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Effects of Dielectric Values of Human Body on Specific Absorption Rate (SAR) Following 800 *MHz* Radio Frequency Exposure to Ingestible Wireless Device*

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***Abstract*—In order to assess the compliance of Ingested Wireless Device (IWD) within safety guidelines, the Specific Absorption Rate (SAR) and near fields of IWD in two realistic human body models whose dielectric values are increased from the original by ±10 and ±20% are studied using the Finite-Difference Time-Domain (FDTD) method. The radiation characteristics of the IWD in the human body models with original and changed dielectric values are compared. Simulations are carried out at 13 scenarios where the IWD is placed at center positions of abdomens in the two models at the operation frequency of 800 *MHz*. Results show that variation of radiation intensity near the surface of abdomen is around 1.6 *dB* within 20% variation of dielectric values at the frequency of 800 *MHz*. Electric fields in the anterior of the human body models are higher than those in the posterior for all scenarios. SAR values increase as the conductivities of human body tissues increase and usually decrease as the increase of relative permittivities of human body tissues increase. The effect of the dielectric values of human body on SAR is orientation, human body and frequency dependent. An increment up to 20% in conductivities and relative permittivities alone or simultaneously always causes a SAR variation less than 20%. As far as the compliance of safety was concerned, the IWD was safe to be used at the input power less than 9.3 *mW* according to IEEE safety standards.**

I. Introduction

THE wide application of wireless communication has attracted much concern about safety of wireless devices in compliance with the international safety standards [1-2]. Recently, the research on the safety of ingestible or implantable wireless devices in human body has been proposed particularly due to the persistence and high local-energy-deposition of antennas that are imbedded in human tissues [3]. The wireless multi-parameter monitoring of gastrointestinal (GI) tract [4-5]. Xu *et al.* analyzed biological effects and radiation efficiency of IWD in a realistic human body model in 21 scenarios at frequencies ranging from 430 *MHz* to 2.4 *GHz*. Results showed that high values of SAR and temperature rise were localized at the area near the location of IWD [6].

Conductivity (Sigma σ) and relative permittivity (Epsilon ε) of human tissues are the determined factors to both optimal radio frequency communication and dosimetry. Recently, the variability of dielectric parameters of human tissues has been found [7-8]. The changes of dielectric properties of body tissues might influence the input return losses of IWDs. Having analyzed the variability of the radiation characteristics of IWD at the operation frequency of 430 *MHz*, we found that the SAR variation was less than 10% within 20% variation of dielectric values [9]. In this paper, we will investigate the influence of dielectric properties of human body tissues on radiation characteristics of IWD placed in small intestine at the operation frequencies of 800 *MHz*. The FDTD method is applied to analyze the electromagnetic interaction with human body. This article is organized as follows. The models and methods applied in this paper are described in Section II. In Section III, variations of SAR, and near fields are illustrated. Finally, discussion and conclusion are offered in Section IV.

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II. MODELS & METHODS

A. Human body models

Two human body models used in this paper are constructed by the NMR group at Hershey Medical Center from visible human body data and the electric characteristic data of human biological tissues are referred to the results proposed by C. Gabriel [10]. Firstly, we use the original dielectric values to analyze the interaction of electromagnetic field with the human body models [10]. We then change all conductivities of human body tissues by ±10%, and ±20%, respectively. Next, we change all relative permittivities of human body tissues by ±10%, and ±20%, respectively. Finally, we simultaneously change all the conductivities and relative permittivities of human body tissues by ±10%, and ±20%, respectively. Thus, we analyze these 39 scenarios with different dielectric values for the female and male body models at the operation frequency of 800 *MHz*.

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B. Source model

In this manuscript, the helical antenna is used in IWD. The helical antenna is constructed using an approximation of rectangular helix in the FDTD grids [11]. Similar to [12], the thin single component helical antenna model is employed because the radius of the helical antenna is approximately 1/4 of the cell size or less. We apply adaptive mesh technique to model the human bodies and the helical antenna at different cell sizes. A sine voltage source with a 50 *Ohm* internal resistance is fed to the base of the helical antenna and all calculations involve 16 full-amplitude cycles of the sine wave at least.

III. RESULTS

Simulations are performed with the IWD sources placed at the center position in GI tract of the human model. It is also noted that the variations of port impedances vary greatly with dielectric parameters of female and male body tissues. The input impedance increases as the conductivity increases. The imaginary part of the input impedance increases with the increase of relative permittivity, while the real part of input impedance decreases with the increase of relative permittivity. When both relative permittivities and conductivities are increased simultaneously, the imaginary part of input impedance will usually increase higher than that of increasing the conductivities or relative permittivities alone. Both the female and male body models confirm these results. The maximums of SAR increase with the increase of conductivities, while the maximums of SAR sometimes decrease with the increase of relative permittivities. The averaged SAR decrease with the increase of conductivities and increase with the increase of relative permittivities both in female and male body models. The un-averaged SARs in the female body model are also higher than those in the male body model, while the averaged SARs in the female body model are smaller. Here, the maximum of 1g-averaged and 10g- averaged SARs are 4.3159 and 0.79 *W/kg*, respectively. Therefore, these simulation results demonstrate that the IWD is safe to be applied in clinic at the input power less than 9.3 and 62 *mW* according to the IEEE and ICNIRP standards for safety levels, respectively.

As illustrated in Fig. 1, we demonstrate one XY slice of the 1g-averaged SAR and 10g-averaged SAR them in contour planes for better readability in this revision. For better demonstration, we enlarged the distribution of SAR values. Figs. 1 (a)-(b) illustrate the difference between the 1g-averaged and 10g-averaged SAR in the scenario when the conductivity increased 20% and the scenario of original dielectric values. The variation of SAR values depends on the characteristics of the antenna and the structure of the media. Here, the ground plane of the helical antenna in IWD is small and its radiation is similar with paper [13]. The center blank place is the position that the IWD located. In the lower position near the center, the SAR increases greatly with the increase of the conductivity. However, in the upper position, the SAR decreases because more radiation energy was absorbed in the tissues near IWD. The maximums of SAR and temperature rise are found at the positions where the IWD located. Then the SAR values attenuate nearly 40 *dB* at a distance of 50 *mm* from the IWD. In the position, which is 50 *mm* away from the IWD, the SAR has nearly no variation. The variations of maximum of un-averaged and averaged SARs are less than 20% when the conductivities and permittivities of human body tissues increase up to 20%. When the conductivities increase, the maximum of averaged and un-averaged SAR values will increase too. When the relative permittivity increases, the maximum of SAR usually decreases. In addition, the variation of 10g-veraged SAR is often less than that of 1g-averaged SAR.

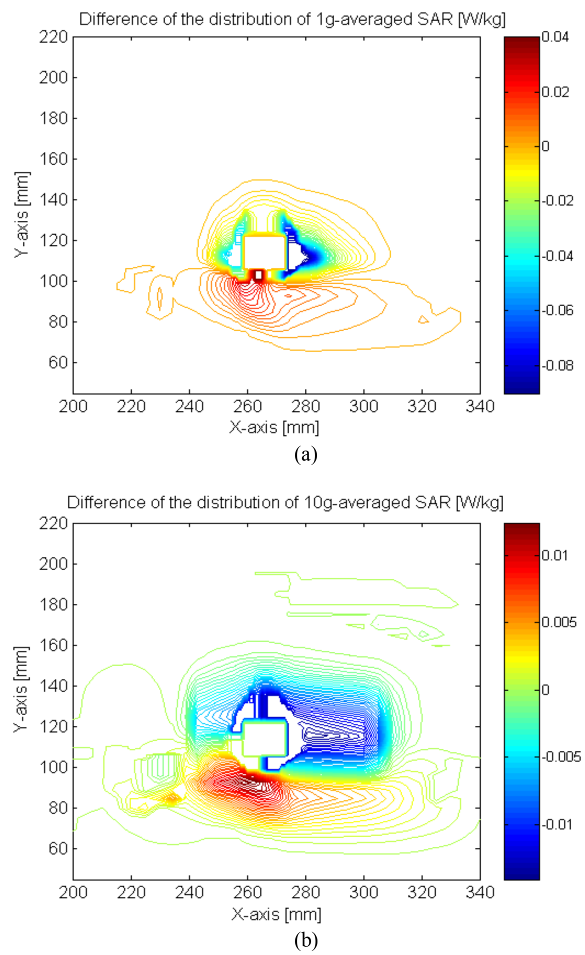
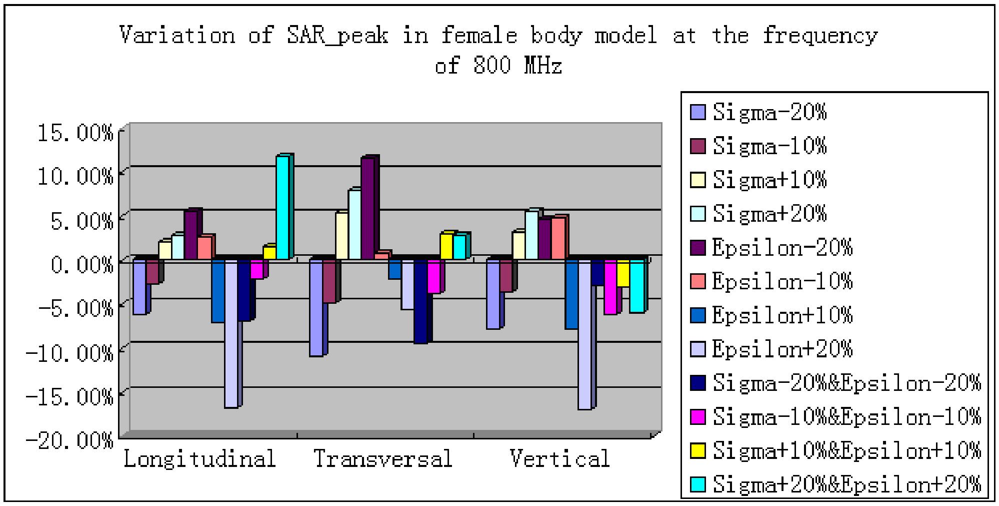
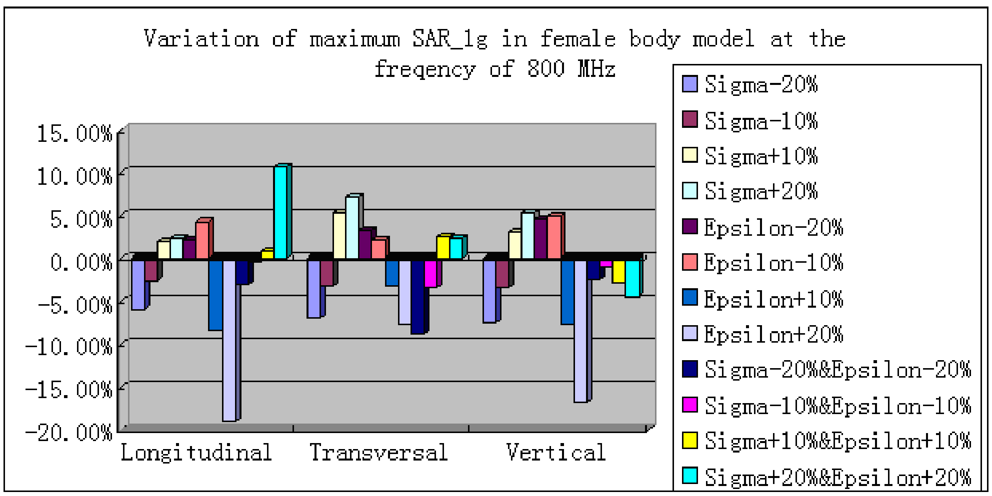


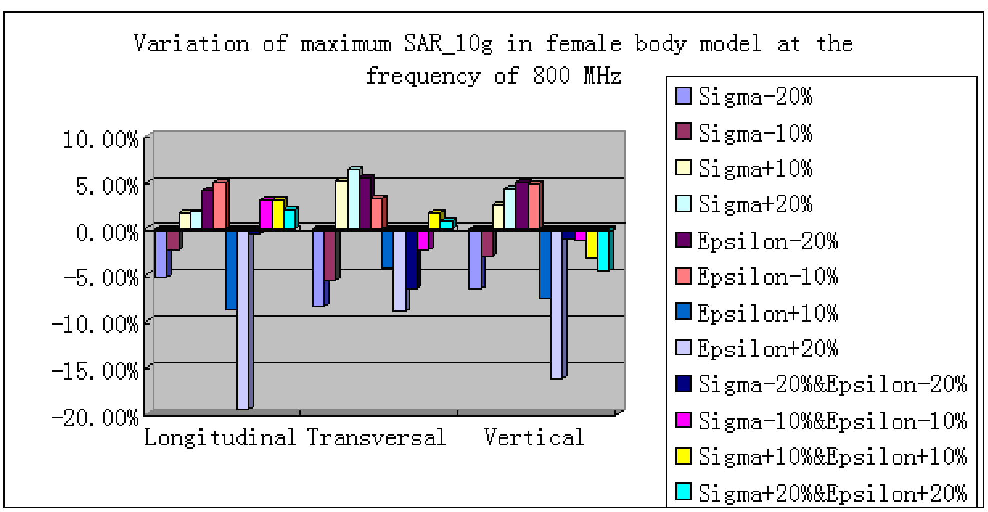
Fig. 1. (a) Difference of the distribution of 1g-averaged SAR between conductivity 20% increased and original at the frequency of 800 *MHz* with X orientation; (b) Difference of the distribution of 10g-averaged SAR between conductivity 20% increased and original at the frequency of 800 *MHz* with X orientation.



(a)



(b)



(c)

Fig. 2. Variations of the SAR peak, maximum of 1g-averaged and 10g-averaged SAR in the female body model with different dielectric properties at the operation frequency of 800 *MHz*. (a) Variation of SAR peak; (b) Variation of maximum of 1g-averaged SAR; (c) Variation of maximum of 10g-averaged SAR.

Fig. 2 demonstrates the variations of the maximums of SARs of female body model at the frequency of 800 *MHz*. The variations of maximum of un-averaged and averaged SARs are less than 20% when the conductivities and permittivities of human body tissues increase up to 20%. When the conductivities increase, the maximum of averaged and un-averaged SAR values will increase too. When the relative permittivity increases, the maximum of SAR usually decreases. In addition, the relative permittivity influences SAR much more than the conductivity. The SAR variation of male body model is smaller than that of female body model.

The electric fields outside the female body models and near the abdomen of human body models predicted by FDTD. The intensity of electric field had 1.6 *dB* variations when dielectric parameters change within 20% at the frequency of 800 *MHz*. The maximum of the intensity of the electric field outside human body model corresponding to the scenarios that the conductivities decreased by 20% and decreased by 20% are the most and least, respectively.

IV. DISCUSSION AND CONCLUSIONS

This paper has analyzed the variability of un-averaged and averaged SAR values, and near fields of the IWD in realistic human body models in 13 scenarios by varying dielectric values by ±10% and ±20% at the frequency of 800 *MHz*. Results have shown that the intensities of electric fields near the surface of abdomen of human body have the variation of 1.6 *dB* when all dielectric parameters vary within 20%. All the electric fields near the surface of human body are the biggest when the relative permittivities increased by 20%, while the electric fields are the smallest when the conductivity increased by 20% at all the three operation frequencies and two realistic human body models. From the equation of SAR calculation, we might take it for granted that the SAR value would increase with the increment of dielectric values. Even the maximum peak SAR value does not increase with the increase of dielectric values. In fact, un-averaged and averaged SAR values are not only influenced by dielectric properties of the media, but also by the impedance matching that is also influenced by dielectric properties. The SAR depositions in female body model are larger than those in male body model. Increasing dielectric parameters would not necessarily cause an increase in SAR. In some scenarios the SAR decreases. The SAR is dependent on the orientation of RF source and its operation frequency. As far as the safety level is concerned, we need to add a factor, which has considered the variability of the dielectric properties of biological tissues of various individuals. These results suggest that some estimation on the dependence of the calculated radiation characteristics of IWD and the SARs in human body on the variability in dielectric values of surrounding human body tissues should be determined.

The variation of SAR with dielectric parameters is also dependent on the structure of human body, exposure scenario and so on. The variability of dielectric values in lossy media can result in impedance mismatching of the antenna in IWD. The worst-case of radiation should consider the influence of variability of dielectric properties. These estimations can increase the confidence in the validity of numerical calculations. This study also demonstrates that the same increment in dielectric values in female and male body models resulted in mostly same variations of SAR and electric field even though their SARs and electric field distributions are different at same dielectric values.

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