The effect of battery charge levels of Mobile phone on the amount of Electromagnetic waves emission

Javad Sajedifar^{1,2} · Parvin Nassiri³ · Mohammad Reza Monazzam³ · Mansour Shamsipour⁴ · Ramin Ramezani⁵

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Abstract

Purpose Over the past decades, mobile phone usage have increased dramatically. Extensive development and use of mobile telecommunication services has increased exposure to radio frequency electromagnetic waves (RF-EMW) in the daily lives of humans, and concerns about the harmful effects of mobile phones have also increased on human health. Therefore, this study aimed to investigate the effect of battery charge levels of the mobile phone on electromagnetic waves emission.

Methods The mobile phone used in the current study was HTC One E9+ (0.181 W/kg SAR) with a non-removable battery model Li-Po 2800 mAh. The power density was measured with the mobile phone set to operate at the 2G mode by a SMP2 Portable Electromagnetic Field Monitoring System. Power density was measured in Calling mode (50 sec), Called mode (40 sec) and Talking mode (360 sec) at the battery charge levels of 1, 5, 10, 15, 20, 30, 50, 60, 70, 80 and 100%.

Results In Calling mode, the maximum electromagnetic waves were determined when the mobile phone had 1% battery charge and also while it was being charged. Contrary to Calling mode, there is no statistically significant difference between the power density emitted in Called mode and Talking mode at the various battery charge levels. Power density was found to be highest in the Called mode ($29.11 \mu\text{W}/\text{cm}^2$), and to be higher in the Talking mode ($23.005 \mu\text{W}/\text{cm}^2$) than in the Calling mode ($10.27 \mu\text{W}/\text{cm}^2$).

Conclusions The data of the present study can be used to monitor the daily exposure of mobile phone users as well as to estimate exposure levels in the laboratory and non-laboratory studies. As long as a mobile phone that is in the standby mode remains within the geographic domain of the operator's service zone, the power density emitted from that phone will be virtually zero, and any background wave can be attributed to other sources.

Keywords Battery charge level · Mobile phone · Electromagnetic field · Power density

Introduction

Over recent decades, the world has witnessed a dramatic increase in the usage of mobile phones. As with any modern technology, the prevalent use of mobile phones raises some concerns about its potential impacts on human health [1].

These concerns arise from the fact that extensive growth and development of mobile telecommunication services over the past few decades has significantly increased the radio frequency electromagnetic waves that people are exposed to in their everyday life. In 1996, the World Health Organization (WHO) launched the International EMF (Electromagnetic Field)

✉ Parvin Nassiri
nassiri@sina.tums.ac.ir

Javad Sajedifar
sajedifarj1@num.s.ac.ir; javad.sajedifar@yahoo.com

Mohammad Reza Monazzam
mmonazzam@hotmail.com

Mansour Shamsipour
shamsipour@sina.tums.ac.ir

Ramin Ramezani
rramezani@tadbirsanjesh.com

¹ Department of Occupational Health Engineering, School of Public Health, Neyshabur University of Medical Sciences, Neyshabur, Iran

² Department of Occupational Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran

³ Department of Occupational Health, School of Public Health, Tehran University of Medical Sciences, Tehran P.O.BOX:14155-6446, Iran

⁴ Department of Research Methodology and Data Analysis, Institute for Environmental Research, Tehran University of Medical Sciences, Tehran, Iran

⁵ Wavecontrol S.L., Tadbir Sanjesh Tavana Company, Tehran, Iran

Project (as part of its Public Health Protection Act) to acquire scientific evidence concerning the potential effects of electromagnetic waves in the frequency range of 30 Hz to 300 GHz. Despite extensive research carried out in this area, the potential damaging impact of electromagnetic radiations is still under debate [2]. Recently, several studies have shown the adverse effects of mobile phones on human health, and the public concern about these effects has been on the rise [1]. The WHO is particularly concerned that any claim about the adverse health implications of mobile phones can become a colossal public concern. Even the slightest health concerns about this technology can have a major impact on public health, particularly in developing countries that have expanded this technology as an alternative to more expensive landlines [3]. There have been several studies on mobile phones and mobile communication technologies to better understand their impacts on the cardiovascular system, sleep, cognitive functions, neurosecretion, hormone secretion, tumor induction, and genotoxicity potential [4–14]. Researchers have also proposed some mechanisms that illuminate the various aspects of damaging impacts of the mobile phone on human health, and male fertility in particular [1]. Mobile phones emit electromagnetic radiation in the frequency range of 880–2200 Hz, which can be absorbed by the human body [15]. The primary mobile communications standard used by the majority of European and Asian countries, including Iran, is the Global System for Mobile Communications (GSM) originally developed in 1987. In the GSM system, the waves transmitted from the phones to the BTS (Base transceiver station) range from 870 to 915 MHz (uplink) and those transmitted from the BTS to the Mobile phones range from 935 to 960 MHz (downlink) [16]. The GSM system is the pillar of mobile communication and is widely used in all corners of the world [17]. In 2010, approximately 37 million Iranians were using GSM-based mobile phones [18]. It has been reported that while using a mobile phone, the head temperature increases by up to 0.6 °C [19]. A research conducted by Golmohammadi et al. on the electromagnetic fields of mobile phones commonly used in Iran has shown significant differences between the power densities of these phones while the user is having a phone conversation [20]. A study by Elcin Ozgur et al. examined the differences between the callers and the recipients of calls in this respect [21]. In a study by Riddervold et al., exposure to the electric field of mobile phones was measured to the range of 0.9–2.2 V/m [22]. The strength of electromagnetic fields can be expressed based on electric field strength (E) expressed in terms of (V/m), magnetic field strength (H) expressed in terms of (A/m), and power density expressed in terms of (W/m^2) [23]. Considering the suspected health implications of mobile phones as one of the most important and prevalent sources of electromagnetic radiation and a growing public belief that the mobile phone radiations depend on the battery charge level, this study aimed to investigate the effect of battery charge

level on the emission of electromagnetic waves from mobile phones.

Materials and methods

The method used in this study to determine the level of electromagnetic radiation emitted by mobile phones at different battery charge levels is illustrated in Fig. 1. The power density of the mobile phone was measured in an acoustic chamber at a constant temperature [21]. The electromagnetic waves generated by the mobile phone were measured by a SMP2 Portable Electromagnetic Field Monitoring System attached to a WPF18 Field Probe, which is capable of measuring electromagnetic fields in the frequency range of 300 kHz to 18 GHz in RMS and Isotropic modes. This device has a sensitivity of about 0.5 V/m, and has the best attenuation at the frequencies of 60–50 Hz. This probe can be used to measure the field strength in telecommunication equipment (GSM, 3G, LTE, TDT, AM, FM, Wi-Fi, etc.), as well as military sites, laboratories, and industries where people are exposed to electromagnetic waves generated by devices and equipment [24]. The exposure to electromagnetic waves was determined through IS measurement, which is the most typical set up developed in line with international standards. Using this measurement set up, field strengths were measured at 1-s log intervals and then averaged over a 6-min period [24]. Using an optical fiber, the recorded data were transferred from the measurement device to a computer, where it was stored for analysis. The mobile phone used in this study was HTC One E9+ (0.181 W/kg SAR) with a non-removable battery model Li-Po 2800 mAh. The radiations were measured with the mobile phone set to operate at 2G mode. The SMP2 sensor (SMP2 Portable Electromagnetic Field Monitoring System, wavecontrol company, Barcelona, Spain) was positioned 5 cm away from the mobile phone. Before the tests, several pretest sound measurements were performed in the acoustic chamber to determine the sound pressure levels generated by a person talking in a normal tone into a mobile phone held in front of his mouth. In this pretest, the user was asked to read a phonetic script continuously for 6 min in front of a tape recorder. The minimum, maximum, and average sound pressure levels measured in this pretest were respectively 47, 77, and 71 dB. This sound was also recorded to be later used in the main tests. In the main tests (in the Talking mode explained below), the recorded sound was played through a speaker with the volume adjusted so that mobile microphone captured it with an average pressure of 71 dB. Before these tests, the background electromagnetic waves were also measured for 6 min [21, 25]. For each battery charge level, power density was measured in three modes:

Fig. 1 Measurement of electromagnetic waves emitted by mobile phones in different battery charges

- (i) Calling mode: when the phone was making a call (for 50 seconds);
- (ii) Called mode: when the phone was receiving a call (for 40 seconds);
- (iii) Talking mode: when a call was established and a conversation was being made (for 360 seconds).

Field strength measurements were made at the battery charge levels of 1, 5, 10, 15, 20, 30, 50, 60, 70, 80 and 100%. A separate measurement was also performed when the phone had 1% battery charge and was plugged into a power outlet (while it was being charged). The measurements were replicated three times for each determination. Comparison of power density between the battery charge levels was done by a one-way analysis of variance test. Analyses were performed using Prism version 7.03. Post hoc pairwise comparisons were done using a bonferroni test, P values of $0 < 0.05$ were considered to be significant.

Results

The power density emitted during the Calling mode, Called mode, and talking mode at different battery charge levels was measured in $\mu\text{W}/\text{cm}^2$. The results of electromagnetic field

measurements were analyzed using the software Graph Pad Prism ver. 7.03.

Figure 2 shows the power density emitted from the HTC One E9+ mobile phone in the Calling mode at different battery charge levels. As mentioned, before the main tests, the background waves in the measurement chamber were measured as well. The waves emitted from the mobile phone in the Calling mode were found to be significantly stronger than the background waves. As shown in Fig. 1, however, the highest electromagnetic emission level was measured when the phone had 1% battery charge and was plugged into a power outlet. The measurements showed no statistically significant difference between the waves emitted at charge levels of between 5% and 80%. In the Calling mode, the highest power densities were measured at 1% charge level ($38.08 \pm 19.08 \mu\text{W}/\text{cm}^2$), charging state ($29.16 \pm 14.31 \mu\text{W}/\text{cm}^2$), and 100% charge level ($19.44 \pm 14.71 \mu\text{W}/\text{cm}^2$) in that order. Meanwhile, the background values of power density in the Calling mode were $0.028 \pm 0.009 \mu\text{W}/\text{cm}^2$. The waves emitted in the above-mentioned conditions were significantly stronger than those emitted at other battery charge levels.

Figure 3 illustrates the power density ($\mu\text{W}/\text{cm}^2$) of the waves emitted from the HTC One E9+ mobile phone in the Called mode at different battery charges. In this case, the only significant difference was observed between the waves emitted when the phone was receiving a call and the background

Fig. 2 Power density ($\mu\text{w}/\text{cm}^2$) emitted from mobile phone (HTC ONE E 9+) when make a call in different battery charges. N=50 (Mean $\pm$ SD)

values. In other words, unlike the Calling mode, there was no statistically significant difference between the waves emitted when the phone was receiving a call at different battery charge levels. It is also interesting that for all battery charge levels, over the first 10 s after the call is received, the power density

peaks in 2 s and then declines to a lower level. In this mode, the power density at different charge levels varied from 25.06 to 35.05 $\mu\text{w}/\text{cm}^2$.

Figure 4 shows the power density of the waves emitted from the HTC One E9+ mobile phone in the Talking mode

Fig. 3 Power density ($\mu\text{W}/\text{cm}^2$) emitted from mobile phone (HTC ONE E 9+) when receive a call in different battery charges. N=40 (Mean $\pm$ SD)

Fig. 4 Power density ($\mu\text{W}/\text{cm}^2$) emitted from mobile phone (HTC ONE E 9+) during a call in different battery charge. N=360 (Mean $\pm$ SD)

at different battery charge levels. As indicated in this figure, significant differences were found between the power densities measured in the Talking mode at different battery charge levels. In all of the aforementioned modes (Calling, Called, and Talking), there was a significant strength difference between background waves and phone waves. After comparing the power densities measured in the Calling, Called, and Talking modes in Figs. 2, 3 and 4, power density was found to be highest in the Called mode ($29.11 \mu\text{W}/\text{cm}^2$), and to be higher in the Talking mode ($23.005 \mu\text{W}/\text{cm}^2$) than in the Calling mode ($10.27 \mu\text{W}/\text{cm}^2$).

Discussion

The rapid growth of mobile communication technology, which by 2009 was serving about 4.6 billion mobile users, has raised major concerns about the health implications of overexposure to radio-frequency electromagnetic waves emitted by mobile phones and their antenna stations [26]. The regular monitoring of public exposure to electromagnetic waves through scientific means is therefore essential for protecting public health and interest [21]. The present study aimed to investigate the effect of battery charge of a mobile phone on its electromagnetic radiation. When assessing the exposure to high-frequency waves, it is recommended to focus on the far-field regions, where there is a direct and constant relationship between the electric field (E) and the magnetic field (H), and after measuring one field, the other field and the power density (component of electromagnetic field) can be easily calculated (refer to (1) and (2)). In contrast, assessments of the exposure to low-frequency waves must focus on the near-field region, where the electric and magnetic fields must both be measured before the power density can be calculated (refer to (3)) [24]. It is worth noting that the internal antennas typically used in mobile phones (almost all conventional mobile phones currently use an internal antenna) have an average maximum size of 30 to 50 mm [27]. Refer to (4), the far-field region of mobile phone emissions (with frequencies of 900–2500 MHz) starts at the distance of 4.16 cm from the antenna. Therefore, all measurements of this study were carried out at the 5-cm distance from the mobile phone antenna.

$$\text{Power Density } \left(\frac{\text{W}}{\text{m}^2} \right) = \frac{E^2 \left(\frac{\text{V}}{\text{m}} \right)}{377 \Omega} \quad (1)$$

$$\text{Power Density } \left(\frac{\text{W}}{\text{m}^2} \right) = H^2 \left(\frac{\text{A}}{\text{m}} \right) \times 377 \Omega \quad (2)$$

Where:

E: Electric field (V/m)

H: Magnetic field (A/m)

$$\text{Power Density } \left(\frac{\text{W}}{\text{m}^2} \right) = H^2 \left(\frac{\text{A}}{\text{m}} \right) \times E^2 \left(\frac{\text{V}}{\text{m}} \right) \quad (3)$$

$$R_{ff} = \frac{2D^2}{\lambda} \quad (4)$$

Where:

R_{ff}: The distance from which the far field starts

D: The largest antenna dimension

λ: The radiation wavelength

Buckus et al. suggested that the second generation (2G) Global System for Mobile (GSM) phones that operates in the frequency band of 900 MHz and 1800 MHz have stronger values of electric field strength than (3G) UMTS smart phones that effectively use high (2100 MHz) radio frequency band for the duration of conversation [20]. Therefore in this research 2G network of cell phone was assessed. The review of literature in this area reveals a lack of consensus about the effects of waves emitted from the mobile phones at different battery charge levels. A research conducted by Zilberticht et al. on the impact of personal habits of mobile phone users on sperm quality has reported that talking to a mobile phone when battery is charging is a risk factor for reduced sperm quality. That study showed that people who talk on the phone when battery is charging have 66% abnormal sperm ratio, which is significantly higher than the 35% ratio observed in other people [15]. However, Zilberticht's study did not investigate the effect of other variables such as phone model, phone antenna type, connection network technology (2G, 3G, 4G), signal reception strength, distance from the nearest BTS, and many other uncertainties that play a role in the amount of radiation emitted from a mobile phone. Golmohammadi et al. [20] studied the power density of mobile phones typically used in Iran. In that study, electromagnetic fields of different mobile phones were measured at a 5–20 cm distance from the mobile phone's antenna using a single-probe Electromog meter (TES-593) in the frequency range of 10 MHz–8 GHz. The power density of Nokia, Sony Ericsson, and Samsung mobile phones in the Talking mode was measured to, respectively, 17.57, 102.62 and 43.28 $\mu\text{W}/\text{cm}^2$, and a statistically significant difference was found between the power densities of mobile phones of different models. In that study, the power density of mobile phones in standby, calling, and talking modes was measured to 0, 50.14 and 65.72 $\mu\text{W}/\text{cm}^2$, respectively, which shows a high power density in the talking mode than in the calling mode. These values are also higher than the measurements made in the present study. This difference can be attributed to the differences in the model of the tested mobile phone, the type of measurement device, the type of network, the distance from BTS antenna [28], the strength

of background waves, etc. It should be noted that Golmohammadi's study has not clarified whether "establishing a call" means "making a call" or "receiving a call". Furthermore, because of hardware limitations of that study, the measured power densities were not integrated, and this could be a cause of difference between power densities in talking and calling modes. It should also be noted that when a mobile phone is in the standby mode (When a call is terminated), it sends only a single signal when necessary or at regular intervals [29] (every six hours) to the operator's nearest antenna to confirm its presence and position. This is, however, unless the phone leaves the current service zone. Consequently, as long as a phone in the standby mode remains within the geographic domain of the operator's service zone, its power density will be the same as background's. This argument is consistent with the results of Gulmohammadi et al. The higher power density of mobile phones in this study as compared to Golmohammadi's can be due to the advancement in precautionary measures adopted by mobile phone manufacturers to increase the safety of their products. Studies conducted by other researchers, including Ozgur et al. [21], have reported no significant difference between the electric field of the caller and the receiver of a call (7.7 ± 0.2 V/m vs. 4.52 ± 0.14 V/m). Their study also showed that talking during a phone call produces a three times stronger field than listening. According to their study, although the waves emitted from mobile phones are directly related to their SAR, the sound pressure levels produced during talking on the phone can also affect the power density in the area [21]. In the present study, a significant difference was found between the power density in the Calling mode ($10.27 \mu\text{W}/\text{cm}^2$) and the Called mode ($29.11 \mu\text{W}/\text{cm}^2$). Seada et al. [30] measured power densities emitted from a mobile phone (Nokia 6230i, type RM-72, Nokia corporation, Budapest, Hungary) at the distance of 1 cm in various modes including; Sending-ring ($0.014 \mu\text{W}/\text{cm}^2$), Receiving-ring ($0.017 \mu\text{W}/\text{cm}^2$) and Talking mod ($0.007 \mu\text{W}/\text{cm}^2$). Their results demonstrate that the power density of the mobile phone differed significantly among the different modes of use. These values are much lower than the values of power density in the present study. It seems that Seada et al. did not pay sufficient attention to distance of measurement probe to the mobile phone (near-field area/far-field area) and performed measurements at the distance of 1 cm. According to the manual instrument recruited there (RF-EMF meter (Extech 480,846, FLIR Commercial Systems, Nashua, NH, USA) [31], the meter measures the electrical component of the field; the default units are those of electrical field strength (mV/m, V/m). The meter converts the measurement values to the other units of measurement, i.e. the corresponding magnetic field strength units ($\mu\text{A}/\text{m}$, mA/m) and power density units ($\mu\text{W}/\text{m}$, mW/m^2 , W/m^2 , $\mu\text{W}/\text{cm}^2$ or mW/cm^2) using the standard far-field formulae for electromagnetic radiation. The conversion is invalid for near-field measurements, as there is no

generally valid relationship between electrical and magnetic field strength in this situation. In addition, according to Fig. 3 for all battery charge levels, over the first 10 s after the call is received, the power density peaks in about 2 s and then declines to a lower level. This findings is consistent with the study conducted by Muhammed Abdelati's [29] showed that the level of emission at call setup is greatly higher than that for the duration of Talk mode. During this stage the cell phone starts by checking all control channels in order to determine the BTS with the strongest signal and therefore will give the best connection. Then the cell phone sends the origination message which is a very short message (about 1 to 2 s). After the cellular service provider confirms that caller is valid, the BTS sends a channel assignment message to the cell phone. This message notifies the cell phone on which channel the conversation will take place. Subsequently, the cell phone turns to the assigned channel and begins the call. At this step, the ring back signal or busy signal is heard. Both of these are transmitted by the BTS as an audio signal just like the voice of the person on the destination. Moreover, the magnitude of the signal may differ depend on the cell phone model and its location relative to the BTS. It should be noted that the intensity of power density values ranged from 10.27 (2.27% of ICNIRP reference level (General Public; Intensity at 900 MHz: $0.451 \text{ mW}/\text{cm}^2$)) to $29.11 \mu\text{W}/\text{cm}^2$ (6.45% of ICNIRP reference level (General Public; Intensity at 900 MHz: $0.451 \text{ mW}/\text{cm}^2$)) are within the recommended exposure limits [4, 5].

Conclusion

The present study showed that as long as a mobile phone that is in the standby mode remains within the geographic domain of the operator's service zone, the power density emitted from that phone will be virtually zero, and any background wave can be attributed to other sources. The data provided in this paper can be utilized in the monitoring of daily exposure of mobile user and the estimation of exposure levels in the laboratory and non-laboratory studies. To prevent the potentially harmful effects of radio-frequency electromagnetic field, it is recommended to consider precautionary measures such as using reputable phone brands with proper safety and health credentials, minimizing the exposure by reducing the time of talking on the mobile phone, using hands-free devices, and using safer mobile handsets with lower SAR (SAR is a measure of the rate at which the human body absorbs energy when exposed to a radio-frequency electromagnetic field) values. Proper protection against adverse health implications of radio-frequency radiation requires strict regulation of technologies based on SAR levels. With the rising public concern over the issue of radio-frequency radiation, people may be misinformed about the nature of potential threats and how to reduce their exposure to this type of radiation. Therefore,

public awareness campaigns are needed to provide people with accurate information about the practical precautionary measures that can be taken to address the possible threats. Radio-frequency radiation protection specialists may use the data provided in this study to devise general guidelines and recommendations for the use of mobile phones.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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