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Calculation of electromagnetic field from mobile phone induced in the pituitary gland of children head model

Izračunavanje elektromagnetnog polja mobilnog telefona unutar hipofize na modelu glave deteta

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Abstract

Background/Aim. A mobile phone is a source of electromagnetic radiation located close to the head and consequently its intense use may cause harmful effects particularly in younger population. The aim of this study was to investigate the influence of electromagnetic field of the mobile phone on the pituitary gland of the child. **Methods**. In order to obtain the more accurate results for this research 3D realistic model of child's head whose size corresponds to an average child (7 years old) was created. Electric field distribution in child head model and values of Specific Absorption Rate (SAR) at the region of pituitary gland were determined. This study was performed for the frequencies of 900 MHz, 1800 MHz, and 2100 MHz, as the most commonly used in mobile communications. The special attention was dedicated to the values of the electric field and the values of the SAR in the pituitary gland. For all frequencies over 10 g and 1 g of tissue average SAR was calculated. The electric field distribution and values of average SAR for 10 g and 1 g trough the model of child's head were obtained by the using numerical calculation based on the Finite Integration Technique (FIT). **Results**. The largest value of electric field in the region of the pituitary gland was at the frequency of 900 MHz, as a consequence of the highest penetration depth. Lower values of the electric field in the region of the pituitary gland were at frequencies of 1,800 MHz and 2,100 MHz. The SAR in the pituitary gland decreased as the frequency increased as a direct consequence of lower penetration depth. **Conclusion**. The electric field strength from a mobile phone is higher than the value specified by standards for the maximum allowable exposure limits. The high values of the electric field are not only in the vicinity of a mobile phone but also in tissues and organs of the human head. Particular attention should be paid to the exposure of children to radiation of mobile phones. Smaller dimensions of children's head and smaller thickness of tissues and organs have as a consequence greater penetration of electromagnetic waves.

Key words:
cellular phone; electromagnetic fields; child; models, theoretical; pituitary hormones.

Apstrakt

Uvod/Cilj. Mobilni telefon je izvor elektromagnetnog zračenja u blizini glave i zbog toga njegova preterana upotreba može prouzrokovati štetne efekte osobito kod mlađe populacije. Cilj ovog rada bio je da istraži uticaj električnog polja mobilnog telefona kao izvora elektromagnetnog zračenja na hipofizu deteta. **Metode**. U cilju dobijanja što tačnijih rezultata napravljen je realan 3D model glave deteta čije dimenzije odgovaraju dimenzijama deteta od 7 godina. Određena je raspodela električnog polja unutar modela glave deteta i vrednosti specifične količine apsorbovane energije *Specific Absorption Rate* (SAR) u predelu hipofize. Ovo istraživanje izvršeno je za frekvencije od 900 MHz, 1 800 MHz i 2 100 MHz kao najčešće korišćene frekvencije u mobilnom komunikacionom sistemu. Posebna pažnja bila je posvećena vrednosti električnog polja i vrednosti SAR u hipofizi. Za sve pomenute frekvencije proračunat je usrednjeni SAR za 10 g i 1 g tkiva. Raspodela električnog polja i vrednosti usrednjenog SAR za 10 g i 1 g dobijene su korišćenjem numeričkog metoda koji je zasnovan na tehnici konačnih integrala (FIT). **Rezultati**. Najveća vrednost električnog polja u hipofizi bila je na frekvenciji od 900 MHz zbog veće dubine prodiranja. Za frekvencije od 1 800 MHz i 2 100 MHz vrednosti električnog polja u hipofizi bile su manje. Vrednosti SAR u hipofizi su se smanjivale kako je frekvencija rasla što je direktna posledica manje dubine prodiranja. **Zaključak**. Vrednosti električnog polja koje su posledica zračenja mobilnog telefona veće su od maksimalnih graničnih vrednosti koje su propisane standardima. Velike vrednosti električnog polja nisu samo u okolini telefona, već i u organima i tkivima ljudske glave. Posebnu pažnju treba obratiti na izlaganje dece zračenju mobilnih telefona. Manje dimenzije dečije glave kao i manja debljina tkiva i organa za posledicu ima veću dubinu prodiranja elektromagnetnih talasa.

Ključne reči:
mobilni telefon; elektromagnetna polja; deca; modeli, teorijski; hipofiza, hormoni.

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Introduction

The wide variety of available options of mobile phones such as games, the internet, calls and video calls, as well as their accessible prices, have led to the daily use of mobile phones mostly in the younger population (children) which can be measured in hours. The mobile phone is a source of electromagnetic radiation which is located close to the head and because of that, the intense use of mobile phones in the younger population causes concern for health effects.

The influence of electromagnetic field from a source of electromagnetic radiation such as mobile phone close to child's head is bigger than an influence on the adult head. This is due to smaller dimension of child's head and consequently thinner pinnae and skulls. Because of that in the case of child's head, the source of electromagnetic radiation is closer to the brain and pituitary gland than in the case of adults head. Relevant data show that the exposure of children to electromagnetic radiation is higher than adult exposure [1, 2].

Because of ethical considerations, human exposure to electromagnetic fields in experimental purposes is limited. Due to this, it is much more convenient to develop a realistic model of the human head by using numerical simulation [3]. Numerical analyses of the human head exposed to electromagnetic radiation of mobile phones provide useful information about absorbed electromagnetic energy under different conditions of exposure. The International Agency for Research on Cancer (IARC) has classified the radiation of electromagnetic fields in 2B group as possibly carcinogenic to human, based on an increased risk of a malignant type of brain cancer. In this category, there is a limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals [4].

The most important indicator when considering the health risk as a result of the effect of electromagnetic fields is the Specific Absorption Rate (SAR). SAR is directly dependent on the electromagnetic properties of biological tissues exposed to the effects of electromagnetic waves and can be defined as (Equation 1):

$$\mathrm{SAR} = \frac{\sigma |E|^2}{\rho}$$

where E is the maximum value of the internal electric field, σ is the conductivity of the tissue and ρ is the density of the tissue. Maximum values of SAR which must not exceed, are defined in Regulation of the limits of exposure to non-ionizing radiation, Official Gazette of the Republic of Serbia, no. 36/09. This regulation defines the limits of exposure to non-ionizing radiation, or the basic restrictions and reference boundary levels of the population exposure to electric, magnetic and electromagnetic fields of different frequencies [5].

In this research, the level of electric field strength due to mobile phone and SAR values at the region of pituitary gland were determined.

The pituitary is a small gland which has a diameter of around 1cm and a weight of about 0.5–1 g, and it is located at the base of the brain. Physiologically it can be divided into two parts: the front part called the adenohypophysis and the rear part called neurohypophysis. Adenohypophysis secretes six very important hormones, which have a very significant role in the control of metabolic functions of the whole organism such as prolactin, growth hormone (GH), adrenocorticotropic hormone (ACTH), thyroid-stimulating hormone (TSH), luteinizing hormone (LH), follicle-stimulating hormone (FSH). The main role of rear part or neurohypophysis is to store antidiuretic hormone (ADH) and oxytocin. Hormones from the hypothalamus almost completely regulate the secretion of pituitary hormones which are delivered through the bloodstream to the pituitary gland.

As shown in one study [6], exposure to 900 MHz of global system for mobile communication radio frequency (GSM RF) on pituitary hormone levels in healthy males such as: TSH, GH, prolactin and ACTA, led to significant decreases of concentrations of GH and cortisol for about 28% and 12%, respectively.

Due to a higher level of electromagnetic radiation within the child's head compared to that found inside adult's head, the electric field can be one of the causes of serious biological effects on the pituitary gland. Because of harmful effect previously mentioned on the pituitary gland and consequently on the concentration of GH which is essential for normal growth of the child, in this paper special attention is devoted to numerical calculation and distribution of electrical field and SAR in the region of this gland for 7-years old child. Also in this study, an overview of the possible biological effects that may occur in pituitary gland due to exposure to electromagnetic fields is presented.

Methods

In order to obtain more accurate results for this research 3D realistic model of child's head whose size corresponds to an average child (7 years old) had to be created [7, 8]. This model of child's head consisted of following tissues and organs: skin, fat, muscle, skull, jaw with teeth, tongue, eyes, vertebrae, cartilage, spinal cord, cerebrospinal fluid, brain, and pituitary gland.

All of these tissues and organs had to be described by adequate electromagnetic parameters such as electric conductivity, permittivity, heat capacity, density and thermal conductivity [9]. These electromagnetic characteristics vary with frequency and their values for frequencies of 900 MHz, 1,800 MHz, and 2,100 MHz), as the most often used in mobile communication, are shown in Table 1.

Modeling of 3D child's head model was performed in two stages. First external look for every tissues and organs was created in 3D Max Studio [10]. The second step was creating a full model with actual tissues and organs and connecting certain electromagnetic properties with corresponding tissues and organs by using software package CST Microwave Studio [11]. The same software was used for simulation of the electromagnetic field and its influence on child's head. Numerical calculation method used in this software was based on the Finite Integration Technique [12].

External look, horizontal and vertical cross-sections of actual tissues and organs are shown in Figures 1 and 2 with organs numbered according to their numbers in Table 1.

Table 1

Average values of electromagnetic properties of tissues and organs at frequencies of 900 MHz, 1,800 MHz and 2,000 MHz

Tissue/Organ	ε_r	σ (S/m)	ρ* (kg/m^3)	Heat* capacity (kJ/kgK)	Thermal conductivity (W/m°C)
1 – Cortical Bones	12.45[a]	0.143 [a]	1,908	1.313	0.32
	11.8 [b]	0.275 [b]	1,908	1.313	0,32
	11.6[c]	0.328 [c]	1,908	1.313	0.32
2 – Brain	45.805[a]	0.7665 [a]	1,046	3.630	0.51
	46.1[b]	1.710 [b]	1,046	3.630	0.51
	45.50[c]	1.880 [c]	1,046	3.630	0.51
3 – Cerebrospinal Fluid	68.60 [a]	2.410 [a]	1,007	4.096	0.57
	67.2 [b]	2.920 [b]	1,007	4.096	0.57
	66.80 [c]	3.150 [c]	1,007	4.096	0.57
4 – Fat	11.30 [a]	0.109 [a]	911	2.348	0.21
	11.0 [b]	0.190 [b]	911	2.348	0.21
	10.90[c]	0.224 [c]	911	2.348	0.21
5 – Cartilage	42.70 [a]	0.782 [a]	1,100	3.568	0.49
	40.2 [b]	1.290 [b]	1,100	3.568	0.49
	39.50 [c]	1.490 [c]	1,100	3.568	0.49
6 – Pituitary Gland	59.70 [a]	1.040 [a]	1,053	3.687	0.51
	58.1 [b]	1.500 [b]	1,053	3.687	0.51
	57.70 [c]	1.700 [c]	1,053	3,687	0,51
7 – Spinal Cord	32.50 [a]	0.574 [a]	1,075	3.630	0.51
	30.9 [b]	0.843 [b]	1,075	3.630	0.51
	30.50 [c]	0.951 [c]	1,075	3.630	0.51
8 – Muscle	55.00 [a]	0.943 [a]	1,090	3.421	0.49
	53.5 [b]	1.340 [b]	1,090	3.421	0.49
	53,20	1.510	1,090	3,421	0,49
9 – Eyes*	49.60 [a]	0.994 [a]	1,052	3.615	0.53
	46.3 [b]	1.369 [b]	1,052	3.100	0.50
	47.88 [c]	1.530 [c]	1,052	3.043	0.50
10 – Skin	41.40 [a]	0.867 [a]	1,109	3.391	0.37
	38.9 [b]	1.180 [b]	1,109	3.391	0.37
	38.40 [c]	1.310 [c]	1,109	3.391	0.37
11 – Tongue	55.30 [a]	0.936 [a]	1,090	3.421	0.49
	53.6 [b]	1.370 [b]	1,090	3.421	0.49
	53.10 [c]	1.560 [c]	1,090	3.421	0.49
12 – Teeth	12.50 [a]	0.143 [a]	2,180	1.255	0.59
	11.8 [b]	0.275 [b]	2,180	1.255	0.59
	11.60 [c]	0.328 [c]	2,180	1.255	0.59

***values are the same for all frequencies.**

ε_r – permittivity, σ – electric conductivity, ρ – density

[a] – value at frequency of 900 Hz

[b] – value at frequency of 1,800 Hz

[c] – value at frequency of 2,100 Hz

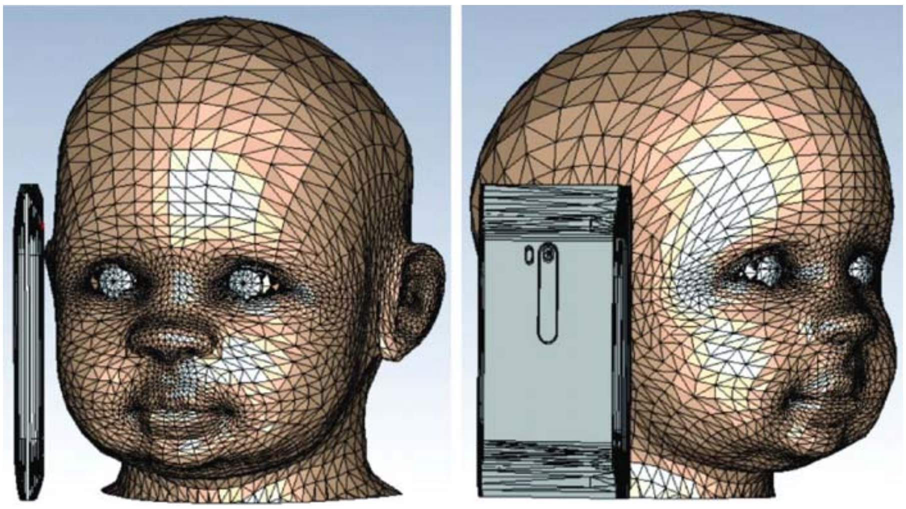

Fig. 1 – External look of the child's head model.

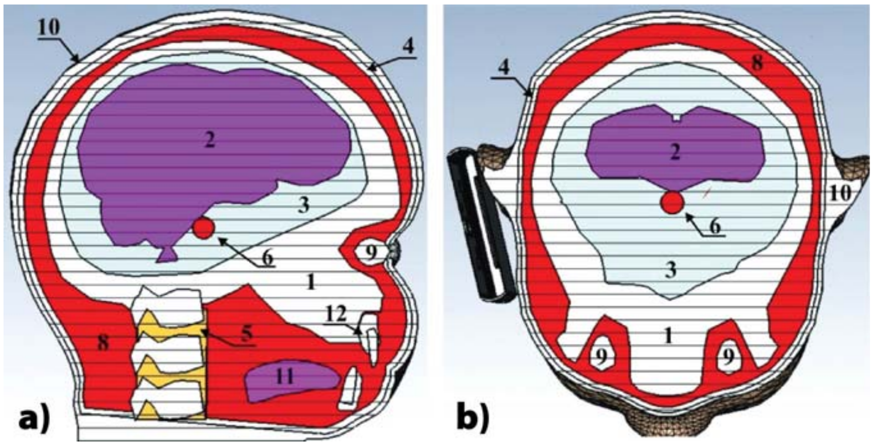

Fig. 2 – a) Vertical and b) Horizontal cross-section of the child's head model.
1 – cortical bones, 2 – brain, 3 – cerebrospinal fluid, 4 – fat, 5 – cartilage, 6 - pituitary gland, 8 – muscle, 9 – eyes, 10 – skin, 11 – tongue, 12 – teeth (the numbers are the same as in Table 1).

In this study actual smartphone (Figure 1) was used as a source of electromagnetic radiation. The mobile phone consisted of following parts: planar inverted F antenna (PIFA), display and mobile housing. The planar inverted F antenna (PIFA) as a source of electromagnetic radiation was modeled for three different frequencies: 900 MHz, 1,800 MHz, and 2,100 MHz, with reference power of P = 1W [13] and impedance of Z = 50 Ω.

The numerical calculation was performed for open space (reflected electromagnetic waves and the other sources of electromagnetic radiation were not taken into consideration). The only source of electromagnetic radiation in this simulation was a mobile phone with an output power of 1W, defined according to the Standard of the Institute of Electrical and Electronics Engineers (IEEE) C.95.3 [13].

Results

The penetration depth of the electric field was the largest in the case of the electric field at a frequency of 900 MHz (Figure 3a). On the other hand, the penetration depth of the electric field at the higher frequencies was smaller resulting in a stronger electric field in tissues that are close to the source of electromagnetic radiation such as mobile phone (Figures 3b and 3c). The peak of the electric field in the pituitary gland at the frequency of 2,100 MHz was less than those at the frequencies of 1,800 MHz and 900 MHz (0.3045 V/m, 0.8643 V/m, and 5.6615 V/m, respectively) (Figure 4).

SAR values averaged over 1 g and 10 g of the tissue for all three frequencies used in this study are presented in Figures 5 and 6, respectively.

Because the penetration depth of electric field was the largest in case of the frequency of 900 MHz (Figure 6), SAR values in the region of the pituitary gland was the highest for this frequency and amounted SAR1g = 0.08521 W/kg (Figure 5) and SAR10g = 0.10325 W/kg (Figure 6).

Discussion

In this study, the electric field distribution within the child`s head model was investigated for different frequencies

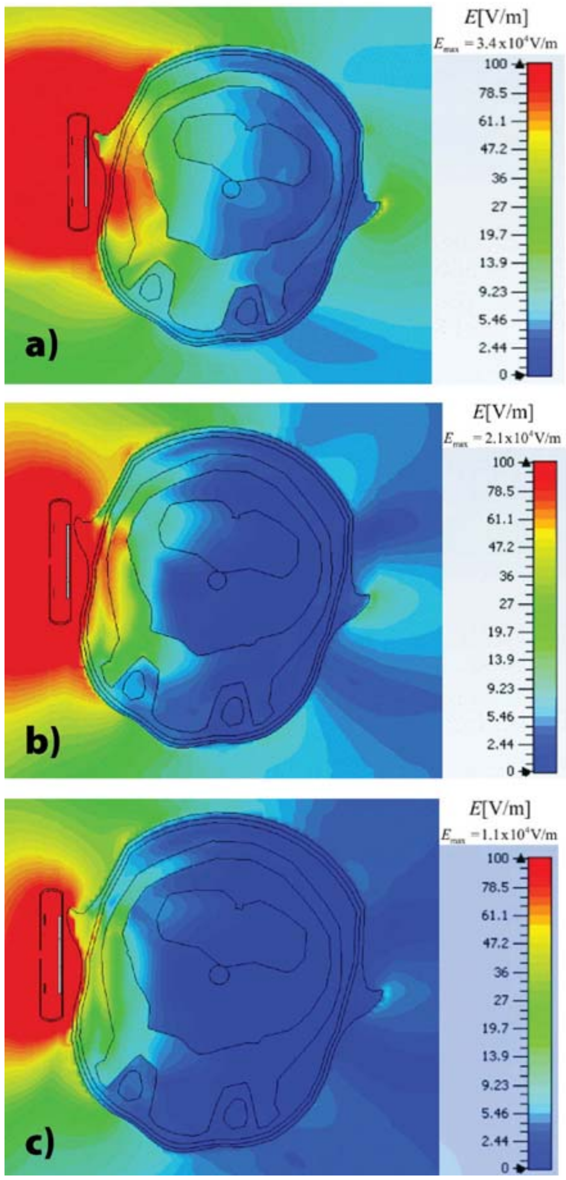

Fig. 3 – Electric field distribution within the child's head model for frequency of
a) 900 MHz, b) 1,800 MHz, and c) 2,100 MHz.

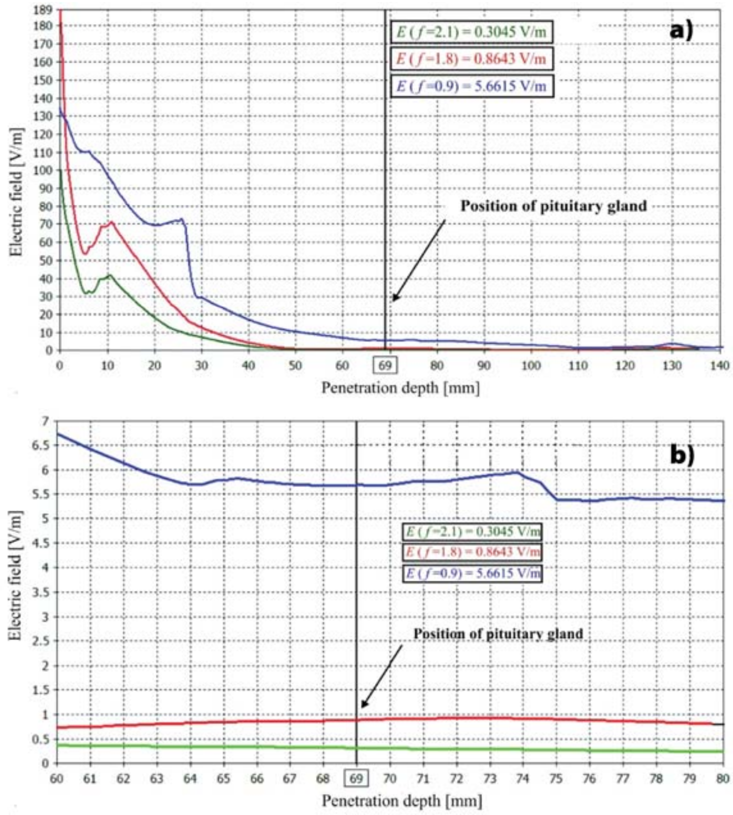

Fig. 4 – Penetration depth of electric field through the child's head model for three different frequencies (f). a) from 0 mm to 140 mm; b) from 60 mm to 80 mm.

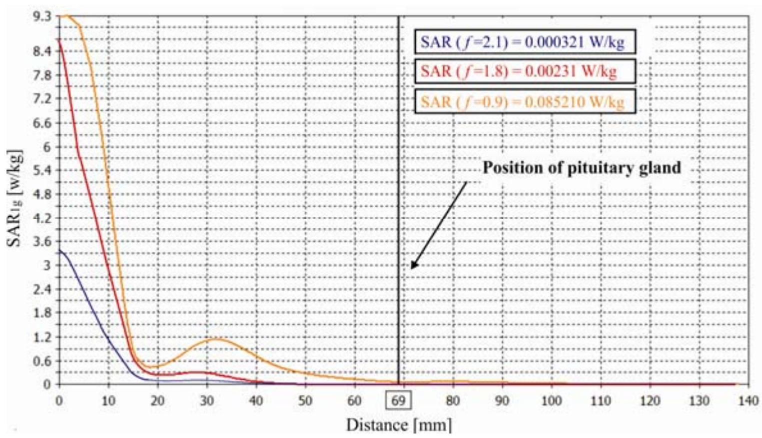

Fig. 5 – Comparative analysis of specific absorption rate (SAR_{1g}) for different frequencies (f) through the child's head model.

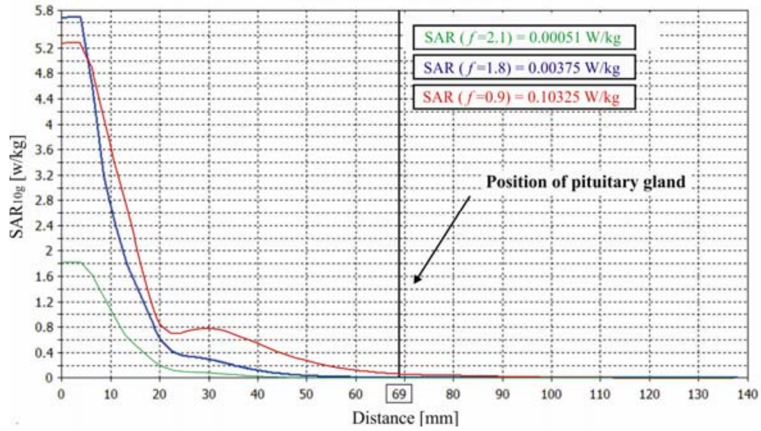

Fig. 6 – Comparative analysis of specific absorption rate (SAR_{10g}) for different frequencies (f) through the child's head model.

of a mobile phone. Our results showed that the penetration depth of the electric field was the largest at a frequency of 900 MHz and decreased at higher frequencies resulting in a stronger electric field in tissue that was close to the source of electromagnetic radiation like a mobile phone. The wavelength of electromagnetic waves has an impact on penetration depth because it varies for different frequencies and it has to be taken into consideration that electromagnetic properties are different for different biological tissues [14].

Generally, the one part of the energy due to the propagation of electromagnetic waves penetrates into certain biological object and it is being absorbed. Differences of wave energy at the boundaries of a biological object (the input energy and output energy) represent the absorbed energy. Because of the need to precisely introduce this absorbed energy it was defined as the term Specific Absorption Rate - SAR. The values of the SAR are different for different tissues and electromagnetic waves of different characteristics, in this case, different frequencies. It can be said that SAR characterizes the interaction of electromagnetic fields with biological tissue. SAR is related to a certain point as an extremely small area in a biological tissue in which the electromagnetic field can be considered as homogeneous one. More practical value is the average SAR as the ratio of the absorbed power in the body and the body mass of biological entity.

For this research, values for the average SAR over 10 g and 1 g of tissue were calculated. Because of different frequencies values of SAR varied. Accordingly, the penetration depth of the electric field was the largest in case of a frequency of 900 MHz, and SAR values in the region of the pituitary gland were the highest for this frequency

The results obtained in this paper are compared with those obtained in the study of Krstić et al. [15]. After comparison, it can be concluded that the value of SAR in the region of pituitary gland for child`s head model used in this research, is greater than SAR in a model of adult person`s head with few layers in that study [15]. SAR in a case of child`s head model is almost five times greater than results in a case of adult`s head model. This is expected due to different characteristics of the model: size, different thickness of layers and therefore the pituitary gland was at greater distances from the source in case of adult person`s head model.

There are many differences among different countries in Europe in terms of upper limits for RF radiation from GSM mobile telephony. Based on Recommendation 1999/519/EC, the limit values which are prescribed for the electric field strength for the following frequencies: 900 MHz, 1,800 MHz, and 2,100 MHz, are 41 V/m, 58 V/m i 61 V/m, respectively[16]. The certain European governments have adopted lower values such as for example Greece (32 V/m, 45 V/m and 47 V/m), Belgium (21 V/m, 29 V/m and 31 V/m), Serbia (16.5 V/m, 23.3 V/m and 24.4 V/m), Slovenia (13 V/m, 18 V/m and 19 V/m), Poland (7 V/m, 7 V/m and 7 V/m), Italy (6 V/m, 6 V/m and 6 V/m), Switzerland (4 V/m, 6 V/m and 6 V/m), etc. for all three frequencies, respectively [17].

The values for the maximum field strength that are prescribed by the standard are given for free space in the absence of people. We have to keep in mind that the values for field strength inside the biological tissues or organs are lower because of the propagation through the material environment and due to the increasing distance from the radiation source.

If the value of the field is known inside biological tissue then, based on the boundary conditions at the surface of the two separate areas, the value of the incident field can be evaluated. Since the value of the electric field in the pituitary gland is known, based on the relationship that is valid for the normal vector components of the electric field at the separate area, the value of the field before the penetration of EM waves in the pituitary gland can be determined.

Based on the value of the dielectric constant and conductivity of air and pituitary gland for different frequencies, the ratio of electric fields strengths at the separate surface of these two areas can be approximately determined. This is certainly the worst case, from the standpoint of the electric field strength, because in this case it does not take into consideration the impact of other layers on the weakening of electromagnetic wave that spreads from the radiation source. However, this approach can give us information about the minimum field strength to which man is exposed, and if it is greater than allowed.

The ratio of normal vector components of electric field at the crossover semiconductor environment is determined from the expression

$$\frac{\underline{E}_1}{\underline{E}_2} = \frac{\sigma_2 + j\omega\varepsilon_2}{\sigma_1 + j\omega\varepsilon_1} \quad (2)$$

For different frequencies and the corresponding values for the dielectric constant and conductivity of the air and the pituitary gland, the ratio of the normal components of the electric field for these two environments is calculated by using previously formula (2) and results are:

$$\left|\underline{E}_{\text{air}} / \underline{E}_{\text{p. gland}}\right|\Big|_{f=0.9\text{GHz}} \approx 63 \text{ V/m},$$

$$\left|\underline{E}_{\text{air}} / \underline{E}_{\text{p. gland}}\right|\Big|_{f=1.8\text{GHz}} \approx 60 \text{ V/m, and}$$

$$\left|\underline{E}_{\text{air}} / \underline{E}_{\text{p. gland}}\right|\Big|_{f=2.1\text{GHz}} \approx 59.5 \text{ V/m}.$$

Based on the previously obtained values for the electric field strength in the pituitary gland, the values of the electric field strength in the air are:

$$\underline{E}_{\text{air}}\Big|_{f=0.9\text{GHz}} \approx 356.67\,\text{V/m}$$

$$\underline{E}_{\text{air}}\Big|_{f=1.8\text{GHz}} \approx 51.86\,\text{V/m} \text{, and}$$

$$\underline{E}_{\text{air}}\Big|_{f=2.1\text{GHz}} \approx 18.12\,\text{V/m}.$$

If we compare this value with the maximum permissible values specified in the above mentioned countries, we can conclude that they are considerably higher or in range with the maximum allowable ones. Of course, if we take into account the impact of all other layers between the radiation source and pituitary gland obtained values would have been far greater.

Pituitary gland as one of the most important glands of the endocrine system, *via* ACTH has an impact on the cortex of the adrenal gland. In this way, it stimulates the secretion of steroid hormones.

Some investigations revealed that stimulation of the adrenal axis by electromagnetic radiation from a mobile phone in rats has as a consequence general hyperthermia. In animals exposed to high levels of electric fields, stimulation of the hypothalamic-hypophysial-adrenocortical (HHA) axis was found, mediated by the central nervous system (CNS) [18].

Another very important function of the pituitary gland is that it secretes gonadotropins FSH and LH that regulate testicular spermatogenesis and steroidogenesis. The impact of a mobile phone radiation on gonadotropins level has been considered in man and animals. The results of some studies have shown that a mobile phone radiation cannot cause significant biological effects. But there is a possibility that the time of exposure to radiation from a mobile phone in these studies was not long enough to show some significant biological effects [19–20].

Research conducted by Fang et al. [19] showed progressive histological derangement in rat pituitary glands. These derangements were manifested in the form of swollen mitochondria as well as dilatation of Golgi complex and diffusive lysosomes. Also, this research revealed that with increasing duration of exposure and electromagnetic wave energy this disorder increased. For instance, it has been observed also and mitochondrial vacuolization, the formation of myelin figures, distinct dilatation of endoplasmic reticulum, the occurrence of numerous secondary lysosomes, and clustering of heterochromatin under the nuclear membranes[19].

In the study of Eskander et al. [21], it was shown that people living a long period of time in the vicinity of base stations have a significant reduction of the release into the blood of a number of hormones, including ACTH which is produced and secreted by the anterior pituitary gland [21]. The highly significant decrease of serum cortisol levels in people exposed to electromagnetic radiation was also found.

Conclusion

The penetration depth of the electric field is the largest at the frequencies of 900 MHz and decreases, at the higher frequencies, resulting in a stronger electric field in the tissues that are close to the source of electromagnetic radiation (mobile phone).

Results obtained by numerical analysis show that the electric field at the frequency of 900 MHz has the greatest impact on the pituitary gland, which is a consequence of the highest penetration depth as mentioned before.

This level of radiation may cause substantial harmful health effect in children having in mind our study results that the level of electric field strength inside pituitary gland is higher than the values for the maximum field strength specified by the standard.

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