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Infrared thermography based studies on mobile phone induced heating

B.B. Lahiri [a], S. Bagavathiappan [a], C. Soumya [b], T. Jayakumar [a], John Philip [a,*]

[a] *Radiography and Thermography Section, Non-destructive Evaluation Division, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu 603102, India*

[b] *Department of Optoelectronics, University of Kerala, Thiruvananthapuram 695581, India*

HIGHLIGHTS

- Effect of skin temperature rise due to mobile phones induced heating is studied.
- Skin temperature monotonically increases with time during talking.
- Magnitude of the temperature rise increases with specific absorption rate.
- Increase in skin temperature in non-contact mode ~1 °C.
- Our study suggests that the use of mobile phones in non-contact mode is safe.

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ABSTRACT

Here, we report the skin temperature rise due to the absorption of radio frequency (RF) energy from three handheld mobile phones using infrared thermography technique. Experiments are performed under two different conditions, viz. when the mobile phones are placed in soft touch with the skin surface and away from the skin surface. Additionally, the temperature rise of mobile phones during charging, operation and simultaneous charging and talking are monitored under different exposure conditions. It is observed that the temperature of the cheek and ear regions monotonically increased with time during the usage of mobile phones and the magnitude of the temperature rise is higher for the mobile phone with higher specific absorption rate. The increase in skin temperature is higher when the mobile phones are in contact with the skin surface due to the combined effect of absorption of RF electromagnetic power and conductive heat transfer. The increase in the skin temperature in non-contact mode is found to be within the safety limit of 1 °C. The measured temperature rise is in good agreement with theoretical predictions. The empirical equation obtained from the temperature rise on the cheek region of the subjects correlates well with the specific absorption rate of the mobile phones. Our study suggests that the use of mobile phones in non-contact mode can significantly lower the skin temperature rise during its use and hence, is safer compared to the contact mode.

1. Introduction

The use of handheld mobile phones has seen tremendous growth in recent years. Recent reports indicate that approximately 7 billion mobile cell phone users exists throughout the world [1] and among that 935.35 million mobile users exist in India with an average monthly growth rate of 0.55% [2]. The wireless teledensity in India is approximately 75% which shows that a huge section of population is exposed to radiofrequency (RF) radiations emitted from handheld mobile phones. It must be noted that exposure to RF radiations below International Commission on Non-Ionizing Radiation Protection (ICNIRP) and National Radiological Protection Board, UK (NRPB) guidelines does not pose serious threat to the general health of exposed population [3]. The rise in the skin temperature is due to the energy absorbed from oscillating RF electric fields. There have been concerns on thermally induced tissue damage on long exposure to RF fields during mobile phone usage. Specific absorption rate (SAR) is a dosimetric quantity which is most widely used in safety standards related to RF exposure. SAR is defined as the rate of absorption of RF energy per unit mass of body tissues [4]. Majority of European countries have adopted ICNIRP guidelines of SAR limit of 2.0 W/kg averaged over 10 g of

* Corresponding author at: Radiography and Thermography Section, Nondestructive Evaluation Division, Metallurgy and Materials Group, Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India. Tel.: +91 44 27480500x26447; fax: +91 44 27480356.

E-mail address: philip@igcar.gov.in (J. Philip).

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tissue [5]. United States of America and India have adopted a stringent SAR limit of 1.6 W/kg averaged over 1 g of tissue [5,6].

Repacholi [7] and Pakhomov et al. [8] comprehensively reviewed the biological and associated health issues related to RF exposure. Repacholi classified the effects of RF exposure into three main categories, viz. (a) high level thermal effects, (b) intermediate level a-thermal effects and (c) low level non-thermal effects [7]. Absorption of RF energy results in the increase of tissue temperature and an increase beyond the thermoregulatory capacities of the subjects causes serious health hazards (like eye cataracts, skin burns and testicular degeneration) [4]. The required power density of a RF source to cause high level thermal effects is estimated to be around 1000 W/m^2 [4]. With stricter guidelines on handheld mobile phones it is highly unlikely that handheld mobile phones will cause high level thermal effects. On the other hand, the a-thermal and non-thermal effects of RF exposure are associated with the "oscillatory similitude" of the non-ionizing radiation in the living organisms [9]. Several in vivo and in vitro studies have been carried out on the a-thermal effects of RF exposure of varying intensity and frequency, which suggested some effects of RF exposure on blood–brain barrier, electrophysiology, neurotransmitter activities, immune system, genetic and chromosomal changes, cell mutation rates, brain tumors, chromatin conformation in human lymphocytes, etc. [4,10–13]. However, there is no consensus on the exact nature of the health hazards related to a-thermal and non-thermal effects of RF exposure. Therefore, further studies are required for a proper understanding of the underlying mechanisms.

As the SAR values of commercially available handheld mobile phones generally ranges from 0.1 to 1.6 W/kg [14], increase in tissue temperature is observed due to absorption of RF energy emitted from the handheld mobile phones. Using numerical modeling, it has been reported that the maximum increase in tissue temperature is within 0.1 °C [15]. Substantial effort has been concentrated on numerical modeling of interaction of RF radiation with human body [15,16] and calculation of SAR for various antenna morphologies [17,18]. On the other hand, limited experimental studies on real-time quantification of temperature rise during usage of handheld mobile phones have been reported. Here, we report real time transient temperature measurement during the usage of handheld mobile phones by applying infrared thermography.

Infrared thermography (IRT) is a non-contact temperature measurement methodology, where the infrared rays emitted from an object under investigation is detected using a suitable infrared camera and the temperature of the object under investigation is measured from the intensity of the emitted infrared radiation using the following radiometric equation [19].

$$M_{cam} = \tau\varepsilon M_{obj} + \tau(1-\varepsilon)M_{env} + (1-\tau)M_{atm} \quad (1)$$

Here, M_{cam} is the radiance received by the infrared camera, M_{obj}, M_{env} and M_{atm} are the radiance emitted from the surface of the object under investigation, environment (surrounding objects) and atmosphere, respectively. τ and ε are atmospheric transmittance and emissivity of the surface of the object, respectively. For an ideal black-body $\varepsilon = 1$ and for real surfaces, ε is always less than unity. If atmospheric transmittance is considered to be nearly equal to unity, then Eq. (1) reduces to the following simple form: $M_{cam} = \varepsilon M_{obj} + (1-\varepsilon)M_{env}$. Radiance received by the camera is converted to an electrical signal in the infrared detector of the camera and the object temperature is determined using suitable calibration functions [19]. IRT has been widely used for non-destructive evaluation [19–23], condition monitoring [24] and bio-medical applications [25,26]. For bio-medical applications, in general, passive thermography is used without any additional heat sources. Historically temperature has been found to be a good indicator of health [27] and abnormal thermal patterns on skin surfaces due to clinical illness can be mapped using IRT. IRT has found widespread applications in various medical fields like breast cancer monitoring, diabetic neuropathy and vascular disorder, fever screening, and dentistry [28–31].

IRT based techniques for estimation of temperature rise and SAR determination in human phantoms exposed to electromagnetic fields were initially proposed by Guy [32] and Hochuli and Kantor [33]. Taurisano and Vorst conducted a series of experiments to determine the temperature increase on various body parts exposed to 900 MHz radiation emitted from GSM (global system for mobile communication) mobile phones [34]. They observed a linear temperature increase of 1–2.4 (±0.2) °C under various conditions. Kargel used IRT for investigating local temperature rise in the ear–skull regions of human subjects during usage of two different commercially available models of handheld mobile phones [35]. He reported an average temperature increase of 0.4–0.7 °C for the mobile phone with a SAR value of 0.39 W/kg, whereas, temperature rise was found to be 1.2–2.3 °C for the other mobile phone with a SAR value of 1.26 W/kg. Rusnani and Norsuzila [14] reported an average temperature increase ranging from 0.3 to 2.9 °C for 30 min of standardized conversation on three different models of handheld mobile phones. Mat et al. [5] performed IRT based experiments on temperature rise during usage of handheld mobile phones and concluded that mobile phones with external antenna, operating at 900 MHz frequency band caused higher temperature rise in the subjects compared to the mobile phones with internal antenna operating at 1800 MHz frequency band. It has also been reported that Bluetooth hands free devices caused lower temperature rise compared to the wired hands free devices when used along with handheld mobile phones [36]. Considerable amount of variations in the magnitude of temperature rise, due to absorption of RF power, exist in the reported literature. Moreover, very few attempts have been made on empirical modeling of the obtained experimental data which necessitates further studies in this domain.

In this article we have systematically studied the temperature rise on the ear and cheek regions of five human subjects (2 males and 3 females of similar age group) during usage of three different commercially available handheld mobile phones for two different positions, viz. when the mobile phones were placed in soft touch with the skin surface and when the mobile phones were kept approximately 0.5–0.8 cm (within 1 cm) away from the skin surface. An attempt has been made to empirically model the experimental data with a theoretically predicted equation. This article does not attempt to focus on the biological effects of RF exposure on human population, neither does it profess about the safety or health hazards related to the usage of mobile phones. Rather the main objective of this study is to provide a quantitative measure of temperature increase on the ear–cheek regions of human subjects using mobile phones which may be of immense importance considering the rapid growth in the use of mobile phones.

2. Materials and experimental methods

2.1. Materials

The experiments were performed on five healthy adult subjects (two males and three females) from an age group of 28–43 years. The height and weight of the subjects varied from 145–165 cm and 48–75 kg, respectively. Prior to experiments, the objectives and experimental methodologies were explained to the subjects in detail.

2.2. Experimental methods

The experiments were performed in a temperature and humidity controlled room far from secondary sources of electromagnetic