Mathematical Modeling of the Impact of Cell Phone Radiation on the Human Brain

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Abstract: The human brain is conscious to tiny variations in temperature. Temperature rises have impact on enzyme mission, which lead to expected undesirable organic repercussions. Alive tissues are insulating materials, which are exposed to insulation heating through radiation. The cell phone is a communal basis of radiation. Ordinary people normally keep their mobile phones beside their ears, which might aggravate the impacts of radiation, and then, temperature alteration. The level at which point tissue engrosses heat from radiation is known as the specific absorption rate, i.e. SAR. Over interpretations of SAR standards, the thermal implication of the electromagnetic wave heating of insincere tissue inside the brain can be calculated. The aim of this investigation is to model heating of tissue sheets inside the brain caused by mobile phone radiation subjection by means of COMSOL Multiphysics so as to assess effects of mobile phone use on brain occupation. This can be done by means of leading equations for electromagnetic waves and temperature. Also, Maxwell's equation for electromagnetic waves has been utilized to control the electric field and the SAR that would regulate heat generation relations. The 3D heat equation was then utilized to govern the temperature rising inside the brain after an explicit time period. 3D was essential meanwhile there is no regularity in the head in the attendance of a mobile phone. To precisely pretend thermo controlling procedures in the head, metabolic heat generation from these tissues and convective blood pour were comprised in the heat calculation.

Keywords*:* Cell Phone Radiation, Mobile Phone, Human Brain, Specific Absorption Rate (SAR), COMSOL Multiphysics

1. Introduction

Before discovering mobile phone there was radio which was found 100 years ago. It had listening and talking action at the same time and it was introduced in 1930s and used by police officers (Oliphant, 1999). The slighter size came later at 1940s that was easy to carry for the soldiers in the World War II. There was a public mobile phone system in St. Louis, Missouri, by 1946 (Farley, 2005). It did not work well, but people already dreamed of tiny radios and phones. Several persons tried to design mobile phones; the first one was Martin Cooper. The first wireless was made by Martin Cooper in 1973 that could be held in one hand, and he also completed the first call from his "handset". That was not heavy, 25 centimeter (10 inches) long and 7.6 centimeter (3 inches) and about 0.9 kilograms, he first developed in Japan then in Europe (Farley, 2005).

The usage of mobile phones dates back to the 1980's and since then it has quickly improved. In the 10 years between 2000 and 2010, mobile phone usage has improved three times. Ten years ago, about 90% of the American people were pledged to mobile phone devices.(Zhao, Zou & Knapp, 2007) As mobile phone treatment develops more progressive and common international, the impacts of emission caused by these tools are becoming a greater anxiety. Mobile phone emission has been related to brain cancer, salivary gland growths, communication problems, and migraines. These threats have been exposed to be greater in individuals who have utilized mobile phones for at least 10 years. Nevertheless, investigations on brain cancer cast distrust on these outcomes as it is problematic to precisely measure danger issues in human being (Moulder et al., 1999). Explicitly, radiation produced by mobile phones is in the arrangement of nonionizing radio frequency energy. This electromagnetic radiation possesses equally direct and indirect impacts on the human body. The heat produced by electromagnetic waves has a straight effect and it can destroy organs and tissues. This heat is calculated by the Specific Absorption Rate, *i.e.* SAR (Abdulrazzaq & Aziz, 2013). The indirect impacts produced by radiation have not been exposed to possess any important impacts on humanoid health. Due to the growing need of mobile phones in our everyday lives, it is really significant to control the health concerns of mobile phone radiation under numerous conditions (Tomovski et al., 2011).

The likelihood that the mobile phone is a gentle killer holds the greatest attention for the community (Agar, 2013). Much of the cloud of danger rises from the mystery of the unseen. Holding a 0.2 Watt light bulb nearby the body would possibly not attack most people as a hazardous or destructive action. Nonetheless the electric and magnetic field nearby and originating from cell phones lie outer the visible spectrum. In addition the human brain is sensitive to small changes in temperature. It is obvious that the living tissues are dielectric materials, which are exposed to dielectric heating by radiation. People frequently hold cell phones beside their ears, which may increase the effects of radiation, and hence, temperature changes (Kargel, 2005). People use mobile phones extremely produced by a few massive companies. The chief company was Nokia in 2007 based in Finland (Jose & Lee, 2007). More than 1 billon cell phones were made in the world in 2007. The second business was Samsung in 2007. Samsung made more than 160 million phones. It is based in South Korea. The third one was Motorola Company which made virtually mobile (Agar, 2013).

In some countries there are more mobile phones than people (Kaplan, 2006). For example, In Europe, Italy had 134 cell phones for every 100 people in 2006 (Krishna, Boren & Balas, 2009). All mobile phones change sound into electrical signals. They send the signals to the telephone network. They also receive electric signals from the network. It also turn the signals into sound. Phones send electric signal and receive in different techniques. Line phones use wires but Mobile phones don't use it. Their signals are passed through the air by radio waves. Radiowaves are electromagnetic waves, in which energy travels from one place to another (Kerker, 2016). Visible, invisible light and ultraviolet are forms of electromagnetic waves which have different wavelength and frequencies. Another form is X-rays spectrum which doctors are using when someone breaks one of the parts of the body (Hall & Giaccia, 2006).

Earlier studies have investigated the impacts of mobile phone radiation on body temperature Wainwright (2000) by means of a regular phone output of 2 Watts, stated that the extreme temperature rise would be about 274 K. Additional investigations have been done on the impacts of radiation on cancer threat and numerous brain dimensions, *i.e.* kids and adults. The research led by Wessapan and Rattanadecho (2012) approves that temperature influences are considerably dissimilar in body parts of kids, than the adults. While adults possess a superior rise in skin temperature, kids possess more rises in brain temperature. Furthermore, Wiart et al. (2008) agreed that kids' heads would absorb twofold radiation than the adult heads.

This investigation aims to assess the consequence of radiation exposure on tissue heating by means of execution 2-Dimentonal and 3-Dimentional demonstrating of radiation to the head using COMSOL Multiphysics 5.3. The impacts of cell phone radiation on tissue temperature have been demonstrated in the previous investigations, demonstrating a 273.2 K rise in the brain. This study will increase on present representations and pretend mobile phone radiation in the brain with variable voltages and thermal characteristics. These adjustments explain for personal mobile phone treatment favorites and offer more accurate outcomes of tissue heating through mobile phone radiation.

2. Theory

Electromagnetic wave from mobile phones, normally, moves over air and enters tissue layers inside the human-head (Makris et al., 2008). The quantity of electromagnetic wave enthralled inside each tissue layers is reliant upon the tissue characteristics. The captivated electromagnetic radiation is, thus, a basis of heat providing, and the analogous heat period can be computed utilizing Equation 2. It can be noticed that, the extra electrically conductive the tissue layer, the greeter the heat created through a certain magnitude of an electric field. This electromagnetic heat basis, sequentially, rises the temperature at a specified location inside the tissue layer (Zhadobov et al., 2015).

In this theoretical model, electromagnetic and thermal calculations were joined via first defining the electric field sketch inside the tissue layers. This electric field sketch may be able to utilize in order to find the temperature increment as it differs with distance from the surface. The authors characterize the temperature and electromagnetic controlling equations as following.

First we need to work on the temperature profile, *i.e.* thermal profile inside the brain and external layers (skin, fat, and skull) (Wessapan, Srisawatdhisukul & Rattanadecho, 2012) because of metabolic-rate, electromagnetic captivation, and blood movement.

$$P_{tissue}\, C_{tissue}\, \frac{\partial T}{\partial t} = \nabla(k\nabla T) + P_b C_b \omega_b (T_b - T) + Q_{EM} + Q_{metabolism} \qquad (1)$$

$$Q_{EM} = \frac{1}{2}\sigma_{tissue}|E|^2 \qquad (2)$$

$Q_{metabolism}$ is the heat produced from metabolic-rate in watts per volume, and Q_{EM} is the heat created from, the electromagnetic radiation.

Second, electromagnetic radiation profile, *i.e.* wave spread of the electric field, acquired from Maxwell's equations (Tyras, 2013) devoid of a magnetic field ($\nabla B = 0$):

$$\nabla \frac{1}{\pi_r} \nabla E - k_0^2 \varepsilon_r E = 0 \qquad (3)$$

COMSOL Multiphysics 5.3 was utilized to interpret these two controlling equations with the proper borderline circumstances explained underneath.

2.1 Representation of the 2D and 3D Simulations

In order to model electromagnetic radiation for the head, one needs first to calculate the temperature variation in the head equally in 2D (Figure 1) and 3D (Figure 2). A 2D model gives us an opportunity to comprehend heating profile inside the diverse layers of the head, whereas a 3D model offers more accurate calculation of electromagnetic wave spread into the head layers (Ismail, 2007). The representation diagrams of the 2D and 3D models utilized in this study are clarified below. For the 3D model, rather than having diverse layers inside the head model, the authors utilized a special profile which encloses inserted standards of the head with 109 slices of a magnetic-resonance image (MRI) (Levoy, 2001).

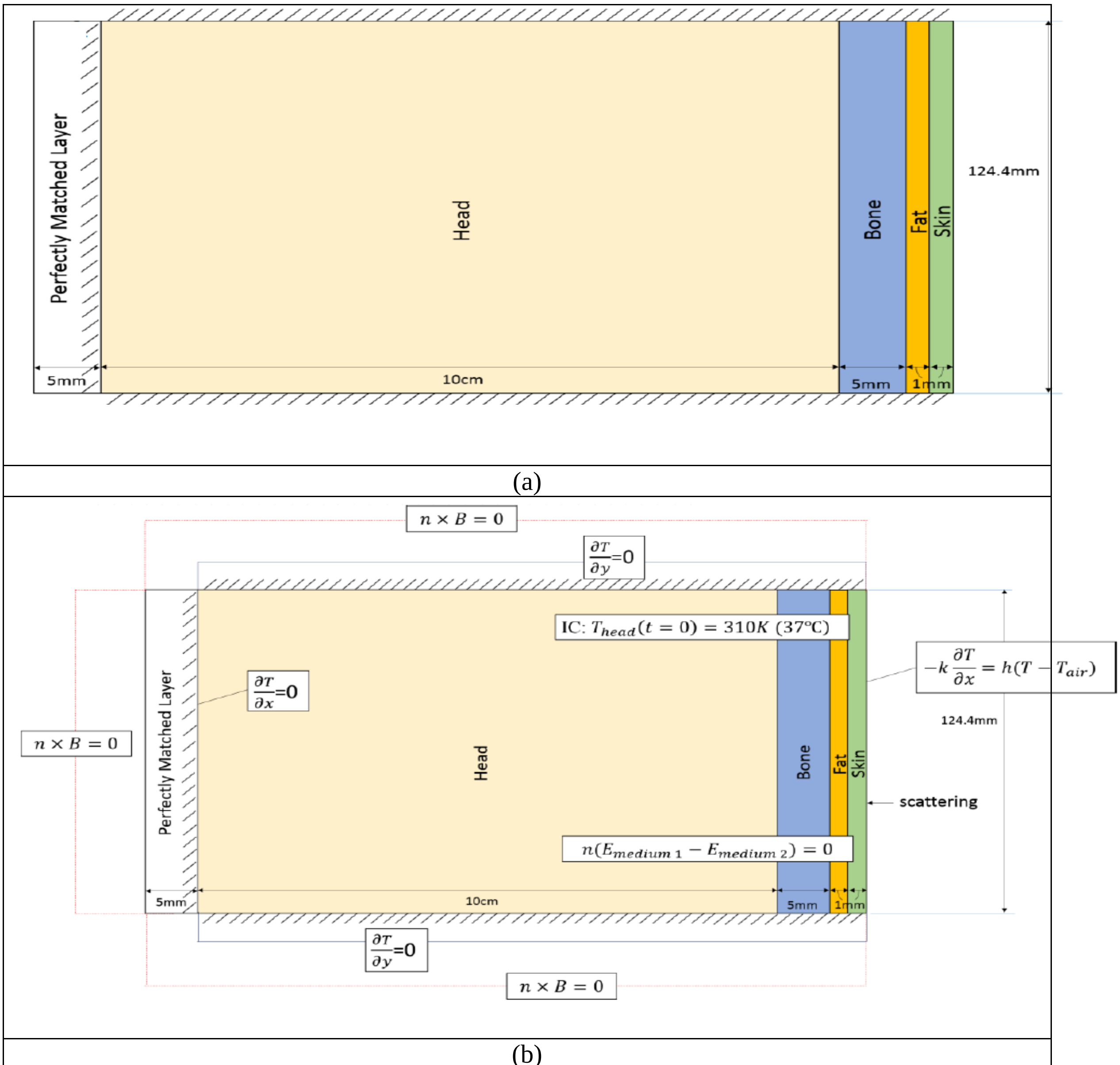

Figure 1: 2D model of head layers. (a) There present of air layer next to the head (skin layer) and mobile phone borders (scattering boundary), consequential of a convective heat transferal period. The mobile phone field is demonstrated as a borderline circumstance in COMSOL Multiphysics. (b) Thermal and electromagnetic state-line circumstances, in addition to early circumstances, are as presented.

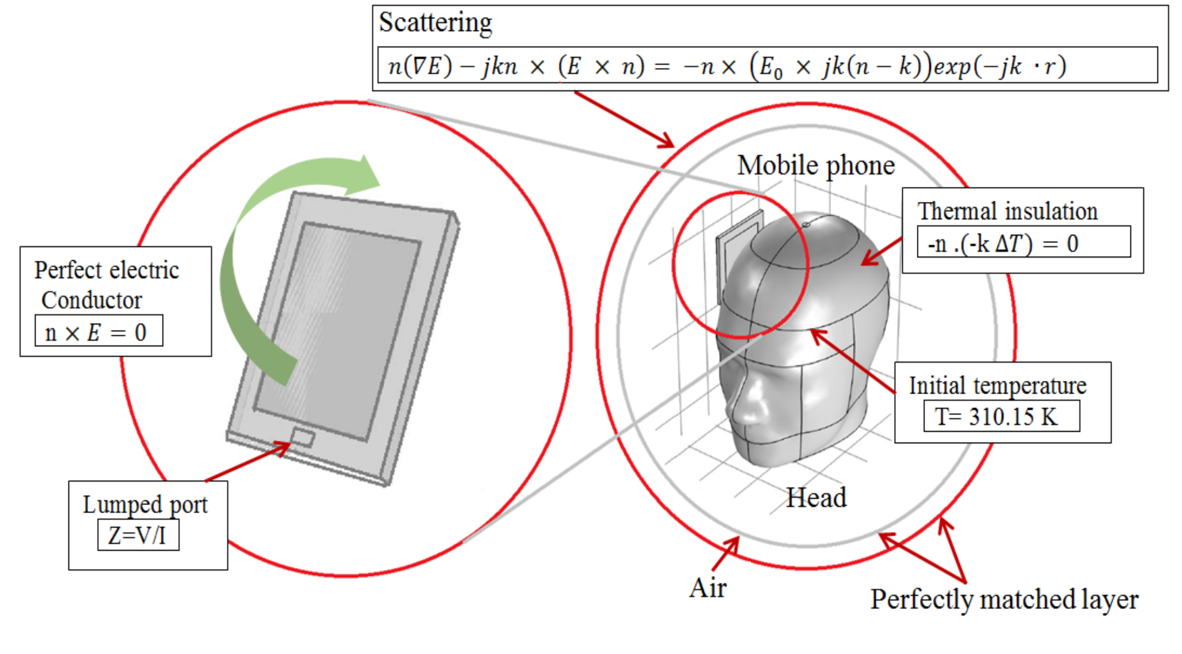

Figure 2: 3D model of the head, mobile phone, and rotund air area. A close up of the mobile phone domain (inset), with the mobile phone demonstrated as a quadrangular endured port at the bottommost.

2.2 Boundary conditions

In order to study boundary and preliminary circumstances for heat transferal and electromagnetic equations one needs to comprehend the thermal and electromagnetic circumstances. These circumstances are put into the COMSOL Multiphysics program so as to clarify the combined temperature and electromagnetic leading equations.

In earlier investigations electromagnetic radiation did not enter more than half the head's width (Wessapan & Rattanadecho, 2012). Thus, one can adopt semi-boundless geometry into the brain. In 2D, there is no heat fluctuation alongside the inward borderline of the brain layer and the highest and lowest layers not in touching base with the mobile phone (Figure1). In 3D, the external surface of the brain is thermally isolated (Cvetković, Poljak & Hirata, 2016) (Figure 2).

$$\frac{\partial T}{\partial x} = 0 \text{ and } \frac{\partial T}{\partial y} = 0 \quad (4)$$

In 2D, the left borderline of the skin layer is unprotected from the air; therefore one can apply the convective (Angelova, 2017), *i.e.* the main way of heat transmission in fluids, borderline circumstance.

$$-k\frac{\partial T}{\partial x} = h(T - T_{\text{air}}) \quad (5)$$

The authors made utilization of an effortlessly corresponding borderline layer equally in the 2D (left borderline) and 3D (air) representations (Manapati & Kshetrimayum, 2009). This borderline enables electromagnetic waves to be captivated by the borderline and stops replication of waves back to soft-tissue layers, which is suitable for open borders (namely air).

For effortlessness of calculation, one can adopt those electrical characteristics variances between the soft-tissue layers do not have impact on electromagnetic wave transmission (Duck, 2013). This enables us to relate steadiness borderline circumstances alongside the borders between various media (specifically amongst skin and fat, fat and bone, and bone and brain) together in 2D and 3D:

$n(E_{medium1} - E_{medium2}) = 0$	(6)

Along the highest, lowest, and left faces of the 2D exemplary, one can utilize the ideal magnetic conductor borderline circumstance. One can also accept that these surfaces have high surface impedance; electric fields and lateral magnetic fields cannot move across these restrictions, causing zero electric field level, a typical of electrodes (Nunez & Srinivasan, 2006). The ideal magnetic conductor borderline circumstance is similar to the no motion borderline circumstance in heat transference.

$n \times B = 0$	(7)

Beside the external surface of the skin unprotected to the mobile phone in 2D, one may have a sprinkling borderline circumstance for the basis period from the mobile phone ($E_o = 40.3$ V/m), where waves orthogonal to the surface entirely leakage the soft-tissue equally if the surface is translucent, even though all other waves are replicated back into the soft-tissue. In 3D, this is just smeared to the air round area.

$n(\nabla E) - jkn \times (E \times n) = -n \times \left(E_0 \times jk(n-k)\right) exp(-jk \cdot r)$	(8)

Where *n* the regular vector, and $j = \sqrt{-1}$

In 3D, the mobile phone is demonstrated with superlative electrical conductor borderline circumstances on the forward and backward facing surfaces (Vander et al., 2006) (Figure 2):

$n \times E = 0$	(9)

The reception apparatus is displayed as a lumped port on the lowest frame of the mobile phone area:

$Z_{in} = \frac{V_1}{I_1}$	(10)

According to this simulation model, one can accept that the head is at natural efficient temperature at the beginning (time = 0s):

$T_{head}(t = 0) = 310.15k(\sim 37°c)$	(11)

3. Results and Discussion

Once we create our 2D model, we measured temperature rise after 60 minutes, electric field power scattering all the way through the head, and the heat cause term as a result of electromagnetic emission. The electric field and heat basis term do not change with time since the authors controlled the electromagnetic wave equation by means of a frequency province in the COMSOL Multiphysics program, self-governing on time.

In our summarized 2D model, one can notice a temperature rise of 2.6°C amongst the highest temperature and preliminary temperature in an area of the brain once convection was neglected on the right borderline (fluidity=0) (Figure 3). Additionally, one can notice that temperature stopped fluctuating with time after 1800 s (Figure 3). As a matter of fact, it would be more precise to generate an area for the mobile phone itself when resolving the electromagnetic wave equation (Siauve et al., 2003). Flawless magnetic conductor limitations on the left, right, and highest limitations of the mobile phone and a power source boundary on the lowest might be smeared to pretend more accurate considerations (Wessapan & Rattanadecho, 2012). Nevertheless, this model was capable to capture attention by effectively joining electromagnetic heating as a basis term in the heat equation, causing a rise in temperature shown in Figure 3.

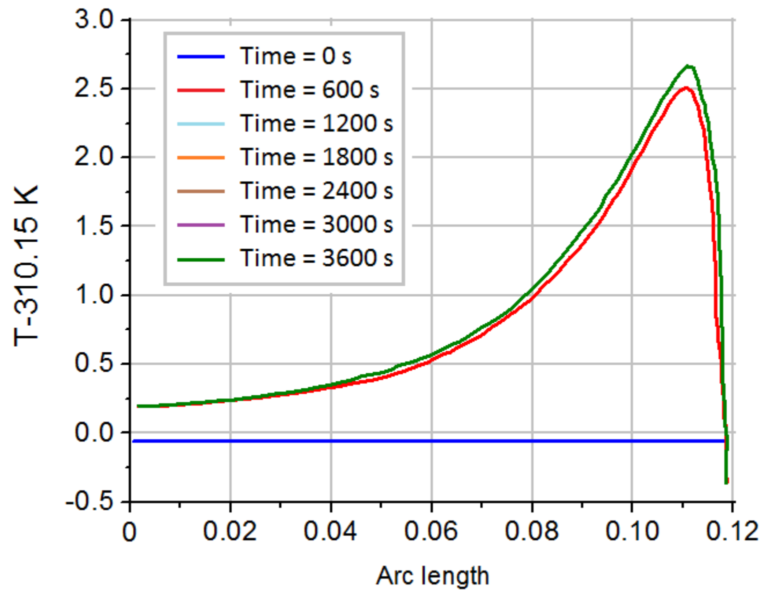

Figure 3: 2D temperature sketches of the head, temperature rise over time, in seconds, and location. There is a 2.6 °C alteration amongst the highest temperature and the beginning temperatures.

In the 3D model, one can find that the extreme temperature rise in this model after 60 minutes, temperature difference near the surface of the head over time, and the SAR circulation in the head. Likewise in our 2D model, the SAR circulation does not differ with time since the authors explained that the electromagnetic wave equation by means of the frequency province in the COMSOL Multiphysics simulation program.

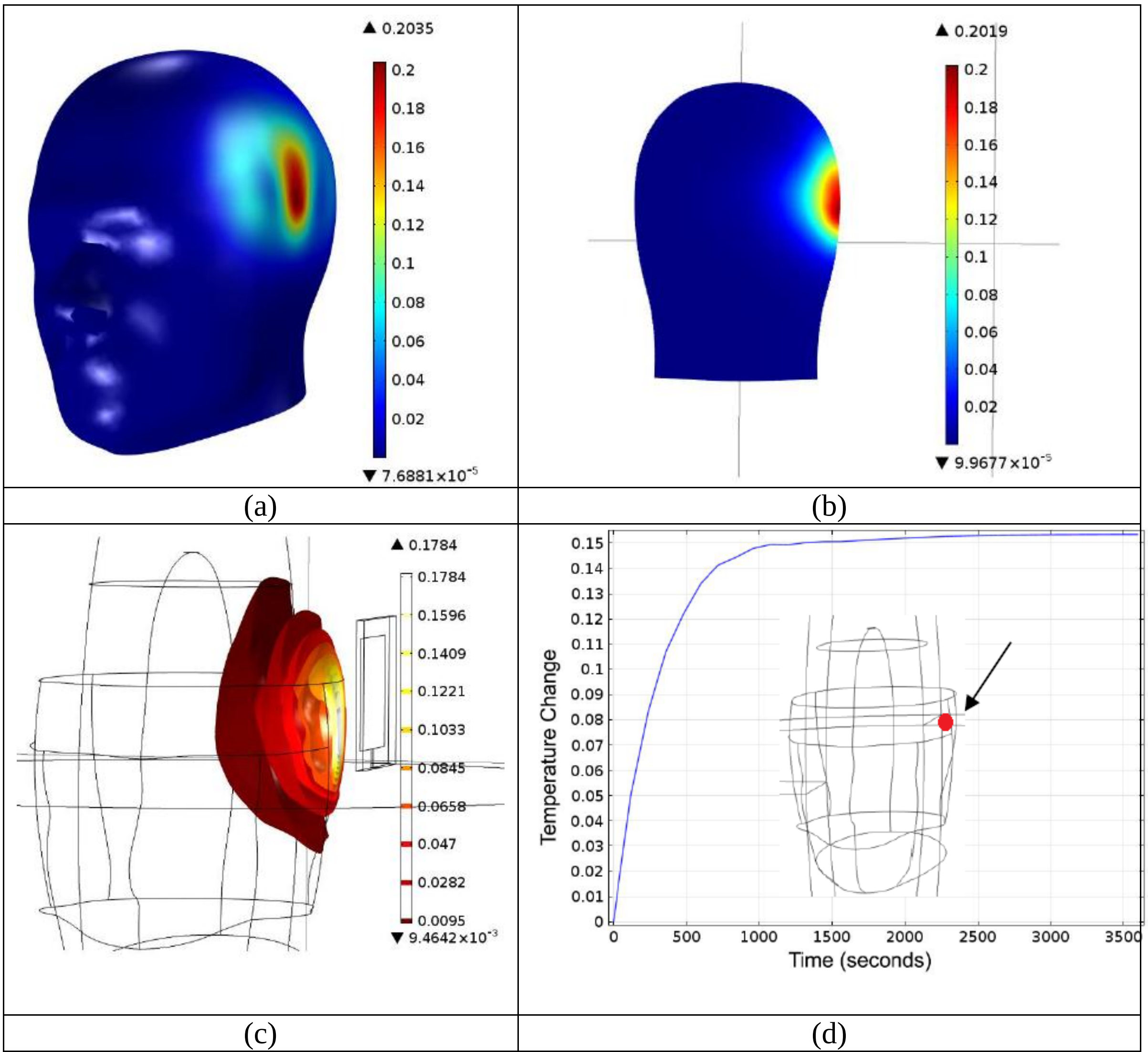

Figure 4: 3D temperature sketches of the head: (a) Temperature sketch of the entire head, (b) of a front plane portion, after 1 hour of mobile phone contact. (c) Isolated outlines surrounded by the head after 1 hour of mobile phone contact. (d) Time-temperature diagram at a point right inside the head (identified by the red spot) for 1 hour of mobile phone contact.

In the 3D model, the authors noticed that there is a temperature rise of 0.2°C, which is, fundamentally, one extent smaller than what we found in the 2D model (Figure 4). The highest temperature rise happened close to the surface of the head, through the highest SAR related to it (Figure 5). Furthermore, the temperature pauses varying with time afterward around 2500 s (Figure 4). This is owing to the calculation alterations amid 2D and 3D demonstrating and the changing extreme right borderline circumstance selections (Leabman & Brewer, 2016). Additionally, our 3D model simply pretends changing electrical characteristics of the brain layers, not the thermal characteristics. In the 2D model, a basic sprinkling borderline circumstance was smeared as the far right borderline circumstance with a quantified electric field scale.

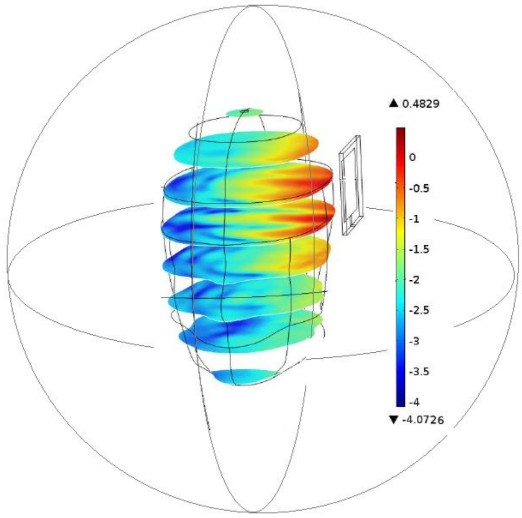

Figure 5: Logarithmic scales of the limited SAR rate in the brain. In agreement with the temperature sketch, the SAR captivation is highest nearby the mobile phone (SAR_{max} = 1W/kg).

3.1 Sensitivity Analysis

We accomplished sensitivity investigation on the applied electric field, room temperature, and the heat transmission coefficient in the 2D model. In all likelihood, as indicated by Christ et al. (2010) temperature variation inside the head improved with growing functional electric field scale (Figure 6). Temperature variation is similarly linearly reliant upon the heat transmission coefficient, such as; wind speed, and air temperature (Al-Baghdadi, 2010). At an assumed heat transmission coefficient, temperature variation inside the head improved with growing air temperature. This suggests that a temperature rise in the brain is further important in the summer than in the winter (Zwebner, Lee & Goldenberg, 2014).

Additionally, with varying heat transmission coefficients, there is a confident linear correlation with temperature variation when air temperature is beyond body temperature and an undesirable linear correlation when air temperature is underneath body temperature. Heat transmission coefficient basically improves the heat exclusion (when $T_0 < 37°C$) or heat absorption (when $T_0 > 37°C$) effects of the room temperature. For a tiny variation in heat transmission coefficient (±10%), the temperature rise would alter by around 0.2°C.

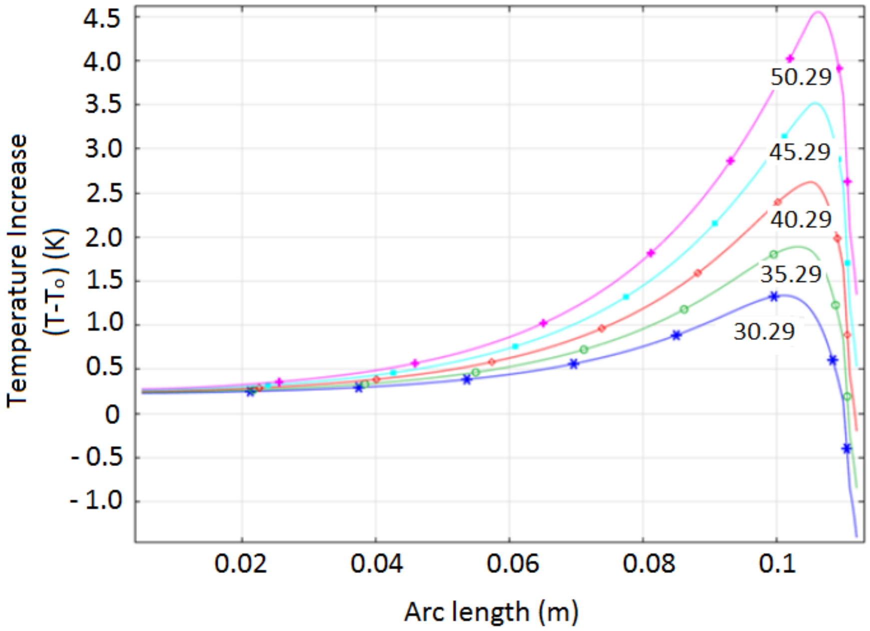

Figure 6: Temperature rise from standard body temperature (37 °C) as a function of electric field input after 1hour of mobile phone emission contact in the 2D model. The room temperature is represented by the several lines

Sensitivity investigation for the 3D model was accomplished with changing electric fields, primary temperatures, and thermal conductivities. Near the midpoint of the head, we detected the highest variation in temperature as a result of changing electric fields (Figure 7). At the surface of the head, the impact of growing electric fields was insignificant (Faruque, Islam & Misran, 2011). The outcome of changing preliminary temperature on temperature crossways the head after 1 hour was similarly insignificant. Thus, minor variations in preliminary temperature do not have impact complete effects in the 3D model.

Temperature sensitivity to thermal characteristics was investigated by changing the thermal conductivities from 0.2 W/mK to 0.5 W/mK. These standards were nominated from the variety of thermal conductivities for the diverse tissue layers (skin, bone, brain, and fat). The resultant temperature consequence of thermal conductivity is important with an alteration of around 0.025 K among the smallest and highest standards. This specifies that the emission influence in the head is thoughtful to thermal characteristics, and one need to guarantee that our standards are as precise as promising (Moon, Prstic & Chiu, 2008).

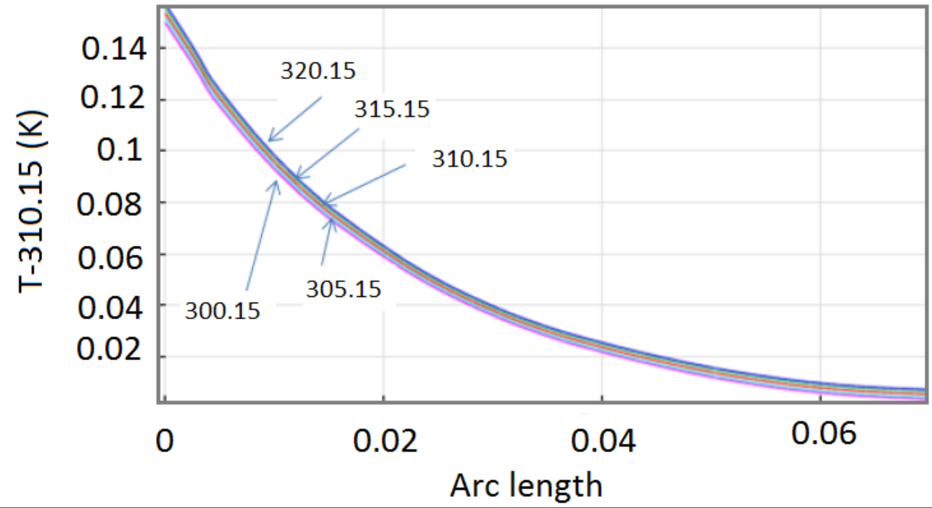

Figure 7: Temperature rise from standard body temperature (37 °C) verses position with changing electric field in the 3D model after 1 hour.

So as to certify the outcomes of the 2D model, the authors associated the temperature rise in the head with the Dlouhý and Rozman's study (2008). The temperature variation, measured as the change between highest and lowest temperature, for the 2D model was around 2.8 °C after 5 minutes (Figure 3). Likened to our standards, the highest temperature rise in the Dlouhý and Rozman's work after 5 minutes were considerably fewer: 0.0085 °C and 0.0019 °C temperature rises for mobile phone frequencies of 900 MHz and 1800 MHz, correspondingly. This huge change in the temperature variation might be because of the statement that our SAR standards were considerably poles apart from each other. According to Dlouhý (2008) for each mobile phone consumer, the SAR rate need not be greater than 0.08 Wkg^{-1}. Built upon this hypothesis, he utilized adapted tissue characteristic standards. Through doing so, he was capable of acquiring a SAR rate of 0.0516 Wkg^{-1}.

Nevertheless, related to his assessment, the rate that this study utilized was 1.25 W/kg for the iPhone 6 (the current model)(Pakkathillam & Kanagasabai, 2017). Because of this change, there was a substantial rise in the considered electric field rate, causing the bigger rise in temperature for the 2D model. Additionally, the 3D model with smaller amount expectations possibly will be extra precise model for data investigation on the influence of mobile phone emission on temperature rise in the head. Associating the borderline circumstances between 2D and 3D model, the 3D model comprises sprinkling borderline circumstance on the external layer of the air. Accordingly, for the 3D model simply a percentage of the electromagnetic waves touch the head while for the 2D model the whole electromagnetic waves emitted from the mobile phone source touches the head (Aronsson & Askeroth, 2002).

To authorize the results in this investigation for the 3D model, the authors likened the highest temperature rise in the head with that of Wessapan and Rattanadecho's study (Wessapan & Rattanadecho, 2012). The highest temperature rise in the 3D model from the original temperature was about 0.2 °C after 60 minutes. After half an hour, Wessapan and Rattandecho originate a highest temperature rise of 0.118 °C. Built upon the 3D model in this investigation of temperature against time outcomes (Figure 4d), the temperature of the head did not extent a stable state rate after half an hour, with a temperature rise of nearly 0.15 °C at the half an hour spot. The tiny change between the temperature rises establish in the other investigations and this model might be because of our absence of thermal characteristics interruption inside the head layers. Besides, the authors associated the SAR sketches with other previous work (Wessapan & Rattanadecho, 2012) and both conveyed a highest SAR rise of nearly about 1 W/kg (Figure 5).

4. Conclusion and Recommendations

In this study the authors applied in the 2D and the 3D to model the thermal impact of mobile phone emission on the head. Although our shortened 2D model concentrated on calculation time expressively, it produced a highest temperature rise of 2.6 ^{o}C but our 3D model produced a highest temperature growth of 0.2 ^{o}C. This may be because of the comparative greater electromagnetic wave degree in the 2D from the sprinkling borderline circumstance utilized. Nevertheless, the 3D model proposes that there is a negligible temperature rise in the brain because of mobile phone emission. In sensitivity investigation, the authors presented that temperature rise relies upon voltage source and thermal conductivity equally. A greater voltage source would produce a higher temperature rise. This illustrates that it is vital to preserve electric field beneath specific starting point to avoid brain injury.

On the other hand, a greater thermal conductivity would cause a minor temperature. This unpredicted relationship is because of the influence of thermal diffusivity on emission: a greater thermal diffusivity (from an upper thermal conductivity) might raise heat transmission amongst heated and unheated sections, reducing the influence of emission on soft-tissue.

Thus, for an ordinary adult, a highest of roughly 50 V in a mobile phone antenna have to be used to reduce temperature rise in the brain. Conversely, supplementary unexpected results must be deliberated when consuming this voltage. As this investigation pointed toward, temperature variation touches a stable state after 40 minutes of emission contact, however a minor contact time is continuously sensible.

Moreover, there are numerous expectations characteristic in this models that might bound their application. For instance, the authors expected that electromagnetic waves are constant between tissue layers all over the head. Nevertheless, meanwhile the soft-tissue layers possess dissimilar electromagnetic characteristics; the natural surroundings of electromagnetic wave spread might be pretentious by means of these changes. Extra accurate models might display a minor change in temperature spreading inside the human head.

Finally, forthcoming investigations in this arena might look at the influence of changing head lengths and characteristics on the thermal impacts of emission. Moreover, this investigation would redirect differences in varied inhabitants, from grown person to young people, and to model soft-tissue characteristics variations with age. Furthermore, the place of the mobile phone likewise stayed stable in this model. Distance from mobile phone to the head changes on an separate basis, forthcoming investigations might, likewise, differ the location of the mobile phone from the superficial of the head.

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