Experimental finding of temperature rise and SAR values created by 900 MHz-1800 MHz-2450 MHz electromagnetic radiation on human brain tissue

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Today there are a set of numerical model studies concerning mobile phones, wireless devices and human brain interaction; however since it is not feasible to conduct experiments on humans it becomes a necessity to simulate biological tissues. In the present study temperature rise created by 900 MHz-1800 MHz and 2450 MHz frequency electromagnetic radiations on human brain tissue has been searched by using brain-tissue phantom model. Three distinctive brain-equivalent tissues have been prepared and by paying heeds to the mixture ratios, their electrical features have been specified. At this point it has been detected that frequency is a critical factor. Phantom volume of 900 and 1800 MHz frequencies, depending on the volume skin effect, can be affected to a certain degree from the exposure. However an exposure of 2450 MHz cannot exhibit the desired level of temperature rise inside phantom liquid. This may be attributed to the skin effect in this frequency.

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1. Introduction

Parallel to the rising industrialization in modern age, use of electromagnetic-field creating devices and exposure to these devices in daily life are climbing further likewise. The potential harms of electromagnetic field, causing exposure at different varieties and velocities, on biological systems have still not been clearly identified in modern age. The increasing number of mobile phones in general introduced with itself boosted concerns on the effects of these devices on the overall quality of life and health [1-8].

Electromagnetic waves may bring about huge disorders in human organism. It has been verified that they may create carcinogenic and genetic effects on body and leave adverse effects on free radicals, protein synthesis, immune system, reproductive system, growth and development systems. Continuous weakening in immune system has, as put forth by a number of recent studies, a triggering or boosting or stimulating effect in cancer formations [9-13].

In addition to the increasing use of mobile phones, significant improvements have been achieved in the field of Wireless Local Area Networks (WLAN) enabling one or a number of users' interaction with an access point in a shorter distance. WLAN systems are being installed continuously in homes, hotels, workplaces, airports, parks, campuses of corporations or universities [14]. Thus in WLAN frequency exposure to electromagnetic field is usually longer termed and even steady in some instances.

However despite the increasing public awareness onmobile phone use, limited information is available on the potential dangers of WLAN and similar wireless technologies [15].

The fundamental magnitude recognized in electromagnetic field interaction is specific absorption ratio or temperature-rise created by electromagnetic energy absorbed by human brain tissue. The intake dose due to electromagnetic field exposure cannot be directly measured on human brain, so it can be detected in labs with phantoms of which tissue equivalent value is filled with liquid or via computer environment simulations. Equivalent liquid's electrical features must be, in terms of dielectric fixation and conductivity, compatible with biological tissue [16,17].

Specific Absorption Rate (SAR) is the quantity used as a measurement of temperature rise in the exposure limitation to 100 kHz and 10 GHz. SAR is defined as absorption rate of electromagnetic energy per unit weight and its unit is W (W/kg) [18,19] per kg. Specific absorption rate is a vital quantity in dosimetry. That is because it is described as an indicator of temperature rise which is a typical indicator of the energy absorbed in tissue and the other biological effects created in tissue linked to internal fields. Specific absorption rate exhibits variation with respect to tissue characteristics and frequency [20].

Specific absorption rate is mathematically formulated as in Equation 1. Here E represents electrical field (V/m), σ conductivity (S/m), ρ density (kg/m^3) [17].

$$SAR = \frac{\sigma}{2\rho} E^2 \quad (1)$$

Another common technique used to detect SAR in tissue or in vitro culture environment is measuring the temperature change. The linkage between SAR and temperature rise can be formulated as in Equation 2 [21].

$$SAR = \frac{c_H \Delta_T}{\Delta t} \quad (2)$$

Here c_H represents specific heat capacity of J/kg ^{o}C type tissue; ΔT represents temperature rise in ^{o}C type tissue; Δt represents exposure length per seconds [22]. Depending on temperature rises in measuring thermal specific absorption rate, temperature rises increases that occur in the tissue due to electromagnetic energy can be measured via precision temperature measurement systems [23].

In humans and in lab animals, under normal conditions, a temperature increase equivalent to 1°C can be explained with a SAR value of 4 W/kg. However this rise in temperature can be balanced within people's temperature regulation capacity gap. Under the same environmental conditions with the existing heat and humidity the same SAR value can trigger 1°C rise and temperature rises that go far beyond the licensed normal limits. In the end, due to the unwanted temperature pressure in the body, bodily reactions may accelerate. The preliminary guide for protection against exposure to temperature rise is ICNIRP (The International Commission on Non-Ionizing Radiation Protection) exposure guidelines approved by World Health Organization and widely used all around the world. In this guideline a temperature increase exceeding 1°C has been the reference value for humans and violation of this threshold value is considered to be dangerous [24,25].

In he current study, temperature rise and specific absorption rate created in human brain tissue exposed to 900 MHz-1800 MHz and 2450 MHz frequency electromagnetic radiations have been examined by utilizing brain-equivalent tissue model.

2. Material and methods

In this study brain equivalent tissues have been concocted for 900 MHz, 1800 MHz and 2450 MHz. Preparation of equivalent mixtures "resembling" to biological tissues is one of the most vital stages of experimental study. The mixtures have been favorably prepared in Süleyman Demirel University Medical Faculty Physiology Laboratory. The method followed in the preparation of mixtures is as given below.

Percentage (%) weight ratios have been measured via "SCALTEK SPB 33" precision scale. Water has been heated up to 40°C with special "MK 418" device capable of heating and automatic mixing. While mixing the water, bacteria acid and water have been added. Next, sugar has been put. Mixing process has continued until air bubbles in the solution were minimized. Next HEC has been added to the mixture and heating procedure has ended. Last it has been left to cool until reaching room temperature. Afterwards these liquids have been put into closed glass bottles and sealed. With tissue phantom models that can be such obtained, it is feasible to create realistic human tissue models in electromagnetic dosimetry.

Dielectric constants and conductivities of prepared mixtures have been detected via measuring with "HP4194A Impedance/Gain-Phase Analyzer". In order to use this prepared brain-equivalent tissue mixtures for a long time without spoiling, "Bakterisid" has been added to the mixtures [26]. Prepared equivalent-liquid mixtures and materials used in the mixture and their ratios have been given in Table 1, 2 and 3.

Table 1. Brain-equivalent liquid mixture prepared for 900 MHz and chemical material ratios used in the mixture [26]

Tissue	Frequency (MHz)	Water (%)	Sugar (%)	Salt (%)	HEC (%)	Bacterium Asis (%)	Dielectic Constant	Conductivity
Brain	900	43.55	54.66	0.72	0.90	0.17	44.0	0.92

Table 2. Brain-equivalent liquid mixture prepared for 1800 MHz and chemical material ratios used in the mixture [26]

Tissue	Frequency (MHz)	Water (%)	Salt (%)	Glycol (%)	Bacterium Asid (%)	Dielectric Constant	Conductivity
Brain	1800	54.90	0.18	44.92	0.17	40.5	1.4

Table 3. Brain-equivalent liquid mixture prepared for 2450 MHz and chemical material ratios used in the mixture [27]

Tissue	Freqecny (MHz)	Water (%)	Salt (%)	HEC (%)	Bacterium Asid (%)	Dielectric Constant	Conductivity
Brain	2450	74	0.9	3.0	0.17	39.8	1.88

Temperature measurement scale has been set as seen in Fig. 1.

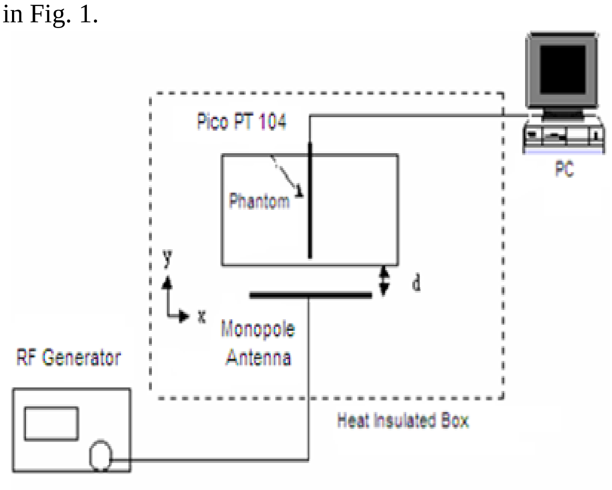

Fig. 1. Testing apparatus from which temperature increase measurement is made from the created equivalent liquid

Testing apparatus has been set in Süleyman Demirel University Faculty of Engineering Department of Electronics and Communications Engineering laboratory which has been adequately demetalized and spacious (larger than ten wave length). Once it has been confirmed that sufficiently-clean electromagnetic field and adequately isolated thermal conditions are set, experiments have started. To provide heat insulation, testing apparatus in Figure 1 has been insulated by a nonmetallic, hypethral, rectangular prism shaped styropor. The measurements have been made in an isolated box of which temperature change is close to zero. Temperature change inside the box has constantly been measured and when it was around 22^{o}C ±0,2^{o}C measurements have been taken.

While performing the measurements Pico Technology trademark PT 104 (PT-104 Platinum Resistance Thermometer Data Logger) Temperature measurement system has been harnessed. When PT 104 system is used with PT 100 temperature sensor it has 0,001 ^{o}C solubility and 0,01^{o}C precision and prob is SE012 Tip PT 100 temperature prob. It is compatible with IEC171:1983 standards. PTFE cable device's cable length is 2 m, temperature distance is between –50 and 250^{o}C, precision is 0.03^{o}C +/- at 0^{o}C. The used RF generator has a feature to give outlet between 0-4 W and adjustable between 850-950 MHz. In the measurements a monopole antenna has been employed for every single frequency.

3. Measurement results

In 900 MHz frequency (P=1.5 W) the distance of prob to fantom ground is y=7 mm. Depending on the time, temperature change has been observed in the liquid. Here measurement started to be taken in room temperature, on the 100th second transmitter has been switched on and on the 460th seconds it has been switched off. Total length of measurement is 500 seconds.

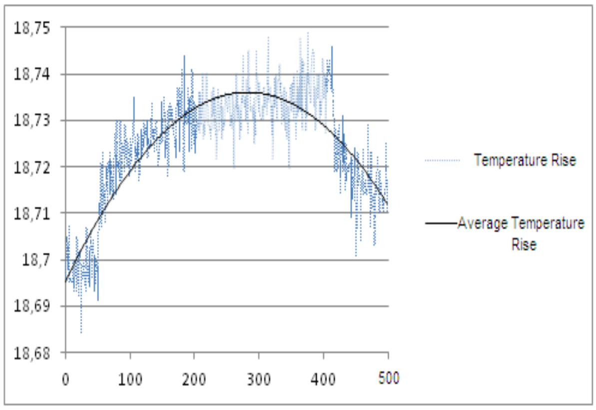

Fig. 2. In 900 MHz temperature change in the mixture in brain model

The first arrow sign from left to right indicates the time transmitter was switched on. Second arrow shows the time it was switched off. As seen in Figure 2 the moment transmitter is switched on, temperature inside equivalent liquid rises. The moment transmitter is switched off temperature value falls. For this frequency σ= 0.77 (S/m) [28], $\mu_0=4\pi10^{-7}$ N/A^2, $\mu_r=1$ values and equation $\delta=\sqrt{\dfrac{2}{\omega\mu\sigma}}$ (m) have been used and skin thickness has been measured as 19 mm. The deepness in which magnitude of δ electromagnetic wave falls to 1/e is termed as skin-thickness (as ω=2πf).

In 1800 MHz frequency (P=1.5 W) distance of prob to phantom ground is y=7 mm. Depending on the time, temperature change has been observed in the liquid. Here measurement started to be taken in room temperature, on the 100th second transmitter has been switched on and on the 460th seconds it has been switched off. Total length of measurement is 500 seconds.

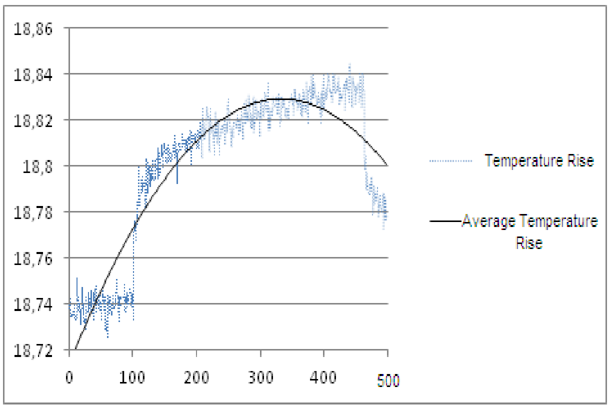

Fig. 3. In 1800 MHz temperature change in the mixture in brain model

As seen in Fig. 3, the moment transmitter is switched on temperature inside, equivalent liquid rises. The moment transmitter is switched off, temperature value falls. For this frequency σ=1.15 (S/m) [28], $\mu_0=4\pi 10^{-7}$ N/A^2, $\mu_r=1$ values and equation $\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$ (m) have been used and skin thickness has been measured as 11 mm.

In 2450 MHz frequency P=1.5 W distance of prob to phantom ground is y=7 mm. Depending on the time, temperature change has been observed in the liquid. Here measurement started to be taken in room temperature, on the 100th second transmitter has been switched on and on the 460th seconds it has been switched off. Total length of measurement is 500 seconds.

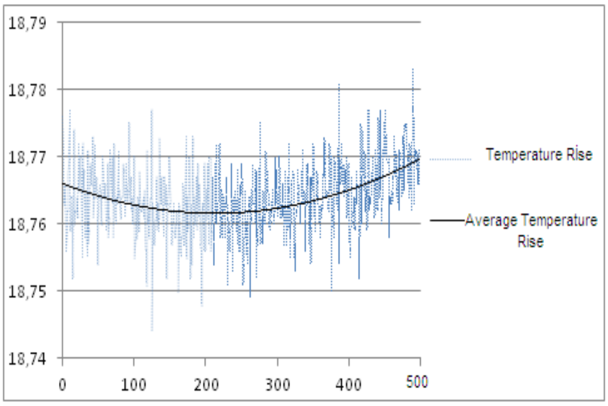

Fig. 4. In 2450 MHz temperature change in the mixture in brain model

Fig. 4 demonstrates that electrical field RF test device created in the area close to 2450 MHz cannot be effective enough to create a temperature rise in brain-equivalent liquid. Skin effect in this frequency is considered to be the explanatory factor for this output. For this frequency σ= 1.5 (S/m) [29], $\mu_0=4\pi 10^{-7}$ N/A^2, $\mu_r=1$ values and equation $\delta = \sqrt{\frac{2}{\omega\mu\sigma}}$ (m) have been used and skin thickness has been measured as 8.3 mm.

4. Mathematical model of SAR distribution, electrical field and temperature rise in brain equivalent liquid

For every single frequency analyzed, by using brain liquid's conductivity, density, specific heat capacity and temperature increase data retrieved from picologger have been used to measure SAR values and electrical field in the liquid. For the frequencies analyzed in Table 4 mathematically computed SAR, local electrical field values and temperature increase data retrieved from picologger have been displayed. In Table 5 for brain equivalent liquid electrical parameters in 900 MHz, 1800 MHz and 2450 MHz have been provided.

Table 4. Inside brain liquid mathematically computed SAR values, local electrical field values and temperature increase data retrieved from picologger

Operating frequency	SAR value (W/kg)	Local electric field value (V/m)	Amount of temperature increase occurred as a result of 6-minute exposure (°C)
900 MHz	0.46	35.08	0.046
1800 MHz	1.08	48.67	0.107
2450 MHz	0.026	5.82	0.003

Table 5. Electrical parameter values for the frequencies employed for brain liquid

Frequency (MHz)	ε_r	σ (S/m)	ρ (kg/m^3)	c (J/kg °C)
900	45.8	0.77	1030	3600
1800	43.5	1.15	1030	3650
2450	42.5	1.5	980	3137

ε_r , σ and ρ values in Table 5 have been taken from [28] for 900 MHz, 1800 MHz and from [29] for 2450 MHz. c value has been converted to °C and taken from [30] for 900 MHz, from [25] for 1800 MHz and from [31] for 2450 MHz.

For all the analyzed frequencies (900 MHz, 1800 MHz and 2450 MHz) SAR value found by using Equation 1 has been equalized with Equation 2; thus specific heat capacity (c) has been computed. For 900 MHz, equation 1 has been used and SAR value has been measured as 0.46 W/kg. When this value is equalized with Equation 2 and put in the place of $\Delta T/\Delta t$ rate, c value has been measured as 3600 (J/kg °C). The computed value and c value detected by Bernardi and his colleagues [30] have been identically the same.

For 1800 MHz, SAR value has been measured as 1.08 W/kg. For this number c value has been measured as 3633 (J/kg °C). The computed value and c value Al-Mously and Abousetta [25] received have been almost identical. For 2450 MHz, SAR value has been measured as 0.56 W/kg. For this value too, c value has been computed as 3150 (J/kg °C). The computed value and c value Leonard and his colleagues received [31] have been almost identical. Measured c values are as displayed in Table 6.

Table 6. Measured c values of the equivalent brain liquid in analyzed frequencies

Frequency (MHz)	c (J/kg °C)
900	3600
1800	3633
2450	3150

Table 6 presents that measured c values are quite close to the values retrieved from relevant literature. This finding proves us the validity of our mixture preparation method and measurement studies.

5. Discussion and conclusions

In the present study a brain equivalent liquid has been created to analyze the effects of electromagnetic radiation which is, as a consequence of developing technology, present anytime anywhere today. This radiation is mostly visible in mobile phones and wireless devices of which anytime-anywhere usability is almost inescapable. As a result via giving exposure during the length of specified frequency dosage and interaction, temperature change has been examined.

In brain model as seen in Fig. 2 and Fig. 3 for 900 MHz and 1800 MHz respectively, measurement has been taken in room temperature and after operating transmitter device for 360 seconds (6 minutes) temperature level within the liquid started to rise. When the device is switched off, equivalent liquid temperature started to fall down once again. As seen in Fig. 4, for 2450 MHz, measurements started to be taken in room temperature. Electrical field created by operating RF test transmitter for 360 seconds (6 minutes) could not be effective enough to trigger a temperature rise in brain equivalent liquid. That is attributed to the skin effect in this frequency. As the thickness of skin is smoothed (as the frequency is climbed) frequency effects remain close to the surface and cannot reach deeper parts. This is an expected outcome as also emphasized in the study of Khalatbari and his colleagues [17]. As indicated in the objective of this research, this is another vital criterion that should be considered in measuring temperature rise in brain tissue per frequency.

What matters is not which parameters are used for basic dosimetry parameter. The crucial thing is identifying EM field in the exposed tissue. Among these parameters SAR is widely recognized by researchers analyzing medical applications and biological impacts of EM field as a measurement unit. Without measuring the field inside an object exposed to EM field or the amount of energy it is rather toilsome to compare research findings obtained from various animal species and different parameters of EM exposure. Additionally by knowing outer space values only but not knowing inner space values it is impossible to conduct extrapolation of biological effect research findings on humans in order to develop RF exposure safety standards.In the future, brain equivalent liquids could be formed to analyze the effects of electromagnetic energy for other specific frequencies. As regards the biological structures and dielectric features of children in particular, there is still a wide scope of unknown data. Hence it matters greatly to continue the researches on children. These topics shall be the research domains of the future. To wind up, EM exposure conditions should be examined in all areas and required adjustments should be made to set national standards. Continuing to conduct researches on this subject would bear utmost importance for scientific and social health.

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