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EFFECT OF HUMAN HEAD SHAPES FOR MOBILE PHONE EXPOSURE ON ELECTROMAGNETIC ABSORPTION

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Key words: cellular phone, the finite-difference time-domain (FDTD) method, head size, specific absorption rate (SAR).

Abstract: In this paper, the local Specific Absorption Rate (SAR) induced in spherical, cubical, and realistic human head models exposed to a mobile phone is investigated. Three human head models of the highest degree of different shapes but of almost the same volume are considered. Obtained local maximum SAR induced in these three human head models for homogeneous cases are established to have average differences of about 12% and 9% at 900 and 1800 MHz respectively. A comparison analysis of SAR induced in the realistic human head model for homogeneous and inhomogeneous cases are also discussed. From the results, it can be observed that the local maximum SAR induced in the homogeneous human head model is larger than that induced in the inhomogeneous human head model.

Vpliv oblike človeške glave na absorpcijo elektromagnetnega sevanja pri izpostavljenosti mobilnih telefonov

Kjučne besede: mobilni telefon, FDTD metoda, velikost glave, parameter SAR

Izvleček: V tem članku je raziskujemo odvisnost parametra SAR (Specific Absorption Rate), ki se inducira v sferičen, kubični in realističen model človeške glave, ki je izpostavljena mobilnemu telefonu. Predstavljeni so trije različni modeli človeške glave s skoraj enakimi volumni. Lokalni maksimumi parametra SAR pri treh modelih homogenih človeških glav so si v povprečju različni za okoli 12% in 9% pri 900 in 1800 MHz. Prav tako so predstavljene analize parametra SAR pri realističnih modelih človeških glav za homogene in nehomogene primere. Iz rezultatov lahko razberemo, da je lokalni maksimum parametra SAR pri homogenih modelih človeških glav večji kot tisti pri nehomogenih modelih.

1. Introduction

With the rapid and ever more widespread use of mobile phones, public concern regarding the possible health hazards has been growing, that brings an increased requirement on electromagnetic (EM) dosimetry for mobile phones. The basic parameter in the EM dosimetry is defined in terms of the specific absorption rate (SAR), or the absorbed power in unit mass of tissue /1/. The SAR is generally evaluated using either phantom measurement or computer simulation. The finite-difference time-domain (FDTD) method is currently the most widely accepted means for the SAR computations /2/. In Europe the basic limit of SAR set for the general public is 2 W/kg averaged over a volume equivalent to 10 gm and a period of 6 min. /3/. The ANSI/IEEE standard /4/ defines a stricter limit for an uncontrolled environment of 1.6 W/kg averaged over a volume of 1 gm and a period of 30 min.

To analyze the possible range of variations of the induced field strengths in the various tissues requires an extensive effort, since the local field strengths strongly depend on a large number of parameters, such as: operational frequency and antenna input power; position of the device with respect to the head; design of the device; the outer shape of the head; the distribution of the different tissues within the head, and the electric properties of these tissues.

The electric parameters of a human body vary with levels of physical and metabolic activity, health, and age. The variations in all these properties lead to a stretch in the analyzed absorption distribution. Currently the most often used system for testing handheld cellular telecommunications equipment is the measurement setup using a homogeneous anatomically-shaped phantom filled with a liquid simulating brain tissue /5-14/. The rationale behind this approach comes from the energy absorption mechanism in the close near-field of antennas /15-19/, which concludes that the most determining parameters for volume-averaged values are the time-averaged antenna input power, operational frequency, design of the device, and its position with respect to the head, and to a much lesser extent, on the physical properties of the head.

In this paper the authors focus on the effects of the factors of head properties, such as size, shape, and electrical properties of tissues in order to calculate the SAR induced in human head models exposed to a cellular phone. To find the effects of head size or shape on electromagnetic absorption characteristics, the realistic head model, spherical head model, and a cubical head model are scaled and then SAR distributions for these models, when exposed to a cellular telephone model have been investigating using the FDTD method.

2. Numerical Method

The finite-difference time-domain (FDTD) method was used to obtain the electromagnetic field distribution in three types of head models. In electrodynamics by far the most flexible way to investigate effects which depends on multiple parameters is with computer simulations, since geometry and domain properties can be easily varied. Many numerical techniques exist for the analysis of complex near-field scattering problems, whereby the FDTD technique /2/ has proven to be the most efficient method for studying absorption in strongly inhomogeneous bodies. FDTD is currently used by various groups to study the absorption in the human head from mobile phones /6-9/ and to test novel antenna designs /10-11/.

CST Microwave Studio (CST MWS) which adopted finite integral time-domain technique (FITD) proposed by Weiland in 1976 was used as the main simulation instrument in permutation of the perfect boundary approximation (PBA). Thin sheet technique, significantly developed in geometry approximation with computation speed was used to achieve highly accurate results. Non-uniform meshing scheme was adopted so that major computation endeavor was dedicated to regions along the inhomogeneous boundaries for fast and perfect analysis. This technique is conceptually slightly different than FDTD but leads to the same numerical scheme. The open domain is bounded by second-order Mur absorbing boundary conditions. Excitation is done by a smoothly-increasing harmonic function and the computation is terminated after steady state is reached (usually after 10 to 20 periods). The results of local maximum SAR induced in the two homogeneous human head models will be presented. Then the FDTD method is again used to calculate the local maximum SAR induced in the realistic human-head model, which is simulated as a homogeneous model with six electrical property sets, counting the head tissue, simulating the bone tissue, the skin tissue, the eye tissue, the blood tissue, the muscle tissue, the brain tissue, and simulated as an inhomogeneous model with six tissues, at 900MHz and 1800MHz, respectively. Comparisons of the SAR induced in the realistic human head model for homogeneous and inhomogeneous models will also be presented in this paper.

3. Head Phantoms

Accurate phantoms of homogeneous human heads can be generated on the basis of magnetic resonance imaging (MRI). The translation of the three-dimensional (3-D) data sets of relaxation times into the tissue distribution is a difficult task and generally requires a person trained either in medicine or biology, and who is able to distinguish both transitional and marginal regions. MRI produced in different laboratories, by different scientists and from different test subjects predictably contains differing discretizations.

In these studies different shapes, different dielectric constant, different conductivity, and different mass density of homogeneous phantoms in different tissues based on MRI data, sets of three different adults are used, and they are also simulated to inhomogeneous phantoms and their results are compared. Fig. 1 shows the outer shapes and two cross-sectional views of these head phantoms and Table I gives the data of discretization. The ear closest to the antenna needs special attention: During normal use of a hand-held telephone, the ear is pressed against the head and, therefore, changes its shape. In order to avoid effects caused by the different ear modeling, which may mask the effects of the head itself, the outer right ear of the head phantoms was removed.

The first phantom in realistic head model was taken with the highest resolution. Its voxel size is 1 mm in all three Cartesian dimensions. Realistic head model has the largest volume. The brain region was segmented very carefully. For the entire head, 13 tissue types were simulated. However, the lower part of the head was assigned to only one tissue type.

The second head phantom is considered as cubical, and has nearly the same voxel size. It was developed for the training of medical students and distinguishes among 120 tissue types. For the EM analysis this large number is needed to be reduced to 13 different tissues for which electric parameters are available /16/.

The third head phantom is considered as spherical that has taken and has a voxel size of about 12 mm^3. The discretization is relatively crude. In the original MRI model the skin was not identified. In the computer model the skin was added as an outer layer with a thickness of one voxel. The brain region of head phantom Spherical is homogeneous and assigned only one tissue type comparing the data of different publications reveals a spread in the values given for the electric parameters of different types of tissue. Table-2 and Table-3 show the electric parameters to be chosen for this study. The permittivity and the conductivity of the tissues of phantoms were taken from the dielectric database /16/.

Table 1 Three different head models for simulations

	Realistic head model [20]	Spherical head model [21]	Cubical head model [7]
Head Volume	4.44 dm^3	3.35 dm^3	4.26 dm^3
Tissues	13	120	12
Computa-tional	175 × 230	159 × 208	159 ×206
Space	×226	×201	×249
Voxel Size	(1 mm)^3	(1.075 mm)^3	(1.875 mm)^2 × 3 mm

With numerical simulations, using FIT or other finite- difference codes, it is easy to attribute different tissue parameters to different mesh cells. However, the tissue discretization and the assignment of the electrical parameters to various tissues are fraught with considerable uncertainties. Therefore, the question of whether these parameters significantly alter the absorption has been studied by relating different parameters to the various tissues: 1) anatomically correct head phantoms with tissue distributions derived from MRI (referred to as Realistic, Cubical, Spherical), 2) simplified head phantoms, which have the outer shape of the MRI phantoms, but which contain only one tissue with high water content (ε_r = 43.5, σ = 0.9 mho/m) and one with low water content, using the parameter of bone tissue, i.e., ε_r = 21, σ = 0.33 mho/m (referred to as realistic, cubical, spherical); and 3) homogeneous head phantoms with the outer shape of the MRI phantoms which contain only one tissue type with ε_r = 43.5, σ = 0.9 mho/m (referred to as realistic, cubical, spherical).

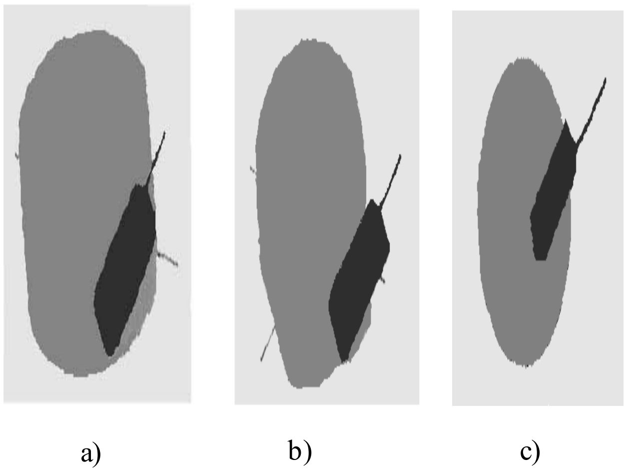

Fig. 1 Test view of three MRI phantoms. a).Realistic head model b) Spherical head model c) Cubical head model

4. Phone Model

The numerical phone model operating at 900 MHz and 1800 MHz consists of a conducting box, a plastic casing, and a helix antenna, as shown in Fig.2. The antenna was fed using the coaxial feeding method. The electric field components of the same amplitude, tangential to the top surface of the phone, were applied at the source point, as shown in Fig.2 (c). For both of the head models, the phone was located on the reference plane, which is defined by auditory canal openings of both ears and the center of the mouth. Regarding the direction of the phone, the touch position that is a normal operating position was used for the anatomical models, and for the simple models, phone was directed parallel to the sagittal plane of the head, as shown in Fig.2.

The cellular-phone model is constructed with a quarter-wavelength helix antenna mounted on the top of a rectangular box with dimensions height h = 108 mm, width w = 46 mm, and thickness d = 23 mm, which is filled with equivalent material, as shown in Figure 2. The material on the outside surface of the handset box is adopted by a dielectric material (ε_r = 3.84, σ = 1.0 x10^{-5} S/m) and (ε_r = 3.78, σ = 1.0x10^{-5} S/m) at 900 and 1800 MHz, respectively. According to a study in ref. /20-23/, the dielectric material used for the outside surface of a handset box has significant impact on the reduction of the SAR induced in a human head. The transmitted power of the cellular phone is assumed to be 0.6 W at 900 MHz and 0.125 W at 1800

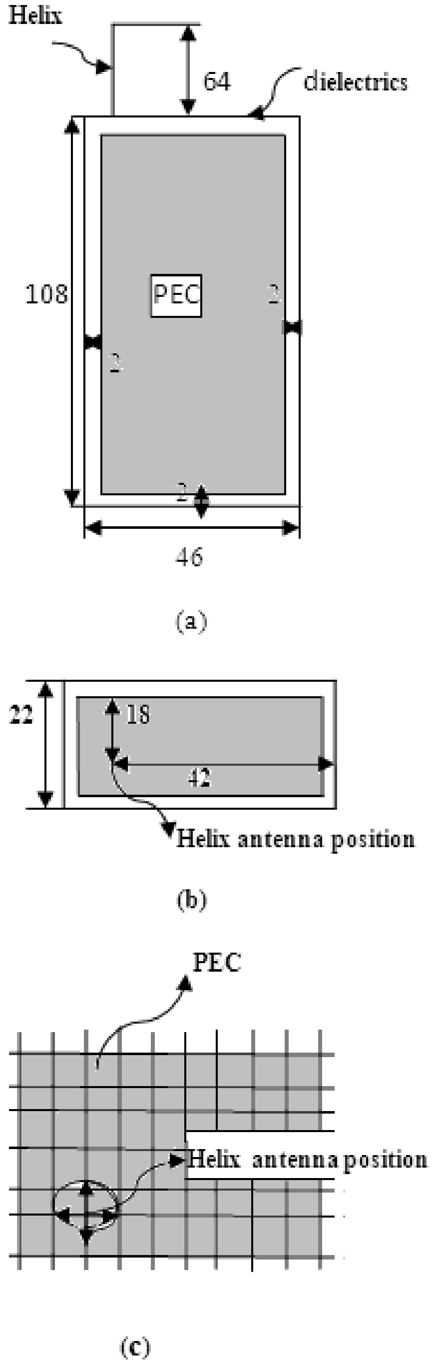

Fig. 2 Phone model (unit: mm). (a) Front view. (b) Top view. (c) Feeding part in FDTD mesh

MHz, respectively. Following the equation in ref. /24-26/, $V = \sqrt{px8xR}$, where the excitation source voltage V at the feeding point of the monopole antenna can easily be calculated. Here R and P are the resistance and transmitted power of the cellular phone in free space, respectively. Using the method of moments (MoM) /16-18/, the impedance of the monopole antenna in air obtained is 45.0 + j19.34 Ω and 50.81 + j14.85 Ω at 900 and 1800 MHz, respectively. The calculations of SAR distribution induced in the human head are made with an initial sinusoidal time-varying electric .field Ez = (V/σ) sin(ωt) located at the gap between the helix antenna and the upper center of the box case, as shown in Fig. 2, where δ = 2.0 mm is the cell size used in the FDTD simulation. A metallic material with ε_r =1.0 and σ = 3.72 10 S/m is employed to simulate the helix antenna. Three homogeneous human-head models (Fig. 1) including spherical, cubical, and realistic shapes, are discretized into 656419, 656253, and 656132 cubic cells of 2.0 mm on each side in the FDTD simulations, respectively. The relative dielectric constant εr conductivity σ and mass density ρ of the three homogeneous phantom-muscle head models (ε_r =57.4, σ = 0.82 S/m, ρ = 1.04 g/cm^3) and (ε_r = 53.5, σ = 1.34 S/m, ρ = 1.04 g/cm^3) at 900 and 1800 MHz are obtained from the literature /5–10/, respectively. The cellular phone and human-head models are assumed to be of nonmagnetic material (μr = 1.0).

5. Results

The results of maximum local SARs induced in three homogeneous human-head models versus the distance between the cellular phone and the human-head model are shown in Figs. 3 and 4. From Figs. 3 and 4 it is clear that the spherical head model has the maximum value of the local maximum SAR, while the realistic human head model has the minimum value of the local maximum SAR. The results of the local maximum SAR induced in the cubical and spherical head models are closer and they are between those obtained by the realistic head models. The average difference of the local maximum SAR induced in these three head models is approximately within 12% at 900 MHz and 9% at 1800 MHz, respectively. This observation emphasizes that the shape of the human head plays a minor role in calculating the SAR induced in the human-head models. These yield that the conclusion made in ref /25-26/ that the maximum local SAR is scarcely affected by the shape of the human head exposed to a cellular phone. In the following study, the realistic human-head model is simulated six times as a homogeneous model with six electrical property sets, such as the bone tissues, the skin tissues, the blood tissues, the eye tissues, the muscle, and brain tissues, and one time as an inhomogeneous model with six tissues taken into account to calculate the SAR results at 900 and 1800 MHz, respectively.

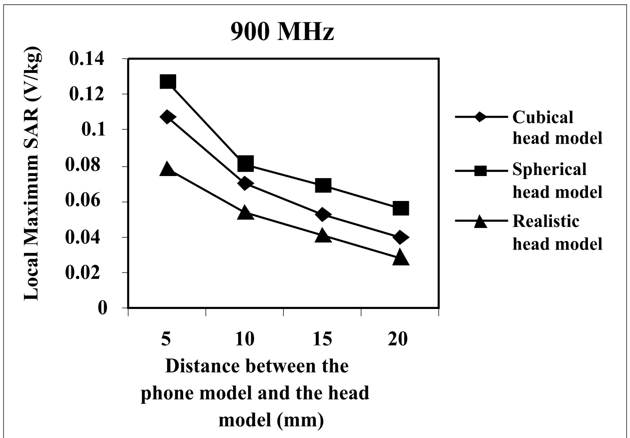

Fig. 3 SAR induced in four homogeneous phantom-muscle head models with relative dielectric constant ε_r = 57.4, conductivity σ = 0.82 S/m, and mass density ρ =1.04g/cm^3 at 900 MHz

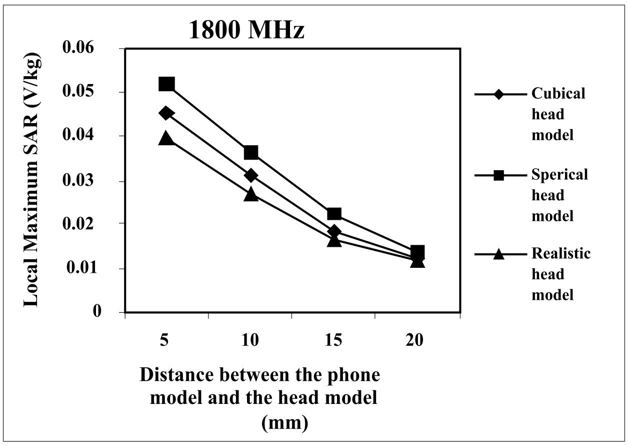

Fig. 4 SAR induced in four homogeneous phantom-muscles head models with relative dielectric constant ε_r = 53.5, conductivity σ = 1.34 S/m, and mass density ρ = 1.04 g/cm^3 at 1800 MHz

The electrical properties of muscle /24/ are (ε_r = 57.4, σ = 0.82 S/m, ρ = 1.04 g/cm^3) and (ε_r = 53.5, σ = 1.34 S/m, ρ = 1.04 g/cm^3) 900 and 1800 MHz, respectively. A comparison of the data found in different publications reveals a spread in the values given for the electrical properties of different types of tissue /24-27/. The electrical properties of the inhomogeneous human-head model with six tissues at 900 and 1800 MHz are shown in Table 2, and Table 3.

Table 2 Dielectric tissue properties at 900 MHz

Tissue Type	Density, ρ (1000 Kg-m^{-3})	Conductivity, σ (S-m^{-1})	Dielectric Constant ε_r
Air	0.0012	0.0	1.0
Bone	1.85	0.34	20.8
Skin	1.10	0.68	43.7
Blood	1.06	1.54	61.4
Eye	1.01	1.90	70.0
Brain	1.03	0.77	45.8
Muscle	1.04	0.82	57.4

Table 3 Dielectric tissue properties at 1800MHz

Tissue Type	Density, ρ (1000 Kg-m^{-3})	Conductivity, σ (S-m^{-1})	Dielectric Constant ε_r
Air	0.0012	0.0	1.0
Bone	1.85	0.59	19.3
Skin	1.10	1.21	41.4
Blood	1.06	2.04	59.37
Eye	1.01	2.03	68.6
Brain	1.03	1.15	43.5
Muscle	1.04	1.34	53.5

Comparisons of maximum local SAR induced in the realistic human-head model for homogeneous and inhomogeneous cases at 900 and 1800 MHz are shown in Figs 5 and 6, respectively. It is found that local maximum SAR induced in homogeneous models has larger values than those induced in inhomogeneous models. It should be noted that the electrical property of a human head significantly affect the result of the SAR induced in homogeneous or inhomogeneous head models. Today, correct calculation or measurement of SAR distribution in a human head while using a cellular phone has become an important issue.

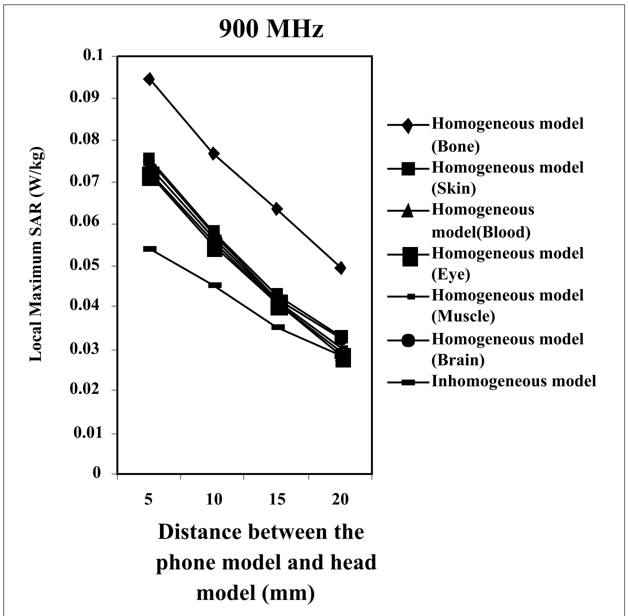

Fig. 5 Comparisons of maximum local SAR induced in the realistic human head model for homogeneous and inhomogeneous cases at 900 MHz

6. Conclusions

In this paper, the results prove that the spatial peak SAR is barely affected by the size, different dielectric properties, and the shape of the human head for electromagnetic

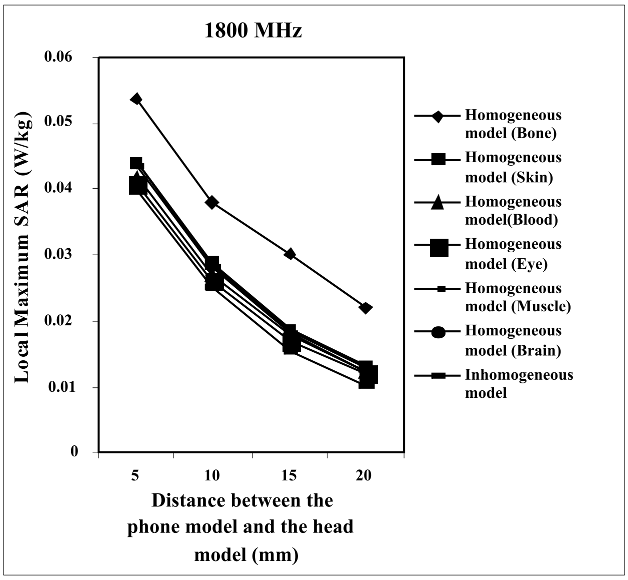

Fig. 6 Comparisons of maximum local SAR induced in the real human head model for homogeneous and inhomogeneous cases at 1800 MHz

sources at a defined distance from the human head. Compared to other factors, such as distance of the source from the head and design of the devices, the effects caused by the complex anatomy are minor especially in the case of volume-averaged values. The comparison of the results obtained from the inhomogeneous and homogeneous phantoms suggests that homogeneous phantoms are highly suited to be used in compliance tests for handheld cellular telecommunications equipment operating in the 900 and 1800 MHz respectively. The results of our study can also be used to investigate differences of biological effects between human species and ages.

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