Thermal Effect of Mobile Phones on Skin Temperature: Heat Reduction due to a Homogeneous Aluminum Card

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ABSTRACT

We report the effect of thermal energy produced by cell phone on human skin and the heat reduction from a homogeneous aluminum card (Bodywell Card, BWC) which has previously shown a significant specific absorption rate (SAR) reduction. Two (2) healthy volunteers using mobile phones at the GSM frequency of 1,900 MHz participated in this study; a non-invasive thermal imaging method is used to measure skin temperature changes. Thermography is used to evaluate temperature changes of the right ear pinna and surrounding tissue of the head exposed to a mobile phone, and to the dorsal of the left hand holding a mobile phone. The subjects under test (SUT) were exposed to mobile phone communication for 45 minutes (head) and 20 minutes (hand). Measurements made with the mobile phone in communication mode show significant temperature increase of human skin and directly underlying tissue and confirm previously reported results. By adding the BWC to the back of the phone, a significant reduction in heating in both the head and hand was shown.

Key words: mobile phone; homogeneous; radiofrequency electromagnetic; ear; dorsal

INTRODUCTION

“In 2013 there are almost as many mobile-cellular subscriptions as people in the world” according to the International Telecommunication Union (ITU) [1]. Cellular phones also referred to as mobile phones operate worldwide in the ultra-high frequency (UHF) range of the radio frequency (RF) spectrum. For mobile phones, ITU approved frequencies in the following ranges: 806-960 MHz, 1,710-2,025 MHz, 2,110-2,200 MHz and 2,500-2,690 MHz. RF is a rate of oscillation from an alternating current and propagates in space in electromagnetic waves (EM) which radiates off a conductor. The energy of the RF-EM waves is known to be non-ionizing but thermal effects in human tissue have been reported [2-7]. The heat dissipated in the skin from mobile phones may be due to thermal insulation by the phone heating of the mobile phone resulting from its electric circuitry, and from RF radiation (RFR) [8]. The first two produce significant rise in skin temperature while the latter still being investigated and may be less significant. Temperature increase in surrounding soft tissue of facial nerves due to RFR has been reported to cause temporary facial nerves dysfunction [9]. It is also established that moderate level exposures to RFR can cause heat stress and behavioral changes, and as that level of exposure increases, the potential for harm increases. For example, temperatures above 107^{o} Fahrenheit can seriously and permanently damage human cells. The most vulnerable are the eyes which have virtually no blood flow that can provide cooling from other body parts. Cataracts were shown to be caused from long RFR exposure [10]. Thermal burns due to mobile phone have also been reported [11].

Because of the invasiveness of the temperature probes, it remains very difficult to assess the real thermal effect in humans due to mobile phones. Experimental methods to measure thermal effects due to mobile phone consist mainly of thermo sensors and infrared imaging. Temperature increases have been shown in theoretical models accounting for different factors and conditions [6, 7]. In fact many factors impact how much the body heats up in presence of significant RF energy. The Specific Absorption Rate (SAR) was established as a basis of major RF exposure standards worldwide and a guideline to mobile phone manufacturers. SAR defines the rate of absorption of heat into the human body in units of Watts per kilogram. SAR tests use liquids that simulate brain or body tissue, mimicking human tissue when subject to specific RF. Cellular phone manufacturers have improved their products to meet standard SAR limits but mobile phones continue to produce heat from thermal insulation, electronic circuitry and RFR. Many people use a mobile phone applied against their ear for a lengthy period of time, causing serious health concern especially for the youth and children who have become daily users [12].

Ongoing research looks at methods to minimize thermal and non-thermal effects of RFR as wireless communication expands to become one of the greatest types of air pollution of modern times. RF not being part of our natural background radiation, current and future generations will have to control its exposure and adapt to it. The main objective of this study is to report a reduction in RFR heating of human tissue by using a homogeneous aluminum card which has been reported to show a significant SAR reduction [13]. We use thermal imaging to measure surface temperature both on the head and on the hand. We report temperature increase in depth of human tissue through the thickness of the hand exposed to heating from mobile phone. There is a difference in structure between head and hand tissue, nevertheless the heat that extends from the palm to the back of the hand is indicative of the heat that is absorbed by brain tissue. Many factors such as output power of the mobile phone, duration of the use of the phone and features related to the IR camera technology may influence the results of the tests. However, these experimental factors will have little effect on our results because our objective is to compare temperature distribution using the same mobile phone with and without the BWC. Possible sources of errors to measure temperature using IR camera do exist and will be reviewed in the methods and discussion sections.

MATERIALS AND METHODS

To test the temperature increase in the head and the hand we use thermography on healthy volunteers. All tests were conducted at Green Health Thermography (Ann Arbor, Michigan) under the supervision of a certified nurse and a Medical Doctor. All tests were in accordance with national ethical standards including informed consent from the subject. The exposure levels were within the limits of the ICNIRP guidelines [14].

Subject Under Test

Two healthy males in their early fifties volunteered to do the testing. One of the subjects presented facial characteristics appropriate for the intended tests, offering more than 75% of skin surface area for thermal imaging. The second subject’s left hand was exposed to heating from a mobile phone as in

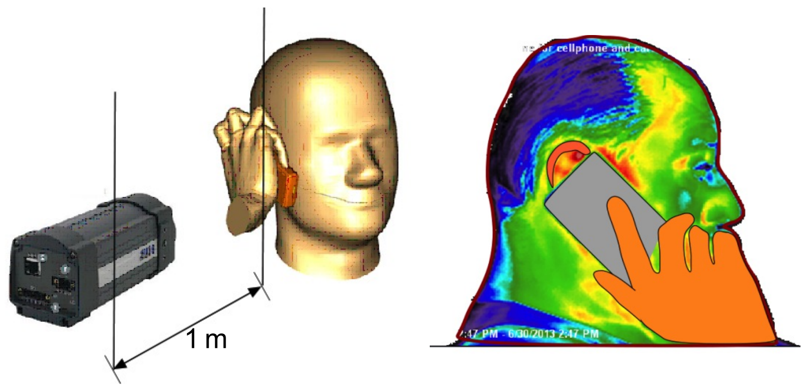

Figure 1: Subject under test holding the mobile phone. IR camera is on a tripod 1 meter away and focused on the pinna of the right side (picture not to scale, part of the figure is from www.cst.com).

normal usage. Informed consents were received from both subjects and care was taking not to over stress them or to create any discomfort during testing. One subject was seated comfortably with his right side to the IR camera about 1 m away. His right elbow was rested comfortably on a pillow with his right hand holding the phone. His fingers would hold the phone in a manner to minimize the surface contact of the hand to the phone (Figure 1). The second subject had his left elbow rest on a pillow while holding a mobile phone and the dorsal of his left hand exposed to the IR camera 50 cm above (Figure 2).

RF Exposure

A BlackBerry Z-10 mobile phone operating at 1900 MHz was used for mapping the temperature distribution around the right ear of the SUT. The phone was in talk mode for 45 minutes and the SUT sat in a comfortable position with his elbow resting on a pillow, “active mode” corresponds to the mobile phone turned “ON” and communicating with another wireless device. Testing position corresponds to normal mobile phone usage by most people applying the unit against their pinna with a more or less soft pressure. During the test the phone is held without motion against the ear with a gap between the phone and the right cheek, the battery of the phone is fully charged at the beginning of the test. The test is repeated in the same conditions with the phone and the BWC attached to the cover of the battery compartment. Prior to the RF exposure test, a baseline image was measured without the mobile phone and the temperature color template was locked for all measurements.

During the hand test, the SUT extended his left arm while holding the mobile phone as shown in Figure 2 (A Samsung Galaxy S4 was used for the hand test). The phone was applied with a light pressure against the palm to produce good surface contact between mobile phone and hand tissue. The SUT had his left hand dorsal exposed to the IR camera 50 cm above. The duration of this test was reduced to 20 minutes to avoid fatigue of the hand muscles and the fingers pressing on the phone. Protective cover of the Galaxy S4 was removed during test.

Figure 2: Hand test with a Galaxy S4 and a Bodywell card (Picture not to scale, phone cover removed during tests).

Infrared (IR) Camera

Tests were conducted using overlays built into the software designed with protocols from the Institute for the Advancement of Medical Thermography (IAMT) for the head and neck. We used a FLIR 320x240 array size 76,800 total pixel image resolution camera (Med-Hot Max 76 (FLIR A320), FLIR Systems Inc., Boston, MA). The Med-Hot Thermal Imaging System meets specifications based on the AAT device guidelines. The camera has a 25° X 18.8° / 0.4 m field of view and an uncooled microbolometer focal plane array (FPA) of 320 X 240 pixels. Image frequency is 60 Hz. The spectral range of the camera is 7.5–13 mm. The thermal sensitivity is less than 0.05°C at + 30°C ambient temperature. The following values were set in the software: emissivity at 1.0; room temperature at 72^{o}F; relative humidity at 25%. Skin emissivity is 0.98 and absolute temperature changed by about 0.5°C when emissivity was set to 1.0. The absolute temperature which depends on emissivity, ambient temperature and humidity did not fluctuate significantly as checked prior to our tests. The temperature accuracy was ±2°C and ±2% of reading with all the variables (emissivity, temperature and humidity) correctly set.

Measurement of Temperature Change

The images were taken from only the right lateral posture for the head imaging and above the hand for the hand imaging. The images were captured automatically with 1 minute interval, and the temperature distribution for each image was constructed at the end of 45 minutes (head) and 20 minutes (hand) with the same color template with respect to the baseline in each of the two tests.

To measure the temperature change over the pinna of the right ear, images were captured at the start of communication by the mobile phone to the end after 45 minutes. Then the phone was removed and images of the side area by the right ear were captured every minute. The software controlling the IR camera allowed setting up time capture interval. This would expose the whole right side immediately after the 45 minutes and during cooling off.

Still images were taking for the hand every 1 minute for a period of 20 minutes; in this case the phone did not block capturing images of the back hand. The mobile phone would be removed after that period and the hand was allowed to cool to its initial temperature as recorded. IR images were continuously captured during cooling off period. The ambient temperature was maintained at 72 degrees Fahrenheit

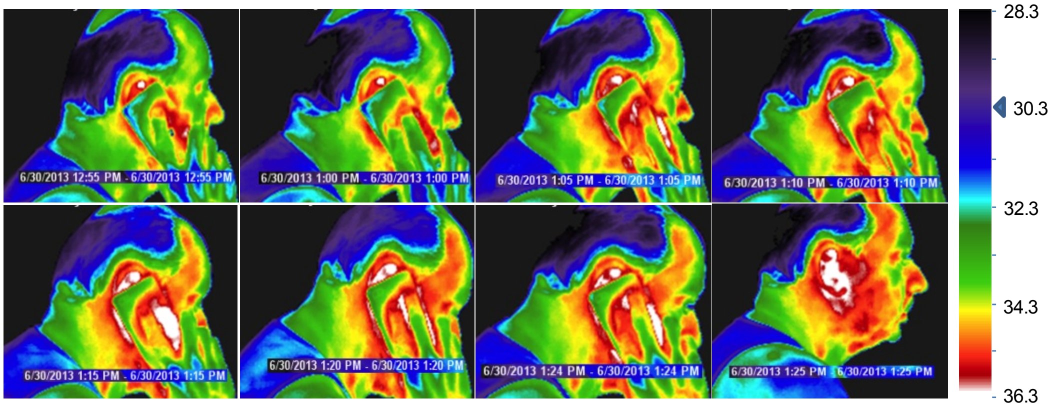

Figure 3: Thermal images of the head during heating from a mobile phone (Black Berry). Exposure time to RFR is shown from 12:55 pm to 1:24 pm (30 minutes). Immediately after 1:24 pm, the phone was removed and images were captured during the cooling period starting at 1:25 pm (numbers in colorbar are temperatures in ^{o}C).

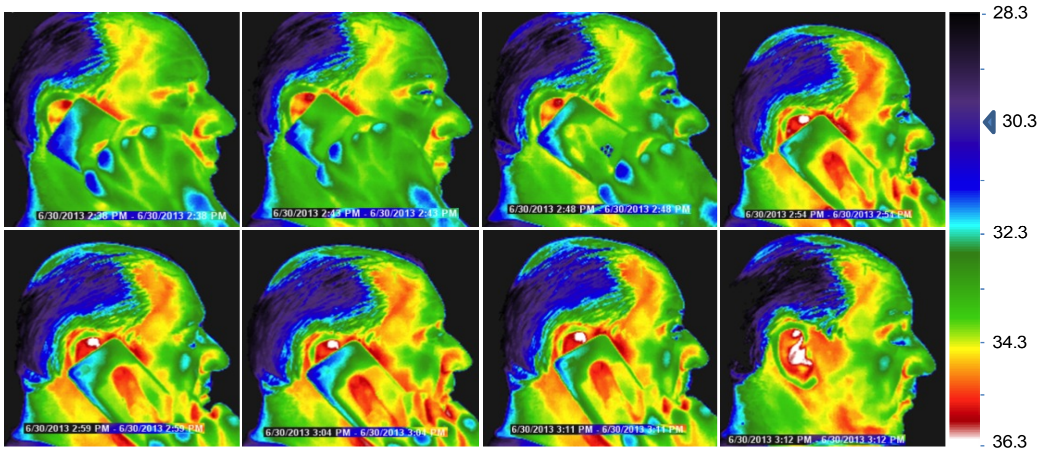

Figure 4: Thermal images of the head during heating from a mobile phone (Black Berry) and BWC. Exposure time to RFR is shown from 2:38 pm to 3:11 pm (34 minutes). Immediately after 3:11 pm, the phone was removed and images were captured during the cooling period starting at 3:12 pm (colorbar as in Figure 3).

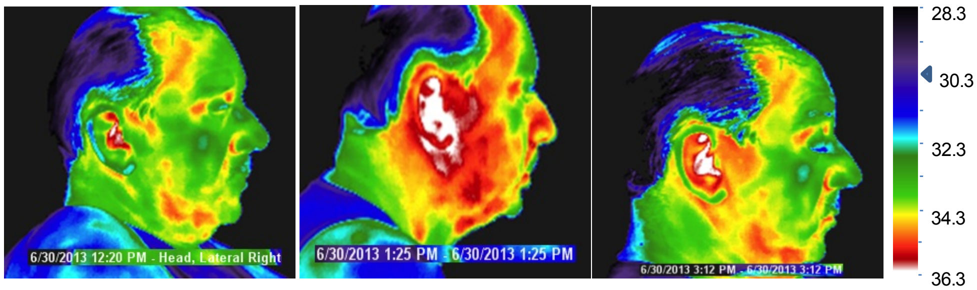

Figure 5: Thermal images of the head: normal temperature distribution (left); temperature profile following removal of the BlackBerry phone at 1:25 pm (center); temperature profile following removal of the phone and BWC at 3:12 (right). Exposure time for both conditions in the center and right images was 45 minutes.

throughout the tests. Temperature was measured from single point for consistency using Reid's base line [15].

RESULTS

We compare three conditions of skin temperature distribution: without exposure to mobile phone; exposure to mobile phone; exposure to mobile phone and BWC.

Head Thermography

The mobile phone BlackBerry Z10 was turned ON and set in active mode. The SUT had the phone against his right ear pinna as shown in Figure 3. Heating of the skin behind the phone and in surrounding tissue is clearly shown as expected and previously reported [8]. The heating after 45 minutes of exposure to the BlackBerry phone is shown in Figure 3 at 1:25 pm (lower far right). The exposure to the BlackBerry phone with the BWC attached to its battery compartment is shown in Figure 4. Heating after 45 minutes of exposure is shown immediately after removal of both the phone and BWC at 3:12 pm in Figure 4 (lower far right). The SUT is allowed to rest at ambient temperature until normal temperature profile is measured on the heated right side of the head (Figure 5-left).

Figure 5 shows a comparison of temperature distribution: in normal condition of no RFR exposure (left); with the SUT at rest under normal activity, after exposure to Blackberry phone (center); and after exposure to BlackBerry and BWC (right). There is a significant reduction in heating due to the BWC; center and right images correspond to heating from initial condition (left) after 45 minutes of exposure to BlackBerry. The cooling period shown in Figure 6 represent the period following removal of the BlackBerry phone. Infrared images are shown for 10 minutes from 1:25 pm to 1:34 pm. SUT was allowed to completely recover from mobile phone heating before next test was performed. Figure 7 shows cooling period following exposure to the active mode of the BlackBerry with the BWC attached to its back on the battery compartment.

Numbers on the colorbar of Figure 1-7 are temperature values in ^{o} C. We set the same temperature baseline for all measurements as allowed by the software. There is clearly a significant reduction in heating when the BWC is used. The BWC showed a significant reduction in SAR tests in previous reports [13] and gave negative results during Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS) tests [16] which indicate that the card did not impede phone functions during communication reducing its heating power.

We clearly show that after 10 minutes the SUT has not recovered from heating by the mobile phone while he recovers after 11 minutes from heating when the mobile phone is used in conjunction with the BWC. We compare the following conditions: in Figure 6 at 1:34 pm and in Figure 7 at 3:22 pm (both lower right images). Because of the amount of heat absorbed by the SUT during mobile phone communication, the head tissue on the right side around the ear takes much longer to regain its normal temperature before exposure. Temperature increase deep within the tissue contributes to a slow recovery as will be discussed below (discussion section).

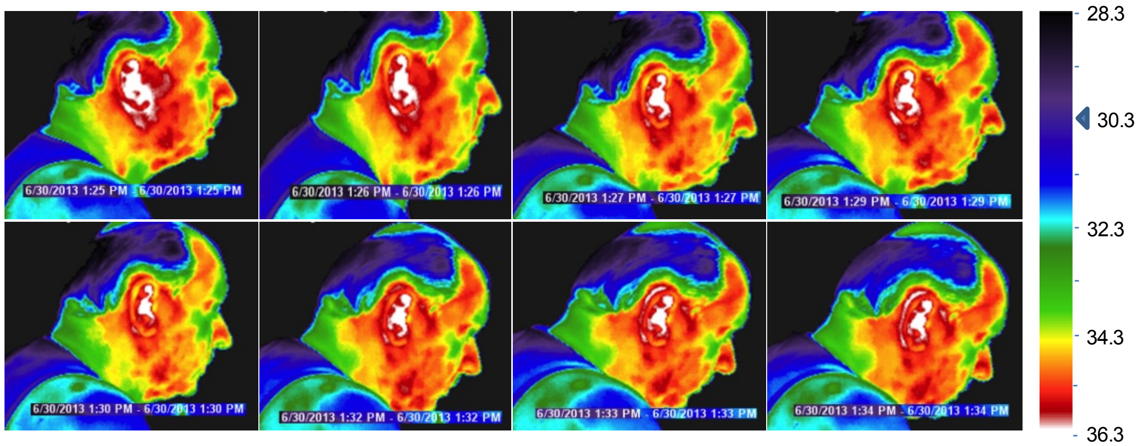

Figure 6: Thermal images of the head immediately following removal of BlackBerry phone at 1:25 pm. Shown images are for 10 minutes up to 1:34 pm, the skin has hardly recovered to its normal temperature.

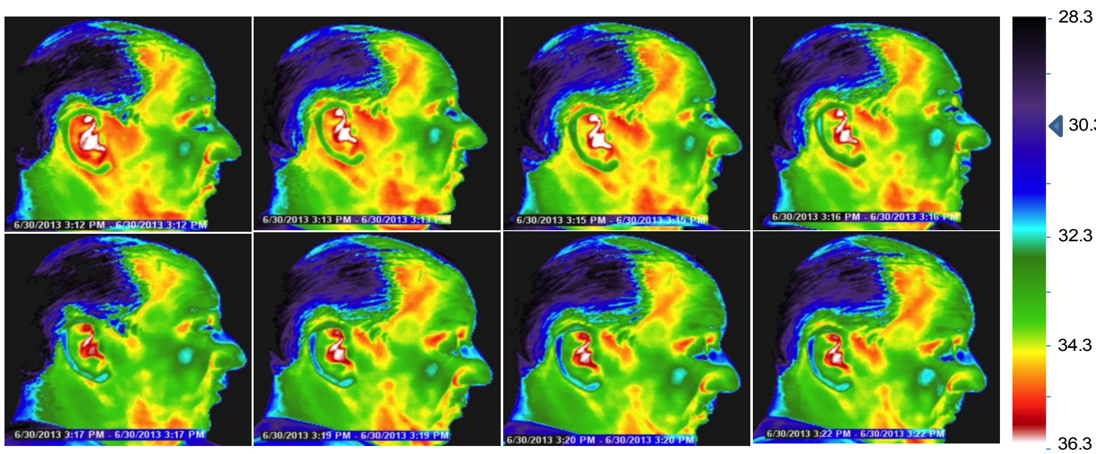

Figure 7: Thermal images of the head during cooling immediately following removal of the BlackBerry and BWC at 3:12. Shown images are for 11 minutes up to 3:22 pm.

Hand Thermography

Temperature measurements during heating of human tissue are difficult to evaluate inside the tissue because of limited noninvasive techniques. The thermal imaging of the hand during heating produced by exposure to a communicating mobile phone is recorded as shown in Figure 2 (far right). Figure 8 shows temperature increase transmitted from a Galaxy S4 (in active mode) in contact with the palm of the left hand of the SUT as shown in Figure 2 (far left), the thermal image is of the dorsal of the left hand as marked by the blue area in Figure 2 (far right). Temperature increase due to heat transfer throughout the hand (from palm to dorsal) is shown in Figure 8 from 3:46 pm (upper far left) to 4:00 pm (lower far right). Figure 9 shows the temperature increase in the palm and dorsal of the left hand after 10 minutes of exposure to a Galaxy S4 in active mode as shown in Figure 2. The heat transfers from the palm via the

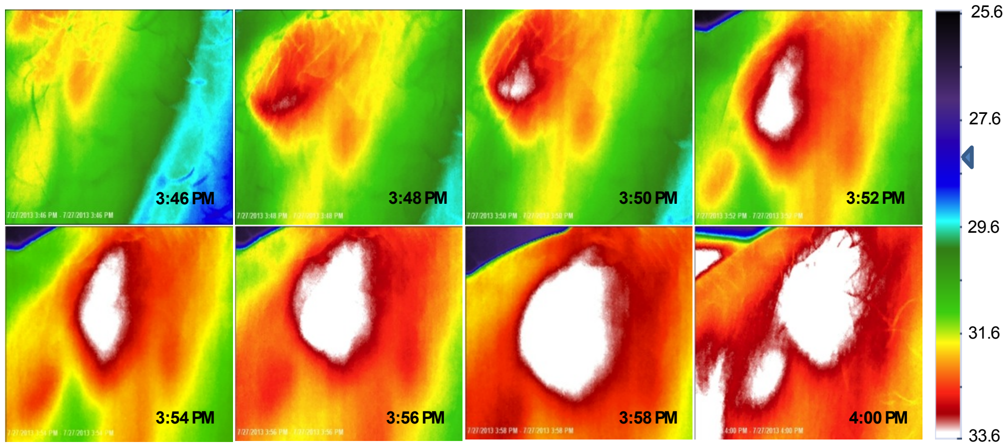

Figure 8: Thermal images of the left hand dorsal of the SUT. Images represent temperature increase of the region in blue as shown in Figure 2 (far left). Test was conducted for 15 minutes starting at 3:46 PM with a Galaxy S4 in active mode and held in the palm as shown Figure 2 (far right).

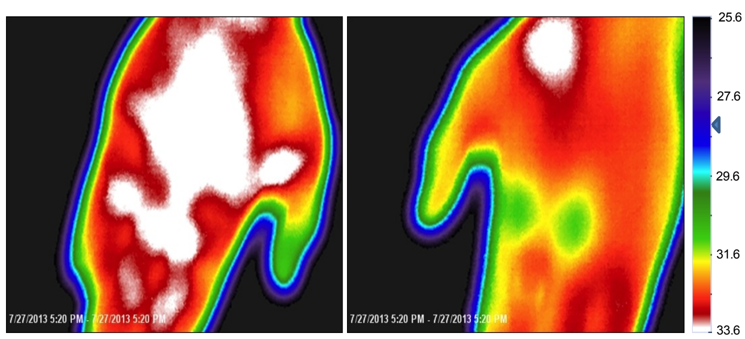

Figure 9: Thermal images of the left hand: palm (left) and dorsal (right). Images represent temperature increase after holding for 10 minutes a Galaxy S4 in active mode as shown in Figure 2.

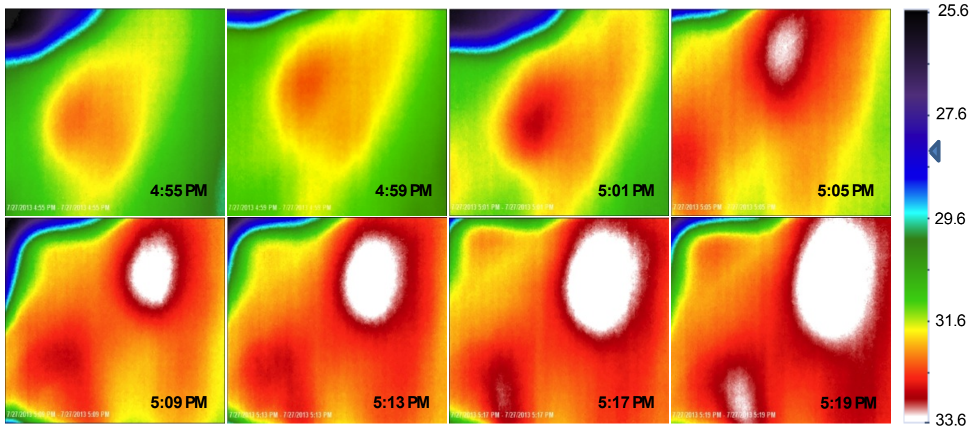

Figure 10: Thermal images of the left hand dorsal of the SUT. Images represent temperature increase of the region in blue as shown in Figure 2 (far left). Test was conducted for 25 minutes starting at 4:55 PM with a Galaxy S4 in communication mode and a BWC as shown in Figure 2.

muscles, bones and other structures to the dorsal. After removal of the phone, the hand recovers from heating more rapidly because of exposure to ambient temperature of both the palm and the dorsal.

Figure 10 shows the temperature increase of the left hand dorsal with the Galaxy S4 and the BWC held as shown in Figure 2. The mobile phone was activated in communication mode and the test run for 25 minutes. Thermal images are shown from the start of the test (4:55 pm) to the end of the test (5:19 pm). For the purpose of comparison, this test (Galaxy S4 and BWC) was conducted longer than the previous one (Galaxy S4 alone) to detect enough temperature increase. Image from Figure 8 at 4:00 pm should be compared to image of Figure 10 at 5:09 pm for the same exposure time (15 minutes).

Results are consistent with previous reports indicating a temperature increase in human tissue due to contact with mobile phone. In addition our results indicate that the BWC reduces the thermal effects from mobile phone on human tissue.

DISCUSSION

Measurements of human tissue temperature changes due to mobile phone exposure are affected by many factors related to mobile phone performance and functions and to the SUT own conditions. The SUT physiological and biological responses to thermal effects are important factors in assessing individual temperature increase during cellular phone usage in contact with the skin. Mobile phones have different circuitry. The heat produced during communication varies significantly, a reason the Specific Absorption Rate (SAR) is established to limit the level of energy that can be dissipated in human tissue. Other operational conditions related to ambient temperature, humidity and weather conditions affect wireless phone performances boosting its energy level and hence its heat production [17].

Thermal effects produced by cellular phones are of three kinds: thermal insulation, heat transmitted to the skin or tissue that would otherwise be dissipated in air; heat propagating from the cellular phone as a heat source to the skin in contact as a heat sink; heat induced from duration of RFR exposure [18]. The temperature rise within the cells from electromagnetic absorption can be described in photon-phonon interaction of a homogeneous medium whose elements are in harmonic modes of vibration. While theoretical models have been presented to explain the thermal effects of RFR, direct measurements have not been reported. There are also indications that electromagnetic waves in the frequency range used by the cellular phone do not penetrate deeply into the body ; most of the RF energy is absorbed by the skin and directly underlying tissue as has been reported [19, 20].

In the present study, we report results using thermography of the heat dissipated by contact of mobile phone with the skin. Our results clearly show the significant temperature increase during wireless communication with the device applied against the ear. Thermography provides a distinct heating of the ear, pinna and surrounding tissue. Our tests did not consider limiting factors, our analysis is comparative and therefore we assume all conditions to be present in conducted tests. The variables uncounted for have affected all of the tests and therefore the only contribution in temperature changes are under controlled variables. In our case the only contributing factor is the presence of the BWC.

The significant temperature reductions can be explained by many factors. First the card could very well be acting as a heat sink drawing most of the heat away from the tissue the phone is in contact with, in which case we would have a relative increase of temperature of the card which would depend on the structure of the card, its surface coating, and other variables. That was outside the scope of this research. Second, the BWC previously tested in an FCC certified lab [13] showed significant SAR reduction (80.3%) which indicates its effect to be in the medium used to simulate brain tissue (a sugar base solution). The BWC was also tested for wireless communication interference using the TRP and TIS tests [16]. TIS and TRP metrics have become increasingly important for carriers, as they can quantify “over-the-air” performance with a single value [21]. The BWC had no significant effect on both tests.

Reduction of thermal effects on skin and directly underlying tissue are directly related to the BWC. The hand test indicates the amount of heat prohibited from dissipating deep within the tissue as is seen from a faster recovery with the BWC as compared to a longer cooling period without the card.

CONCLUSION

There are serious concerns over the thermal effects produced by mobile phone when in contact with the skin. Many studies have reported the temperature increase which may have a serious health impact for lengthy communications. Current mobile phone users spend as much as 50 minutes on a communication with the device touching their ear pinna. In youth and children the thermal effects can be five folds more damaging implying serious health conditions [22]. Any means to reduce heat transfer from the mobile phone to the skin, surrounding area and underlying tissue must be considered especially if it does not impede mobile phone function as it is in this case. Ideally all wireless devices producing heat should be kept away from our body but an added measure of safety would certainly not be a nuisance, especially when children and youth have become more and more exposed to RF EM radiation. Interaction of heat producing mobile phones with tissues of skeletal muscles and bone of human beings need to be further investigated to study the long term thermal effects.

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