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Evaluation of the thermal effect of LTE 2600 MHz (4G) electromagnetic field (EMF) exposure: Thermographic study on rats

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Abstract

Exposure to LTE 2600 MHz microwaves is increasing very fast as new technologies and become accessible worldwide, and the smartphones being the main source of these waves. The aim of this study is to assess the thermal effect of 4G signals on rats. Forty adult Albino rats were used throughout the study, assigned as control and exposed groups, equally. Rats were kept in Plexiglas cages with intermittent exposure to LTE mobile-phone like signals at an average of 2h/day for up to 30 continuous days with SAR value of 0.982 W/kg. Infrared images were snapped immediately after the end of the exposure time, then one hour, two hours, and four hours later at a rate one collection/week during the study. IR images were analyzed by FLIR Tools software. The results exhibited variation in reflected skin temperatures in the exposed group compared to control images. Furthermore, the analysis of collected data revealed significant variations over the course of the study compared to the first week. The rise in skin temperature observed in response to exposure in the first week, which decreased gradually increased exposure and this drop in reflected skin temperature was significantly related to amount of exposure. The study concludes that the LTE 2600 MHz exposure under controlled laboratory conditions has a thermal effect on the rats.

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Introduction

The dependency on mobile communication technology has increased exponentially. It has been reported that more than 4 billion people (57% of world population) totally depend on mobile telephony for communication purposes. Therefore, the effect of Electromagnetic Fields (EMF) from wireless technologies on humans has become a major issue around the globe. Health concerns regarding EMF exposure have been raised immensely due to the popularity of mobile phone handsets. Numerous of confirmations for human health potentials from non-ionizing radiation RF-EMFs intensities that do not cause determinable tissue heating, and many governmental agencies in many countries have not taken the real steps to warn against the health risk arising from thermal and non-thermal radiation, nor have they set exposure guidelines which are sufficiently health protective (1-6). The emergence of fourth-generation (4G) technology, has been in the news lately because the wireless telecommunications industry has been growing rapidly as a result of the urgent need for modern communication technologies to provide wider and better services for the consumer at the lowest cost and highest quality. 4G operates high-band frequencies (2.4 GHz and higher) that consist of millimeter waves (MMWs), a type of electromagnetic radiation with wavelengths of one to ten millimeters and frequencies ranging from 30 to 300 GHz (7). With the distribution of (4G) of wireless infrastructure (4G), many people are likely to be exposed to MMWs, and be more vulnerable to these waves as a result of the increasing needs for faster services and new technologies. In the frequency range of mobile communication bands, as well as Wi-Fi, one of the relevant interactions of radiofrequency electromagnetic field (RF-EMF) with biological tissue is the absorption and conversion of EMF energy into the thermal energy (8,9). RF radiation at tolerable energy levels cause tissue heating (10). The physiological impacts of microwaves are basically combined with heat generation, and these effects include increased body temperature (>40˚C) (11). The best method to determine the thermal effects of RF-EMFs and allow for thermographic analysis is the use of infra-red cameras and thermography is a demonstrative method useful as an integral strategy to support other medical tests (12). Thermography is a non-invasive, non-contact method, and doesn't utilize any harmful radiation. Infrared thermography is used for measuring and analyzing physiological functions and pathology related to the body's thermal homeostasis and temperature as consequence of RF energy absorption by different tissues (13). This technique is used to detect surface emitted heat as reflected skin temperature. The superficial inflammation or circulatory impairments are indicative of primary sign of inflammation processes reflected on microcirculation of the skin (14).

Exposure to continuous Wi-Fi signals up to 30 days at average 7h/day, showed significant effects on mice body temperature as a result of energy absorption and interaction between this energy and cellular metabolism as biological responses (15). The usage time of mobile phones is escalating rapidly, and this has led to public fear of EMF exposure risk from their mobile phones. Due to ethical reasons, it is difficult to use human subjects to study the biological effects of EMF. Nevertheless, the question here is how to determine the side effects of exposure to non-ionizing radiation at 2.6 GHz (4G) on biological system in terms of measurable tissue heating. Thus, the aim of this study is to investigate the thermal effect of LTE 2600 MHz EMF exposure and whether long-term (chronic) exposure may have detrimental effect(s) on health by using adult rats as animal models.

Materials and methods

Animals

The experimental protocols and the use of animals in this research were reviewed and approved by the scientific committee and the council of Veterinary Medicine College, University of Mosul. Forty female Albino rats, three months old were used throughout the study and distributed as control and exposure groups (20 each group). The rats were housed in separate plastic cages, and then they were placed in special laboratory plastic cages measuring 60 x 40 x30 cm. Rats were acclimatized for two weeks prior to the start of the experiment in the specially designed laboratory room at 25°C, 12/12-hour light and dark schedule. Clean tap water and standard rat pellets were provided *ad libitum* throughout the experiments. Clinical observation was performed on daily basis in order to detect any unhealthy rats which were immediately excluded and replaced before starting the experiment during the adaptation days.

LTE 2600 MHz like signal exposure system setup

For rats weighing between 200 and 250 grams, whole-body average specific absorption rate (SAR) was determined to be 1.25 W/kg. This is equivalent to the amount of maximum daily exposure amount allowed for the general public. To measure SAR, electromagnetic field values were measured with an electric field probe while the transmitter was on, and then these measured values were used in an electromagnetic field solver to determine the electric field distribution in the cage and inside the rat. Rats were exposed to LTE mobile-phone like antenna. A uniform E-field strength was formed by placing antenna on the top center box where each rat received approximately the same amount of exposure as in Figure 1, which shows the exposure session using the mobile-phone like LTE signal in a laboratory environment. The animals were kept in the cage made out of Plexiglas. The power was generated by a specific generator operating at 2.104 GHz continuously. The signal source of the mobile phone antenna was a standard 4th Generation Partnership Project (4GPP) LTE Frequency Division Duplex (FDD) signal at 2600 MHz. The distance between antenna and the rats are estimated to be 25 cm. This distance was within near field radiation limits, which can emulate the near field exposure by the mobile phone to the user. The rats were exposed to the LTE mobile-phone like signal for 2h/day for 30 continuous days. The rat model was built using software scans of a rat was achieved by CST as used in the field simulations. Simulated field values were compared to those of measured electric field values obtained with the field probe, and simulations were rerun for SAR calculations.

Infra-red thermography and sampling

An infra-red camera model FLIR-i5 (FLIR system Inc, USA) was used for thermographic imaging throughout the study (Figure 2) and to monitor temperature changes. All experiments were performed in a temperature-controlled room guaranteeing temperature variations not larger than 0.3 C. The temperature, humidity and emissivity of the objects are the main factors that play an important role in measurement of absolute temperatures. The IR camera was positioned 3 m away from the walls and focused on the subject with a distance of 1m, reflected temperature 30°C, atmospheric temperature 28°C and humidity 60%. The thermographic images were analyzed using FLIR Tools software with emissivity 0.95.

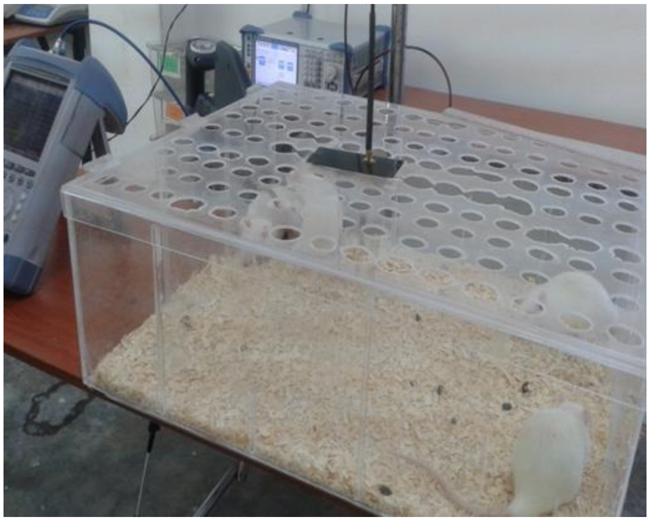

Figure 1: Exposure session using mobile-phone like LTE signal on the female rats in the lab environment.

Data collection and statistical analysis

Thermal images were snapped four times / at each collection point and represented different intervals: immediately after the end of the exposure time, one hour, two hours and four hours at a collection rate of once a week during the trial period of 30 days. The IR images were analyzed by FLIR Tools software and whole body temperatures from the tip of the nose to the tail of the animal, i.e. head, trunk and tail regions were measured. Minimum, maximum and mean temperatures were recorded. SPSS V.23 statistic software was employed to analyze data. Data were interpreted as mean ± Standard Error (S.E.). One-way and Two-way ANOVA were employed to examine the significance between groups and within each collection and *P* values of less than 0.05 were considered as significant.

Results

IR images show a reflections of symmetrical skin surface temperature in both groups of rats before the start of the experiment (Figure 2). The colours of the thermal images represent different temperatures, highlighting hot and cold spots showing the thermal distribution map of body surface, and demonstrating the distribution of thermal energy emitted by the rats' body. IR images showed hot spots (highlighted by red arrows) and cold spots that were distributed homogeneously in both control and pre-exposure groups. It was observed that the area of the hot zone significantly increased due to exposure to electromagnetic waves throughout the body regions compared to the control group and the period before exposure. This could be seen in the form of a large variation in colors towards the hot color (highlighted by red arrows) particularly at during the period of immediately after exposure (Figure 3). Thermal images taken 1 and 2 hours after exposure also showed a widening thermal effect represented by significant variation in the distribution of the hot spots compared to the control group albeit to a lesser extent than observed immediately after exposure.

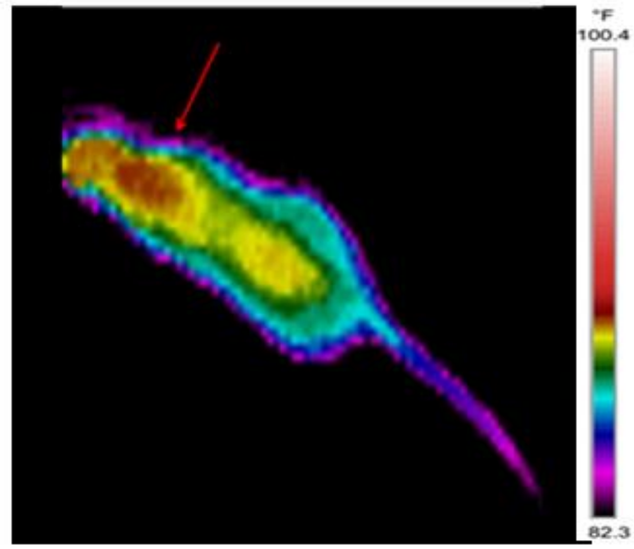

Figure 2: IR image showing a symmetrical reflection of skin surface temperature in both groups of rats before the start of the experiment.

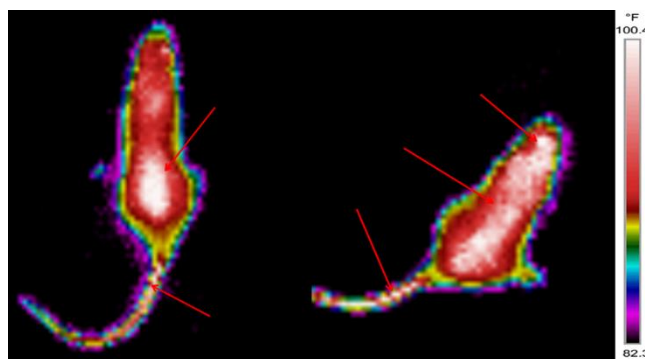

Figure 3: IR images shown a large change in colors of hot spots indicated by red arrows after the end of exposure periods.

Two-way ANOVA of head region skin surface temperatures showed that there were significant variations between each collection time point and within these collection times throughout the study at *P* value (0.000). Furthermore, post-hoc Duncan test revealed that thermal imaging results measured 4 hours after exposure were significantly higher than those recorded pre- exposure but less than values measured immediately, 1 and 2 hours after exposure at *P* value (0.000). Also, the Duncan test showed significant variation between the first collection time point and subsequent collection times in the form of lower skin surface temperatures with increasing exposure (Figure 4).

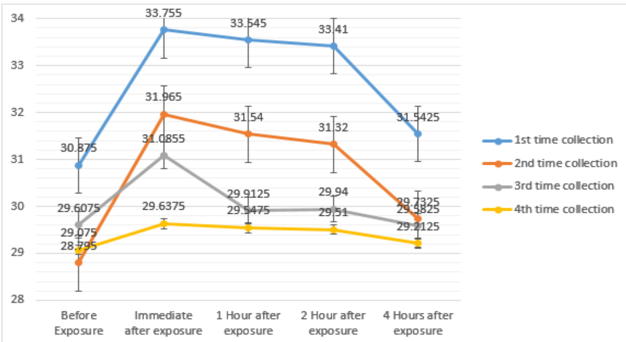

Figure 4: Variation in surface skin temperature (°C) of the head region throughout the study.

In addition, after repeated exposure to the electromagnetic waves as the study progressed, there was a decrease in the reflected temperature of the skin of the whole body as shown by IR images analysis. This drop in temperature was more pronounced four hours after exposure compared to values measured immediately after exposure and after 1 and 2 hours, which showed the highest reflected temperature compared to the IR images taken before exposure to EMF. There was also a significant decrease in the mean of reflected temperature of the whole body of the rats over the whole time course of the study, compared to values measured in the first week and pre-exposure and this drop in reflected skin temperature significantly related to collection (Figure 5).

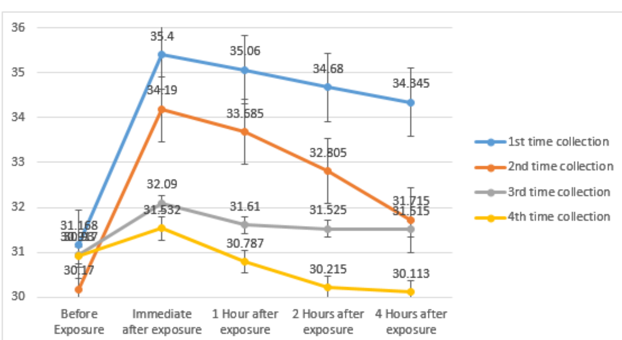

Figure 5: Variation in surface skin temperature (°C) of the whole body throughout the study.

Statistical analysis of thermal image data for the tail area showed a significant increase in the reflected temperature immediately after the end of the exposure period and in all periods compared to the pre-exposure period. Upon analyzing the thermal images in periods after exposure revealed a decrease in reflected temperatures in comparison to the images taken immediately after exposure at *P* value (0.000). Moreover, the statistical variations among collection time's points were also significantly represented by elevation in skin surface temperature at the first collection time point. This temperature dropped significantly and gradually over the whole time course of the study, compared to values measured in the first week and pre-exposure at *P* value (0.000), (Figure 6).

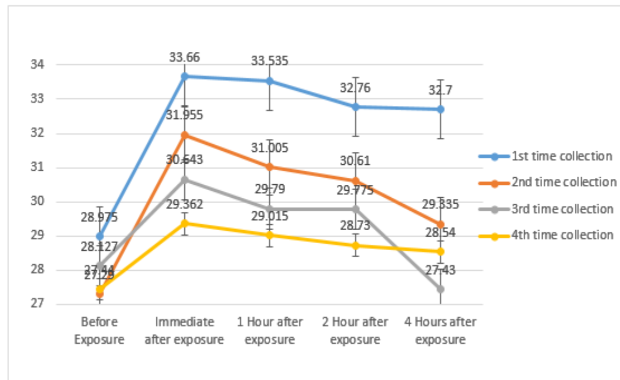

Figure 6: Variation in surface skin temperature (°C) of the tail region throughout the study

Overall, all thermal images showed that reflected skin surface temperatures four hours after exposure were lower than those measured immediately, 1 hour and 2 hours after exposure, but remained significantly higher than temperatures observed in the control group.

Discussion

Infrared imaging is a sophisticated technique used for screening changes in surface body temperature whether in biological or non-biological subjects. Furthermore, it is a non-contact, non-invasive approach that detects surface heat emitted as infrared energy. As long as surface skin temperature reflects the condition of internal tissues and blood circulation, this technique could monitor and identify possible states of the thermal stress in humans and animals, such as the abnormal thermal patterns of superficial non-pathogenic inflammation or circulatory impairment.

The aim of the study was to determine the thermal effect of LTE 2600 MHz EMF exposure on different body parts of the rats. The electromagnetic waves or radiation emitted from all wireless communication devices is characterized by low energy and is located within the range of microwave radiation in the electromagnetic spectrum. The physiological effects of microwaves are generally associated with heat generation deep in the body (11). The current findings showed that LTE 2600 MHz EMF exposure led to a rise in surface body temperature in different parts of the rat's bodies which was observed as an expansion of surface hot spots compared to the control group. The results of this experiment are consistent with the results of (15) who showed that there was an increase in surface body temperature in mice exposed to Wi-Fi signals for 7h/day for one month as a consequence of high metabolic activity within the mice. (11) also found that exposed rabbit limbs with titanium alloy implants exposed to 2450 MHz microwaves exhibited a significant increase in temperature with acute thermal injuries to nerves and muscles adjacent to implants. In humans, a previous work by (14) found that the intensity of localized temperature gives an indicator of the energy absorbed by local tissues due to exposure to radiofrequency electromagnetic radiation from mobile phones. Furthermore, (16) recorded that juvenile rats exposed to a low-intensity RF-EMF 900 MHz for up to five weeks showed a shift in thermal preference towards higher temperatures in response to a cold sensation.

The generation of heat as physiological effect of microwave radiation has been related to the heat regulatory system within the biological body which includes heat genesis and heat dissipation. In general, SAR and power density of an emitted device play an influential role in heat generation which should not exceed 100 mW/cm^2 (17). Heat dissipation depends on three mechanisms: transfer, convection and radiation of thermal energy (18). Humans and animal's body tissues are very sensitive to electromagnetic radiation in terms of heat genesis due to the absorption and conversion of electromagnetic energy to heat energy by translational and vibrational excitation of the atoms inside the cell leading to heat generation (19-21). The generation of heat in the tissues is connected to the amount of radiation energy absorbed, which depends on the radiation frequency and exposure time in a sufficient degree of tissue warm-up leading to cellular dysfunction (22,23).

In the present study the IR images showed a high thermal effect on exposed rats particularly in the time immediately after exposure and after 1h which was observed as highly widespread heating spots along the rats' body. The degree of temperature rise was lesser 2h and 4h after exposure. This variation in the degree of spreading hot spots during the time of IR imaging and also over the duration of the study might be due to two responses; firstly the thermoregulatory process that involves cutaneous vasodilatation and a grooming behavior (24), and secondly to thermal acclimatization (25). A threshold temperature response should be obtained before thermoregulatory processes are started. The estimated increase in temperature also plays an important role in thermoregulation, demonstrating activation of certain thermal receptors in the central nervous system. The evaporative heat loss and tail vasodilation processes in rats were directly proportional to the heating rate (26,27). Exposed rats consistently required a long time to recover from the thermal effect which was very clearly recorded during the four periods following irradiation. However, an examination of the temperature curves obtained during these periods and intervals revealed the cause of the longer recovery time was probably due to thermoregulatory process initiation and development. These data indicate that heat dissipation is related to the pattern of heat distribution and heat radiation via warmed blood from the cutaneous area through cutaneous vasodilation. Furthermore, deep body heating is accomplished through conduction and circulatory heat transfer from the periphery (28).

Other thermoregulatory responses observed were increasing heat loss by sweating, increased drinking water and increased urine secretion all of which were clearly noted in exposed animals as compared to control animals. The rising panting in resting animals after exposure was also noticed; heat loss by evaporation plays another role in the thermoregulation process (29). The high tail temperature above 36°C led to tail vasodilation as a defense mechanism and part of thermoregulatory process and adaptation to heat dissipation; the tail can lose up to 20% of the total heat production of the rat which might be considered as non-evaporative heat loss area of the animal (25,28). Our present study has proved that the pattern of heat dissipation within EMF exposed animals is extremely thermoregulatory process-dependent.

Conclusion

The current results confirm that thermography is a non-invasive and novel technique that can be useful for detecting a thermal effect in laboratory animals. The IR images showed increased reflected skin temperatures which spread throughout the whole body. Exposure to LTE 2600 MHz (4G) EMF has a thermal effect on the rats' bodies and the thermoregulatory response initiation and development has played an important role in recovery time and adaptation to heat stress. This study has led us to pay attention to the seriousness of thermal effect on exposed biological systems.

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Conflict of interest

The authors declare that there are no conflicts of interest.

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تقييم التأثير الحراري للتعرض المجال الكهرومغناطيسي MHz 2600 LTE (4G): دراسة حرارية على الجرذان

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الخلاصة

يزداد التعرض لموجات المايكروويف ذي التردد LTE 2600 ميجاهرتز بسرعة كبيرة مع زيادة استخدام التقنيات الجديدة المنتشرة عالميا، وتعد الهواتف الذكية هي المصدر الرئيسي لهذه الموجات. تهدف هذه الدراسة إلى تقييم التأثير الحراري لإشارات G4 على الجرذان. تم استخدام أربعين جرذا بالغا من نوع الأبيض (الألبينو) طوال الدراسة، تم تقسيمها إلى مجموعات السيطرة والتعريض. تم وضع الجرذان في أقفاص بلاستيكية خاصة أثناء التعرض المتقطع للإشارات الميكروية المشابهة لإشارات الهاتف المحمول بمتوسط ٢ ساعة / يوم لمدة تصل إلى ٣٠ يومًا متواصلًا بمعدل امتصاص للأشعة بقيمة ٠,٩٨٢ واط / كجم. تم التقاط صور الحرارية مباشرة بعد نهاية وقت التعرض، ثم بعد

ساعة، وساعتين، وأربع ساعات بعد ذلك بمعدل مجموعة / أسبوع أثناء الدراسة. تم تحليل صور الحرارية بواسطة برنامج FLIR Tools. حيث أظهرت النتائج تباين في درجات حرارة الجلد المنعكسة في المجموعة المعرضة مقارنة بالصور لمجموعة السيطرة. علاوة على ذلك، كشف تحليل البيانات التي تم جمعها عن اختلافات كبيرة على مدار الدراسة مقارنة بالأسبوع الأول. لوحظ كذلك ارتفاع درجة حرارة الجلد المنعكسة نتيجةً للتعرض لهذا الأمواج المايكروويفية في الأسبوع الأول وأن هذه الاستجابة انخفضت تدريجيا وكان هذا الانخفاض في درجة حرارة الجلد المنعكسة مرتبطًا بشكل كبير بكمية التعرض. وخلصت الدراسة إلى أن تعرض 2600 LTE ميجاهرتز في ظروف مختبرية محكومة له تأثير حراري على الجرذان.