ORIGINAL ARTICLE

Measurement and Calculation of SAR Due to 900 MHz Electromagnetic Waves

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Abstract

Purpose: The widespread use of mobile phones and Base Transceiver Stations (BTSs) has generated public concern about exposure to Electromagnetic (EM) waves. In this study, the electric field intensity and Specific Absorption Rate (SAR) in the emergency, general hospitalization, radiology, and laboratory departments of four hospitals in Arak (Iran) are reported.

Materials and Methods: Electric field strength in the 900 MHz frequency band was obtained using a TES 592 radiometer. Then, SAR induced in the brain, skin, fat and bone tissues were calculated based on equations and the obtained values were compared with the thresholds recommended by the International Commissions.

Results: The obtained results showed that the electric field's mean value was 1.334 V/m which is almost 2.7% of the threshold introduced by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and 2.6% of the threshold adopted by the Institute of Electrical and Electronics Engineers (IEEE). The highest SAR value was 1.6 W/kg for the skin, which is lower than the threshold values presented by ICNIRP (2 W/kg) and IEEE (1.6 W/kg).

Conclusion: The findings of the present work show that for both quantities in Arak hospitals the SAR values are less than the thresholds announced by IEEE and ICNIRP committees. To deal with the concerns of the community that is generally caused by a lack of awareness, the executions of educational and public awareness programs are recommended.

Keywords: Electric Field Intensity; Specific Absorption Rate; Electromagnetic Waves; Measurement.

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1. Introduction

Nowadays, the application of mobile phones is an inseparable part of human life so that the level of use of such devices by a community is an index denoting the development of that community. On the other hand, the use of mobile phones exposes humans to Electromagnetic (EM) radiation and this has resulted in concerns about the adverse effects of these devices. In the last decade, numerous researchers have warned about the potentially harmful effects of EM waves. Adequate coverage of mobile phone operators depends on the quantity and quality of Base Transceiver Stations (BTSs), and besides mobile phones, these antennas are also responsible for the development of the internet network coverage. BTSs have three sectors, each with 120 degrees to cover blind points, which altogether provide a 360 degrees coverage [1]. They normally have a 30 km range in a free region without buildings, which is practically assumed to be 20 km. If a BTS is installed in a city with high buildings, it is assumed that its useful range of coverage is ranging between 2 to 5 km [2].

The effects of exposure to EM waves are divided into two main groups: thermal effects, which are originated from high intensities; and nonthermal effects, which are due to the low levels of these waves. The latter is included in the subject of the present research. Although exposure to low levels of EM waves from mobile phones has nonthermal effects, long-term or even permanent exposure can lead to effects that are comulatative or equal to thermal effects [3]. Specific Absorption Rate (SAR) is the quantity describing the absorbed energy per mass from EM radiation that was received by a person [4].

Besides, hospitals must be evaluated and be safe from toxic, infectious, and viral factors; it is also necessary to evaluate such environments from other radiation factors such as ionizing, ultraviolet, and EM radiations. Although the evaluation of different parts of hospitals based on X- and gamma-rays has a long-term background, there was not enough attention to EM waves and fields. It is important to evaluate such environments from the point of view of exposure to EM waves, based on comparison with the thresholds and limits determined by international organizations such as the World Health Organization (WHO) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). This is also important because the hospital personnel attend these departments for a long period of time. High levels of EM waves can also have adverse interference with unshielded units with radiofrequency communications in these locations [5].

In 2013, Bhat and Kumar [6] carried out a study by measurement of SAR in a human head model from EM waves in 900 MHz and 1800 MHz frequencies, as the working frequencies of mobile phone operators. The temperature increase was measured at different points of the head using a non-reflective chamber. Their results showed that based on the international committees such as WHO and ICNIRP, the SAR values higher than 1.6 W/kg can have adverse biological effects for a 75-kilogram-weight human. It was also observed that the thermal effects due to exposure to EM waves for bone are less than soft tissue. Kaur and Dhami [7] in 2012 measured SAR and intensity of EM waves around BTS antennas using a TES 593 device. At first, the electric field strength was measured and then the SAR was calculated based on a mathematical formula. The measurements were done in 8 directions at different distances. Their results showed that there were maximum and minimum values in some directions, while the levels were less than the permissible limits in all of the measurements. In 2012, Bortkiewicz *et al.* [8] designed a study to evaluate the health and mental conditions of people living around mobile phone BTSs. The relation between clinical symptoms and the level of exposure to EM radiation was investigated. The symptoms included were: headache, memory disorders, skin changes, depression, fatigue, eye irritation, vertigo, visual, hearing, and some other disorders.

Eger and John [9] in 2008 studied the health condition of people living near BTSs, based on their distances from such stations. The people had filled questionnaires indicating their health condition. They were divided into 7 groups based on their received radiation level and distance from BTS. The results indicated a relationship between the distance from BTS and disorders such as sleep disorders, depression, infection, skin sensitivity, cardiovascular, and some other disorders.

In 2012, Fragopoulou *et al.* [10] carried out a study on the long-term effects of whole-body EM irradiation on mice brains. The mice were divided into three groups, two of them were exposed to different levels of EM waves, and the last one was considered as the sham group. Their results revealed that long-term irradiation with the EM fields has changed the expression of 143 proteins. This finding on different proteins can be a scientific explanation for various human health hazards such as headache, memory deficits, sleep disturbance, etc. due to exposure to EM radiation. In a cohort study by Frei *et al.* [11] on 400 Swiss people in 2012, it was mentioned that EM waves from BTS could not affect non-specific health symptoms and tinnitus. The study groups included 30-60-year-old males and females who were living at close or far distances from the antenna (at the region of interest), at least for 5 years. In another study, Kato *et al.* [12] performed a questionnaire survey on 75 Japanese people to evaluate the effect of different EM sources on 43 health symptoms. The maximum symptoms were related to fatigue (85%), headache (81%) and sleep disorders (76%). The most concerns about the health effects were respectively related to the people who were near the mobile phone BTSs (71%), those who were close to a person having mobile phone call (64%), and using a personal computer (63%), and those who were near the power transmission lines (60%) and television (56%).

In 2012, Komeili *et al.* [13] examined the effect of EM waves on the electrocardiogram parameters. The evaluations were on 40 students in the Zahedan university and the subjects were divided into two groups: having phone calls and not having phone calls. The results indicated a significant difference in the heart beating in both male and female students due to the mobile phone calls between the two groups.

Although different studies were done in various regions, the intensity of EM waves in different cities depends on various factors and should be evaluated for each city. The present work aims to measure and evaluate the SAR level from 900 MHz EM waves in different departments of several hospitals in Arak city. This quantity is measured for the different body tissues.

The 900 MHz frequency (the frequency that is used in cell phones) was used in this research because of these reasons: 1) These days most people are cell phone users and most population of society has concern because of thesedevices. 2) the extensive use of cell phone as a device that has the ability to provide services such as transferring audio, video, cyberspace, news, and social networks by using 900MHz waves. 3) The mobile waves emitted from the BTS have a longer range than waves such as Wi-Fi or wire-less phones, so in most departments, hospitals, companies, and outdoor places, pepole use cell phones instead of traditional phones, so evaluating the effect of these waves (900MHz) was the aim of this paper.

2. Materials and Methods

A TES 952 radiometer was calibrated in terms of electric field strength in 900 MHz band frequency. This radiometer has the potential for isotropic measurement in three axes directions. For each measurement, to be confident about the isotropic response in three directions, a primary evaluation was performed. Measurement of electric field strength was carried out in the mean and the maximum of the mean modes during 6 minutes, based on the recommendations by ICNIRP and Institute of Electrical and Electronics Engineers (IEEE) reports [5], and the results were recorded in appropriate tables. Following this procedure, the SAR value was calculated according to the following Equation:

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

Where σ is the conductivity, E is the electric field strength and ρ is the mass density.

The SAR values were calculated for bone, fat, brain and skin tissues. The conductivity and mass density for these tissues are presented in Table 1 based on the literature.

The measurements were performed in the emergency, general hospitalization, radiology, and laboratory departments. It was taken into account any mobile phones near the radiometer were avoided during the measurements. The measurements were done in four hospitals, including Ayatollah Khansari, Amir Al Momenin, Vali -e- Asr, and Qods hospitals in Arak city (Iran).

Table 1. Conductivity and mass density for bone, fat, brain and skin tissues

	Bone	Fat	Barin	Skin
Conductivity (Siemens/m)	0.34	0.11	0.765	0.87
Mass density (kg/m^3)	1990	916	1038	1125

3. Results

The SAR ($\times 10^{-3}$ W/kg) and electric field strength (V/m) values in the emergency, general hospitalization, radiology, and laboratory departments in the hospitals number 1 to 4 are presented in Tables 2-5.

Table 2. SAR values (×10^{-3} W/kg) and electric field strength (V/m) in departments of hospital number 1

	Bone		Fat		Brain		Skin		Electric field strength (V/m)	
	Maximum	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**
Emergency	0.309	0.083	0.217	0.058	1.333	0.359	1.398	0.376	1.345	0.698
General Hospitaliziation	0.058	0.030	0.041	0.021	0.248	0.130	0.261	0.137	0.581	0.421
Radiology	0.180	0.091	0.126	0.064	0.774	0.390	0.812	0.410	1.025	0.728
Laboratory	0.049	0.010	0.034	0.007	0.209	0.041	0.220	0.044	0.533	0.238

Table 3. SAR values (×10^{-3} W/kg) and electric field strength (V/m) in departments of hospital number 2

	Bone		Fat		Brain		Skin		Electric field strength (V/m)	
	Maximum	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**
Emergency	0.166	0.051	0.117	0.036	0.717	0.221	0.752	0.232	0.986	0.548
General Hospitaliziation	0.106	0.018	0.075	0.013	0.457	0.078	0.480	0.083	0.788	0.327
Radiology	0.082	0.021	0.058	0.015	0.354	0.091	0.371	0.096	0.693	0.352
Laboratory	0.032	0.004	0.022	0.003	0.136	0.015	0.143	0.016	0.430	0.145

Table 4. SAR values (×10^{-3} W/kg) and electric field strength (V/m) in departments of hospital number 3

	Bone		Fat		Brain		Skin		Electric field strength (V/m)	
	Maximum	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**
Emergency	0.673	0.260	0.473	0.182	2.904	1.122	3.047	1.177	1.985	1.234
General Hospitaliziation	0.162	0.072	0.113	0.051	0.699	0.313	0.733	0.328	0.974	0.652
Radiology	0.137	0.033	0.096	0.023	0.594	0.145	0.623	0.153	0.898	0.445
Laboratory	0.037	0.008	0.026	0.005	0.160	0.036	0.167	0.038	0.466	0.223

Table 5. SAR values (×10^{-3} W/kg) and electric field strength (V/m) in departments of hospital number 4

	Bone		Fat		Brain		Skin		Electric field strength (V/m)	
	Maximum	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**	**Maximum**	**Mean**
Emergency	0.080	0.021	0.056	0.015	0.346	0.093	0.362	0.098	0.685	0.356
General Hospitaliziation	0.115	0.052	0.081	0.036	0.498	0.224	0.522	0.235	0.822	0.552
Radiology	0.139	0.051	0.097	0.036	0.600	0.221	0.629	0.232	0.902	0.548
Laboratory	0.075	0.025	0.053	0.017	0.327	0.109	0.343	0.114	0.666	0.385

As it is evident from Table 2, for hospital number 1, the maximum value of the mean electric field strength is related to the radiology department which is 0.728 V/m.

The highest value of the maximum electric field is related to the emergency department which is 1.345 V/m. The maximum value of the mean SAR for skin is 0.410 W/kg×10^{-3} which is related to the radiology department and is considerably less than the 2 and 1.6 W/kg recommended by ICNIRP and IEEE [14-16]. The calculations show that the maximum value of the mean SAR for the brain in the radiology department is 0.359 W/kg, which is considerably less than the 2 W/kg of ICNIRP and the 1.6 W/kg of IEEE [14-16].

As it is evident from Table 3, for hospital number 2, the maximum value of the mean electric field strength is related to the emergency department which is 0.548

V/m. The highest value of the maximum electric field is related to the emergency department which is 0.986 V/m. The maximum value of the mean SAR for skin is 0.232 W/kg$\times 10^{-3}$ which is related to the emergency department and is considerably less than the 2 and 1.6 W/kg values recommended by ICNIRP and IEEE respectively [14-16]. The calculations show that the maximum value of the mean SAR for the brain in the emergency department is 0.221 W/kg, which is considerably less than the 2 W/kg of ICNIRP and the 1.6 W/kg of IEEE [14-16].

As it is evident from Table 5, for hospital number 4, the maximum value of the mean electric field strength is related to the general hospitalization department which is 0.552 V/m. The highest value of the maximum electric field is related to the radiology department which is 0.902 V/m. The maximum value of the mean SAR for skin is 0.235 W/kg$\times 10^{-3}$ which is related to the general hospitalization department and is considerably less than the 2 and 1.6 W/kg values recommended by ICNIRP and IEEE, respectively [14-16]. The calculations show that the maximum value of the mean SAR for the brain in the radiology department is 0.221 W/kg, which is considerably less than the 2 W/kg of ICNIRP and the 1.6 W/kg of IEEE [14-16].

4. Discussion

In recent years, facilities were provided by mobile phone operators for the communication of information using wireless networks. Since the transfer of the information is based on the transmission, of EM

As it is evident from Table 4, for hospital number 3, the maximum value of the mean electric field strength is related to the emergency department which is 1.234 V/m. The highest value of the maximum electric field is related to the emergency department which is 1.985 V/m. The maximum value of the mean SAR for skin is 1.177 W/kg$\times 10^{-3}$ which is related to the emergency department and is considerably less than the 2and 1.6 W/kg values recommended by ICNIRP and IEEE respectively [14-16]. The calculations show that the maximum value of the mean SAR for the brain in the emergency department is 1.122 W/kg, which is considerably less than the 2 W/kg of ICNIRP and the 1.6 W/kg of IEEE [14-16].

waves, there are concerns in the public about the adverse effects of such waves. Limits and thresholds for EM radiation were developed by international committees in terms of the SAR. Estimation of the SAR is normally performed by simulation or in-phantom measurement, which are based on mathematical calculations and computer programs. In the present study, SAR and electric field strength were estimated based on measurements and calculations in four departments of four hospitals in Arak city in Iran.

There are several frequencies in the EM spectrum. Mobile phones are low-powered radiofrequency transmitters, operating at frequencies between 450 and 2700 MHz with peak powers in the range of 0.1 to 2 watts. In Iran, the common frequency is 900 MHz. So, our measurements were based on calibration in 900 MHz frequency. The maximum electric field strength is related to the emergency department of hospital number 3, which is 1.334 V/m. The evaluations have shown that the maximum value at this location can be due to a larger number of people who communicate via mobile phones, the presence of official and private centers using wireless communications, and different communication towers which are located near this department. The results show that while the maximum value is related to the emergency department of hospital number 1, its value is 2.7% of the threshold announced by ICNIRP and 2.6% of the threshold announced by IEEE [17]. This is in agreement with the research done by Henderson and Bangay [18] in Australia. In that study, it was reported that the level of EM radiation around the antenna was about 0.2% of the permissible limit. The difference between these two works is that in the present study the radiation level was based on measurement of the electric field strength but in the study of Henderson *et al.* it was based on the intensity in terms of W/m^2.

The range of electric field strength was 0.012-0.343 V/m, based on the results reported by Schüz and Mann [19]. These values are less than most of the values presented in the present work. Some differences between the values in these studies can be due to the date of making the measurements since that study is related to the year 1999. One decade of advancement and growth of communication and information technology in the form of wireless data can result in a higher intensity of EM waves. This implies the necessity of continuous and annual measurement of EM radiation and also updating the related protocols.

The study by Urbinello *et al.* in 2014 [20] indicates that the mean electric field strength related to Amsterdam (Netherland) and Basel (Switzerland) regions were 0.41

V/m and 0.22 V/m, respectively. The value for Basel is in agreement with the results of the present work. They reported that 95% of the measured values in Europe are between 0.82 V/m for Amsterdam and 0.46 for Basel. Their values also indicate that the measured electric field strength values were less than the limits by ICNIRP. Based on the mean values obtained through practical measurements, they believed that there is not a need to review the regulations developed by the international committees.

There is a considerable difference in the SAR values between the present work and the study of Sallomi in 2012 [21]. The results in that study show that the SAR values for Global System for Mobile (GSM) 900 MHz EM waves for brain, skin, fat, and bone are 0.0270, 0.1029, 0.0596, and 0.0406 W/kg, respectively. Their results show differences with an order of 10^{-3} with the present values. These differences may be because in that study the method for the estimation was simulation and calculation, but the values were measured in the present work. Furthermore, there are other practical differences between the methods in these two studies.

The results of the present work for the SAR and electric field strength are in agreement with the study by Wout *et al.* [22] in 2010. In that study, the electric field strength was 0.36 V/m. For the two 1- and 10-year old children and male and female people who were simulated, the whole-body SAR was ranging between 7.9 µW/kg to 11.5 µW/kg. The values obtained in both studies are below the limits reported by standards. The difference between the methods in these two studies is that the SAR was reported for different tissues in the present work, but it was reported as the whole-body value in that study.

The results in the present work are not in agreement with those presented by Kumar *et al.* [23]. In that study, both the SAR and electric field strength are higher than those in the present work. The difference may be due to different distances of measurement points from the antenna in the two studies. In that study, the measurements were mostly performed at a few centimetres from the towers.

The aim of comparing the results of the present study with other studies (BTS antennas) was to evaluate the threshold of the standard protocols (regardless of the unit used). In addition, in the present study, we intended to compare the possible effects of the waves between the performed studies, regardless of the unit of measurement.

5. Conclusion

The results of the present study show that the SAR and electric field strength values in the departments in hospitals in Arak city are less than the threshold announced by the standard committees, ICNIRP and IEEE. There is also an agreement between the results of the present study and those reported by Dhami *et al.* The advantage of the present study is that the SAR values are reported for different tissues (bone, fat, brain, and skin). The concerns of the community from electromagnetic waves with frequency of 900 MHz are generally caused by the lack of public awareness and therefore to overcome the concerns from in the public, executive of public awareness programs are recommended. It is suggested that more departments and locations, including schools and kindergartens, be evaluated based on the measurement of electromagnetic waves in future studies. Additionally, measurement of other quantities such as intensity and comparison with the thresholds introduced by standard reports can be useful.

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