methods, such as the well-known finite difference in time domain (FDTD), enable us to achieve a very good accuracy in the SAR computation[2]. Based on this, several studies have used 3D human body models to analyze the relationship between the WBSAR and the electromagnetic field[3]. However, these studies did not thoroughly explore the relationship between WBSAR and external morphology of human body. Hirata et al. [4]found that there is a linear relationship between WBSAR and BSA/ weight ratio. However, there is no statistical data about this ratio in the literature.

In this paper, we determine the influence trend of body surface area on WBSAR of phantom in standing posture and exposed to vertical polarization and plane wave reaching in front of them. The objective is to build a model that describes the WBSAR as a function of the morphology. The obtained result will allow us to analyze and extrapolate the exposure to large and different populations. The method is based on the construction of regression models that makes it possible to estimate the statistical distribution of the WBSAR for Chinese people.

2. Materials and Methods

2.1Data collection

First of all, according to the average height and weight data of Chinese reference population[5]（Table 1）, we used Latin hypercube sampling method to generate the human data needed for the experiment.

Table 1 Mean and standard deviation of height and weight of Chinese male adult

	Mean value	standard deviation
height(cm)	165	11.14
Weight(kg)	59.59	15.54

In this case, the formula of Dubois and Dubois (1916) [6]is used. BSA is defined as a function of the height and the weight, as given in equations (1)

$$\text{BSA}\ (\text{m}^2) = 0.007184\left(\text{weight}_{\text{kg}}^{0.425}\ \text{height}_{\text{cm}}^{0.725}\right) \quad (1)$$

2.2Deformable human phantoms

The deformable human phantoms were recently generated for the human torso and head while representing the physical parameters in a given Chinese population. The phantoms were created based on a training set of trunk computed tomography (CT) images from normal Chinese subjects[7]. Through the deep learning method, statistical morphological models of different tissues and organs are established to obtain the proportion relationship in the process of physical characteristics change. This allows the organs and tissues in the human body to change with the shape parameters, that is, the digital human model with correct anatomy can be generated by using the basic human parameters control.

Some representative male models are shown in Figure 1.

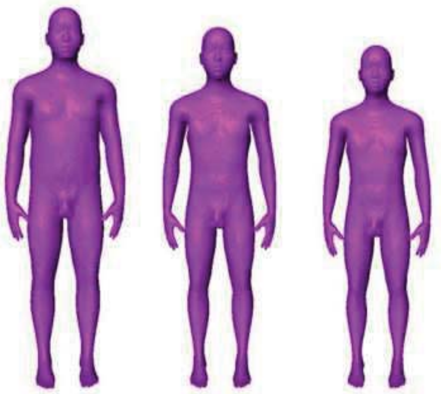

Figure 1. Diagram of partially representative male models with different body parameters

2.3Deterministic dosimetry

Stochastic framework is developed to quantify the uncertainty of EMF exposure, upon a series of WBSAR derived by deterministic simulations using selected input parameters following their probability density functions. The frequency-dependent WBSAR was calculated by finite-difference time-domain (FDTD[8]) in the configuration that the E-field direction was parallel to the length of the anatomical model and the wave propagated toward the frontal side of the model. FDTD spatial lattice was $2*2*2mm^3$ for 0.9 and 1.8 GHz, while 1.5*1.5*1.5 mm^3 for 2.6 and 3.5 GHz. WBSAR were normalized to the plane wave incident power density as 1 W $/m^{-2}$.

3. Results

Here, we obtain numerical results corresponding to 900MHz, 1.8GHz, 2.6GHz and 3.5GHz frequencies according to the above method. And use the following polynomial to build the surrogate model:

$y = \varepsilon + \alpha * x + \beta * x^2$ (2)

where y represents the WBSAR, ε, α and β are the unknown parameters of the models, x represents the BSA.

The parameters ε, α and β were estimated using the well-known least square method. The estimates of these parameters give good WBSAR estimates (about 5% error) for each frequency regression. Table 2 gives the values of ε, α and β estimated by the least-squares method.

Table 2. Estimation of the parameters $\boldsymbol{\varepsilon}$, α and β

	0.9GHz	1.8GHz	2.6GHz	3.5GHz
ε	0.0247	0.0158	0.0112	0.0097
α	-0.0158	-0.0085	-0.0042	-0.0037
β	0.0031	0.0014	0.0004	0.0003

Figure 2-5 shows regression curves obtained for WBSAR using external factor BSA at different frequencies.

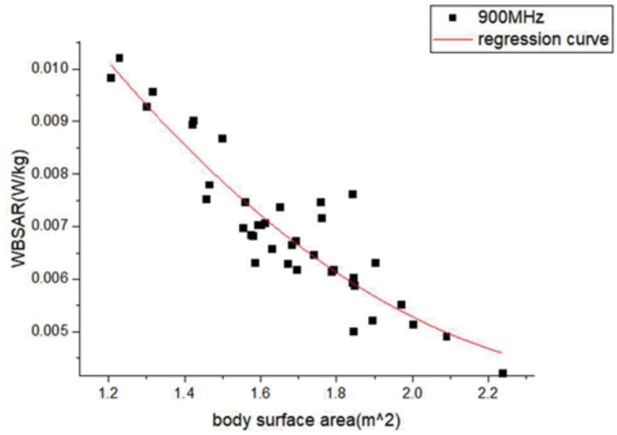

Figure 2. The regression curve obtained for WBSAR at 900MHz

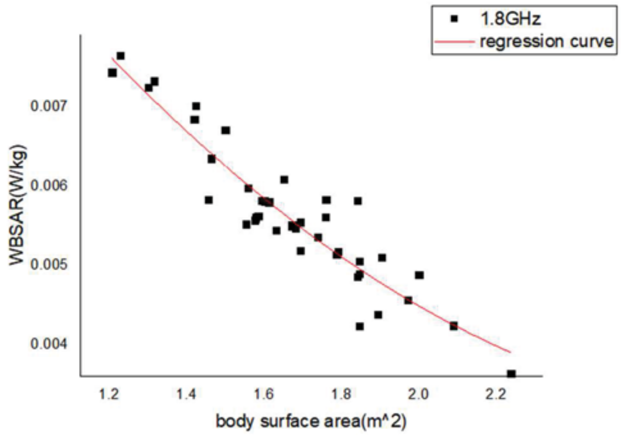

Figure 3. The regression curve obtained for WBSAR at 1.8GHz

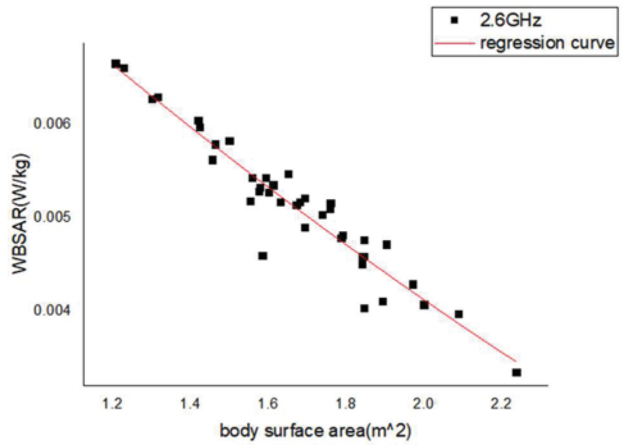

Figure 4. The regression curve obtained for WBSAR at 2.6GHz

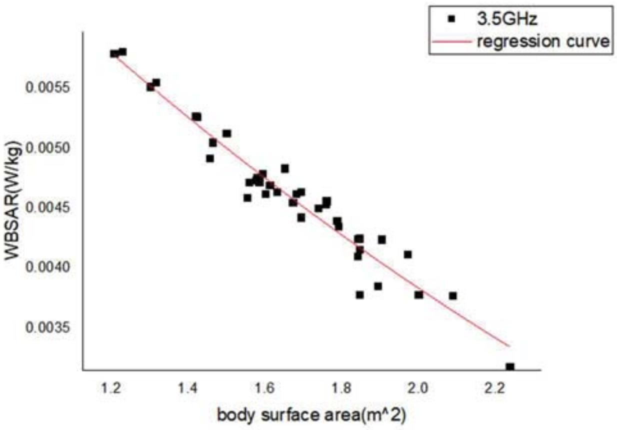

Figure 5. The regression curve obtained for WBSAR at 3.5GHz

Figure 2-5 shows that for the male model, the frequency levels of 900MHz and 3.5GHz reduced WBSAR by 32% on average. The experimental results show that the body surface area is closely related to WBSAR under the same electromagnetic incident condition. Larger body surface area at the same frequency may result in lower electromagnetic exposure. With the increase of frequency, the negative correlation gradually decreases.

The main differences of WBSAR in these frequency regions can be attributed to the skin depth of electromagnetic waves and the correlation between body surface area and body weight. In other words, electromagnetic waves reach the inside of the human body in the resonance frequency region and are absorbed around the body surface. In addition, larger body surface area may lead to higher body weight.

4.Conclusion

In this study, the regression model of SAR and surface area in human body under electromagnetic radiation is given. Using deformable phantoms to build male models needed for the experiment. The height and weight of model are generated by the average data of Chinese reference people, which can be regarded as close to the true value of Chinese adults, which is of great significance in terms of population representation. For WBSAR exposed to plane waves from 900 MHz to 3.5 GHz, the front incident condition is used for calculation. All the experimental results are significantly lower than the reference level introduced by the ICNIRP guidelines as a basic limit of exposure to the general public.

Although there is an acceptable error in the result, we can confirm the analysis result from the surrogate model, that is, the relationship between body surface area and WBSAR is obviously negatively correlated, and this relationship gradually weakens with the increase of frequency. This result confirms the results of previous studies and discusses the more comprehensive frequency. However, this experiment only tried one incident condition, which may hider further analysis. Future work will focus on introducing different electromagnetic environments. This will help to better understand the interaction between electromagnetic field and human external morphological parameters.

5. Acknowledgements

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