

Dental Amalgam Influence on the Amount of Absorbed Energy from Mobile Phone

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Abstract—The topic of the research presented in this paper is numerical calculation and analysis of the electric field and Specific Absorption Rate (SAR) distributions in the vicinity of dental amalgam exposed to the radiation of mobile phone at the frequencies corresponding to 3G and 4G mobile networks. This is carried out by numerical solving of the electromagnetic propagation equation. The results related to different tissues and organs placed in the vicinity of dental amalgam and exposed to radiation are presented and analysed. In order to obtain the most accurate results, the realistic 3D model of human jaw has been created. A comparative analysis of models with and without dental amalgam has been carried out, with aim to determine the impact of amalgam on biological tissues in its vicinity. According to the obtained results, the maximum values of electric field strength and SAR are higher in the presence of dental amalgam. In both cases, maximum values are out of bounds of safety limits.

Index Terms—Dental amalgam; Electromagnetic radiation; Mobile communication; Specific absorption rate.

I. INTRODUCTION

In the last few years, mobile phones and communication systems as well have been developing at an astounding rate. Due to numerous advantages and opportunities, one can observe the massive growth in the usage of mobile phones, including the time spent using them. This brings significantly increasing exposure to electromagnetic radiation caused by a cell phone, which turned the focus towards researching the impact of electromagnetic waves on human organism and estimation of human health risk. The cell phones, as non-ionizing electromagnetic radiations sources placed in the vicinity of the human head, should be considered as the potential health hazards. There are many previously realized studies dealing with this problem. Based on them, the corresponding safety measures prescribing maximal allowable values for electromagnetic field exposure have been included in published safety standards and recommendations [1]–[4]. In addition, it is necessary to emphasize that electromagnetic field has been characterized

as potentially carcinogenic risk for humans and classified as 2B carcinogen [5]. The initial researches of electric field and Specific Absorption Rate (SAR) distributions firstly included simple models containing only one layer that was supposed to represent the human brain characteristics. Results obtained in such a way, for understandable reasons, do not reflect the real situation related to the certain tissues. In addition, because of their simplicity, these models could not consider the boundary conditions at the transitions between different biological tissues and organs [6]–[8]. Numerous studies refer to the cell phone radiation impact inside realistic 3D model of a human head containing different tissues and organs [9]–[13]. These 3D models are very good approximations of actual human head state, which provide accurate analysis of electric field and SAR distributions in biological tissues inside the head. However, the framework of these studies has not focused on the oral region of a head.

The main aim of this study is to determine the electric field distribution and values of SAR in the vicinity of dental amalgam exposed to the source of electromagnetic radiation. As a source of radiation, the actual smart phone has been modelled. It is a well-known fact that the dental amalgam (silver fillings) is a mixture of metals consisting of liquid mercury and a powdered alloy composed of silver, tin, and copper. The concentration of mercury in the dental amalgam varies depending on the manufacturer and can cause serious health problems.

Some of previous studies refer to the impact of electromagnetic field on dental amalgam. Many articles have been researching health problems and unpleasant symptoms caused by the electromagnetic waves emitted by wireless devices [14]–[26]. Some of them reported the involuntary movements of the subject that were treated using a gold alloy dental inlay caused by electromagnetic waves [17].

Due to the lack of numerical analysis of electric field distribution, as well as values of SAR in the vicinity of dental amalgam in available literature, researching in this field has been performed. Hence, the main aim of this paper is to evaluate and estimate of the mobile phone radiation exposure effects in the dental amalgam vicinity based on determining of induced internal electromagnetic field and

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SAR values. The anatomical shape of human jaw, which includes teeth model, and its characteristics are of great importance for absorbed electromagnetic energy measurement. The same is for the operating frequency and the distance between the electromagnetic source and the exposed object (dental amalgam). This study includes numerical calculation of the electrical field and SAR values at the frequencies of 900 MHz and 2600 MHz corresponding to 3G and 4G mobile networks, respectively.

II. NUMERICAL METHOD, MODELLING, AND SIMULATION

A. Model

In order to determine the electric field distribution and values of SAR in the vicinity of dental amalgam exposed to the radiation from mobile phone, a 3D model of a human head and the model of a jaw have been developed. The model of a human jaw has been created with features, which are the closest possible to the actual human jaw. The process of modelling has been performed in few stages. First, the artificial jaw with teeth has been created by dental prosthetics (Fig. 1(a)). Further, based on dimensions and shape of that artificial model, the external looks of jaw model, which replicates the artificial model, has been designed (Fig. 1(b)). In addition, in order to perform the most accurate numerical analysis of electric field distribution and values of SAR, the model of a human jaw has been positioned inside the model of a human head. The human head model has been realized, including the morphological and anatomical characteristics corresponding to an average adult person (Fig. 2) [18]–[20]. The complete model used for simulation of electromagnetic wave propagation consists of human head with certain tissues and organs and model of human jaw. Note that layers were ideally superimposed, so that it is possible to consider the boundary conditions at the separation area between two tissues during the propagation of EM (Electromagnetic) waves from one tissue to another.

The human head model with related mobile phone position, position of the jaw, vertical cross section of the head and head tissue structure observed from above are presented at Figs 2(a), 2(b), 2(c) and 2(d) respectively. Numerical designations of tissues and organs from Fig. 2 correspond to those ones shown in Table I.

In order to understand the impact of electromagnetic radiation on the body, the detailed knowledge of the electromagnetic properties (permittivity, conductivity, and permeability) of tissues and organs is necessary. The propagation, reflection, and attenuation effects of electromagnetic waves in the human body strongly depend on these electromagnetic properties. In Table I, the electromagnetic parameters of biological tissues and organs are given [21].

Since the main goal of this study to determine electric field distribution and values of SAR within biological tissues in the vicinity of dental amalgam exposed to EM radiation, comparative analysis of two simulations was performed. One numerical calculation of electromagnetic waves propagation was carried out for human teeth without dental amalgam and the other one - with dental amalgam.

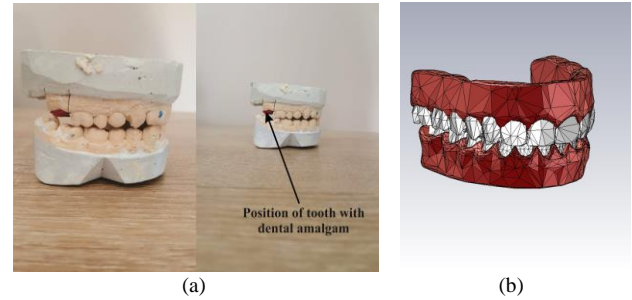


Fig. 1. External appearance of the jaw: (a) artificial human jaw created by dentist prosthetics and (b) jaw model created for simulation.

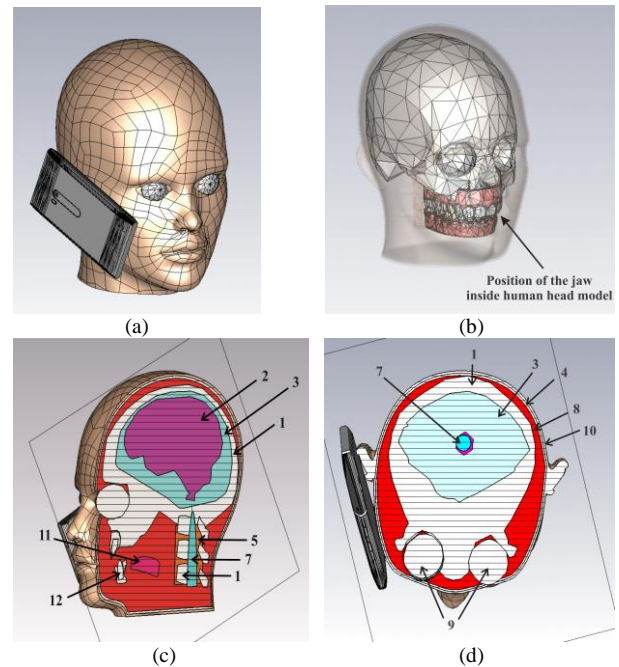


Fig. 2. External appearance and construction of the human head model with (a) related mobile phone position; (b) position of the jaw; (c) vertical cross section of the head, and (d) head tissue structure.

The dental amalgam was modelled with the following dimensions: 3 mm length, 2 mm depth, and 5 mm width [22]. The model of dental amalgam was modelled as a conventional dental amalgam alloy, which contains 65 % silver, 25 % tin, 5 % copper, 2 % zinc, and 3 % mercury [23]. The electromagnetic characteristics of these materials are taken from material library of software package (see Table II).

As a source of electromagnetic radiation, the mobile phone model with characteristics corresponding to an actual smart phone has been developed (Fig. 3). The mobile phone model contains the following parts: the display, mobile housing, and planar inverted F antenna (PIFA). Some of the latest smart phones have PIFA antenna positioned in the microphone area or in the mouth region of the user; the latter kind of mobile phone was used in this investigation. The planar inverted F antenna (as radiation source) was modelled for the frequencies of 900 MHz and 2600 MHz. Thereby, the output power and the impedance values are $P = 1 \text{ W}$ [24] and $Z = 50 \Omega$, respectively. The antenna position inside the cell phone is shown in Fig. 3. Generally, the PIFA construction depends on manufacturer. Some examples of PIFA performance, construction, and radiation pattern for certain frequency values are presented in [25].

TABLE I. ELECTROMAGNETIC PROPERTIES OF TISSUES AND ORGANS AT $f = 900$ MHz AND $f = 2600$ MHz.

Biological tissue		3G 900 MHz	4G 2600 MHz	ρ [kgm ⁻³]
Cortical Bones	ϵ_r	12.45	11.3	1908
	σ [Sm ⁻¹]	0.143	0.424	
Brain	ϵ_r	49.4	44.5	1046
	σ [Sm ⁻¹]	1.26	2.2	
Cerebrospi nal Fluid	ϵ_r	68.60	66	1007
	σ [Sm ⁻¹]	2.410	3.6	
Fat	ϵ_r	11.30	10.8	911
	σ [Sm ⁻¹]	0.109	0.28	
Cartilage	ϵ_r	42.70	38.4	1100
	σ [Sm ⁻¹]	0.782	1.87	
Pituitary Gland	ϵ_r	59.70	57	1053
	σ [Sm ⁻¹]	1.040	2.09	
Spinal Cord	ϵ_r	32.50	30	1075
	σ [Sm ⁻¹]	0.574	1.15	
Muscle	ϵ_r	55.00	52.5	1090
	σ [Sm ⁻¹]	0.943	1.84	
Eyes	ϵ_r	49.60	47.3	1052
	σ [Sm ⁻¹]	0.994	1.85	
Skin	ϵ_r	41.40	37.8	1109
	σ [Sm ⁻¹]	0.867	1.54	
Tongue	ϵ_r	55.30	52.4	1090
	σ [Sm ⁻¹]	0.936	1.92	
Teeth	ϵ_r	12.50	11.3	2180
	σ [Sm ⁻¹]	0.143	0.424	

TABLE II. ELECTROMAGNETIC PROPERTIES OF DENTAL AMALGAM MATERIALS.

Materials	σ (Sm ⁻¹)	ρ (kgm ⁻³)
Silver	6.3×10^7	10490
Tin	8.7×10^6	7287
Copper	5.96×10^7	8960
Zinc	1.69×10^6	7130
Mercury	1.04×10^6	13550

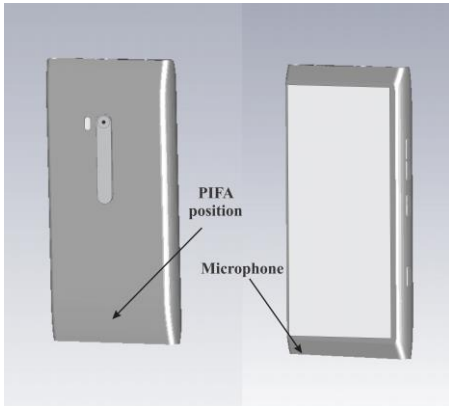


Fig. 3. External look of smart phone and position of PIFA.

For realization of precise numerical model, which correctly includes morphological and electromagnetic properties of biological tissues and organs providing calculation of the electromagnetic field distribution within the body model, the CST software package is applied [26]. CST software is based on well-known Finite Integration Technique (FIT) [27].

B. SAR Calculation

The SAR provides a direct means for measuring the RF (Radio Frequency) exposure characteristics of electromagnetic radiation source in order to ensure that source features are within the safety guidelines prescribed by safety standards and recommendations.

During the propagation of the electromagnetic wave

through the human tissue, the electromagnetic energy is absorbed. The interaction between tissues and electromagnetic waves is quantitatively modelled with SAR. Actually, SAR is defined as the speed of power dissipation normalized by material density, and it can be described by expression [28]

$$\text{SAR} = \frac{\sigma}{\rho} |E|^2, \quad (1)$$

where σ and ρ are the electrical conductivity (Sm⁻¹) and the density of tissue (kgm⁻³), respectively. It is necessary to emphasize that the electric field E (V/m) is the RMS (Root Mean Square) value.

In addition, the averaged SAR (SAR_{av}) is defined as the ratio of the power absorbed in the tissue and the tissue mass. It is obtained as

$$\text{SAR}_{\text{av}} = \frac{1}{V} \int_V \text{SAR} dV = \int_V \frac{1}{V} \frac{\sigma}{\rho} |E|^2 dV. \quad (2)$$

Mass-averaged SAR is usually determined for 1 g (SAR_{1g}) and 10 g (SAR_{10g}) samples. In this study, SAR is averaged only for 1 g due to the small teeth volumes.

III. RESULTS

In this section, the distribution of the electric field and SAR values are shown for different cross-sections of the human head model. Comparative analysis of the obtained results for models with and without dental amalgam is performed. The positions of cross-sections A, B, and C used for the analysis of the EM radiation impact can be seen in Fig. 4. It should be noted that the cross-sections are in planes, in which the tooth with dental amalgam is positioned. Accordingly, this investigation is focused on the electric field distribution and amount of absorbed energy near the dental amalgam (silver fillings).

A. Electric Field Distribution

This part of the paper refers to a comparative analysis of the electric field distribution within the models exposed to EM radiation at the mentioned frequencies, with and without dental amalgam. The electric field strength for the cross-sections A, B, and C located at the mouth region is shown in Figs. 5–7, respectively. In order to make results comparable, the model with dental amalgam (right side) and model without dental amalgam (left side) are represented at the same figure. In addition, the electric field maximum value in the colour palette on the right side of the figures is set to be the same for both models in order to enable the easier comparison of the electric field distribution inside the model.

It should be mentioned that the electric field allowable values are 41 V/m for frequency of 900 MHz and 24.4 V/m for frequency of 2600 MHz [1]–[4]. These values prescribed by standard imply analysis of free space domain, when the human is absent.

From the previous Figures, if we compare the electric field distribution when the dental amalgam is present and without the dental amalgam, a significant increase in the

strength of the electric field within the certain tissues can be noted. The highest increase of the electric field is observed in tissues that are closest to the dental amalgam (Figs. 5–7), and these values are represented in Table III for 3G and 4G frequencies.

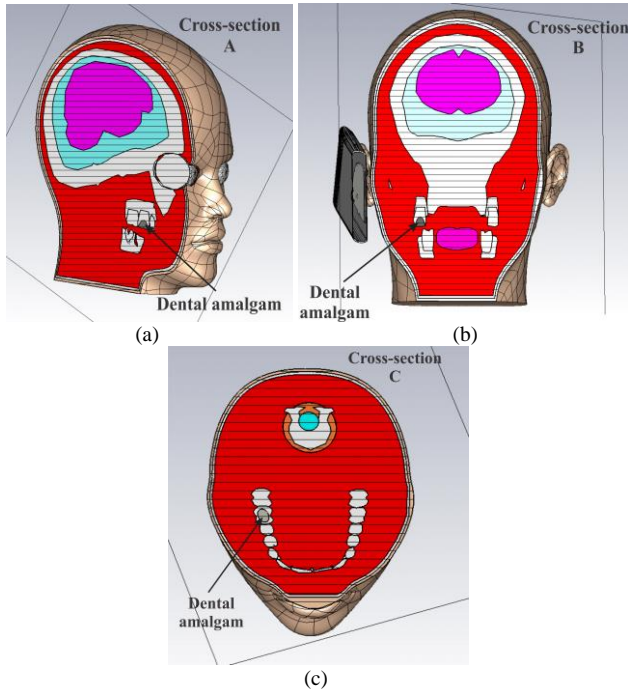


Fig. 4. (a) cross-section A; (b) cross-section B; (c) cross-section C.

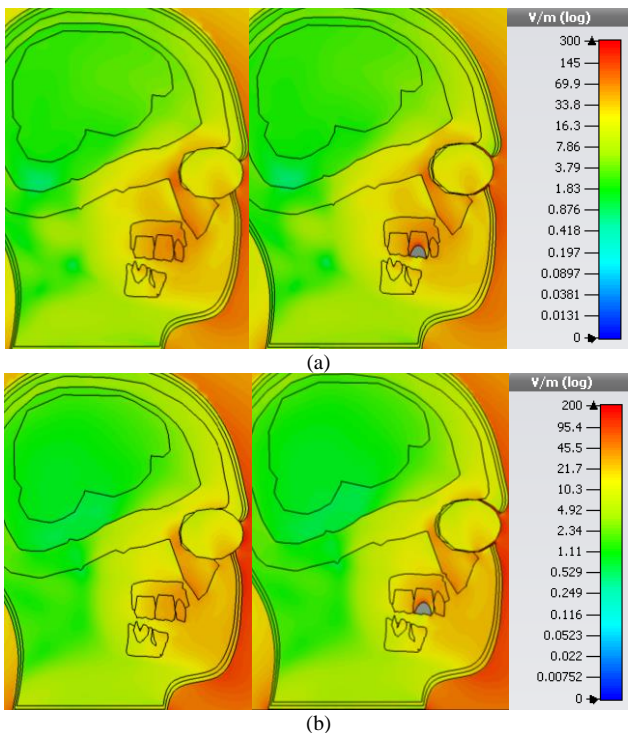


Fig. 5. Electric field distribution – cross-section A: (a) $f = 900$ MHz and (b) $f = 2600$ MHz.

TABLE III. MAXIMUM ELECTRIC VALUES IN THE VICINITY OF DENTAL AMALGAM [V/m].

Model	3G-900 MHz	4G-2600 MHz
Without amalgam	78.04	39.34
With amalgam	296.11	136.52

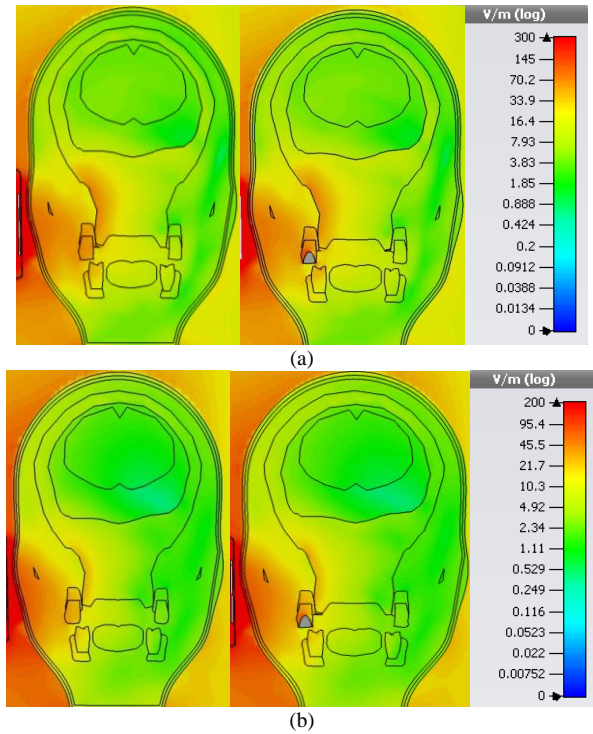


Fig. 6. Electric field distribution - cross-section B: (a) $f = 900$ MHz and (b) $f = 2600$ MHz.

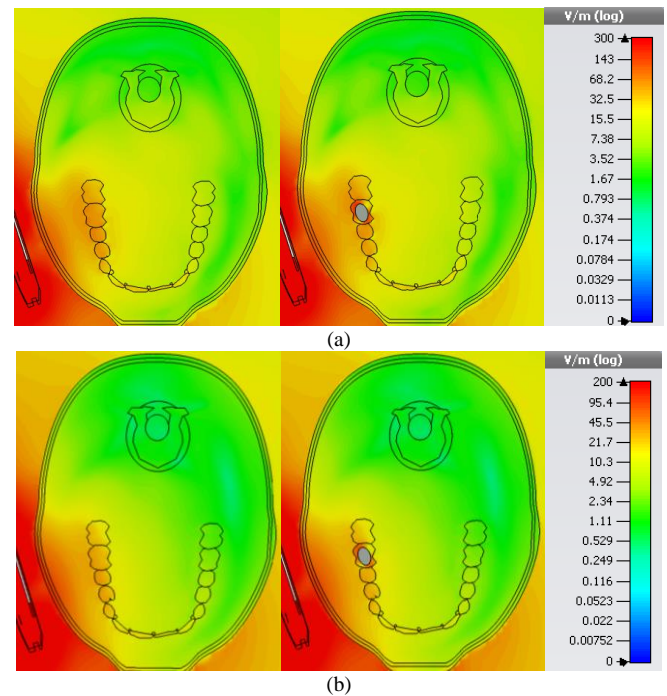


Fig. 7. Electric field distribution – cross-section C: (a) $f = 900$ MHz and (b) $f = 2600$ MHz.

The higher electric field values are observed at the frequency of 900 MHz, while these values at the LTE-4G mobile network at 2600 MHz are lower. The electric field strength peak for the model without amalgam at the 3G frequency is 78.04 V/m and this is almost four times lower than in case with dental amalgam (296.11 V/m). This ratio is lower for 4G frequency and the electric field peak is 3.5 times higher inside the model with dental amalgam (136.52 V/m).

The penetration depth decreases with the frequency

increasing since the electric field absorption is higher in the surface layers of the organs and tissues. According to the Figures 5–7 above, the impact of electromagnetic radiation on dental amalgam is smaller at the 4G frequency, but the values at both frequencies are larger than the maximum allowed values prescribed by standards. In Fig. 8 and Fig. 9, the electric field distribution at the surface of a human tooth for the model without dental amalgam (left side) and for the model with amalgam (right side) are represented for the frequencies of 900 MHz and 2600 MHz, respectively.

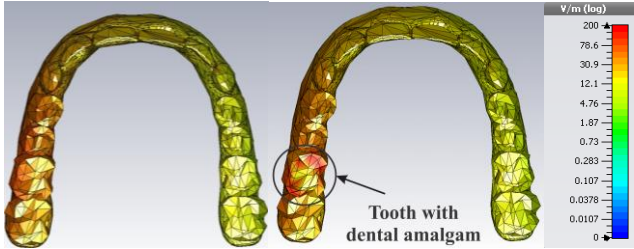


Fig. 8. Electric field distribution at the surface of model for $f = 900$ MHz.

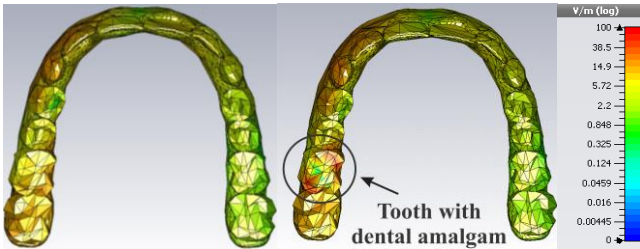


Fig. 9. Electric field distribution at the surface of model for $f = 2600$ MHz.

Based on the Figures 5–9, the overall conclusion is that the presence of dental amalgam (silver fillings) increases the electric field strength inside the biological tissues in its vicinity. The electric field strength is increased by four times, and therefore it cannot be neglected, because this value overcomes the allowable values mentioned above.

B. SAR Calculation

In this sub-section, a comparative analysis of the SAR values averaged for 1 g (SAR_{1g}) within the models (with and without dental amalgam) at the 3G and 4G mobile networks frequencies is represented. The values of SAR_{1g} for the cross sections A, B, and C located at the mouth region are shown in Figs. 10–12, respectively. Also, as previously, on the right side of the figures, the maximum values of SAR in the colour palette are set to be the same for both models.

The SAR limit for public exposure from mobile phones in accordance with appropriate safety standards amounts 1.6 watts per kilogram (1.6 W/kg) [2].

From the previous Figure 8 and Fig. 9, comparing the values of SAR_{1g} in the cases of presence and absence of dental amalgam, a significant increase in absorbed energy amount can be noticed when the amalgam is present. The maximum increase of SAR_{1g} occurs inside tissues in the vicinity of dental amalgam (Figs. 10–12), and these values are given in Table IV.

The value of the SAR_{1g} at the frequency of 900 MHz is higher than at the frequency of 2600 MHz for the LTE-4G mobile network. The SAR_{1g} peak for the model without amalgam at the 3G frequency is 1.41 W/kg, and this is 1.8 times lower than in case with dental amalgam (2.6 W/kg).

This ratio in the case of 4G frequency is higher, and the peak of SAR_{1g} is 1.9 times higher for the model with dental amalgam.

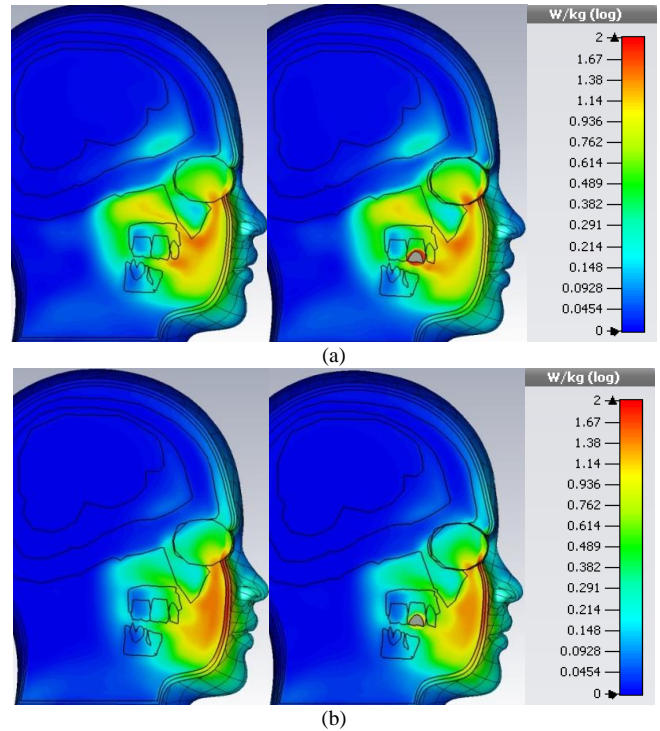


Fig. 10. Specific Absorption Rate - cross-section A: (a) $f = 900$ MHz and (b) $f = 2600$ MHz.

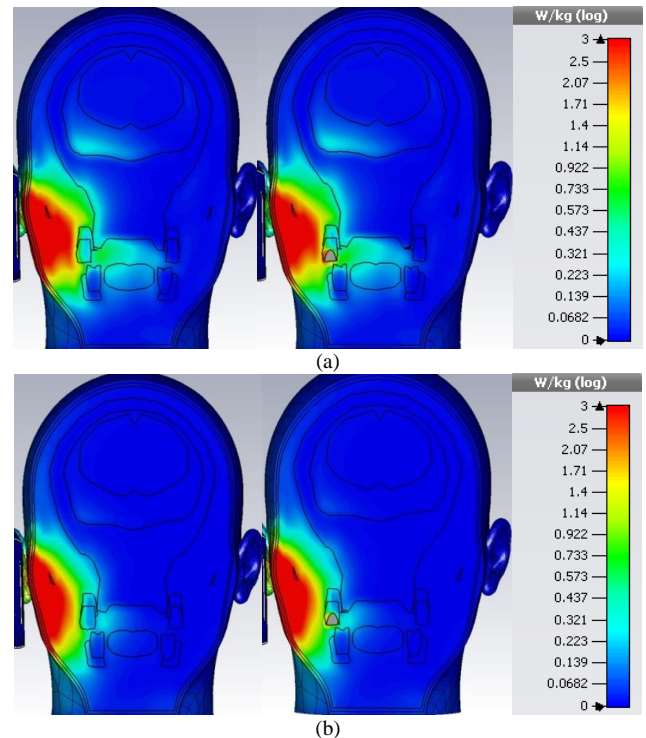


Fig. 11. Specific Absorption Rate - cross-section B: (a) $f = 900$ MHz and (b) $f = 2600$ MHz.

TABLE IV. MAXIMUM VALUE OF SAR_{1g} [W/kg].

Model	3G	4G
	900 MHz	2600 MHz
Without amalgam	1.41	0.91
With amalgam	2.6	1.74

According to the limit of SAR_{1g} , one can conclude that the

SAR value of the model without dental amalgam is inside the safety limits for both frequencies (Table IV). When the amalgam is present, the amount of absorbed energy increases and the SAR_{1g} peak overcomes the safety limits. These values amount 2.6 W/kg for 3G frequencies and 1.74 W/kg for 4G network, and therefore are not negligible. In addition, the SAR_{1g} peak at the frequency of 900 MHz is 1.6 times higher than the values prescribed by safety standards, while this ratio in the case of 2600 MHz is almost 1.1.

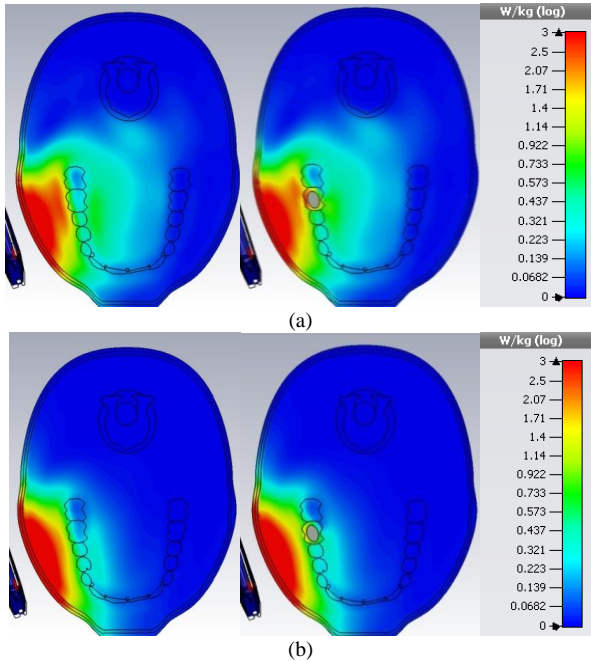


Fig. 12. Specific Absorption Rate – cross-section C: (a) $f = 900$ MHz and (b) $f = 2600$ MHz.

It is evident from the previous Figure 10 and Fig. 11 that the increase of electromagnetic wave energy absorption exists in the vicinity of dental amalgam. Obviously, the value of SAR_{1g} at the surface of tooth with dental amalgam is higher than without amalgam. This increase occurs in the case of both network frequencies (3G and 4G), but the peak of SAR_{1g} is higher at the frequency of 3G network.

IV. DISCUSSION

According to the obtained results presented in the previous Section, it is shown that the electric field maximum value in the vicinity of dental amalgam exposed to the mobile phone radiation is higher in a presence of dental amalgam than without it. This increase of electric field is higher in the case of 3G mobile network. It is expected, since it is well known that the electromagnetic waves penetration depth is larger at lower frequencies. At 3G frequency, the maximum value of electric field strength in the vicinity of tooth without dental amalgam amounts 78.04 V/m, while with amalgam is 296.11 V/m, which is almost four times higher. These values at 4G frequency are 39.34 V/m (without dental amalgam) and 136.52 V/m (with dental amalgam), which is 3.5 times higher.

As it has been previously mentioned, the allowable values for the electric field are 41 V/m and 24.4 V/m at the frequencies of 900 MHz and 2600 MHz, respectively. Comparing the results obtained by numerical calculation

with the allowable values prescribed by adequate standards, it is evident that obtained results exceed the safety limits. The values of electric field strength in the vicinity of tooth without dental amalgam at 3G and 4G frequencies are 1.9 and 1.6 times higher than the allowable values, respectively, while this ratio is higher in the case of dental amalgam presence. The maximum values of electric field in the vicinity of dental amalgam at 3G and 4G frequencies are 7.2 and 5.6 times higher than the allowable values, respectively. It has been already emphasised the use of these values include presumption that human is absent, i.e., that observed domain is actually free space.

Based on the obtained results for SAR in the vicinity of dental amalgam, one can notice significant increasing of the absorbed energy amount when the dental amalgam is present. The maximum increase of SAR_{1g} occurs inside tissues in the vicinity of dental amalgam. The higher value of the SAR_{1g} in the vicinity of tooth with amalgam is observed at the frequency of 900 MHz, while the lower value is observed for the LTE-4G mobile network. The SAR_{1g} peak in the vicinity of the tooth without dental amalgam at 3G frequency is 1.41 W/kg, while this value in the case of tooth with silver filling is 2.6 W/kg, and this is 1.8 times higher. Based on the results for amount of absorbed energy at 4G and 3G frequencies, it can be concluded that the value of SAR is lower in the case of 4G mobile networks. The SAR_{1g} peak in the vicinity of the tooth without dental amalgam at 4G frequency is 0.91 W/kg, while this value in the case of tooth with silver filling is 1.74 W/kg, and this is 1.9 times higher.

It is necessary to recall the fact stated above that the SAR limit for public exposure from mobile phones in accordance with appropriate safety standards amounts 1.6 W/kg. If we performed comparative analysis of the results obtained by numerical calculation and the allowable values prescribed by adequate standards, we can notice that the obtained results exceed the safety limits only when the amalgam is present. The SAR_{1g} in the vicinity of tooth without dental amalgam at 3G and 4G frequencies is lower than the allowable values. This cannot be said for the SAR_{1g} in the vicinity of tooth with the dental amalgam. The SAR_{1g} in the vicinity of dental amalgam at 3G and 4G frequencies is 1.6 and 1.1 times higher than the allowable values, respectively.

V. CONCLUSIONS

This study investigated the electrical field and SAR values distributions within biological tissues in the vicinity of dental amalgam exposed to the electromagnetic radiation. The numerical calculation was performed for the frequencies of 3G (900 MHz) and 4G (2600 MHz) mobile networks. The comparative analysis is presented for two models, one with and the other without dental amalgam.

The presented results suggest a conclusion that maximum electric field value in the space exposed to the mobile phone radiation exceeds allowable value with and without presence of dental amalgam. The obtained maximal values are higher for the case when dental amalgam is used. In addition, maximal field values for 3G frequency are higher than those ones obtained for 4G frequency.

The Specific Absorption Rate values do not exceed allowable values in the observed domain, without dental amalgam presented. In the presence of dental amalgam, those values are higher than allowable ones, especially for the values corresponding to 3G frequency.

The presented modelling and simulation procedures have been prepared and implemented in a way that justifies confidence in the results obtained. Possible experimental validation is conditioned and limited by both practical requirements and ethical standards.

This research can be a good foundation for multidisciplinary studies involving medical professionals. It is the proper way of studying the biological effects due to the influence of dental amalgam presence in the tooth exposed to the electromagnetic radiation from mobile phone.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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