Should SAR Guidelines Include Variability?

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***Abstract*—Variations in 1-g and 10-g specific absorption rate (SAR) values due to variation in tissue dielectric properties are determined. To accomplish this goal, stochastic finite difference time domain (S-FDTD) and Monte Carlo methods are compared. A 3D head model with variable dielectric properties is exposed to a half wave dipole antenna at 835 and 1900 MHz. The results show that these variations can significantly affect the peak 1-g and 10-g SAR values and should be considered in SAR guidelines for cell phone assessment.**

I. Introduction

Cell phone electromagnetic radiation assessment is one of the most important steps of the design procedure in the cell phone industry [1]–[4]. This non-ionizing radiation can be evaluated using numerical methods to determine the specific absorption rate (SAR) [5]–[7], which gives the power absorbed in body tissues due to electromagnetic exposure. Cell phone SAR guidelines such as ANSI/IEEE C95.1 [1] adopted by the Federal Communications Commission (FCC) [2] and ICNIRP [3] are based on peak SAR over a mass of 1-g or 10-g of tissue, respectively.

Normal variation in tissue properties introduces uncertainty in SAR evaluations [8]–[11]. The impact of this uncertainty has not previously been fully addressed on 1-g and 10-g SAR. In this study we evaluate 1-g and 10-g SAR variances due to variance in the dielectric properties of tissues in a 3D MRI-based human head model at 835 MHz and 1900 MHz GSM frequencies to see how significant these variations are, and if they would be important to consider in cell phone SAR guidelines.

II. Method and Results

We use the 3D stochastic-FDTD (S-FDTD) [8] method for a human head with dielectric properties that have random Gaussian variations. This was used to find the mean and variatiance in 1-g and 10-g SAR values. The head model is a 3D MRI-based head model [7] with the resolution of 2×2×3 mm. The tissue properties and their random variations at 835 MHz are adopted from [12] where the average tissue dielectric properties at 1900 MHz are from [7] and the variances are scaled from 835 MHz properties.

A simulation space with $133 \times 144 \times 115$ voxels was used to implement the scenario of a half wave 835 MHz dipole antenna with the input power of 0.028 μW radiating on the right side of the head. We specifically chose to use a dipole rather than model a cell phone, because we did not want to represent any particular commercial phone, but rather to raise the general question of if variance due to tissue property variance should be considered in SAR guidelines. The SAR in each voxel is shown in Fig. 1. We can see that the standard deviation is similar in magnitude to the mean SAR values, giving an initial indication that the variation caused by variation in tissue properties is significant enough that it should be considered in SAR guidelines. The 1-g and 10-g SAR values (mean and standard deviation) are shown in Table I. Since the guidelines are based on these values (not the voxel values), these are the parameter of greatest interest in our assessment. Here we can see that the 1-g standard deviations are about 50% of the mean SAR values, and the 10-g standard deviations are about 40% of the mean SAR values indicating that it would be important to consider this variation in SAR guidelines for 835 MHz.

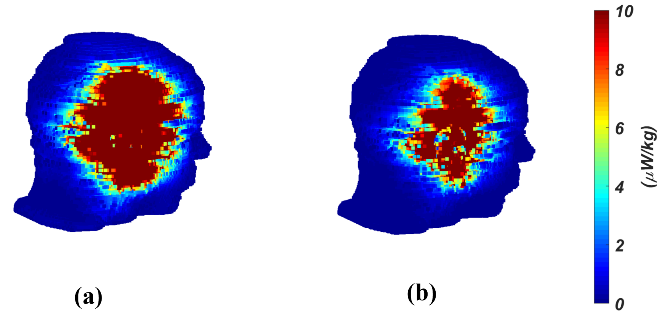

Fig. 1. S-FDTD results at 835 MHz, (a) mean SAR, (b) standard deviation of SAR.

To verify the validity of the S-FDTD method for calculation of SAR, we compared it with Monte Carlo [13] simulations executed with 1000 FDTD runs.The voxel SAR results are presented in Fig. 2. These results are visually almost indistinguishable from the S-FDTD results. The 1-g and 10-g averages for both models are shown in Table I. We can see that although the S-FDTD approach does make some simplifying assumptions, the 1-g SAR mean and standard deviation values are within 4% of those computed with Monte Carlo, and the 10-g SAR is within 15%. This gives confidence in the S-FDTD results, and assessment that the variation should be considered in SAR guidelines. To evaluate the same scenario at 1900 MHz, the cell size in the head model is cut in half, giving

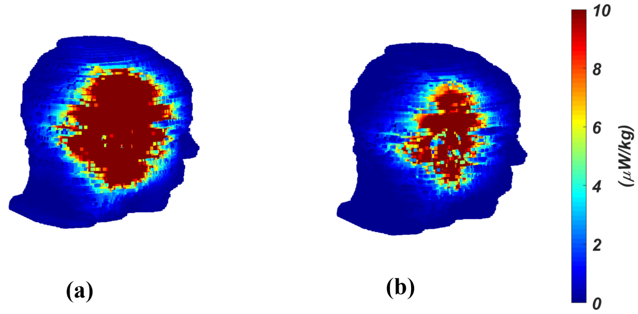

Fig. 2. Monte Carlo results at 835 MHz, (a) mean SAR, (b) standard deviation of SAR.

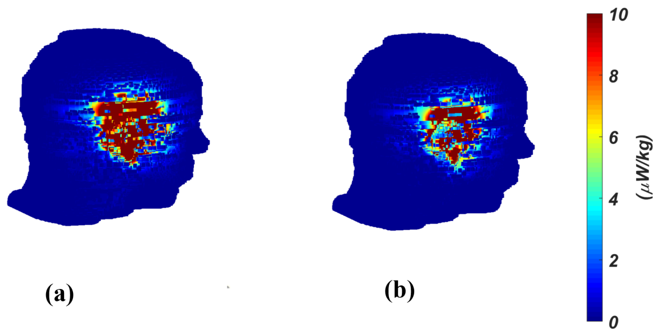

Fig. 3. S-FDTD results at 1900 MHz, (a) mean SAR, (b) standard deviation of SAR.

a resultant simulation space which contains $266 \times 288 \times 230$ voxels. The voxel SAR is shown in Fig. 3. The 1-g and 10-g SAR mean and standard deviation are given in Table I. The 1-g standard deviation is within 45% of the mean, and the 10-g within 40% of the mean.

III. Conclusion

Variations in 1-g and 10-g SAR values caused by dielectric properties variation of the tissues are calculated in this paper. The results are obtained using S-FDTD and Monte Carlo methods for a head model adjacent to a half wave dipole antenna at 835 MHz and 1900 MHz frequencies. S-FDTD results were sufficiently close to the Monte Carlo results at 835 MHz, that we conclude that the more efficient S-FDTD approach can provide the assessment for this study.

TABLE I
MEAN AND STANDARD DEVIATION OF 1-GRAM AND 10-GRAM SAR

Method	1-gram mean SAR	1-gram standard deviation of SAR	10-gram mean SAR	10-gram standard deviation of SAR
S-FDTD (835 MHz)	2.4159	1.1859	2.9217	1.1039
Monte Carlo (835 MHz)	2.5279	1.1126	2.9886	0.9671
S-FDTD (1900 MHz)	6.5285	2.9547	6.9483	2.7163

At both frequencies, the standard deviation of the peak 1-g SAR is within 50% of the mean SAR, and the standard deviation of the peak 10-g SAR is approximately 40% of the mean. A typical interpretation of the standard deviation for a normally distributed random variable, is that we can have a 95% confidence that the values will fall within two standard deviations of the mean. The significance of these results is that the effect of tissue property variation is too large to be ignored in SAR guidelines. The normal, expected variance in SAR should be considered in SAR guidelines. We recommend the next step in this research is to model realistic cell phones, at current (5G) frequencies, to determine the mean and standard deviation of the 1-g and 10-g SAR levels. If these follow the same trends we are seeing from a dipole antenna, it is then imperative that the SAR guidelines be revisited, and that an assessment of the effect of variation in tissue electrical properties be included in them.

References

[1] "IEEE C95.1-1991", *IEEE Standard for Safety Levels with Respect to Human exposure to Radio Frequency Electromagnetic Fields 3 kHz to 300 GHz*, 1992.

[2] D. L. Means and K. W. Chan, Evaluating Compliance with FCC Guide Lines for Human Exposure to Radio Frequency Electromagnetic Fields, Additional Information for Evaluating Compliance of Mobile and Portable Devices with FCC Limits for Human Exposure to Radio Frequency Emissions, document FCC Suppl. C (Ed. 01-01) to OET Bull. 65 (Ed. 97-01), Jun. 2001, pp. 1-53.

[3] "ICNIRP Guidelines for Limiting Exposure to Time-Varying Electric Magnetic and Electromagnetic Fields (up to 300 GHz)", *Health Physics*, vol. 74, no. 4, pp. 494-522, 1998.

[4] D. Bhargava, N. Leeprechanon, and P. Rattanadecho, et al., "Specific absorption rate and temperature elevation in the human head due to overexposure to mobile phone radiation with different usage patterns," *International Journal of Heat and Mass Transfer*, vol. 130, 2019.

[5] J. Wang, Y.-S. Xia, and W.-Y. Yin, "Study on SAR distribution of human body on the vehicle platform using a modified FDTD method," *IEEE Transactions on Electromagnetic Compatibility*, vol. 60, no. 4, pp. 840–848, 2018.

[6] F. J. Meyer, D. B. Davidson, U. Jakobus, and M. A. Stuchly, "Human exposure assessment in the near field of GSM base-station antennas using a hybrid finite element/method of moments technique," *IEEE Transactions on Biomedical Engineering*, vol. 50, no. 2, pp. 224-233, 2003.

[7] Om. P. Gandhi, G. Lazzi, and C. M. Furse, "Electromagnetic absorption in the human head and neck for mobile telephones at 835 and 1900 MHz," *IEEE Transactions on Microwave Theory and Techniques*, vol. 44, pp. 1884-1897, 1996.

[8] S. M. Smith and C. Furse, "Stochastic FDTD for analysis of statistical variation in electromagnetic fields," *IEEE Transactions on Antennas and Propagation*, vol. 60, pp. 3343-3350, 2012.

[9] K. Masumnia-Bisheh, K. Forooraghi, and M. Ghaffari-Miab, "Electromagnetic Uncertainty Analysis Using Stochastic FDFD Method," *IEEE Transactions on Antennas and Propagation*, vol. 67, pp. 3268-3277, 2019.

[10] K. Masumnia-Bisheh, M. Ghaffari-Miab, and B. Zakeri, "Evaluation of Different Approximations for Correlation Coefficients in Stochastic FDTD to Estimate SAR Variance in a Human Head Model," *IEEE Transactions on Electromagnetic Compatibility*, vol. 59, pp. 509-517, 2017.

[11] K. Masumnia-Bisheh, and C. Furse, "Estimating the Variance of SAR in a 3D Human Head Model Using Stochastic FDTD," *2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting*, 2020, pp. 1989-1990.

[12] S. M. Smith, "Stochastic finite-difference time-domain: Ph.D. dissertation," Dept. Elect. Eng., The University of Utah, 2011.

[13] S. Kinase, M. Zankl, J. Kuwabara, et al., "Evaluation of specific absorbed fractions in voxel phantoms using Monte Carlo simulation," *Radiation protection dosimetry*, vol. 105, no. 1-4, pp. 557-563, 2003.