IJOH INTERNATIONAL JOURNAL OF OCCUPATIONAL HYGIENE
Copyright © 2008 by Iranian Occupational Health Association (IOHA)
2008-5435/14/63-1-8

ORIGINAL ARTICLE

Investigating the Mobile Phones Radiofrequency Waves' Impact on Different Cows Brain Tissue Depth and Brain Tissue Temperature Variation

HOSSEIN EBRAHIMI[1], SIAMAK POURABDIAN[1], FARHAD FOROUHARMAJD[1*]

[1]*Department of Occupational Health Engineering, School of Public Health, Isfahan University of Medical Sciences, Isfahan, Iran*

Received September 30, 2018; Revised February 12, 2019; Accepted April 25, 2019

This paper is available on-line at http://ijoh.tums.ac.ir

ABSTRACT

Prevalent use of mobile phones has led to increasing worries about the effect of radiofrequency waves on the physiology of human body. This study was aimed to determine the mobile phones radiofrequency waves' impact on different brain tissue depth and brain tissue temperature. In this empirical research, a cow's brain tissue was placed in a compartment and the effects of radiofrequency waves of the mobile phone were analyzed during and after radiation, in three different brain tissue depths of 2, 12, and 22 mm, in 4 mm and 4 cm distances of the tissue to a mobile phone, for 15 min. Lutron thermometer was used to measure the tissue temperatures. Data were analyzed using Lutron software. The rate of temperature increasing in 22 mm depth was higher than 2 and 12mm depths. The results also showed that during radiation of the brain tissue in 4 mm distance by the mobile phone, the tissue temperatures in 2, 12, and 22 mm depths were increased 0.29 ˚C, 0.31 ˚C, and 0.37 ˚C, respectively, relative to the base temperature (tissue temperature before radiation). Moreover, the brain tissue temperature in 4 cm distance was more sensitive than other depths. There was also a direct relationship between brain tissue depth and tissue temperature increase after mobile phone radiofrequency waves' radiation. The temperature in 22 mm depth increased with higher speed. Not only radiofrequency waves of mobile phones increased the tissue temperature in all depths of the brain tissue, but also the higher temperature was observed in the 22 mm tissue depth. In fact, the radiofrequency wave's thermal affect was higher in higher depths.

KEY WORDS: *Mobile Phone, Radiofrequency Waves, Brain Tissue, Temperature, Tissue Depth*

INTRODUCTION

Expansion of cell phone networks and the diversity of the presented services by service providers such as short message services, easy transmission of images and films, and rapid and easy e-payments have led to increasing usage of these devices by individuals [1]. Cell phones are the main sources of electromagnetic waves that can enter into human body tissues [2]. According to the reports by World Health Organization (WHO), radiofrequency waves are among the polluting sources, and radiation of these

Corresponding author: Farhad Forouharmajd
E-mail: *forouhar@hlth.mui.ac.ir*

waves could be a source of hazard for humans [3]. There are more than 7 billion cell phones in the world which indicates increasing users of these devices [4]. Increasing use of cell phones has caused extensive worries about radiofrequency wave's negative impact. One of these effects is the tissue temperature rise while radiated with mobile phones radiofrequency waves [5]. Using cell phones near the head may hurt the central nervous system of the users [6].

Electromagnetic wave's energy, in short distance with head, absorbed by body especially brain [7]. The feeling of heat or even burning around and behind ears, face skin, as well as headache as heating signs due to using cell phones was reported in a study [8]. Brain is the most important part forming the central nervous system, which is protected by skull. At the time of calling, brain has the highest rate of radiofrequency wave's radiation [9]. In an assessment, the brain tissue radiated with a cell phone for 30 minutes, it was reported that the tissue temperature increased 4.5 ˚C during radiation compared to the time before radiation [5]. Most of the cell phone users complained about warming of the ear during work calling. Battery exhaustion, radiofrequency and electromagnetic waves of cell phones absorbed by the users' heads may lead to increasing temperature in the ear area [10]. Since cell phones antenna usually are close to ear and head, so that different studies was aimed to find the radiofrequency wave impact on brain [11]. In an assessment by Lindholm et al, the confrontation of users with cell phones for 35 minutes, showed that the radiofrequency waves of cell phones increase the temperature of users' ear canals 1.5˚C [6]. Anderson et al. reported that the cell phones' electromagnetic waves during radiation increase skin temperature 0.01 ˚C [12]. The results of studies showed that a negligible increase in hypothalamus temperature (about 0.2-0.3 ˚C) leads to behavioral change in adjusting body temperature [13]. Furthermore, it was stated in a study that temperature increase due to induced electrical field in brain tissues is because of the close distance of head to the radiation source. The more this distance increases, the temperature in brain tissues decreases [14].

Cell phones are one of the important and most applicable radiating sources of electromagnetic waves, being quite popular among the users regardless social and occupational level. On the other hand, there are general worries about the damaging effects of radiated waves from cell phones on the users' health issues. Thus, this study was aimed to determine different reactions of temperatures in different depths of brain tissue while radiated by cell phones radiofrequency waves.

METHODOLOGY

In this empirical study, a cow's brain tissue with the weight of 432 g was used to investigate the temperature reactions. The temperature of cow's body was 38.5 ˚C. Immediately after slaughtering a cow, its brain was transferred in the laboratory. The laboratory temperature was 23.40 ˚C, and the tissue temperature preserved at the same temperature. The brain tissue was placed in a compartment which was considered for measurement purposes.

LABORATORY EQUIPMENT:

To maximize the measurement accuracy and minimize errors due to temperature, humidity, and ventilation systems during the measurement, a compartment with a height of 40 cm, length of 80 cm, and width of 30 cm of Plexiglas material was designed and produced. The tissue was placed in it, to be separated from the laboratory environment conditions. After necessary adjustments, the compartment door was closed. The equal or isothermic temperature of brain tissue and the laboratory was considered as the base measurement temperature.

Lutron thermometer (model: MT-917) with $\pm$ 0.01 precision was used for measuring the tissue temperature. This thermometer had 5 measuring probes, of which the probe "TP100" was applied for this study. This probe is used for measuring different depths and thicknesses. It's made from platinum with a -199.99 to +199.99 ˚C temperature range. Lutron thermometer was able to measure both Fahrenheit and Celsius units, whereas Celsius unit was used for this study. The thermometer was connected to a computer system via a cable (model: USB-01). The temperature range of this USB cable was 0-50 ˚C, being applicable in the humidity of 80%. Temperature changes were measured and recorded in momentary basis after installation of Lutron software program.

PREPARATION AND RADIATION:

The brain tissue was placed in the compartment. Then TP100 probe was located in the

depth of 1, 12, and 22 mm, respectively, for measuring gray matter and white matter of the brain and the precise depths of the tissue was measured by a digital caliper. The first depth was related to the gray matter of the brain with 2 mm thickness. A smart cell phone was used to investigate the thermal effect of the cell phone radiofrequency waves, which was placed on a pod on the left in a 4 mm distance from the brain tissue; similar to the time that a person is speaking on the cell phone. After the adjustments, the thermometer was turned on and connected to the computer system by a USB cable. Then, the related software was run.

No contacts were made primarily between the tissue and the cell phone. To balance the temperature in tissue, the space inside the compartment was created, and the temperature reduced, until the compartment temperature became stable likewise compartment temperature and the thermometer showed a stable temperature. So, the temperature was recorded for 15 minutes after the tissue temperature stability. This temperature was called the base temperature (tissue temperature before confrontation with a cell phone). Then, a contact was made between the tissue and the cell phone, similar to the time that a person is speaking on the phone. The radiation time was considered 15 minutes. By the end of the radiation, the contact was ended. In the next stage, the tissue was kept in the compartment for 15 minutes, to reduce temperature without radiation and the presence of radiofrequency waves. The thermometer was connected to the computer system in all the previous stages, during and after the radiation by the radiofrequency waves of the cell phone, and the tissue temperature variations were recorded using determined software. In this study the cell phone was placed in 4 mm and 4 cm distances from the brain tissue, for 3 different depths of 2, 12, and 22 mm. Finally, the temperature variations were obtained relative to the time.

FINDINGS

A cow's brain tissue was used to examine the different reactions in different depths of 2, 12, 22 mm of the brain tissue at 4 mm and 4 cm distances from the cell phone radiated with the mobile phone radiofrequency waves' before, during, and after the end of the contact.

Temperature of the gray matter of brain in 4 mm distance was increased 0.29˚ C relative to the base temperature (tissue temperature before radiation with the cell phone). The tissue temperatures in 12, and 22 mm depths (white matter of the brain) were increased 0.31 ˚C, and 0.37 ˚C, respectively, relative to the base temperature. For the distance of 4 cm of the tissue and the cell phone, the rates of increases of the tissue temperature relative to the base temperature were obtained as 0.05 ˚C and 0.17 ˚C. According to the obtained results, the tissue temperature in 22 mm depth at the distances of 4 mm and 4 cm of the tissue and the cell phone was higher than the other depths. Table 1 shows the tissue temperature increase relative to the base temperature in different depths of the brain tissue during radiation.

The tissue temperature, 15 minutes after ending the radiation by the cell phone, in 4 mm distance of the tissue and the cell phone was determined as follow: in different 2, 12, 22 mm depths 0.03, 0.19, and 0.22 ˚C, respectively, and in 4 cm distance, the increasing temperature relative to the base temperature at the same depths was 0.03, 0.0, and 0.08 ˚C. The tissue temperatures in of 4 mm and 4 cm distances in each depth deceased as compared to the radiation time, but these were higher compared to the base temperature. In other words, when the brain tissue radiation by the cell phone was finished, the tissue temperature did not return to the base temperature after 15 minutes, and the temperature of the brain tissue was even higher than the base temperature after the radiation finished. After the radiation was finished, the tissue temperature in 22 mm depth was higher than the other depths. The rates of the temperature of the brain tissue in different depths after ending the radiation by the cell phone have been presented in Table 2.

The temperature variations relative to the time, during and after the radiation finish time for each of the three considered depths have been shown in Table 3. In 15-minutes radiation of the tissue by the cell phone, the white matter had the temperature increase faster than the gray matter. In fact, the maximum temperature in deeper tissue parts increased faster than the outer part, such that at the distance of 4 mm of the tissue from the cell phone, the maximum temperature increased 18.23, 19.16, and 19.83 ˚C were obtained respectively, in 2 mm depth after 14 min. and 15 sec, in 12 mm depth after 14 min. and 10 sec., and in 22 mm depth after 13 min. and 40 sec. and the

Published online: August 11, 2019

maximum temperature increases did not change for 15-minute radiation by the mobile phone. After finishing the radiation for 15 min, deeper tissue temperature reduced with slower speed, such that in 4 mm distance of the tissue from the mobile phone, the maximum reduction of temperatures were determined after radiation by the cell phone in 2 mm depth after 2 min. and 55 sec, in 12 mm depth after 4 min. and 10 sec, and in 22 mm depth after 13 min, and 10 sec. In other words, the tissue temperature increased more rapidly when radiated by the mobile phone radiofrequency waves. The tissue temperature reduced with slower speed after radiation by the mobile phone was finished.

In both conditions of during and after radiation by the mobile phone, the temperature increased in 4 mm distance of the brain tissue from the cell phone was more than 4 cm distance, such that these temperature were determined 19.16 ˚C and 18.9 ˚C, respectively, in 12 mm depth for the distances of 4 mm and 4 cm when radiated regarding to the base temperature of 18.85 ˚C. The temperatures in 22 mm depth and comprised to the base temperature of 19.46 ˚C indicated 19.83 ˚C and 19.63 ˚C, respectively. The comparison between temperature increasing in brain tissue during radiation by the mobile phone 4 mm and 4 cm distances has been illustrated in Figure 1.

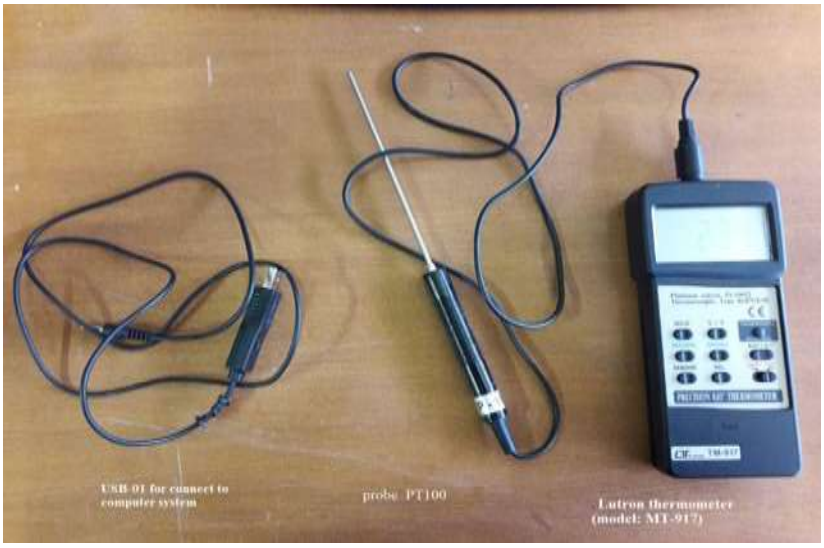

Fig. 1. Lutron thermometer, PT100 probe, and USB cable for connection to the computer

Fig. 2. A view of the measuring equipment

Table 1. Maximum increase of the tissue temperature relative to the base temperature in different depths of the brain tissue during the radiation

Brain tissue depth	Base temperature (C°)	4 mm distance of brain tissue and the cell phone	4 cm distance of brain tissue and the cell phone
		Max. temperature increase (C°)	Max. temperature increase (C°)
2 mm	17.94	0.29	0.19
12 mm	18.85	0.31	0.05
22 mm	19.46	0.37	0.17

Published online: August 11, 2019

Table 2. Temperatures of the tissue in different depths after 15 minutes of ending the radiation

Depth of the brain tissue	Base temperature (C°)	Brain tissue 4 mm distance from the cell phone		Brain tissue 4 cm distance from the cell phone	
		Increasing the tissue temperature relative to the base temperature (C°)	Tissue temperature (C°) after the radiation finish time	Increasing the tissue temperature relative to the base temperature (C°)	Tissue temperature (C°) after ending the radiation
2 mm	17.94	0.03	17.97	0.03	17.97
12 mm	18.85	0.19	19.04	0.0	18.85
22 mm	19.46	0.22	19.68	0.o8	19.54

Table 3. Temperature variations relative to the time during radiation and after ending the radiation in three depths of the brain tissue

Thickness	During confrontation		After ending the confrontation	
	Time to obtain maximum temperature increase at the 4 mm distance	Time to obtain maximum temperature increase at the 4 cm distance	Time to obtain maximum temperature increase at the 4 mm distance	Time to obtain maximum temperature increase at the 4 cm distance
2 mm	After 14 min. 45 sec.	After 13 min. 45 sec.	After 2 min. 55 sec.	After 11 min. 5 sec.
12 mm	After 14 min. 15 sec.	After 13 min. 15 sec.	After 4 min. 10 sec.	After 11 min. 10 sec.
22 mm	After 12 min. 30 sec.	After 12 min. 30 sec.	After 13 min. 10 sec.	After 12 min. 15 sec.

Published online: August 11, 2019

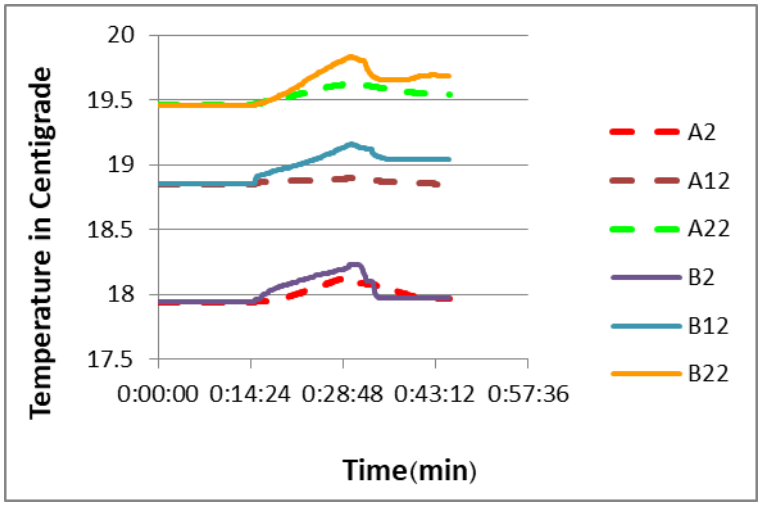

Fig. 1. Comparison between temperature increases in the brain tissue during radiation by the mobile phone in 4 mm and 4 cm distances (A2) 2 mm thickness and 4 cm distance; (A12) 12 *mm thickness and 4 cm distance; (A22) 22 mm thickness and 4 cm distance; (B2) 2 mm thickness and 4 mm distance; (B12) 12 mm thickness and 4 mm distance; (B22) 22 mm thickness and 4 mm distance*

DISCUSSION

The present study was investigated the different reactions of different depths temperatures of brain tissue when radiated by the cell phones' radiofrequency waves. An ascending trend for the tissue temperatures in 2, 12, and 22 mm depths were observed while radiated by the cell phone for 15 minutes, relative to the base temperature (tissue temperature before the radiation). Rusnani et al. in a study analyzed the mobile phone user head and ears for 15 min and 30 min when radiated by the cell phone. They reported an ascending temperature in the head and ears of the users during radiation by the cell phones, and this rate directly correlated by the speaking time. They found that the cell phone radiation for 15-30 min would increase head temperature 0.3-2.9 ˚C [10].

Not only the tissue temperature 22 mm depth during radiation was more than the other depths for the 4 mm and 4 cm distances of the brain tissue and the cell phone, but also it was higher than when radiation was finished. In other words, by increasing the tissue depth, the temperature of the brain tissue was also increased. This result showed that 22 mm depth of the brain tissue, where the white matter of the brain is therein formed, was more sensitive to the effects of radiofrequency waves in comparison with other depths of the brain tissue. The more layers of the tissue, the more temperature accumulated in it. It can be concluded that the deeper parts of the brain tissue were more vulnerable to the mobile phone radiofrequency waves. On the other hand, it is possible that the deep tissues (a white matter of the brain) to be more sensitive whenever radiated by the cell phones and the sensitivity emerges by absorbing more rate of energy, ultimately, the temperature increasing.

According to the findings of this study, the deeper brain tissue temperature increased faster and in a shorter time comprised of outer parts of the tissue during radiation by the cell phone, and even after ending the radiation, the tissue temperature reduced slower and in a longer time. Perhaps, the reason of higher increase of the temperature in 22 mm depth of the brain tissue in shorter time and temperature reduction in a long time was due to less blood flow and higher performance of the brain in generating heat, as compared to other tissues, the two characteristics proved their effects by increasing the depth. Consequently, regarding the thermal effect of

Published online: August 11, 2019

radiofrequency waves of cell phones in deeper depths, it was possible that temperature increasing might changes the tissue specification, especially the white matter of the brain, affecting the cellular activities, finally causing tissue disorders.

Most of the hazardous biologic effects about the mobile phone waves on the human body have been related to the effects of increasing the temperature, such that some of the cell phone waves were transmitted to the human body as heat by passing through an environment with ionized flow induced by the electric field and vibration of polar molecules [15]. In research, Wesspan et al. showed that the generated heat due to radiation by the cell phone in the brain tissue was more than the skin, since the brain is a tissue with high metabolic action in generating heat. Hence, the temperature was higher in the brain tissue compared to the other tissues with low metabolic action in generating heat. High rate of skin blood supply plays an important role in maintaining a low temperature in the tissue, while the blood supply of the brain tissue is less than the skin, which causes the brain temperature to raise more [13].

By increasing the brain temperature, the brain's blood flow was rapidly increased, and the lateral self-regulating thermal reactions were activated. Measuring automatic responses of heart and evaluation of the brain blood was used as the indirect pieces of evidence of blood circulation interactions and temperature adjustments during radiation by the radiofrequency waves. Accordingly, the cell phones' radiation repletion may increase the tissue temperature during radiation, and high temperature of brain tissue even a while after radiation would have improper effects on brain health by the passage of time [6]. About the relation electromagnetic waves impact on the brain in the study fulfilled by Beason and his colleague, they showed that 52% of the cases, similar waves to cell phone communicating systems can lead to increased brain neuron activities, and 17% of the cases, they can lead to reducing brain neuron activities [16]. The results of some epidemiology studies showed that even less density compared to the permissible range, cell phone waves cause symptoms such as headache, a feeling of warm ear, weakness in memory, and fatigue [17]. About the radiated waves generated by the cell phones' impact on the vital signs in the users, in a study, Mortazavi et al. obtained the significant relationship between using cell phones and disorders in attention, learning, and concentration of the users [18]. The negative effect of the mobile phones' waves on the brain activities and capabilities was proved in some studies [18-20]. Papageorgiou stated that using cell phones might reduce the capabilities and performances in some special areas of the brain, affecting memory [21].In investigating electromagnetic waves of cell phones, Koividsto et al. reported that the waves radiated from cell phones reduce the executive memory and behavioral changes in humans, which was recorded as the increasing responding time to stimulants (22).

Saikhedkar et al. studied the effects of the cell phone's wave on the structure and performance of rats' brains. They reported that the cell phone's waves could increase anxiety levels and reduce learning in rats [23]. It was stated in a study that the cell phone's waves cause considerable change in the dopamine amount, norepinephrine, and serotonin densities in four different sections of the hippocampus, hypothalamus, medulla oblongata, and medulla in the brains of mature rats. The changes in the density of neural intermediates can be effective in treating anxiety and related problems to learning and memory [24].

The results of the present study showed that during radiation if the distance of the brain tissue with the cell phone reduced then a significant increase in the tissue temperature was observed. In the contrary, by increasing the distance of cell phones from brain tissue, the thermal effect of the cell phone's radiofrequency waves was reduced. The distance of brain tissue to the cell phone had an inverse relation with the increasing rate of the tissue temperature, it means that more distance causes less rate of increase in the brain tissue temperature. Hossain et al. reported that by increasing the distance of the head to the cell phone antenna, the Specific Absorption Rate (SAR) would be reduced [25]. In an analysis of the internal performance of the cell phones, the relationships among the cell phone antenna, the human body, and SAR, Kivekas et al. reported that the easiest way to reduce the specific absorption rate would be increasing the user's distance from the cell phone antenna [26]. Hirata et al. stated that there are some effective factors for electromagnetic waves specific absorption rates, and the size of the radiated tissue, the tissue electric features, and the distance between the electromagnetic

wave source and the human body can as well be considered [27].

CONCLUSION

The rate of brain tissue temperature was raised by increasing the depth of the tissue for both distances of 4 mm and 4 cm of the tissue to the cell phone, and the thermal effect of the radiofrequency waves of the cell phones could well be observed at higher depths of the brain tissue, such that at the time after ending the radiation of the tissue by the cell phone, the tissue temperatures were higher in 2, 12, and 22 mm depths compared to the base temperature. However, the temperature was higher in 22 mm depth. Higher depths of brain tissue had the most rate of effectiveness from radiofrequency waves of cell phones while radiated with such devices, and the effectiveness of higher depths of the brain tissue was evident by increasing the temperature at a shorter time during radiation and the tissue temperature reduction in a long time after ending the radiation compared to other depths. In fact, the temperature in gray and white matters of the brain, even after the radiation, was cumulative, and this temperature accumulation was higher in higher depths in the brain white matter. On the other hand, the distance of brain tissue and the cell phone had definite effects on the increased rate of the tissue temperature, such that by increasing the distance, the tissue temperature decreased. The distance of the brain tissue and the cell phone was considered a very important parameter in this study, to reduce the thermal effects of cell phone waves.

The temperature variations in different depths of the brain were due to inhomogeneity of the brain tissue on moving from the brain surface to its depth; since the gray matter possesses more water and less fat compared to the white matter of brain. On the other hand, regarding different variables including the wave frequencies and the radiation direction, the optimum induced temperatures in different depths lead to temperature variations in different depths of the brain, all of which should be considered in future investigations.

This study showed that the temperature of brain tissue increased after contact with the mobile phone's electromagnetic waves. However, this temperature increasing can affect the brain performance, similar to what was seen in increasing the temperature due to hyperthermia, fever, or sunstroke. According to the viewpoints of the authors of this study, the more important point was the application of the index of tissue temperature increase as an index regarding contacts with electromagnetic fields, since the definite point was electromagnetic waves with different physical, electrophysiological, and electrochemical impacts on live tissues, being due to the mutual effects of these waves with the matter and they were inevitable. The point when the effects of the waves were observed and recorded or more precisely, the effects of the contacts of the waves was an indication for predicting the mentioned effects and their possible successive phenomena.

ACKNOWLEDGEMENT

This article was the result of the master's degree thesis at Medical Sciences of the Esfahan University, under the No: 3941047. The authors would appreciate the Research Department of Esfahan Medical Sciences University and the head of the Physical Damaging Factors Laboratory of the Faculty of Health for their great aids in accomplishing this study.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests for any of authors.

REFERENCES

1. Khadrawy Y, Ahmed NA, Ezz HSA, Radwan N. Effect of electromagnetic radiation from mobile phone on the levels of cortical amino acid neurotransmitters in adult and young rats. Romanian J Biophys. 2009;19(4):295-305.
2. Anguera J, Andújar A, Huynh M-C, Orlenius C, Picher C, Puente C. Advances in antenna technology for wireless handheld devices. International Journal of Antennas and Propagation. 2013;2013:1-25.
3. Khurana VG, Teo C, Kundi M, Hardell L, Carlberg M. Cell phones and brain tumors: a review including the long-term epidemiologic data. Surgical neurology. 2009;72(3):205-14.
4. Lahiri B, Bagavathiappan S, Soumya C, Jayakumar T, Philip J. Infrared thermography based studies on mobile phone induced heating. Infrared Physics & Technology. 2015;71:242-51.
5. Develi I, Sorgucu U. Prediction of temperature distribution in human BEL exposed to 900MHz

mobile phone radiation using ANFIS. Applied Soft Computing. 2015;37:1029-36.
6. Lindholm H, Alanko T, Rintamäki H, Kännälä S, Toivonen T, Sistonen H, et al .Thermal effects of mobile phone RF fields on children: a provocation study. Progress in biophysics and molecular biology. 2011;107(3):399-403.
7. Khalatbari S, Sardari D, Mirzaee AA, Sadafi HA. Calculating SAR in two models of the human head exposed to mobile phones radiations at 900 and 1800 MHz. PIERS Online. 2006;2(1):104-9.
8. Golmohammadi R, Kamalini M, Abed K, Karim S, Eshagh M. Investigating the Electromagnetic Fields of Common Cell Phones and Self-reported Symptoms of Users. Journal of Ergonomics. 2014;2(1):1-7.
9. Perrin A, Cretallaz C, Collin A, Amourette C, Yardin C. Effects of radiofrequency field on the blood-brain barrier: A systematic review from 2005 to 2009. Comptes Rendus Physique. 2010;11(9-10):602-12.
10. Rusnani A, Norsuzila N, editors. Measurement and analysis of temperature rise caused by handheld mobile telephones using infrared thermal imaging. RF and Microwave Conference, 2008 RFM 2008 IEEE International; 2008: IEEE.
11. Isa R, Pasya I, Taib M, Jahidin A, Omar W, Fuad N, et al .Classification of brainwave asymmetry influenced by mobile phone radiofrequency emission. Procedia-Social and Behavioral Sciences. 2013;97:538-45.
12. Anderson V, Rowley J. Measurements of skin surface temperature during mobile phone use. Bioelectromagnetics. 2007;28(2):159.
13. Wessapan T, Srisawatdhisukul S, Rattanadecho P. Specific absorption rate and temperature distributions in human head subjected to mobile phone radiation at different frequencies. International Journal of Heat and Mass Transfer. 2012;55(1):347-59.
14. Martens L. Electromagnetic safety of children using wireless phones: a literature review. Bioelectromagnetics. 2005;26(S7):S133-S7.
15. Alaei P. Introduction to health physics. Medical Physics. 2008;35(12):5959.
16. Beason RC, Semm P .Responses of neurons to an amplitude modulated microwave stimulus. Neuroscience Letters. 2002;333(3):175-8.
17. Hocking B, Westerman R. Neurological effects of radiofrequency radiation. Occupational Medicine. 2003;53(2):123-7.
18. Mortazavi SMJ, Atefi M .The ability of GSM mobile phone users in detecting exposure to electromagnetic fields and the bioeffects of these fields on their vital signs. Journal of Kerman University of Medical Sciences. 2015.
19. Kesari KK, Siddiqui M, Meena R, Verma H, Kumar S .Cell phone radiation exposure on brain and associated biological systems. Indian J Exp Biol 2013;51(3):187-200.
20. Li H-J, Peng R-Y, Wang C-Z, Qiao S-M, Yong Z, Gao Y-B, et al. Alterations of cognitive function and 5-HT system in rats after long term microwave exposure. Physiology & behavior. 2015;140:236-46.
21. Papageorgiou CC, Nanou ED, Tsiafakis VG, Kapareliotis E, Kontoangelos KA, Capsalis CN, et al. Acute mobile phone effects on pre-attentive operation. Neuroscience Letters. 2006;397(1):99-103.
22. Koivisto M, Krause CM, Revonsuo A, Laine M, Hämäläinen H. The effects of electromagnetic field emitted by GSM phones on working memory. Neuroreport. 2000;11(8):1641-3.
23. Saikhedkar N, Bhatnagar M, Jain A, Sukhwal P, Sharma C, Jaiswal N. Effects of mobile phone radiation (900 MHz radiofrequency) on structure and functions of rat brain. Neurological research. 2014;36(12):1072-9.
24. Ezz HA, Khadrawy Y, Ahmed N, Radwan N, El Bakry M. The effect of pulsed electromagnetic radiation from mobile phone on the levels of monoamine neurotransmitters in four different areas of rat brain. Eur Rev Med Pharmacol Sci. 2013;17(13):1782-8.
25. Hossain M, Faruque MRI, Islam MT. Analysis on the effect of the distances and inclination angles between human head and mobile phone on SAR. Progress in biophysics and molecular biology. 2015;119(2):103-10.
26. Kivekas O, Ollikainen J, Lehtiniemi T, Vainikainen P. Bandwidth, SAR, and efficiency of internal mobile phone antennas. IEEE Transactions on Electromagnetic compatibility. 2004;46(1):71-86.
27. Hirata A, Sugiyama H, Fujiwara O. Estimation of core temperature elevation in humans and animals for whole-body averaged SAR. Progress In Electromagnetics Research. 2009;99:53-70.