

Empirical study on specific absorption rate of head tissues due to induced heating of 4G cell phone radiation

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ABSTRACT

Exposures to electromagnetic radiation mainly from the extended use of mobile phones may initiate biological damages in the human body at the macromolecular level. Several studies on human and animal models have shown significant changes in the functions of neural cells. Present empirical study analyses the thermal changes and the specific absorption rates (SAR) of brain, eye and skin tissues due to prolonged exposure to mobile phone radiation. A phantom, simulating human head with skin, skull and brain was used for the study. The Phantom was exposed to radiation for longer durations (600 s and more) and the temperature variations at different specific points were studied with sensitive thermocouple probes. SAR (1 g of contiguous tissue) values were determined using the variations of temperature and other parameters. The average rise in brain temperature was found to be 0.10 ± 0.05 °C at 30 mm deep in the brain and the estimated SAR was 0.66 ± 0.35 Wkg⁻¹. The increase in temperature for the eye socket was 0.03 ± 0.02 °C with SAR 0.15 ± 0.08 Wkg⁻¹. The average rise in temperature for skin was 0.14 ± 0.05 °C and the SAR was 0.66 ± 0.42 Wkg⁻¹. Although the measured SAR lie within the safe limit of 2 Wkg⁻¹ recommended by the international regulatory body, considering the tremendous growth in the number of mobile phone users and prolonged use of mobile phone in communication purposes, the cumulative effects could be a real concern for human health.

1. Introduction

Nowadays, human lives are heavily dependent on modern technology. Use of wireless devices, such as cell phones, become a part and parcel in daily activities of human beings including from personal to official works which results in exposure to radio-frequency waves in an increasing manner. The World Health Organization has reported the dispersion of radiofrequency waves as one of the most polluting sources, which are hazardous for human beings (Khurana et al., 2009). Electromagnetic radiations from mobile phones cause biological changes, both directly and indirectly. While using mobile phones often and incessantly, biological damages can be initiated at macromolecular level (Isa et al., 2013). Placing the cell phone near to head leads to the confrontation of EM waves with structures in and around the head through interactions of microwave radiations (Tanvir et al., 2016). The users often observe the warming of their ears due to having contact with cell phones. This temperature increase may be due to radio-frequency and electromagnetic waves absorbed by the users' head (Rusnani and Norsuzila, 2008). The studies done on human and animal

models have shown a significant increase in incidents of headaches, variation in the sleeping pattern, and changes in the functions of neural cells. There are scientific reports arguing that the absorption of electromagnetic energy increases the tissue temperature, ocular effects leading to cataract, skin burns, testicular deterioration, occlusions in brain, chromosomal changes, affect immune system, activities of neurotransmitters, brain tumors, and the rate of cellular mutation (Anderson and Rowley, 2007). As for instance, Develi and Sorgucu (2015) reported an increase of brain temperature by 4.5 °C following a 30-min confrontation of a cell phone with brain tissue. Lindholm et al. (2011) stated an increase of temperature by 1.5 °C in ear canals in confronting with the radiofrequency waves of cell phones for 35 min. Anderson and Rowley (2007) observed an increase in skin temperature by 0.01 °C during a confrontation with a cell phone. Christopher et al. (2020) found a significant change in certain hematological parameters due to the exposure to EM waves from mobile phone. While Harell et al. (2006) and Repacholi et al. (1997) have reported the risk of developing brain tumor due to the exposure to cell phone radiation, Salford et al. (1994) have mentioned that blood brain barrier function could also be

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affected due to the exposure to radiation. Phillips et al. (1998) reported DNA damage due to exposure to EMF radiation. While Hirata et al. (2006) observed a correlation between peak Specific Absorption Rate (SAR) and increase of tissue temperature, Anderson and Joyner (1995) have reported the rise of face tissue temperature after 6 min of continuous cell phone operation. Wilén et al. (2007) observed heart rate variability with RF plastic sealer operators. Hillert and Åkerstedt (2008) studied the effect of RF on headache and other ailments, and found that headache was more common after a prolonged exposure of radiation. Preece (2000) and Christina and Pesonen (2007) found memory errors, cognitive function and mental health problems due to exposure to EMF. Ki and Kim (2006) confirmed the decrease of skin resistance via a study on the effects of RF exposure on teenagers. Aly and Barnes (2008) has found significant changes in neutrophil behavior, which includes shrinking, rolling, and neutrophil speed increased by 50% under RF exposure. Recent study on histopathological examination revealed a significant increase in reactive oxygen species and lipid peroxidation level with simultaneous decrease in sperm count, alterations in sperm tail morphology (Gautam et al., 2019) due to 3G mobile phone radiation on male Wistar rats for 45 days (2 h/day). Another study on the effect of overexposure to mobile phone radiation (with different usage pattern like voice calling, video calling, and texting) by evaluating the temperature variation and specific absorption rate showed that radiation exposure rate was elevated in voice calling mode (Bhargava et al., 2019). Another remarkable study on low level GSM radiation (SAR 0.23 W/kg) with exposure time of 10 min thrice a day for 2 consecutive days shows a significant health effect in human neuroblastoma cells. This includes alterations on amyloid precursor protein processing and cellular topology, induction of oxidative stress and cell death, in human neuroblastoma cells (Stefi et al., 2019).

Specific Absorption Rate is the measurement of rate by which a body absorbs energy when the body is exposed to radio frequency electromagnetic field. It can also be considered as a measure of absorption of EM wave energy by tissues. Specifically, it represents the amount of power absorbed per mass of tissue and has a unit of watts/kilogram. SAR provides a measure of the EM radiation exposure characteristics of cell phones to ensure that they are within the safety guidelines. SAR values can be calculated either by direct observations or experimental determination of the increase in temperature of each tissue using skull models (Bernardi et al., 2003). Since during communication, cell phones are placed near the ear and head and also the brain tissue is sensitive to temperature change, this study was designed to estimate the localized SAR values of brain, eye and skin tissues using a real-life situation due to the heat generated by radiofrequency waves. A human skull (hired from Zoology Department, Fatima Mata National College), skin of a goat and brain were used to simulate the human head. A freshly collected sample of goat brain was filled in the skull covered with skin. This experiential study was to obtain thermal variations in different tissues resulting from cell phone radiation. A commercially available sensitive thermocouple with sensitivity 0.01 °C was used for measuring the variation in temperature for tissues. Since very little is known about the effects of 4G cell phone generated non-ionizing radiation on the human brain, eye and skin tissues, the present investigation may provide valuable data on the thermal changes and specific absorption rates due to the prolonged exposure to mobile phone radiation via a controlled experimental study.

2. Materials and methods

For experimental study, instead of human brain tissues, freshly collected goat brains were used. The brains of full-grown goats were collected from the slaughterhouse in Kollam city and were brought to the laboratory in a cool box (i.e., heat-insulating box). Brain tissue temperature during collection was 37.3 °C and each had a weight around 300 g.

In the laboratory, collected samples of brains were transferred to a

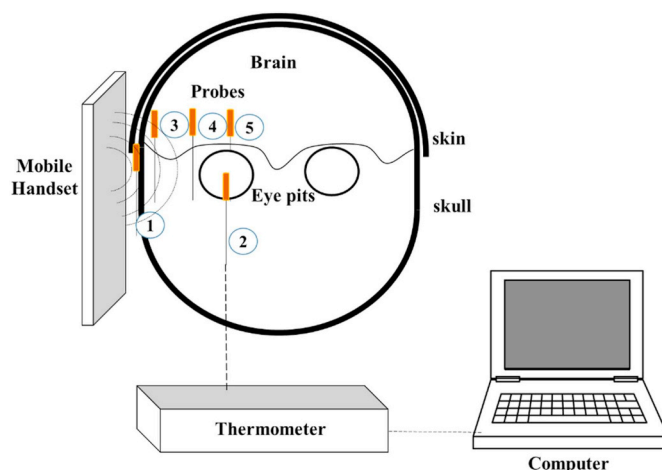


Fig. 1. Schematic diagram of the Experimental set up.

thin polyethylene cover and was fit into the human skull filling the space inside. The outer portion of the skull was covered with a thin skin of a goat as an equivalent substitute for human skin and hair. The temperature measuring probes were kept at specific designated points inside the skull to monitor the temperature. Commercially available digital Lutron thermometer (model: MT-917) with a precision of ± 0.01 °C was used for measuring temperature in the brain tissues. The Lutron thermometer utilizes a K type thermocouple (chromel-alumel) which is the most commonly used general purpose thermocouple. It has a wide variety of probes available in the -200 °C to $+1350$ °C/ -330 °F to $+2460$ °F range. The sensitivity of the used K type thermocouple was approximately $41 \mu\text{V}/^\circ\text{C}$.

Thermocouple probes were also kept in the eye socket to find the temperature variation. A schematic diagram of the arrangement of probes and the associated instruments are shown in Fig. 1. Five measuring probes were used to monitor the temperature inside the brain. The thermometer was connected to a computer installed with the Lutron software to record temperature continuously. From the rise in temperature and other parameters, the SAR (1 g of contiguous tissue) values were determined directly.

Ten smartphones of various brands (Android operating system, frequency range 2300–2400 MHz), with 4G SIM (subscriber identity module), were used for the study. It was presumed that the thermal effects produced by the EM waves from the cell phone which was placed in contact with the skull exactly simulate the brain of a human being communicating with a mobile phone. The experimental set up is shown in Fig. 2.

After adjustments, three thermometer probes were placed at a gap of 0.5 cm between each other inside the brain tissues from the skull. One probe was placed between the skin and the skull and another one in the eye socket of the skull, and the thermometer was connected to a computer system. The tissue temperature before confronting with the mobile phone was considered as the base temperature. The measurements were started after the brain temperature becomes steady. The steady temperature was recorded, and this temperature is called the base temperature (tissue temperature before confronting with the cell phone). The mobile phones were held near to the skin, exactly as a person using the mobile phone while talking. The confrontation time was set to be 600 s. In all the stages, before, during, and after confrontation/exposure with the radiofrequency waves of the cell phone, the variations of the tissue temperature were recorded by the Lutron and MATLAB software packages (Lutron Design and Configuration Software, 2019). The experiment was repeated for 3 samples of the brain.

The temperature was measured for every 600 s for different positions with the same SIM in the mobile phone and power conditions. The



(a) Brain tissues occupying skull



(b) Experimental set up

Fig. 2. Experimental arrangement to determine the temperature variation in head tissues.

localized SAR values for brain, skin and eye tissue were then calculated using the measured temperature increase in respective tissue due to the heat generated by radiofrequency waves. In the case of measurements in the brain tissue, the mean temperature of the three probes was taken to evaluate the SAR. The SAR values for brain, skin and eye were calculated using the equation (Bernardi et al., 2003).

$$\text{SAR} = \frac{\text{Increase of temperature} \times \text{Specific heat capacity of the tissue}}{\text{Time in seconds}}$$

(1)

Table 2

The average values of rise in temperature and the estimated SAR values.

No of Handsets	Tissue	Specific heat Capacity (J K^{-1})	Rise in temp ($^{\circ}\text{C}$)	SAR Values (Wkg^{-1})
10	Brain	3696	0.10 ± 0.05	0.66 ± 0.35
	Eye	3615	0.03 ± 0.02	0.15 ± 0.08
	Skin	3391	0.14 ± 0.05	0.66 ± 0.42

Table 1

Observed instantaneous values of temperature variation and estimated SAR values for eye, skin and brain tissues for positions from the ten handsets.

Radiation Source (Specific model name of the used mobile phone set)	Type of tissue	Specific heat Capacity ($\text{JK}^{-1}\text{kg}^{-1}$)	Rise in temp ($^{\circ}\text{C}$)	SAR Values (Wkg^{-1})
ZTE AXON 7 mini	Brain (average)	3696	0.08	0.49
	Eye	3615	0.02	0.13
	Skin	3391	0.10	0.56
Xiaomi Mi A1	Brain (average)	3696	0.18	1.10
	Eye	3615	0.06	0.36
	Skin	3391	0.21	1.18
Google Pixel 3XL	Brain (average)	3696	0.12	0.73
	Eye	3615	0.03	0.20
	Skin	3391	0.14	0.79
ZTE Blade V9	Brain (average)	3696	0.05	0.33
	Eye	3615	0.02	0.09
	Skin	3391	0.06	0.35
OnePlus 5	Brain (average)	3696	0.12	0.73
	Eye	3615	0.03	0.20
	Skin	3391	0.14	0.79
OnePlus 5T	Brain (average)	3696	0.16	1.01
	Eye	3615	0.05	0.28
	Skin	3391	0.19	1.08
iPhone 8	Brain (average)	3696	0.08	0.52
	Eye	3615	0.02	0.15
	Skin	3391	0.09	0.56
Samsung Galaxy S8	Brain (average)	3696	0.04	0.27
	Eye	3615	0.01	0.07
	Skin	3391	0.05	0.30
iPhone 7	Brain (average)	3696	0.10	0.61
	Eye	3615	0.03	0.18
	Skin	3391	0.11	0.62
LG G3	Brain (average)	3696	0.08	0.52
	Eye	3615	0.02	0.15
	Skin	3391	0.09	0.56
Xiaomi Redmi Note 5	Brain (average)	3696	0.08	0.49
	Eye	3615	0.02	0.13
	Skin	3391	0.10	0.56
Xiaomi Mi Max 3	Brain (average)	3696	0.14	0.86
	Eye	3615	0.04	0.24
	Skin	3391	0.17	0.96

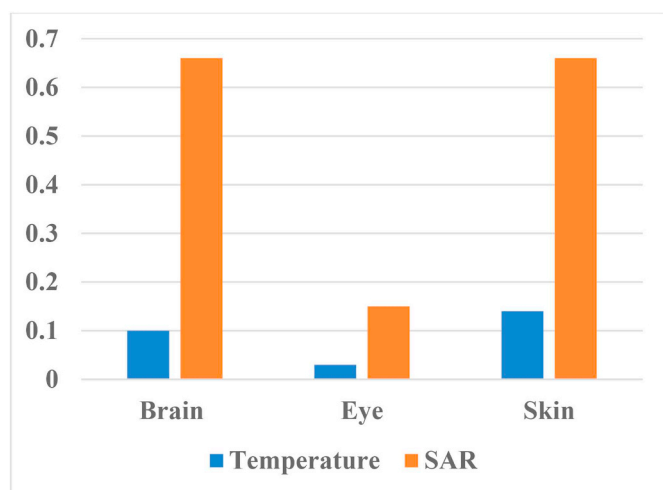


Fig. 3. Variation of Temperature and SAR for different tissues due to the exposure of mobile phone radiation.

The observed temperatures at various points and the SAR values calculated are presented in Table 1.

The experiment was repeated using 10 different handsets and the average values of rise in temperature and SAR are presented in Table 2, and the variation of temperature and SAR are graphically presented in Fig. 3.

3. Results and discussion

This study evaluated the effect of radiofrequency wave exposures of cell phones to the brain, eye and skin tissue due to the heat generated by radiofrequency waves. The observations were made at three distances within the brain. The nearer eye situated about 100 mm from the mobile antenna. In general case, the distance from the antenna to the brain and other nearby tissues varies from 20 mm to 60 mm (Aly et al., 2014). In the present case, an average distance of 30 mm from mobile phone antenna within the brain tissues was used for the estimation of SAR. Here, we focused on the localized SAR values and have given little significance to the whole-body average SAR value. The average rise in brain temperature by radiofrequency wave exposure from the 10 mobile phones was found to be 0.10 ± 0.05 °C at 30 mm distance from the mobile phone, and the estimated equivalent SAR was 0.66 ± 0.35 Wkg⁻¹. The increase in temperature for the eye socket was 0.03 ± 0.02 °C with SAR 0.15 ± 0.08 Wkg⁻¹. The average rise in temperature for the skin for confrontation time of 600 s was found to be 0.14 ± 0.05 °C and the estimated SAR was 0.66 ± 0.42 Wkg⁻¹. Obtained results show that, confronting brain, eye and skin tissues with cell phones for 600 s led in increasing temperature in the tissue as compared to the base temperature, during the confrontation. Rusnaniand Norsuzila (2008) observed that the temperatures of head and ear are increased by 0.3°C–2.9 °C for an increase of confrontation time of head with cell phones for 15–30 min. Besides this, Beason and Semm (2002) reported that cell phone radio frequency waves could lead in 52% of case in increasing brain neuron activities, and in 17% of the cases reduce brain neuron activities. Such an effect might be due to the fact that the increase of the temperature of the brain makes a rapid increase of the blood circulation, hence the thermal self-adjusting reactions are activated.

The international commission on non-ionizing radiation protection (ICNIRP Guideline, 1998) has set a safety limit for the human head at a SAR of 2 W per kilogram of tissue (Belpomme et al., 2018). According to ICNIRP the localized SAR for head and trunk is limited to 2 Wkg⁻¹ for general public. In occupational exposure, this limit is 10 Wkg⁻¹. This is because the occupational sufferers are bothered about their exposure

risk and they adopt a protective tool to minimize the exposure level. On the other hand, from the obtained SAR estimates, it was observed that the radiation from the handsets are within this safety limit recommended by ICNIRP but exceeds the limits of 0.001 Wkg⁻¹ (BioInitiative Report, 2012) for the initiation of biological effects. Most of the hazardous biological effects on humans via the cell phone radiofrequency waves are considered to be due to the effects of temperature increase, such that some of the cell phone waves are transferred to the human body as heat by current activated hyperpolarization induced by the electric field and vibration of polar molecules, in going through an environment (Wessapan et al., 2012; Forouharmajd et al., 2018). However, Hirata et al. (2009) identified a number of factors such as the size of the confronting tissue, electrical properties of the tissue, and the distance between the cell phone and human body etc. effects the absorption rate of electromagnetic waves.

For mobile phones used without headphones, the exposure is largely confined to the head close to the phone's antenna. Based on the analysis of the internal functioning of cell phones and the relation between the distance of cell phone antenna from the human body and SAR, Hossain et al. (2015) and Kivekas et al. (2004) showed that the rate of SAR can be decreased easily by increasing the distance of the users' head from cell phone antennas. Moreover, based on some epidemiologic studies, Hocking and Westerman (2003) show that cell phone waves can cause signs and symptoms such as a headache, feeling of high temperature in ears, weakness of memory, and fatigue. However, present study indicates that a relatively short confrontation (600 s) of the investigated mobile handsets radiofrequency waves with the brain, eye and skin tissues could lead a SAR value within the safety limit of 2 Wkg⁻¹ recommended by ICNIRP. But, there are reports to establish the experimental evidence of biological effects even below the proposed safety limit of 2Wkg⁻¹ (Belpomme et al., 2018). So the modern studies demanded that the international standard limits must be reviewed. In general, a short confrontation time and greater distance of cell phones from the human head may play an important role in reducing the thermal effects due to cell phone waves.

4. Conclusion

This study investigated the effect of radiofrequency wave exposures of 10 different cell phones to the brain, eye and skin tissue under laboratory conditions. The exposure effects were evaluated by placing the cell phones at a distance of 30 mm from the studied tissue and for a confrontation time of 600 s. The localized SAR values for brain, skin and eye tissue were then calculated using the measured temperature increase in the respective tissue. The average elevation in brain temperature was found to be 0.10 ± 0.05 °C and the estimated equivalent SAR was 0.66 ± 0.35 Wkg⁻¹. The increase in temperature for the eye socket was 0.03 ± 0.02 °C with SAR 0.15 ± 0.08 Wkg⁻¹. The average rise in temperature for skin was found to be 0.14 ± 0.05 °C and the SAR was 0.66 ± 0.42 Wkg⁻¹. The results show that the temperature of the brain, eye and skin tissue is increased as compared to the base temperature. The estimated SAR values for the investigated tissues show that the radiation from the hand sets are within the safety limit recommended by ICNIRP but exceeds the limits of 0.001 Wkg⁻¹ (BioInitiative Report, 2012) for the initiation of biological effects. The effects of the EM waves generated by cell phones may be underestimated as these observations are measured in a controlled laboratory condition. However, due to the growing use of cell phones with longer confrontations period, even a small alteration may risk human health resulting in cumulative effects. Therefore, the extended use of cell phones should be reduced to avoid any unwanted health hazards from EM waves.

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Bindhu Christopher: Formal analysis, Writing - original draft.
Sheena Mary Y: Formal analysis, Software, Validation.
Mayeen Uddin Khandaker: Writing - review & editing.
P.J. Jojo: Formal analysis, Conceptualization, Writing - review & editing.

Declaration of competing interest

The authors declare no competing financial interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.radphyschem.2020.108910>.

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