SOME PRESENT PROBLEMS AND A PROPOSED EXPERIMENTAL PHANTOM FOR SAR COMPLIANCE TESTING OF CELLULAR TELEPHONES AT 835 AND 1900 MHz

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ABSTRACT

We compare the peak 1- and 10-g SARs for two different anatomically-based models with the corresponding 6 mm thick plastic ear models recommended for SAR compliance testing both in U.S. and Europe. The SARs obtained with the insulating plastic ear models are two or more times smaller than realistic anatomic models. To alleviate this problem, we propose a 2 mm thin shell phantom with lossy ear that gives SARs within ±15% of those of anatomic models. Also, the SARs for smaller (-9.1%) models are higher than for larger (+11.1%) scaled versions of the two models.

I. INTRODUCTION

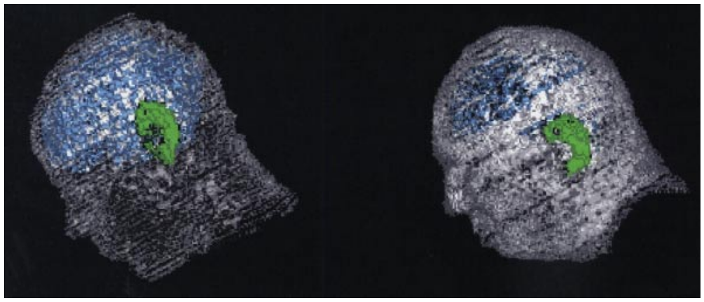
We have previously reported that the peak 1-g SARs for scaled models of children are higher than the corresponding value for full-scale models of the human head [1]. In the same paper, we have also shown that there is a deeper penetration of absorbed energy in smaller models of the head for electromagnetic fields of mobile telephones both at 835 and 1900 MHz. The explanation for both of these observations are the scaled thinner ear and skull and smaller overall dimensions of the brain for children as compared to that for the adult. To examine this issue further, we have taken two different and distinct anatomically-based heterogeneous models of the human head and neck and have scaled them up or down for the voxel size by 11.11% and -9.1% i.e. by approximately ± 10% along each of the three axes, respectively. These variations are certainly within the range of the head sizes encountered for men and women [2]. Three different scaled models for each of the adult heads are thus considered for SAR distributions. Used for the SAR calculations is the finite-difference time-domain (FDTD) method which is extremely popular and has been highly tested for dosimetry of cellular telephones (see e.g. refs. 1, 3). Using the six models thus created, the following issues are examined.

1. Effect of the head size on the peak 1-g SAR both at 835 and 1900 MHz. For these calculations, a number of handset sizes and monopole or helix antennas are considered.
2. Comparison of the peak 1- and 10-g SARs with those obtained using the corresponding 6 mm thick plastic ear models. This study is done since plastic ear models are recommended for SAR compliance testing both in Europe and the U.S. [4, 5].
3. To alleviate the problem of lower SARs with the 6 mm thick plastic spacer (in the shape of pinna) phantoms, we propose a smoothened ear model of the human head.

II. TWO MODELS OF THE HEAD

For the present studies, we have used two different anatomically-based models of the human head and neck. Model 1 – the so-called Utah model was obtained from the magnetic resonance imaging (MRI) scans of a male volunteer. This model described in detail in [1, 3] has a pixel resolution of 2 x 2 mm for the cross sections and 3 mm spacing between the various slices or cross sections. As described in these papers, this model has been segmented into 31 tissues of which 15 tissues are involved for the model of the head and neck considered for the present calculations. To create a 2 x 2 x 2 mm resolution model, we subdivided each of the 2 x 2 x 3 mm resolution voxels of the Utah model into 12 smaller cells of 1 mm resolution along each of the three axes and then combined 2 x 2 x 2 smaller cells into new voxels of dimension 2 mm along each of the axis. The tissue classifications for the new voxels of dimension 2 x 2 x 2 mm was decided by the majority tissue in the subvolume of the voxel i.e. the tissue for five out of eight cells forming the 2 x 2 x 2 mm resolution model. A second tissue-classified model used for the present calculations is based on the scans of the "Visible Man" model, which was kindly provided by John Ziriax and Patrick Mason of Brooks AFB, Texas. This model with 1 mm resolution is classified into 24 tissues. As for the Utah model, here too, we combined 2 x 2 x 2 cells to form the 2 x 2 x 2 mm resolution model of the head and neck.

A visualization of the two heterogeneous models used for the calculations is given in Fig. 1.



(a) The Utah model (b) The "Visible Man" model

Fig. 1. A visualization of the two anatomically-based 30°-tilted models of the head used for SAR calculations.

III. VARIATION OF SAR WITH HEAD SIZE

A thrust of this study is to evaluate coupling of electromagnetic fields from cellular telephones to the various sizes of the human head. Toward this end, we have created two additional sizes of the head for each of the two models, described in Section II by considering the cell size from 2 mm to 2.222 mm for the larger models and down to 1.818 mm, respectively. This results in scaling the dimensions of the two head models up by 11.11% and down by 9.1% i.e. by approximately ± 10% along each of the three axes, respectively. The peak 1-g SAR values determined for a variety of antennas (monopoles and helices), various handset dimensions and larger, average, or smaller scaled versions of the two anatomic models are given in Table 1. Because of the possible revision of the IEEE Safety Standard to focus on the peak 1-g SAR for body tissues instead of all tissue, the data given in Table 1 give only the peak 1-g SARs for body tissues and the brain. The salient features of the results are as follows:

1. The peak 1-g SARs for both the body tissue and the brain increases monotonically with the reducing head size (and pinna thickness) for both of the head models and for all handset dimensions and the antennas i.e. monopoles as well as helices.
2. The peak 1-g SARs for body tissues for smaller models may be up to 50 to 60 percent higher at 1900 MHz and 10-20% higher at 835 MHz as compared to that for the larger head models. This is understandable since the shielding effect of the pinna is larger at the higher frequency of 1900 MHz.
3. Similar to the results previously reported for head models of adult and the children [1], there is a deeper penetration of absorbed energy for the smaller head models as compared to that for the larger head models [6].

IV. COMPARISON WITH SAR FOR PLASTIC EAR MODELS

A 6 mm plastic spacer homogeneous model with brain-simulant properties is presently used by industry and has also been proposed to obtain a "conservative" determination of the peak 1-g SAR of body tissues for SAR compliance testing of cellular telephones [5]. An identical 6 mm "plastic ear" homogenous model has also been proposed to determine peak 10-g all-tissue SAR for compliance testing against the ICNIRP Guidelines [4]. For our calculations, smooth ear models corresponding to the two anatomic models of Fig. 1a, b is used. For example, the model thus developed for the Utah model of the human head shown in Fig. 1a is given in Fig. 2. A dielectric constant ε_r = 2.56 is assumed for the plastic in the shape of the smoothened ear and the 2 mm thick container, while homogeneous dielectric properties representative of the head tissues (ε_r = 41.5, σ = 0.9 S/m at 835 MHz and ε_r = 40.0, σ = 1.4 S/m at 1900 MHz) are assumed for the rest of the model [5].

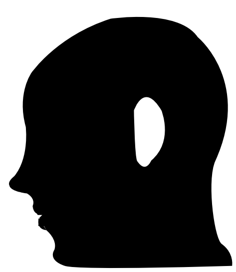


Fig. 2. A proposed 6 mm thick smooth lossy ear phantom to obtain peak 1- and 10-g SARs within ±10-15% of those obtained for anatomically-realistic models. This model with the lossy ear replaced by a 6 mm thick plastic ear (ε_r = 2.56) gives SARs that are a factor of 2 or more lower as given in Tables 2, 3.

In Tables 2 and 3, we compare the peak 1-g all tissue and body tissue SARs and peak 10-g any tissue SARs calculated for the average size versions of both Utah and "Visible Man" models, with the corresponding 6 mm thick smooth plastic ear average models of homogeneous brain-simulant dielectric properties suggested in [4, 5]. The calculated SARs are normalized to the maximum possible radiated power of 125 mW for the PCS telephones at 1900 MHz and 600 mW for the analog AMPS mode of 835 MHz telephones. As seen from Tables 2 and 3, the plastic ear model gives peak 1- and 10-g SARs that are lower by factors of two or more than the all-tissue SARs required for compliance testing against the present ANSI/IEEE and ICNIRP safety guidelines, respectively. This is due to a physical separation of 6 mm and absence in the plastic ear model of the high SAR region e.g. the pinna. For an anatomic model, on the other hand, the lossy ear acts as a coupler conducting EM fields into the head resulting in higher SARs.

V. A PROPOSED EXPERIMENTAL PHANTOM FOR SAR COMPLIANCE TESTING

To alleviate the problem of underestimation of SARs with the 6 mm thick plastic spacer (in the shape of pinna) phantoms, we propose a smoothened ear model of the human head such as that shown in Fig. 2. Since the SAR in the pinna region is substantial, the proposed phantom will use homogeneous lossy dielectric properties (ε_r = 41.5, σ = 0.9 S/m at 835 MHz and ε_r = 40.0, σ = 1.4 S/m at 1900 MHz) everywhere including the volume occupied by the smoothened pinna. For a 2 mm plastic shell of ε_r = 2.56 or ε_r = 4.0 assumed to contain the fluid for the desired dielectric properties, the calculated peak 10-g all-tissue SARs are within ±15% of the SARs obtained with realistic anatomic model of the head. A similar agreement for peak 1-g SARs within ±10% is also obtained for this thin shell lossy pinna phantom with the SARs for anatomic models at 1900 MHz [6], but the SARs are still considerably smaller at 835 MHz. At this lower frequency, it may be possible to use a higher conductivity fluid to get SARs to agree better with those of anatomically-realistic models.

Table 1. Comparison of the peak 1-g SARs for the various **sizes** of the two models of the head.

Handset Dimensions mm	Antenna	Model	Tissue	Peak 1-g SAR (W/kg)		
				Larger Head Model	**Average** Head Model	**Smaller** Head Model
				1900 MHz, 125 mW Radiated Power		
22x42x122	Helix 20 mm length	Utah	Body tissues	0.96	1.32	1.45
			Brain	0.22	0.31	0.45
22 x42x122	Helix 20 mm length	Visible man	Body tissues	1.16	1.22	1.61
			Brain	0.09	0.13	0.18
22x42x82	Helix 20 mm length	Utah	Body tissues	0.89	1.23	1.39
			Brain	0.22	0.33	0.48
22x42x122	Monopole 40 mm length	Visible man	Body tissues	0.95	1.00	1.21
			Brain	0.13	0.14	0.25
22x42x122	Monopole 40 mm length	Utah	Body tissues	0.76	1.02	1.13
			Brain	0.25	0.33	0.45
				835 MHz 600 mW Radiated Power		
22x42x122	Helix 20 mm length	Utah	Body tissues	3.84	3.91	4.20
			Brain	0.83	1.03	1.20
22 x42x122	Helix 20 mm length	Visible man	Body tissues	3.88	4.29	4.36
			Brain	0.37	0.49	0.56
22x42x122	Monopole 80 mm length	Utah	Body tissues	2.92	3.20	3.47
			Brain	1.04	1.24	1.38
22x42x122	Monopole 80 mm length	Visible man	Body tissues	3.01	3.29	3.43
			Brain	0.64	0.80	0.97
22x42x102	Monopole 80 mm length	Utah	Body tissues	2.65	2.81	2.86
			Brain	1.08	1.28	1.43

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Table 2. Comparison of the peak 1-g SARs for all tissues (ANSI/IEEE Guidelines) and body tissues for two anatomically-based models with the corresponding 6 mm thick smooth plastic ear models.

Handset Dimensions mm	Antenna	Model	Peak 1-g SAR (W/kg)		
			1-g all tissues, anatomically-based model	1-g body tissues, anatomically-based model	6 mm thick plastic ear, homogeneous model
			1900 MHz, 125 mW Radiated Power		
22 x42 x122	Monopole, 40 mm length	Utah	2.40	1.02	1.00
22 x42 x82	Monopole, 40 mm length	Utah	2.24	1.00	0.98
22 x42 x82	Monopole, 40 mm length	Visible man	2.55	0.95	0.80
22 x42 x122	Helix, 20 mm length	Utah	3.05	1.32	1.26
22 x42 x82	Helix, 20 mm length	Utah	2.96	1.23	1.30
22 x42 x82	Helix, 20 mm length	Visible man	3.37	1.17	0.97
			835 MHz, 600 mW Radiated Power		
22 x42 x122	Monopole, 80 mm length	Utah	9.09	3.20	2.73
22 x42 x122	Monopole, 80 mm length	Visible man	3.43	3.29	2.80
22 x42 x122	Helix, 20 mm length	Utah	13.20	3.91	3.66
22 x42 x122	Helix, 20 mm length	Visible man	4.46	4.29	3.65

Table 3. Comparison of the peak 10-g SARs for all tissues (ICNIRP Guidelines) for two anatomically-based models with the corresponding 6 mm thick smooth plastic ear models.

Handset Dimensions mm	Antenna	Model	Peak 10-g SAR (W/kg)	
			Anatomically-based model	6 mm thick plastic ear, homogeneous model
			1900 MHz, 125 mW Radiated Power	
22 x42 x122	Monopole, 40 mm length	Utah	1.14	0.62
22 x42 x82	Monopole, 40 mm length	Utah	1.09	0.61
22 x42 x82	Monopole, 40 mm length	Visible man	1.03	0.56
22 x42 x122	Helix, 20 mm length	Utah	1.44	0.77
22 x42 x82	Helix, 20 mm length	Utah	1.37	0.76
22 x42 x82	Helix, 20 mm length	Visible man	1.28	0.67
			835 MHz, 600 mW Radiated Power	
22 x42 x122	Monopole, 80 mm length	Utah	4.03	1.96
22 x42 x102	Monopole, 80 mm length	Utah	3.58	2.28
22 x42 x122	Helix, 20 mm length	Utah	5.53	2.64
22 x42 x102	Helix, 20 mm length	Utah	5.02	3.27