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Specific absorption rate variation in a brain phantom due to exposure by a 3G mobile phone: Problems in dosimetry

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A specific absorption rate (SAR) measurements system has been developed for compliance testing of personal mobile phone in a brain phantom material contained in a Perspex box. The volume of the box has been chosen corresponding to the volume of a small rat and illuminated by a 3G mobile phone frequency (1718.5 MHz), and the emitted radiation directed toward brain phantom .The induced fields in the phantom material are measured. Set up to lift the plane carrying the mobile phone is run by a pulley whose motion is controlled by a stepper motor. The platform is made to move at a pre-determined rate of 2^o per min limited up to 20^o. The measured data for induced fields in various locations are used to compute corresponding SAR values and inter comparison obtained. These data are also compared with those when the mobile phone is placed horizontally with respect to the position of the animal. The SAR data is also experimentally obtained by measuring a rise in temperature due to this mobile exposures and data compared with those obtained in the previous set. To seek a comparison with the safety criteria same set of measurements are performed in 10 g phantom material contained in a cubical box. These results are higher than those obtained with the knowledge of induced field measurements. It is concluded that SAR values are sensitive to the angular position of the moving platform and are well below the safety criteria prescribed for human exposure**.** The data are suggestive of having a fresh look to understand the mode of electromagnetic field -bio interaction.

Keywords*:* Mobile phone exposures, Monopole probe, Phantom material Specific absorption rate

An ever increasing use of wireless communication devices has led to an issue relating to electromagnetic field-bio interaction. In conformity with this, a wealth of data have been generated more so in last three decades and yet the issue is far from resolved. Not to be outdone, microwave based devices have found use in domestic environment (microwave oven etc) thereby adding to the enormity of the problem. In particular the use of mobile phone in communication has shown a geometrical spurt in its usage. There is also a public concern regarding the emission of radiations from these devices and microwave towers, indicating serious health implications. As such the need for laying criteria for safe exposure has been a point of discussion for quite some time. Several agencies[1-3] have suggested guidelines for safe exposures and several countries have adopted these and some have developed their own.

For laying new and scrutinizing these guidelines for safe exposure, demands the need for accurate dosimetry. As of now the most accepted radio frequency (RF) exposure is quantified by computing the mass-normalized rate of electromagnetic energy absorption, the specific absorption rate (SAR). Each set of guidelines[1-3] requires that the SAR values of mobile phone devices must meet the prescribed RF safety limit. Further, since electromagnetic energy absorbed by the human head depends to a large extent on the antenna used for the mobile phone, knowledge of SAR distributions in a simulated media has become a favorite mode of measurement. Presently we have developed a simple method of measuring induced field in an arbitrary shaped box containing a phantom material. The data so generated can also help the industry to design better antennas to improve the performance of the wireless transceivers[4]. In this regard, it may be noted that a significant percentage of the power radiated by the Log periodic and whip antennas (used as micro strip line in mobile phone) in use today goes into absorption in the human head and this could be significantly reduced[5]. Dosimetric studies relating the RF exposure to the human body from mobile phone have been carried out by numerical simulation[6]. Numerical simulation have

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been successful to identify the pattern of power deposition and the identification of “hot spots”[7-10]. The experimentation with regard to these have been largely restricted to measure the field deposited in human models. The public concern regarding health implication of these radiation exposures, particularly in a near field exposure demands more experimental inputs. These efforts are divided into two parts: biological data at a low level of power exposure and the measurement of induced field due to mobile phone in a simulated media. This is all the more necessary because of the fact that in an actual use mobile phone position varies with respect to the head. Also the SAR measurements computed by thermo-dynamical considerations need to be compared with those with field induced measurements. In such a scenario assigning a single value of SAR, during its usage appears to be an over simplified assumption.

A major requirement of the experimental setup is that the system be designed such that it gives absorption peaks in good agreement (±1 dB) with the values obtained using models in a simulated set up. Keeping this in view a number of attempts have been made to compute SAR by measuring fields induced in phantom materials by dipole antenna, energized by external sources of varying power[10]. However, these fields are much higher than emitted by cellular devices and they essentially produce heating. This may lead to SAR values be considerably higher than in a realistic scenario and as such the extrapolation at lower power level is beset with uncertainties. In order to clinch the issues more quantitatively, mobile phone was used to generate frequencies pertaining to its usage.

An automated SAR measurement system was developed that uses mobile phone as such and can be used for compliance testing at 1718.5 MHz. The system is capable of its angular movement in the range (0° - 90°) using a computer controlled stepper motor. This is fitted with a miniature tip monopole probe, used to measure induced field, which in turn is used to compute angular SAR variations.

In the experimental set up a Perspex box (wall thickness 2 mm) equal to the volume (150×50×50 mm) of a small Wistar rat (200-250 g) was chosen for measuring field distribution due to mobile phone exposure. Measurements were carried out in brain phantom, while restricting the mobile phone movement within the range (0^o-20^o), simulating the normal usage in humans. The phantom characteristics used simulate[11] the impedance characteristics in humans. Measurements were confined to inclination values at 10^o and 20^o only. A similar set of measurements were performed by measuring increase in temperature due to mobile phone exposure and data compared.

Materials and Methods

Experimental setup—Plexiglas material was used in fabricating box used for containing brain phantom, irradiated by Mobile phone (Fig. 1a and b). Platform supporting Mobile phone is tied by a thread and is carried over a pulley, whose movement was controlled by a computer controlled stepper motor programmed to a prespecified rate of angular movement of 2^o/ min limited to 10^o and 20^o (Fig. 1a and b). A monopole probe was positioned to measure induced fields at various locations in the phantom material. Induced field measurements were carried out in two configurations. In the first instance (configuration 1a) mobile phone antenna was positioned parallel to the phantom.

The probe was moved parallel to the plane of mobile phone, beginning at location I (25 mm) pierced into phantom material to a depth of 37 mm. The probe was horizontally moved from location I-VI (25-150 mm). Induced field in each location was measured and SAR value computed. In the second scenario (configuration 2, Fig.1a) the mobile phone was placed by the side of the box and the probe was vertically positioned at various depth (2, 10, 15, 25, 37 and 46 mm, from the top) in the phantom material, controlled by the two axis antenna positioner. Field induced was computed by the same Monopole probe connected to a Spectrum analyzer (Agilent Model-N99121A, Fig. 1 b). The plane of the mobile phone was moved to 10^o and 20^o with respect to the horizontal plane and stationed respectively to each position to measure values of the induced fields. Values of the induced fields so obtained were used to compute SAR values at two positions (10^o and 20^o).

Total depth of the box was 45 mm, where the probe was lowered up to a depth of 35 mm. The data at each position were averaged by repeating each measurement thrice, whereby the variation is found to be less than 5%. The mobile phone antenna radiates maximum power in the direction of the phantom contained within the box (Fig. 1a and b). The measurements were performed at the frequency of 3G mobile phone (1718.5 MHz) in all the three locations (10° and 20° and one parallel to the phantom surface), and the data compared (configuration ‘1’).

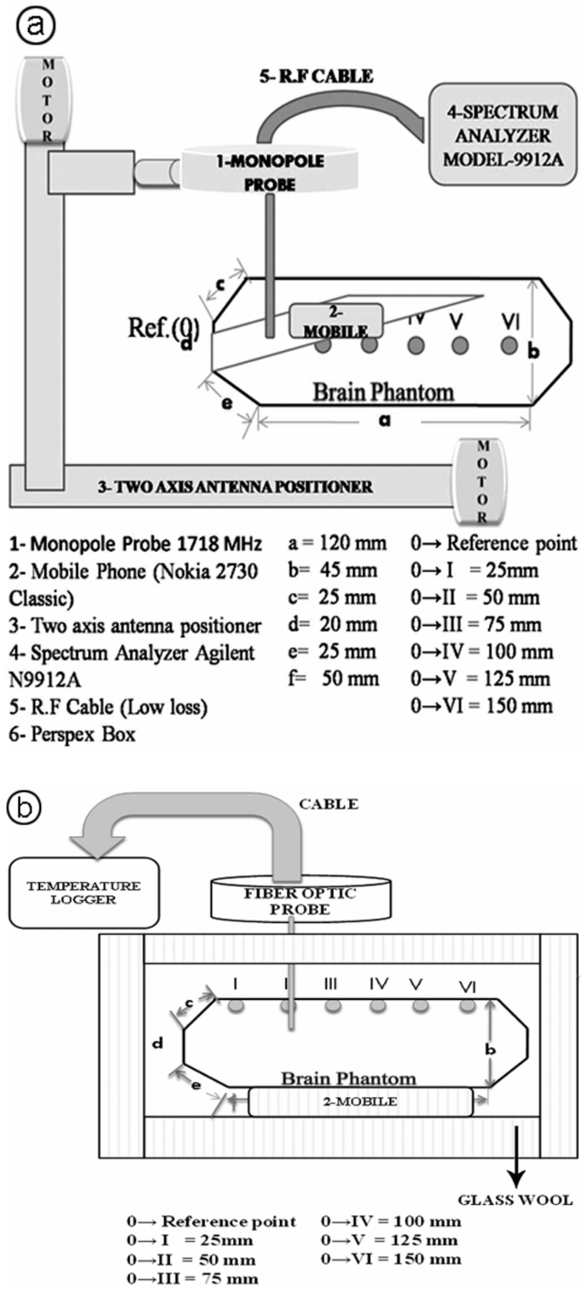

Fig. 1(a)—Induced field measurement probe inserted at a various depth controlled by Two axis antenna positioner and mobile phone adjusted at fixed angle(0^o, 10^o ,20^o) in a Perspex box; (b)—Setup for measurement of temperature rise in 10 g box containing brain phantom.

Rise in temperature measurement—For measuring the temperature rise due to mobile phone exposure a thermally insulated chamber is designed. This consists of a rectangular chamber made up of plexi glass sheet and inner lining covered with glass wool. Outer dimension of the chamber was (length:width:height: 600×300×300 mm) and the plexi glass thickness of the wall was 10 mm. Inside walls were covered with glass wool to a uniform thickness all along, leaving a free space of (300 ×100×100 mm Fig. 1 b).

Top of the box was covered with a sliding type plate. This tightly fits in with the box. At the top of this box cover a 2 mm diameter hole was made for introducing a sensor of fiber optic probe inside the chamber containing the phantom material. For making measurements, a Perspex box (wall thickness 2 mm) equal to the volume (150×50×50 mm) of a small Wistar rat (200-250 g) was chosen for measuring temperature distribution due to the same mobile phone exposure, up to a period of 30 min (Fig. 1b). This box had a material thickness of 1 mm, filled with phantom material. Same mobile phone, as used above (Nokia 2730 classic) was lowered inside the chamber (as mentioned above) and placed in a vertical position touching the wall of the box containing the brain phantom. The system was than used for tracking the temperature data over 30 min, whereby the difference in temperature between inside and outside of the box was measured and the maximum temperature difference recorded was 0.1^oC (sham exposed, passive mode). The temperature rise due to mobile phone exposure in the "receiving mode" (active mode) was estimated by subtracting the data when the mobile phone was in active mode from the one when it was in passive mode (configuration 2).

In a parallel experiment, a rectangular Perspex box (22.5×22.5×22.5 mm) wall thickness 2 mm, containing phantom material was chosen because SAR values in such amount of tissues are recommended for setting standards for safe exposure[12]. The mobile phone touching the box was kept in a passive mode (not excited) for 30 min and the change in temperature measured after every 2 min. The mobile phone was than activated in 'receive' mode and the temperature rise recorded after every 2 min interval over 30 min period. The measurements were carried out in two configurations (induced field measurement and temperature rise) as mentioned above and were chosen to confirm the temperature variations in different volumes and studying the corresponding SAR variations.

To lay a relationship with criteria of safe exposure similar measurements (induced field measurements and temperature rise) were performed in a box containing 10 g of brain phantom. SAR values so obtained were compared with those obtained above.

Design of monopole probe—The monopole probe had its vertical element planted over a solid sheet acting as ground plane. It is a probe having uniform, though a low gain and was optimized for maximum efficiency. In the present work, a monopole probe was designed (Fig. 2 solid metallic sheet and radial wire on ground plane): sensitive to frequency band in the range 1710-1880 MHz. This consists of a probe made up of brass with the specifications: 83.5 mm in length, 2 mm diameter, and metallic ground plane 100 mm in diameter. The probe dimensions were optimized to have a minimum value of VSWR for the purpose of obtaining baseline data. The experimental data were plotted with those obtained with the use of HFSS and Genesis software. The comparison showed a good agreement (maximum difference 11.4%) and provides confidence in making induced field measurement using this probe (Fig. 2). Its voltage standing wave ratio (VSWR) characteristics (Fig. 2) had a minimum value of 1.2 in the region of interest. Probe configured data were optimized using a HFSS and Genesis software to compare its sensitivity. The electrical characteristics of the probe are shown in Table 1. The measurements have all along been carried out when the mobile was tuned to be in "receiving mode.

Computation procedure—The monopole probe so designed was used for measurement of induced field in phantom material contained in a box (Fig. 1 a and b). The induced field data were used for computation of SAR using the expression:

$$SAR = \sigma E^2/\rho \qquad \dots (1)$$

where σ = conductivity, E = Induced field and ρ is the density of the material in question. The SAR

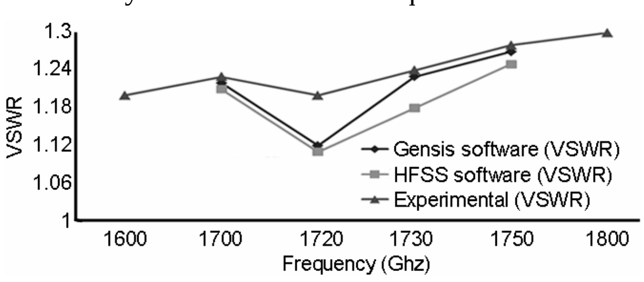

Fig. 2—Experimental and simulated value of monopole probe in respect of voltage standing wave ratio (VSWR). Comparison with HFSS and Genesis software is sought

Table 1—Experimental values of Monopole probe parameters as compared to those obtained using High frequency simulated software V13.0

S.No	Parameter	HFSS Simulated value	Experimental value
1	VSWR	1.10	1.23
2	Impedance (Ω)	48.32	52.13

values were computed at various angles and positions (Figs 4 and 5). The temperature probe (Fiber optic probe Model OFTO con TS2/2555) was used for measurement of temperature in the brain phantom material. The SAR was computed by measuring an increase in temperature using following expression...

$$SAR = C\, \Delta T/\Delta t \qquad \dots (2)$$

where ΔT = Change in temperature (^{o}C), Δt = Duration of exposure (sec), and C = Specific heat capacity (J/kg ^{o}C). The measurements were carried out in two configurations as mentioned above. Brain phantom characteristics are given in Tables 2 and 3, simulating[13] the impedance characteristics in human tissue. SAR values were computed using the equation (2), and are given in (Figs 4 a, b and 5 a, b).

Electrical characteristics of material—The electrical characteristic of the brain tissue can be imitated in the frequency range from 200 MHz to 2.5 GHz. The composition of material used for the phantom is shown in (Table 2). The relative dielectric constant (Table 3) can be controlled using polyethylene powders and the conductivity maintained using a small quantity of NaCl. Phantom is mixed with, Agar for solidification, NaCl for conductivity control, Tx-151 for gelling, and polyethylene powder (PEP) for dielectric control. Since the phantom was used for a period up to ten days, it was mixed with dehydroacetic acid sodium salt (DASS) to maintain its electrical characteristics. A similar probe was used earlier[14] that provided an estimate of emitted power from mobile phone in the range of 2-3 mW. Voltage standing wave ratio of about 1.2 was obtained whereby we get power in the range (2-2.25 mW) as also reported by other workers[15]. This provides confidence in accuracy of our measurements.

Table 2—Composition of equivalent brain phantom material

S.No	Ingredient	Weight (%)
1	Deionized water	60.63
2	Sugar	18.0
3	Sodium chloride (NaCl)	0.4
4	Tx-151	9.60
5	Polyethylene powder(PEP)	20.0

Table 3—Dielectric properties and material density of brain equivalent phantom at 1718.5 MHz

Parameter	Brain phantom
Relative dielectric constant	45.5
Conductivity (S/m)	1.31
Density (kg/m^3)	1000
Specific heat capacity (J/kg ^{o}C)	4000

Results

Power and the SAR of mobile phone were measured in the brain phantom contained in a Perspex box of the above mentioned dimension. The results are shown in Figs 3-5. The angle between mobile and the human head is kept within possible range of variation (ranging from 0^o -20^o) and the SAR values so computed showed a significant variation. This is clear from the variability in SAR values. The miniature sized probe mentioned above was used for measuring fields in the medium. As is apparent from Fig. 3 the pattern was identical and the peak position indicated the field emission profile of the micro strip antenna placed in the mobile phone. This was as obtained in configuration (1, a).

Maximum SAR values were obtained in the horizontal position of mobile phone (parallel with respect to the plane of the container). This corresponds to the fact that the SAR value was maximum when the mobile was parallel to the head position. As the angle of inclination increases ($0° \geq 20^o$) the SAR value along the horizontal plane decreases ($0°›10^o› 20^o$). This is obvious, because with the increase in angle the separation from the head increases. Hence the emitted power dissipates faster. It may be noted that the values in all the cases computed, were well below the accepted criteria for safe exposure. Further in a 10 g box, the temperature rise was linear, which was also the sample size used for setting criteria for safe exposure in humans (Table 4).

However the scenario changed if the probe movement was in the vertical plane. This was so because the field radiated by the mobile phone was variously intercepted (depending upon mobile antenna radiation pattern) by the phantom. The SAR values in this case was lowest at an inclination of 20^o, followed by that at 10^o and then in the horizontal position. SAR of 3G mobile phone was also measured in brain phantom in a 10 g container and also in a box equivalent of small rat volume. While in the 10 g box there was a linear increase in SAR with time, in the animal size box the SAR variations were non linear. This follows from the facts that since the medium charteristics were non linear the temperature rise showed variable pattern in its behavior (Fig. 4a). For first six min there was no measurable increase

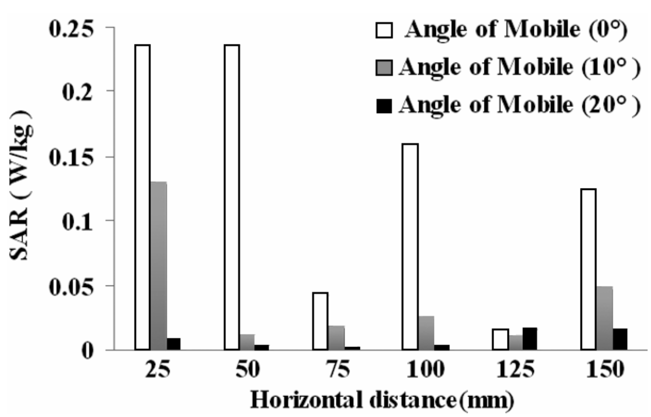

Fig. 3—SAR in brain phantom contained in a given size Perspex box at various mobile phone angles.

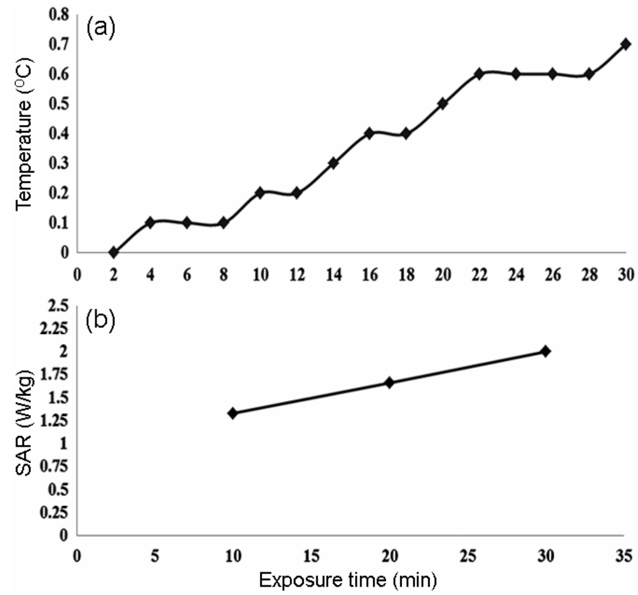

Fig. 4(a)—Temperature rise (a) and SAR measurment (b) in 10 g brain equivalent phantom

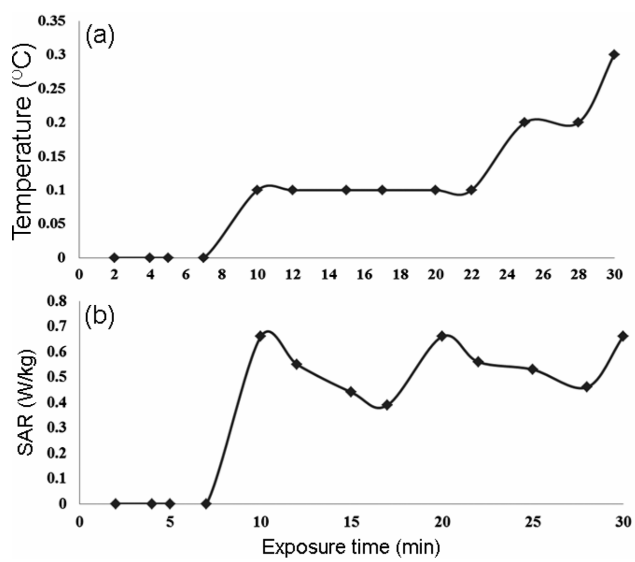

Fig. 5(a)—Temperature measurement in brain phantom contained in animal size box, (b): SAR Measurement in Brain Phantom Contained in a given volume of Perspex box

Table 4 (a)—Specific absorption rate (W/kg) in brain phantom contained in a Perspex box at various mobile phone locations, computed using (a) induced field data and (b) temperature rise data.

(a)

Probe vertical depth (mm)	Parallel to phantom position SAR (W/kg)	10° SAR (W/kg)	20° SAR (W/kg)
2	0.0018	0.0009	0.0031
10	0.0009	0.0004	0.0002
15	0.0011	0.0014	0.0004
25	0.0047	0.0043	0.0014
37	0.0108	0.0023	0.0034
45	0.003	0.0018	0.0015

(b)

Probe vertical depth (mm)	Parallel to phantom position SAR (W/kg)	Orientation of 10° SAR (W/kg)	Orientation of 20° SAR (W/kg)
2	0.0008	0.0029	0.0004
10	0.0002	1.87E-07	1.0E-05
15	0.0008	0.0001	0.0001
25	0.0025	0.0006	0.002
37	0.0044	0.0009	0.0003
45	0.0046	0.0009	0.0002

in temperature followed by a linear increase and then reached a peak followed by a pleateu region. This is because of tissue characteristics. SAR increases with the duration of exposure. As compared to 10 g containing box, animal size box has a larger volume and hence the power deposition may not be uniformly distributed, but showed spatial dependence (Figs 4 and 5)

Discussion

As of now several workers have reported measurements using a dipole antenna as the source for radiating field and computing SAR in the simulated media[16]. The maximum temperature increase in the brain can be estimated in terms of peak SAR averaged over 10 g of tissue. These patterns are affected by the positions and frequencies of a mobile phone. In the present study the maximum temperature increase obtained in the brain phantom as (0.7 ºC, 10 g phantom, and 0.2 °C in box of above mentioned dimension). Corresponding values reported are 0.13 °C for the Federal Communications Commission Standard (1.6 W/kg for 1 g of tissue), while 0.25 °C for the International Commission on Non-Ionizing Radiation Protection Standard (2.0 W/kg for 10 g of tissue). The data of the present study are not in agreement with the results obtained using induced field measurements. Measurements obtained in a 10 g box yielded 2 W/kg (over 30 min time interval) using mobile phone frequency operated at GSM 1718.5 MHz. Since this falls within the limit of safe exposure, it suggests that physiological effects and any possible damage to humans due to EM wave exposure, caused due to mobile phone is not due to temperature increase. These temperature changes are well within normal biological variations in humans[17].

SAR Maxima corresponds to maximum power captured by the site under investigation. SAR measurements in a simulated medium indicate the power deposited and can be assumed to be higher than those in situ. This would be so because of circulating fluid and the moist environment around, that allow heat (if generated) to be dissipated and keep the temperature of the exposed site nearly constant (non thermal). A recent study[20] also confirms a temperature rise of no more than 0.384 °C. Maximum SAR occurs in brain at deeper locations, extending up to a few centimeters. Due to mobile phone, even if there is a temperature rise, it is largely superficial and not much heat is transmitted inside the brain to disturb the internal thermal balance. As the tilt angle increases, the SAR value falls and likely to be so in other position (transmitting mode, missed call). The extreme scenario was chosen where the possibility of power deposition is maximum.

First maximum SAR that occurred in the two methods was spotted after first 10 min of exposure, but then the differential behaviour creeps in. It is suggested that it may be because of the thermal behaviour of the phantom and the mode of heat dispersal in the medium in question. In an *in situ* scenario this may occur due to difference in the dielectric and conductivity values of the adhering tissue. With the use of mobile phone, even if there is a temperature rise, it is largely superficial and not much heat is transmitted deep inside the brain to disturb the on going physiological processes. Thus the biological hazards may be due to a variety of non-thermal effects[18,19].

Conclusion

As was anticipated SAR values had maxima and minima due to possible range of movement of the mobile phone. Since the antenna position is fixed within the mobile phone, varying output field pattern within this range of movement showed a sharp variation in SAR data. Its values so obtained were well within the prescribed safety limit. The location of SAR maxima is dependent not only on the location of the probe, but also on the angular position of the mobile phone. The temperature elevation due to handset antennas can be considered as sufficiently small not to disturb the thermoregulatory response; including the increase in local blood flow and the activation of sweating mechanism.

Some underlying features of the present study are:

1 There is a possibility that due to 10 min of exposure there was a first temperature rise in the human brain due to mobile phone exposure. This was however within the permissible physiological limit.
2 Position of maximum power deposition depends on the mobile phone location, with respect to the position of the head.
3 SAR values fluctuate with respect to probe position. In the temperature rise measurement the heat is transferred all along the phantom material. This is dependent upon its thermal conductivity, rate of temperature rise and duration of exposure. It is further affected by the anisotropy of the media in question. Hence in later case (temperature rise) the SAR fluctuates and while in induced field measurement it varies in a graded manner.

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