FDTD Derivation of Effective Resistance for Grounded Humans

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Abstract —Our group proposed an estimation method of whole-body averaged specific absorption rate for grounded humans at resonance frequency in terms of ankle current and effective resistance. This method is based on an analogy to a quarter-wavelength monopole antenna. However, the effective resistance for the realistic model has not been investigated sufficiently. In the present study, we calculate effective resistance for grounded humans. The main reason for the variability in the effective resistance was clarified as the body shape and model anatomy.

I. INTRODUCTION

There has been increasing public concern about the adverse health effects of human body exposure to electromagnetic waves. According to the international guidelines [1], whole-body average specific absorption rate(WBSAR) is used as a metric of basic restriction for radiofrequency whole-body exposure.

It is well known that WBSAR largely depends on the frequency of the incident wave despite the same incident power density. It is reported that WBSAR at resonance frequency for human models in free space close to basic restriction, especially in models of children exceed. Thus, there has been increasing concern about children (e.g., [2]). WBSAR for a grounded human is larger than that of ungrounded human.

It is difficult to conduct SAR measurement in practical environment. Thus, some human-body equivalent antenna which using liquid [3] have been developed to estimate the ankle current for grounded humans. In previous study, our group estimated WBSAR for grounded humans at resonance frequency from ankle current and effective resistance, based on an analogy to a quarter-wavelength monopole antenna[4]. However, the effective resistance for the realistic model has not been investigated sufficiently. The purpose of the present study is to investigate the resistance for grounded humans.

II. MODEL AND METHODS

A. Models

MRI-based whole-body voxel models for different ages, genders, and races are considered; Japanese adult male (TARO) and female (HANAKO), together with child models of three, five, and seven years of old [5]. A pregnant woman based on HANAKO is also considered [6]. A standardized European and American male models are considered, together with those developed via international project; Virtual Family (Duke, Ella, Billie, Thelonious) [7]. These models have the resolution of a few millimeter and are segmented into 51-70 anatomical regions.

B. Computational Methods and Conditions

The finite-different time-domain (FDTD) method was used to calculate the electromagnetic power absorbed in the human models. For geometries in which the wave-object interaction has to be considered in open region, the computational space has to be truncated by absorbing boundaries. We adopt perfectly matched layers (PML) as the absorbing boundaries.

Either of the models is located on the ground plane. The separation between the human model and PML was maintained at 100 mm. As an incident wave, a plane wave with a vertical polarization was considered. The incident power density was 2 W/m^2. The frequency is respective resonance frequency for each model. The electrical constants of tissues are taken from [8].

III. REVIEW OF ANTENNA THEORY

This section reviews briefly some fundamental theory and definition of antennas toward deriving the effective resistance for grounded humans. The basic theory of this is based on the assumption that the human body grounded approximately considered as a quarter-wavelength monopole. Note that similar derivation has been given for a human body in free space.

Lets us summarize some definitions of antennas. For the current distribution on the antenna $I(z)$ and the maximum current I_o[A], the effective height of the antenna L_e[m] is given by the following equation:

$$L_e = \frac{1}{I_o}\int_0^L I(z)dz\,, \tag{1}$$

where L[m] is the physical height of the antenna.

The power received by the antenna is given by the following equation:

$$P = \frac{R^2 + X^2}{R} I_a^2 \tag{2}$$

where R and X are resistance and reactance of the grounded human, and I_a is the current. The physical quantity we can measure is ankle current and thus (2) is used in the following discussion. Note that $(R^2+X^2)/R$ is considered as an equivalent resistance since the reactance X is approximately nonexistent at the resonance frequency.

IV. COMPUTATIONAL RESULTS

The power absorption in the human body grounded would be considered in analogy with a quarter-wavelength monopole. In order to verify this hypothesis, the vertical conduction current in the human body is shown in Fig. 1 for Japanese anatomically based models. As shown in Fig. 1, the current distributions of the Japanese models are

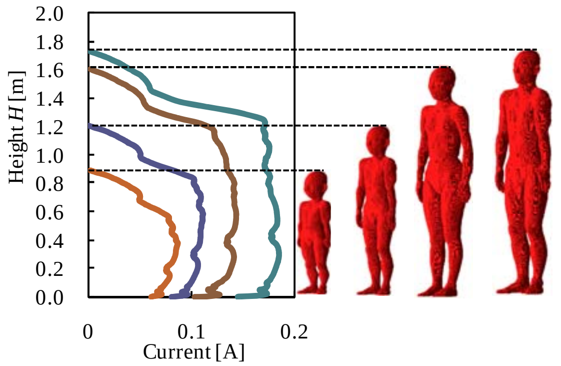

Fig. 1. Vertical conduction current in the Japanese models.

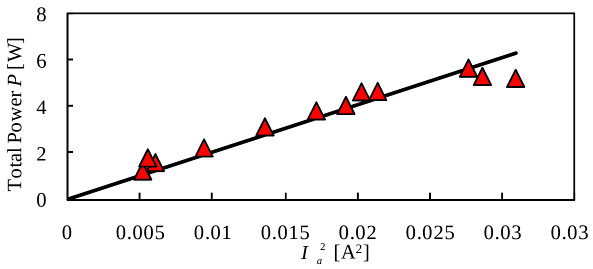

Fig. 2. Relationship between ankle current and power absorption in anatomically-based models at respective resonance frequencies.

similar to that of the quarter-wavelength monopole. Although not shown here, the distributions for the remaining models are also similar to one another. Thus, (2) would be appropriate for deriving the effective resistance for human bodies in the following discussion.

We calculate the effective height with (1) for the current distribution. The strong correlation was obtained between the human height H[m] and effective height H_e[m]. The coefficient of the regression line obtained using the least squares method was 0.783 for the human models. The coefficient of determination was 0.982, suggesting that the human body models behave like antennas similar to one another despite of different shapes.

Then, the relationship between the human body resistance and the ankle current has been investigated for different human models. As seen from Fig. 2, strong correlation was absorbed power P and the ankle current I_a. Their relationship is characterized by the least squares method using the following equation:

$$P = 202.6 I_a^2 \, . \tag{3}$$

The coefficient of determination was 0.900. From the reciprocal of the coefficient in (3), the effective resistance for the grounded human, which includes the radiation resistance and the dielectric loss, was in the range between 170Ω and 324Ω.

One of the reasons for this variability of the effective resistance would be the body shape. In order to obtain some insight on the variability, we show in Fig. 3 the relationship between the body-mass index (BMI) and the effective resistance for the anatomically-based models. As seen from Fig. 3, the effective resistance decreases with the BMI. One

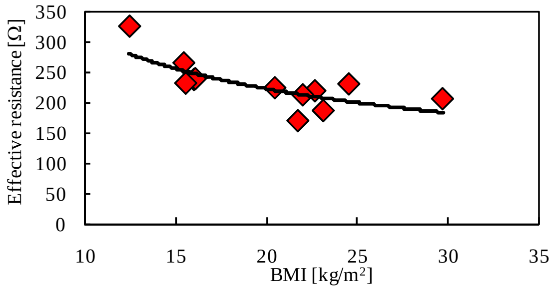

Fig. 3. Relationship between BMI and the effective resistance for anatomically-based models.

intuitive explanation for this tendency is that the cross-sectional area of the human becomes larger with BMI, thereby decreasing the effective resistance for the grounded human, which can be expected from a theory of lumped resistance.

V. DISCUSSION AND SUMMARY

It has been reported that the effective resistance for the human body was 84.6 Ω [9] for a cylindrical model. This value is about a half of that of the anatomically-based models derived herein. One reason for this difference would be attributed to the model inhomogeneity. The current induced in anatomically-based models becomes small around the ankle because of the inclusion of tissues with low conductivity.

VI. REFERENCES

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