Skin Temperature Distribution over Human Head Due to Handheld Mobile Phone Call Using Thermal Imaging Camera

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Abstract—**The possible biological hazards due to the mobile phone electromagnetic (EM) field exposure are caused mainly by a temperature rise in tissue. Hence, the calculation of temperature in tissue may be more realistic than the calculation of specific absorption rate (SAR) due to the more direct relationship between temperature and safety. The heat transfer to human tissue due to a phone call is caused by a combined effect of conductive heat transfer caused by the basic non-microwave-related activity of the mobile phone and the absorption of the microwave. This paper investigates the role of heat transfer in living tissue due to thermal conduction. This is achieved using a thermal imaging camera to measure and map the skin temperature distribution over human head due to mobile phone EM emission. Two commercial mobile phone brands, that is, Apple iPhone 7 Plus and Huawei P20 Pro, are used at 1800 MHz cellular connection and approximate radiated power of 0.125 W to measure the skin temperature over human head at both, cheek and tilt position for 6 and 30 min calls. The results show that in spite of the direct proportion between the deposited SAR and temperature increase in human tissues, the heat transfer due to thermal conduction may not directly proportional to the SAR, where other factors may play important roles, for example, mobile phone chassis material, heated battery, antenna location inside the mobile phone, and mobile phone position in close proximity to head.**

***Index Terms*—Apple iPhone 7 Plus, Huawei P20 Pro, Bioheat transfer equation, Mobile phone, Specific absorption rate.**

I. Introduction

Using mobile phones in proximity to human head at different positions impose an electromagnetic field (EMF) interaction between the mobile phone and the head tissues. The absorption of EM energy generated by the mobile phone in the human tissue, calculated as the specific absorption rate (SAR), has become a point of critical public discussion due to the possible health risks. SAR, therefore, becomes an important performance parameter for the marketing of cellular mobile phones and underlines the interest in optimizing the interaction between the mobile phone and the user by both consumers and mobile phone manufacturers.

In general, SAR is the appropriate metric for determining EM energy exposure in the very near field of an radiofrequency (RF) source (Allen, 1996; Association of Radio Industries and Businesses Standards, 2002; Australian Communications Authority, 2003; European Committee for Electrical Standardization, 2001; European Committee for Electrical Standardization, 2001; Federal Communications Commission, 1997; Human Models, Instrumentation, and Procedures, 2006; IEEE Standard, 2003; IEEE Standards, 2006). SAR is expressed in watts per kilogram (W/kg) of biological tissue and is generally quoted as a figure averaged over a volume corresponding to either 1 g or 10 g of body tissue. The SAR of a wireless product can be measured in two ways. It can be measured directly using body phantoms, robot arms, and associated test equipment or by mathematical modeling (Al-Mously, 2010). The handhold of a mobile phone plays an important role on the deposited SAR value in human head, and this may affect the temperature increase in head (Al-Mously and Abousetta, 2008a; Al-Mously and Abousetta, 2008b; Al-Mously and Abousetta, 2008c).

The main cause of the possible biological hazards due to the mobile phone EM emission is the temperature rise in tissue. Thus, it is preferred to calculate temperature rather than the SAR in human head tissues due to the more direct relationship between temperature and safety. Accordingly, the effect of localized SAR for mobile phones should also be related to the temperature rise in the human head.

The temperature increase in human head tissues during a mobile phone call, at cheek and tilt position, has been calculated in a number of studies (Al-Mously and Abousetta,

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2009; Bernardi, et al., 2000; Bernardi, et al., 2001; Fujimoto, et al., 2006; Gandhi, et al., 2001; Hirata and Shiozawa, 2003; Ibrahiem, et al., 2005; Li and Gandhi, 2006; Rodrigues, et al., 2007; Rodrigues, et al., 2008; Samaras, et al., 2007; Van Leeuwen, et al., 1999; Wainwright, 2000; Wang and Fujiwara, 1999; Zygiridis and Tsiboukis, 2008), and a brief description of their exposure conditions and types of RF source model has been presented in Al-Mously, 2010.

In the previous reported works, the temperature increase in human head tissues has been calculated numerically using both homogeneous and heterogeneous human head phantom during mobile phone calls of 30 min and 6 min, according to IEEE/ANSI/FCC (Federal Communications Commission, 1997; IEEE Standard, 2003; IEEE Standards, 2006) and International Commission on Non-Ionizing Radiation Protection (ICNIRP) (European Committee for Electrical Standardization, 2001; European Committee for Electrical Standardization, 2001), respectively. The temperature increase in human head tissues has been calculated implementing the bioheat equation (BHE) (Pennes, 1948) based on the calculated SAR. The SAR according to IEEE/ANSI/FCC standards is calculated for an averaging mass of 1 g, whereas it is for 10 g according to the standard ICNIRP. The international standards, that is, IEEE/ANSI/FCC and ICNIRP, have been set for SAR limits according to tissue type, that is, head, limb, and whole body. No temperature limits have been set by any standard. This is because the temperature increase in tissue depends on many factors that are difficult to be measured using phantom with test equipment. Rusnani and Norsuzila (2008) used an infrared thermal camera to measure the temperature surface distribution due to three mobile phone brands in close proximity to the user's head after 6 and 30 min calls. The maximum recorded temperature after 30 min calls were 2.9°C, 1.1°C, and 2.0°C due to Nokia 3160 (Max. SAR = 1.14 W/kg), Samsung SGH300 (Max. SAR = 0.74 W/kg), and Sony Ericson T230 (Max. SAR = 0.60 W/kg), respectively. Rusnani and Norsuzila (2008) claimed that the temperature increase in the head is not due to the phone battery heating as long as the maximum temperature of the mobile phone is stayed below the temperature of head. Rusnani and Norsuzila (2008) did not consider the temperature increase in the head skin due to the EM near filed, but the phone battery heating. Moreover, he did not consider the effect of the mobile phone positions, cheek and tile with respect to head, according to the IEEE-Std. 1528-2003. Al-Mously (2010) measured the temperature increase in two mobile phone chases, candy bar type Motorola L71 and clamshell type Motorola RAZR V3i, after 60 min call, and then, the two mobile phones were simulated, using 3D EM simulation software, in close proximity to head at cheek position to measure the temperature increase in pinna tissue due to thermal conduction. Bauer, et al. (2018) investigated the influence of smartphones' operation modes on the superficial temperature distribution in the human pinna region. He observed that there are statistically significant differences between mean temperatures of the pinna before and immediately after the use of the smartphone, independent of whether RF communication was on (normal mode) or off (flight mode). The increase in tissue temperature was caused by a combined effect of conductive heat transfer caused by the basic non-microwave-related activity of the smartphone and the absorption of the microwave.

This paper shows that the temperature increase in head tissue due to the thermal conduction for long phone call duration may play an important role. The temperature increase due to the thermal conduction does not necessary depend on the mobile phone SAR, but on other factors, for example, handheld position (ventilation gap between mobile phone and human head), antenna location inside the mobile phone, battery temperature increase, etc.

II. Pennes BHE

Temperature ($T = T(x, y, z, t)$ [°C]) can be modeled in the head with a numerical implementation, for example, finite difference, of the bioheat transfer equation (BHE), developed by Pennes (1948):

$$\rho c \frac{\partial T}{\partial t} = \nabla\left(k \nabla T\right) + \rho Q_{met} + \rho\left(\mathrm{SAR}\right) - B\left(T - T_{blood}\right) \quad (1)$$

$$B = \rho_{blood}\, c_{blood}\, \rho \omega \quad (2)$$

where the different values of ρ (kg/m^3) (material density), c (J/[kg °C]) (specific heat capacity), k (W/[m °C]) (thermal conductivity), Q_{met} (W/kg) (metabolic heat generation rate), B (W/[m^3 °C]) (blood perfusion coefficient), and ω (L/[s kg]) (blood perfusion rate) for several different tissues were acquired from literature (Bernardi, et al., 2000; Bernardi, et al., 2001; Fujimoto, et al., 2006; Hirata and Shiozawa, 2003; Li and Gandhi, 2006) and are given in Rusnani and Norsuzila (2008) (Al-Mously and Abousetta, 2009). It should be noticed that the results based on experiments involving animals were used for most of the thermal parameters required in the human head model. The uncertainties in the maximum

TABLE I
SAR in Head Tissues of Apple iPhone 7 Plus and Huawei P20 Pro for Non-occupational/Unaware Users in American and European Regions

American IEEE/ANSI/FCC					
Phone brand	SAR (W/kg) in head	Measurement method	Limit (W/kg)	Averaging mass	Time
Apple iPhone 7 Plus	1.190	C95.1	1.6	1 g	30 min
Huawei P20 Pro	1.030				
European ICNIRP					
Phone brand	SAR (W/Kg) in head	Organization/body	Limit (W/kg)	Averaging mass	Time
Apple iPhone 7 Plus	1.340	EN50360	2.0	10 g	6 min
Huawei P20 Pro	0.730				

SAR: Specific absorption rate

temperature increases caused by those in thermal parameters were investigated in Hirata, et al., 2003; Samaras, et al., 2007.

Heat transfer in living tissue is a complex process and includes conduction, convection, and blood perfusion (such as delivery of the arterial blood to a capillary bed), cooling of human body by radiation, and metabolic heat generation (Ghassemi and Shahidian, 2017).

In Equation (1), the term on the left represents the rate of change in the stored internal energy of the tissue, the term $\nabla\,(k\nabla T) = k\nabla^2 T$ is the heat transfer due to thermal conduction, which is under investigation of this work, and the last term relates to convection heat loss associated with blood flow.

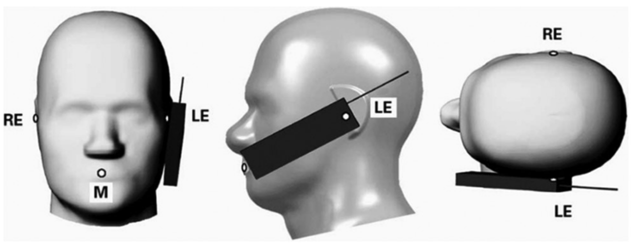

Fig. 1. Specific anthropomorphic mannequin with mobile phone in cheek position on the left side according to the IEEE-Std. 1528-2003. RE: Right pinna, LE: Left Pinna, and M: Mouth.

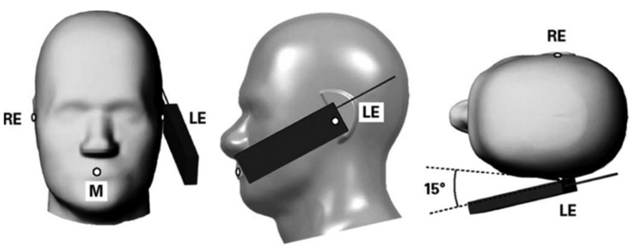

Fig. 2. Specific anthropomorphic mannequin with mobile phone in tilt position on the left side according to the IEEE-Std. 1528-2003. RE: Right pinna, LE: Left pinna, and M: Mouth.

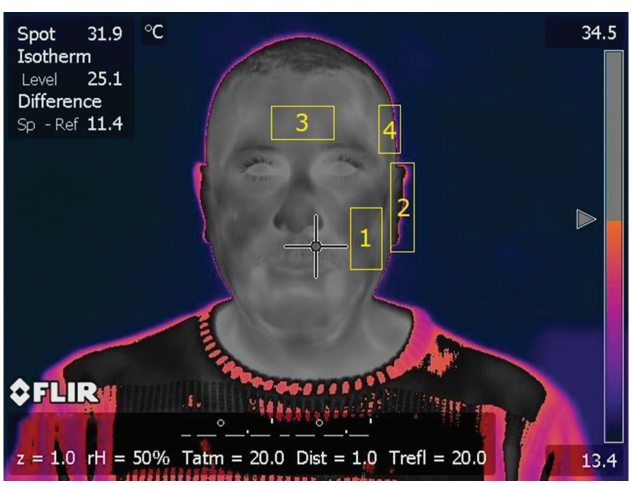

Fig. 3. Front view of the human head with indicated four regions that their surface temperatures are measured due to mobile phone calls using FLIR SC660 thermal imaging camera. Region 1: Cheek, region 2: Pinna, region 3: Forehead, and region 4: Side head.

III. Skin Temperature Measurement Procedure and Results

According to Equation (1), it is very clear that the thermal conduction plays an important role in heat transfer in living tissue. Thus, mapping the surface temperature distribution on human head skin may give a deeper perception about the term $\nabla\,(k\nabla T) = k\nabla^2 T$.

Two commercial mobile phone brands are selected to be investigated in terms of the temperature increase in human head skin that both may cause, that is, Huawei P20 Pro and iPhone 7 Plus. Their SAR values based on the manufacturer datasheet are listed in Table I.

According to Table I, Apple iPhone 7 Plus shows more deposited SAR in human head tissue than Huawei P20 Pro, based on both organization standards; American IEEE/ANSI/FCC and European ICNIRP. Consequently, and based on the reported previous works, the temperature increase in human head due to a phone call EMF emission caused by iPhone 7 Plus is more than the one caused by Huawei P20 Pro. This is true since the temperature increase in human tissue is directly proportional to the deposited SAR.

The procedure of skin temperature measurement over human head is by making phone calls for 6 min and 30 min using the mobile phones Apple iPhone 7 Plus and Huawei P20 Pro, at both cheek and tilt positions. Hence, eight phone

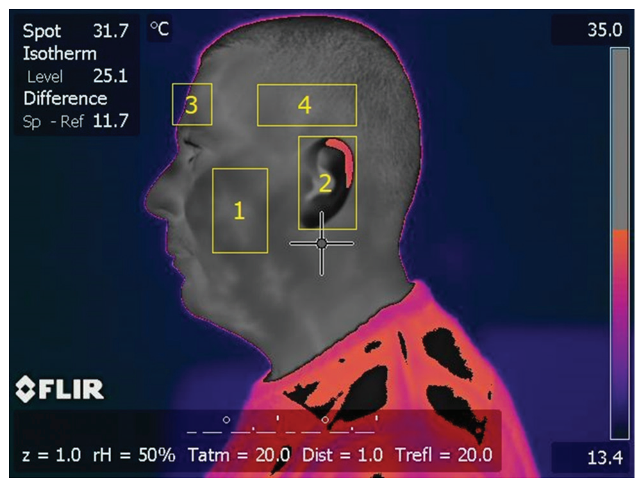

Fig. 4. Side view of the human head with indicated four regions that their surface temperatures are measured due to mobile phone calls using FLIR SC660 thermal imaging camera. Region 1: Cheek, region 2: Pinna, region 3: Forehead, and region 4: Side head.

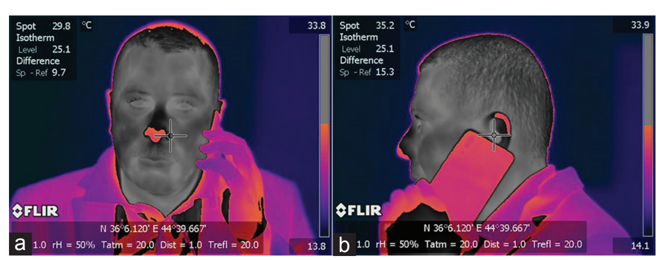

Fig. 5. (a and b) Apple iPhone 7 plus handheld in close proximity to human headshot by the FLIR SC660 thermal imaging camera.

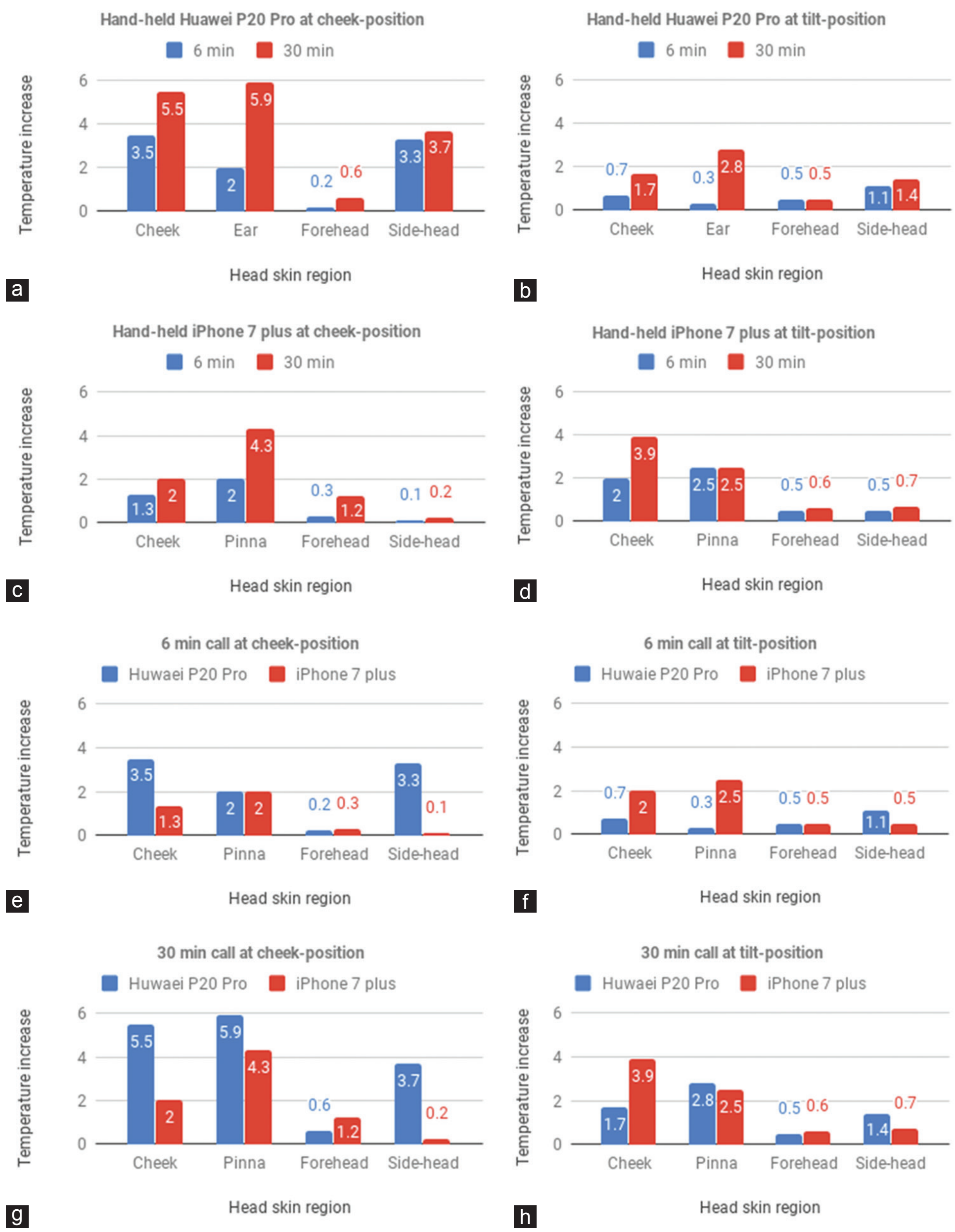

Fig. 6. Measured temperature (°C) distribution in head skin regions, that is, cheek, pinna, forehead, and side head, for different mobile phone brands after 6 and 30 min calls. (a) Handheld Huawei P20 Pro at cheek position, (b) handheld Huawei P20 Pro at tilt position, (c) handheld iPhone 7 Plus at cheek position, (d) handheld iPhone 7 Plus at tilt position, (e) 6 min call at cheek position, (f) 6 min call at tilt position, (g) 30 min call at cheek position, (h) 30 min call at tilt position.

call scenarios of standardized tone are conducted, using the same room temperature and by the same person at the same body and mobile phone temperatures. The temperature is measured by a thermal imaging camera in each scenario after removing the mobile phone, immediately. The cheek and tilt position of the mobile phone in close proximity to head is defined by IEEE-Std. 1528-2003, is defined in Figs. 1 and 2.

A thermal imaging camera type FLIR SC660 is used for the measurement, and four regions over human head are selected to measure the temperature after phone calls of 6 and 30 min. Figs. 3 and 4 show a thermal camera image of the human head, indicating the four regions under measurements, that is, cheek, pinna, forehead, and side head.

Fig. 5 shows the front and side view of human making a phone call using Apple iPhone 7 Plus at tilt position shot by the FLIR SC660 thermal imaging camera.

Fig. 6 shows the temperature values of the skin of the cheek, pinna, forehead, and side head regions, all are measured for the mobile phones Apple iPhone 7 Plus and Huawei P20 Pro at cheek and tilt positions and after durations 6 and 30 min calls.

IV. Discussion and Conclusion

According to the skin temperature distribution is shown in Fig. 6, the following are concluded:

1. The temperature increase in the head skin regions is directly proportional to the phone call duration, for the same mobile phone and the same mobile position with respect to head
2. Huawei P20 Pro causes more skin temperature increase over human head at cheek position than at tilt position. The same scenario exists for the Apple iPhone 7 Plus, but in the pinna and forehead regions, only. This may due to different antenna location inside both mobile brands
3. At cheek position, and though it has less SAR, Huawei P20 Pro shows more temperature increase in the skin of the cheek, pinna, and side head, as compared with Apple iPhone 7 Plus, after 6 and 30 min phone calls. This may due to different antenna locations inside both mobile brands and different battery heat
4. At tilt position, Huawei P20 Pro shows more temperature increase than Apple iPhone 7 Plus in the skin of the pinna after 6 min and on the skin of side head after 6 and 30 min phone calls
5. The results at tilt position do not follow the trend of the results at cheek position. This is due to the ventilation space between the mobile phone and the cheek.

Based on the above conclusions and the results in Fig. 6, it is obvious that the skin temperature distribution over the human head, and consequently the thermal conduction, does not follow the SAR values trend. The temperature increase in the head skin regions is due to both, heated battery and the EM near field of the mobile phone. Although Huawei P20 Pro deposited less SAR in head tissues, as compared with Apple iPhone 7 Plus, Table I, it causes more temperature increase in the head skin at cheek position, at least, for the call durations 6 and 30 min. In summary, the heat transfer due to the thermal conduction depends on other factors rather than on SAR value, only, for example, mobile phone chassis material, mobile phone heated battery, antenna location inside the mobile phone, and mobile phone position in close proximity to head.

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