International Journal of Basic and Applied Sciences, 10 (2) (2021) 32-37

International Journal of Basic and Applied Sciences

Website: www.sciencepubco.com/index.php/IJBAS

Research paper

On the effects of the electromagnetic radiation in human health by using mobile telephone in Mexico

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Abstract

In this paper it is shown the experimental measurements made of the generated radiation by mobile phones, and the corresponding conclusions when comparing them with the values provided by the manufacturers. The so-called specific absorption rate (SAR) is calculated from the amount of electromagnetic energy emitted by mobile phones and absorbed by the human body. It was found that the measurements obtained are within the allowed values, which suggests that the radio frequency emitted by these mobile phones does not have negative effects on human health. These devices have a SAR value provided by the manufacturers, but such values are not completely reliable However, the possibility that its use may cause other harm to human health is not ruled out. The measurements and experimental results were part of the development of a project at a Public University in Mexico City.

Keywords: *Human Health; Mobile Telephone; Electromagnetic Radiation; Use of Mobile; Specific Absorption.*

1. Introduction

In the last hundred years, technological progress has led to a great development in wireless communications. This allowed the appearance of the so-called cell phones and the massive growth of mobile usage. Like with many technological developments, the existence of some impact on the quality of life of human societies is possible. However, human beings have been exposed to electromagnetic radiation since it exists on earth. Many natural sources produce radiation, but the amount of electromagnetic energy that surrounds us today has been strongly increased due to the use of different electronic devices [1,2]. Furthermore, all the biological processes carried out by the human body to function are electromagnetic phenomena [3]. The cells of each organism communicate internally through processes that have an electrical component, so that the electromagnetic radiation generated at low frequencies has effects on the human body, and makes the cells particularly sensitive to any external electrical signal. Thus, electromagnetic radiation is responsible for the orientation of dipole molecules and atoms, stimulating cell reproduction, activating oxidation-reduction reactions, among other aspects [3-6].

As is known, Faraday's Law indicates that when a fixed conductor is traversed by a variable magnetic field an electromotive force (EMF) is generated, the magnitude of which is proportional to the variation of the magnetic field flux over time. Particularly, the human body becomes a fixed conductor when exposed to radiofrequency, since the cells that compose it contain sodium, potassium, chlorine, and calcium ions, and they generate an electromotive force of the order of micro and nano volts whose effects could be inconsequential or have other repercussions at the cellular level in the long term due to prolonged exposure to non-ionizing radiation. Sodium and potassium ions are essential in the communication of nerve cells, so when affected by radiation, they could generate an increase in body temperature, restlessness, irascibility, insomnia, among other disorders. Radiation could affect the natural frequency of oscillation of certain types of cells, if they enter into resonance with the electromagnetic field present, leaving them exposed to the action of external agents that could cause mutations when confronted to a diminished immune system, in addition to alterations that would make them permeable to certain substances that should not enter them. It could be related with various disorders such as Alzheimer [5,7].

Mobile phones work with radiofrequency (RF). They emit and receive electromagnetic waves in a frequency range between 900 MHz and 2100 MHz [1], which is within the known non-ionizing energy, which means that these waves do not have enough energy to damage the cells of our body. Still, energy is absorbed from them. When using a mobile phone, we are exposed intermittently and not continuously to radiofrequency (RF). The amount of RF energy that a person is exposed to through their mobile depends on factors such as time, distance, signal traffic, amount of data, phone model, among others, so it is difficult to know how much RF we are exposed to. The best-known effects produced by RF are known as thermal, non-thermal, and athermic as shown below [5,7].

Thermal effects appear when radiation has enough energy to cause an increase in temperature in certain areas of body. It has been estimated that this energy increases the temperature of the tissues in contact to no more than 0.1 °C. This increase seems to be easily assimilated by our body [1]; although it is also believed that it can produce modifications in the cardiovascular metabolism, the nervous system, among other alterations. The effects of use of mobile phones in humans can be acute in the short term, and these depend on the use of mobile phone and the proximity of the antenna to the body, being an important factor to consider the rate of increase in temperature in this region, since approximately between 70% and 80% of the energy generated by the mobile enters the head. Non-thermal effects are

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produced by prolonged low-intensity RF exposures. Electromagnetic radiation below 1mW/cm^2 induces currents and electric fields in tissues. Athermic effects are produced when there is enough energy to cause an increase in body temperature, but no changes in temperature are observed due to the lower temperature of environment. Low-frequency signals pass through the human body as if it were transparent, so there is no energy to dissipate in the body and the effects of radiation are negligible. At high frequencies, the tissues begin to absorb radiation, and at the frequency in which mobile phones work, most of the energy is absorbed within a few centimeters of depth from the skin's surface. These radiations in children may cause learning disorders, chronic fatigue syndrome, attention deficit disorder, etc.

As mobile phone use increased in the population, there was concern about the possible damage that it could cause due to its daily use [1], without finding a direct relationship between mobile phone use and damage to health. One of the biggest concerns is the damage that electromagnetic waves could cause to parts of the head, mainly the brain, ears, or neck because when making a call the antenna is too close to these areas, energy directly impacts on the tissue [8,9]. Most studies seek to find a link between mobile phone use and the formation of brain tumors of any type of nerve that connects the brain to the ear. Although there are studies that suggest mobile phone use can provoke skin cancer and testicular cancer [8]. Thus, modulated pulsing radiofrequency fields can cause a slight increase in the levels and activity of the enzyme ornithine decarboxylase (ODC), which indicates the possibility of cancer [7].

No study has observed significant changes that indicate the appearance of tumors in animals, due to RF exposure. Studies with humans have shown minor alterations in physiological parameters and a small decrease in reaction times [10]. People with brain tumors have been studied, and even though people claim to have used this device constantly, between 10 and 15 years, no evidence has been found that such fact has caused disease [9]. Experiments with mice exposed to frequencies slightly higher than that emitted by mobiles (2000 MHz to 5000 MHz) do not indicate that said radiation causes tumors, only hyperactivity and decreased memory capacity [7,11]. Even studies conducted irradiating people and mice with frequencies between 800 MHz and 900 MHz only show a predisposition to anxiety and depression [11]. In people chronically exposed to electromagnetic radiation, symptoms of fatigue, irritability, nausea, insomnia and sensory disturbances have been found. And, more often, stress, behavioral disturbances, depression, anxiety, memory loss, mind-blanking, loss of attention in children [7]. The studies carried out are not conclusive, since daily mobile use barely reaches 20 years, increasing in the last decade. It is a short time to be sure about the effects of mobile phones, in adults, in children and in adolescents [8,9].

The present paper estimates the effects of electromagnetic radiation on the human body emitted by mobile phones so that it is possible to recognize the health problems caused by constant exposure to electromagnetic radiation. Using a PCE-EM29 dosimeter, the electromagnetic field produced by different models of mobile phones will be measured when they are turned on, when receiving a call, and during the use of their basic functions in open and closed spaces. When calculating the energy and power emitted by the measured electromagnetic fields, the electromagnetic radiation emitted by mobile phones, to which the eardrum, brain, gonads and hands are exposed, will be evaluated. A brief discussion of the results is carried out and basic conclusions of the measurements are presented, as well as their impact on the functioning of these organs of the human body.

2. A brief history

Only 46 years after the first mobile phone, more than half of the world's population has one. And we are not talking about any mobile phone, but about smartphones, used on a daily basis to send messages, make calls, participate in social networks, surf the Internet, so it is already part of our day-to-day life. The mobile telephone it would not have been possible without the important prior devices: in historical order, the telegraph, the fixed telephone, and the radio. The mobile phone (also known as the cell phone) would not have been possible without the development of the transmission of information via electromagnetic waves [12]. But, although there were already large communication companies, the mobile phone had several challenges to overcome before becoming a reality. Its creation began around 1947 [12], but there was not enough technology to detach a telephone from the cable and to group all its elements in a compact size that any user could carry with. The first device considered a mobile phone was introduced and tested in 1973 by M. Cooper, who made a call on a New York street. This prototype was created by Motorola, a model called the DynaTAC 8000X that was very expensive. This mobile phone weighed more than 2 kg and its battery had to be charged for about ten hours so it could be used for about 20 minutes [13]. This model was the first to be commercialized, serving about 2,000 people for the year 1978 [14]. The first commercial mobile phone service began in Japan in 1979. The United States lagged behind, beginning to market this service until 1983.

In Mexico, Iusacell was the first company to offer calls through mobile phones in 1989 [14]. Ameritech Mobile Communication appeared in the 1980's to provide mobile phone services, on frequencies around 450 MHz, with very bulky mobile phones, like the original prototype [1]. By the '90s, mobile phones had evolved a lot, both in design and in operation, since they already worked with frequencies between 900 and 1800 MHz, as many of today's still do, since this frequency greatly improved the quality of voice in the calls [9]. Massive commercialization began in 1994, and by the end of the decade, mobile phones already had text and multimedia messaging services, a camera and, mp3 capacity [11,14]. At the beginning of XXI century Apple appeared, with its iPhone [12]. This was followed by other models and other companies, with many more functions, such as connectivity to BlueTooth and internet (network connection), television, downloading files, and other applications, completely changing how people use telephony. Smartphones have not stopped evolving since then and work continues on their technology day by day, making them smaller and smaller and with a very large number of functions. So, since the mid-'90s, mobile phones have increasingly become objects for everyday use. In 2002 they exceeded the number of landlines worldwide: 19 out of 100 inhabitants on the planet had a mobile phone. And in 2007, half of the world's population already had one. Only two years later 64% of the world's inhabitants had one [15]. In 2017, 5 billion people, out of a population of 7.5 billion, already had a mobile phone. It is expected that by the end of 2020, 73% of the world's population will have a mobile phone [16].

Mexico is not far behind in the number of users who use their mobile phones every day. According to data from the National Survey on the Availability and Use of Information Technology in Homes (ENDUTIH in Spanish), the total number of users who own a smartphone grew from 64.7 million people in 2017 to 69.6 million in 2018 [17]. The ENDUTIH is a survey that has been carried out every year since 2015, dependent on the National Institute of Statistics and Geography (INEGI in Spanish), in collaboration with the Ministry of Communications and Transport (SCT in Spanish) and the Federal Institute of Telecommunications (IFT in Spanish), provides information on which people use a mobile. During 2018, 73.5% of the population aged 6 years and older used a mobile phone; 83.8% of this population owns at least one smartphone; 0.8% have at least one common mobile and a smartphone at the same time, and 15.4% have at least one common mobile. Also, 93.4% of people who use a smartphone connect to the internet through it; 89.0% of them do so through data connections and only 11.0% do so through Wi-Fi [17,18].

Mexico has a total of 83.1 million mobile phone users throughout the country and the number has increased by more than 5 million in the last 3 years. The entities that registered the highest percentage of mobile phone users in 2018 were Sonora, Baja California and Nuevo

León, with 87.6%, 83.9% and, 82.5% respectively. The states with the lowest percentages of users were Chiapas with 58.1%, Guerrero with 59.8% and, Oaxaca with 60.8% [18]. The average number of hours that a Mexican spends connected to the internet through a smartphone is 10.2 hours. Likewise, 9 out of 10 Mexican adolescents check their cell phone so often that nothing has changed since the last check, and most of them never turn it off [19]; so the mobile phone has become another piece of clothing for almost any individual in today's society, as people take it with them wherever they go, they use it in almost all their free time, and many even sleep with it under their pillow.

3. Development of experiment

Since the Maxwell equations can be defining obtaining the Poynting vector, and the intensity of irradiance as,

$$I = \bar{S} = \frac{1}{\mu_0 \varepsilon_0} \bar{E}_0^2 \tag{1}$$

Being μ_0 and ε_0 permeability an permittivity, respectively, for the empty space. An average value of the magnitude of Poynting vector S is written as $\bar{S}$, and $\bar{E}_0$ is the average of the magnitude of electric field. Intensity can be expressed as function of the root mean square (RMS) of the electric field magnitudes. When defining $E_0 = \sqrt{2}\, E_{RMS}$ and including speed of light c, it is obtained,

$$I = \frac{1}{\mu_0 c} E_{RMS}^2 \tag{2}$$

The total energy flux per unit time, also called power P, for any surface A can be written in terms of the Poynting vector as [3],

$$P = IA = \frac{1}{2\mu_0 c} A E_0^2 \,. \tag{3}$$

On the other hand, the specific absorption rate (SAR) is known as the amount that describes the energy absorbed by the body in the high-frequency field, per kilogram of body weight in a certain time, and that is mainly transformed into heat, measured in W/kg. The SAR value depends on the intensity of the incident fields (or equivalent power density), tissue, properties, geometry, size, the orientation of the object, frequency of incident fields, and exposure time. SAR is used for frequencies between 100 KHz and 100 GHz, non-ionizing radiation, and particularly for mobile phones and magnetic resonance imaging [20,21]. SAR is related to the physical and electrical properties of the absorbent object through the expression,

$$SAR = \frac{\sigma E_{RMS}}{\rho} \,. \tag{4}$$

Where σ is the conductivity of the material in Siemens/meter (S/m), ρ is the density of the material (Kg/m^3) and E_{RMS} is the effective value of the electric field induced through the material measured in Volts/meter (V/m).

Specific Absorption Rate (SAR) is a measure of the rate of absorption of RF energy in the body. It is usually used to measure the energy absorbed by the human body from a mobile phone, and it allows verifying that mobile phone companies comply with the safety guidelines regarding RF exposure [22]. SAR values are an important tool when trying to determine the maximum possible exposure to RF energy emitted by a particular mobile phone model, but a single SAR value does not provide enough information on the low RF exposure level under everyday conditions of use. SAR measurement tests use fluid-filled human heads and body models that simulate the RF absorption characteristics of different human tissues. Each mobile phone is tested while working at its maximum power, in all the frequency bands in which it operates and in different positions, targeting the head and body of the human body model. A probe makes a series of electric field measurements at specific locations based on a design, for final clearance and as part of the equipment test report. The data that must be lower than the values declared by the manufacturers are sent. The allowable SAR in the United States is 1.6 W/kg [7]. Mexico does not have indications of permitted limits speaking of SAR. A recent German study presented mobiles with the highest SAR level [23], which can serve as a guide in the experiment.

The RF waves propagate parallel to the ground, so mobile phone base stations are installed on top of buildings or in towers, between 15 and 50 meters above the ground, so the power of the fields of RF reaches its maximum degree at the origin and decreases rapidly with distance [21]. In the absence of a national health-oriented regulation that specifies the limits for maximum permissible population exposure to radio frequencies (RF), the Federal Commission for the Protection against Sanitary Risk (COFEPRIS in Spanish), recommends the established limits by the highest coordinating authority for health action of the United Nations, the World Health Organization (WHO). But the (WHO) has not issued any official pronouncement on the health effects due to electromagnetic radiation emitted by mobile phones and the respective antennas, as there is not enough scientific evidence to prove such effects [5]. The recommendations of (ICNIRP) for exposure to the general public are 40 V / m (4.2 W/m^2) for the 800 and 900 MHz bands and 57 V / m (8.6 W/m^2) for the bands of 1800 and 1900 MHz. The recommended levels would only be exceeded if a person came within two meters of the antennas [30].

Even though all the phones sold in the current market comply with the established SAR levels, there are various recommendations on how to use the mobile phone for short and essential calls, especially for those under 20 years of age. It is also recommended not to bring the mobile phone immediately to one's ear when making or receiving a call, and several companies recommend the use of hands-free phones and to avoid placing the cell phone in pockets, as well as using it in closed spaces with metallic limits, since more radiant power is used to establish the connection [5]. The instructions manual was reviewed to consult the mobile phone's characteristics and its operation was learned. The PCE-EM29 dosimeter allows measuring the electric field, magnetic field and, power produced by electromagnetic waves with frequencies from 50 MHz to 3.5 GHz. Besides, it can show the electric field measurement in real-time, detect the maximum value within a period, and average the values obtained in a certain time or the maximum values obtained.

Preliminary measurements were carried out on six different mobiles to study the best measurement conditions, for a period of three weeks, at different times, in different spaces, placing the mobile phone approximately 1 cm away from the sensor and placing the mobile phone in different positions with respect to it (the positions can be seen in Figure 1). The electric field was measured while the mobile performed different functions: when blocked, when receiving calls from landlines and mobile phones, when answering calls, during a loudspeaker call, while the cell phone received data from other mobile phones and, while charging. In preliminary tests observations

were made for measuring the position with the dosimeter, obtaining a background radiation was neglected at the time of the electric field measurements for each of the different mobile phones since for cases of calling and sending WhatsApp, it was not truly relevant.
In the preliminary measurements, we decided the proper way to carry out the final measurements. Ten mobile phones were measured (general characteristics are shown in Table 1). To perform the measurements, the mobile phones were placed in position 4, shown in Figure 1. Measurements were made in four different modes of operation: when the cell phone is in airplane mode, when the cell phone receives a call, when a call is ended and when the phone receives a message through the WhatsApp application. Thirty measurements were made for each different mode on each mobile in these four modes, both in an open space and in a closed space. The open space measurements were carried out in the gardens behind a building of the Metropolitan Autonomous University (Azcapotzalco campus). The closed space measurements were made inside a classroom of one of the buildings of the institution. Note that the measurements were not taken in a laboratory, as we sought to study the radiation emitted by mobile phones in daily use conditions.

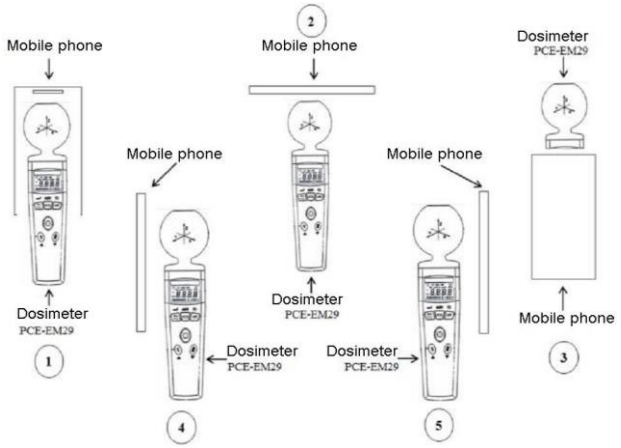

Fig. 1: Possible Positions for the Dosimeter and the Mobile.

In preliminary tests the following observations were made:

- Measuring with the "Max" mode activated in the dosimeter gives the maximum value that the mobile emits when receiving a signal.
- Measuring at different times of the day does not show significant changes.
- Position 4 is the position where the dosimeter registers more radiation with respect to the others in all the mobiles studied. The maximum value of the electric field is reached before the mobile reflects the incoming call.
- The electric field value decreases after answering a call.
- If the call is made on loudspeaker the electric field increases.
- The electric field values present a minimal variation from when the cell phone is charging to when it is being used with its battery.
- Calls from a landline to a mobile phone, in some cases, produce a greater electric field than calls from a mobile phone.
- If the cell phone from which the call is made is in the same room as the cell phone that receives the call, the measurement is not affected as long as the cell phone to be measured is 1 or 2 cm from the dosimeter.
- At the end of a call the electric field increases considerably.
- Background radiation was neglected at time of electric field measurements for each of different mobile phones, since for cases of calling and sending WhatsApp, it was not very relevant.

From the obtained observations in the preliminary measurements, it was decided the appropriate way to carry out the final measurements. 10 mobile phones were measured (their general characteristics are shown in Table 1). To perform the measurements, the mobile phones were placed in position 4, shown in Figure 2. Measurements were made in four different modes of operation: as the cell phone is in airplane mode, when the cell phone receives a call, when a call is ended and when the phone receives a message through the WhatsApp application. 30 measurements were made for each different mode on each mobile, in these four modes, both in an open space and in a closed space. The measurements carried out in open space were made in the gardens behind a building of the Metropolitan Autonomous University (Azcapotzalco campus). The measurements in closed space were carried out in a classroom of one of the buildings of the same institution. Note that the measurements were not carried out in a laboratory, as it was sought to study the radiation emitted by mobile phones in conditions of daily use.

Table 1: General Characteristics of the Cell Phones Studied in the Project

Mobile	Operator	Frecuency (MHz)	Use time (Months)
ALCATEL 5010G	Movistar	1900	12
HUAWEI L23	AT&T	2100	36
HUAWEI RIO-L03	Telcel	2100	36
IPHONE 6	Movistar	1900	60
MOTO X4	Movistar	1900	10
SAMSUNG A310	Telcel	2100	24
SAMSUNG SM-G530H	Telcel	1900	48
SAMSUNG SM-G532M	AT&T	2100	36
UMIDIGI A5 Pro	Movistar	1900	6
ZTE L2 Balde	Telcel	2100	48

Once the measurements were obtained, the average of these was calculated for each cell in the respective chosen modes. The uncertainties were calculated using the standard deviation. Subsequently, the irradiance produced by each mobile in its different modes of operation was calculated. The uncertainties were calculated using the error propagation theory. In Table 2, one can see the SAR values for the phones used in this study, reported by the corresponding companies.

Table 2: SAR Reported for Some Cell Mobiles

Mobile	SAR at the ear in W/kg	SAR in the body, in W/kg (measured at 1.5 cm)
ALCATEL 5010G	0.486	0.755
HUAWEI L23	0.390	1.020
HUAWEI RIO-L03	1.440	0.560
IPHONE 6	0.930	0.970
MOTO X4	0.815	1.540
SAMSUNG A310	0.621	0.524
SAMSUNG SM-G530H	0.412	0.382
SAMSUNG SM-G532M	0.470	0.382
UMIDIGI A5 Pro	No measured yet	No measured yet
ZTE L2 Blade	0.370	1.148

At the beginning of the project, research was carried out on the possible damage to health produced by being exposed to radio frequency, as well as the limits allowed for exposure to it. Once the energy and power calculations had been made for the respective cell phones in different areas of the body, they were analyzed with the information obtained in the previous research (see references in the Introduction). At the end of the analysis of the results, the conclusions of the project were discussed. Once the irradiance was calculated, the power affecting the eardrum, one hand, the male and female gonads, and the brain was obtained. But, for the male and female gonads, and the brain, there is no specific area where it can be said that certain irradiance affects. To study these parts of the body, their physical properties, necessary to calculate the SAR, were investigated, which are shown in Table 3. The SAR was calculated for each phone in its different modes, whose measured irradiance is shown in Table 4 for each operation mode.

Table 3: Physical Properties of Tissues Used to Calculate Irradiance, Power, and SAR

tissue	Density [Kg/m^3]	1900 MHz	2100 MHz
		Conductivity σ [S/m]	Conductivity σ [S/m]
Brain	1046 ± 6	1.765	1.882
Ovaries	1048 ± 0	1.883	2.017
Testicles	1082 ± 54	1.758	1.898

Table 4: Comparison of the Irradiance Measured for the Operating Modes, in Open and Closed Spaces

Mobile	Airplane mode		Receiving call		Ending call		Receiving WhatsApp	
	open	closed	open	closed	Open	closed	open	closed
ALCATEL 5010G	1.720	7.466	10.279	24.358	10.562	24.884	6.588	9.027
HUAWEI L23	5.958	394.214	150.281	295.762	214.167	356.879	18.525	32.612
HUAWEI RIO-L03	12.7470	6.690	109.448	110.996	124.003	197.769	12.129	11.826
IPHONE 6	18.480	414.728	51.381	59.632	94.923	84.073	41.369	69.166
MOTO X4	3.870	9.143	55.267	50.444	79.059	61.858	39.436	58.234
SAMSUNG A310	9.816	96.038	93.916	209.706	152.492	380.276	96.094	102.966
SAMSUNG SM-G530H	271.154	80.971	12.582	13.718	14.567	16.915	14.200	22.847
SAMSUNG SM-G532M	12.747	230.787	170.733	195.694	279.508	387.545	35.957	23.928
UMIDIGI A5 Pro	115.500	66.001	78.017	58.463	97.477	104.185	103.270	91.057
ZTE L2 Blade	246.544	1388.963	2.041	0.606	2.131	63.372	84.306	54.379

4. Results and discussion

For the modalities used in the measurements of mobile phones, and especially for the case of airplane mode where practically the mobile does not emit any signal, it can be said that what was measured was the background electric field. As a consequence, the uncertainty value for this measurement is quite noticeable, since this radiation is constantly changing and at the time it was made it could change drastically from one moment to another.

For the case between the call process and its termination, we observe that of the four measured modes, these are the ones with the highest electric field values for most mobile phones. During the process of terminating calls, a considerable increase in the signal obtained for telephones with frequencies of 2100 MHz could be noticed. This is remarkable, because during the making of a call it is the case that the call has been terminated without consent, which causes an exposure to increased electric field for a certain time.

Regarding the mode of sending messages by WhatsApp, a similar behavior was observed between the used devices and in certain cases not as high as in the call mode. This showed that there is a greater response to high values in the case of the telephone signal when making a call, in contrast to when using the internet on the same data band.

In reference to the measurements obtained in open spaces and closed spaces (Table 4), a difference is clearly observed. For closed spaces the data obtained is larger than for open spaces. It is possible that the place where the measurements were made affected them, making the signal stay longer in the measurement space, and even bouncing off all surfaces, while for open space it is possible that the signal escaped to another place, or that it was slightly overridden by some other signal from the environment, since being an open space the telephone signal is not the only one that is acting at that moment, among them are solar radiation, wireless signals such as Wifi, other telephones, as well as from people passing through in the vicinity of the measurement site. It is also possible that there were traveling signals coming from any other part of the measurement site, because at a certain moment during the measurements the background signal increased sharply, for no apparent reason, taking some time to stabilize, and to be able to perform the measurements again.

Of the mobile phones used, it is important to point out four: Huawei L23, Samsung A3, Samsung SM-G532M and ZTE L2 Blade. Of these, the first three had the highest electric field measurements and the respective calculated physical quantities. It should be noted that they also already had deficiencies that did not allow them to work as they should when they were acquired. Maybe, because the age of use (see Table 1), and because of the time of use that they could have been given. In addition, these phones work at a higher frequency than the others, approximately at 2100 MHz. On the other hand, and being a very special case, the ZTE phone, showed measurements very opposite to those mentioned above, it even also has a lot of use time, and consequently, it has quite a few physical deficiencies. But its radiation level in airplane mode is striking, as it is very high compared to that of other telephones (Table 4), especially in closed spaces.

The UMIDIGI A5 PRO Phone there was no way to compare because there is no information on the specific absorption rate for this mobile. This, the Moto X4 and Alcatel (Table 4) presented medium to low levels in the measurements made. It is important to comment that these are the most recent mobile models obtained, which increases the credibility of the assumption about the age and mode of use that could affect in some way the measurements obtained.
Comparing the irradiance measurements obtained (Table 4) with those recommended by the WHO as the maximum for exposure to the public, with values between 4 and 10 W/m^2 depending on the frequency, it can be noted that for all modalities the measurements are very far from those recommended. In columns 6 and 7 of Table 4, the highest irradiance obtained corresponding to the Samsung SM-G532M is observed, 387.545 mW/m^2. This value does not reach 1% of the maximum value recommended as a limit by the WHO. Power for areas like the eardrum and hands also showed lower levels than might be expected. The irradiance, which is the energy per unit area emitted by the different mobiles, as well as the power that affected the studied areas, turned out to be very small. It was found that there is greater power for the hands than for the eardrum. In WHO records, the maximum field emitted is used using equation (14); in our case the RMS and equation (15) were used. Both equations are equivalent for further calculations.
On the other hand, from the measurement of SAR for the brain and both female and male gonads, it is observed that although the pattern is similar to the electric field levels obtained because they are highly dependent on these, for female gonads there are higher levels of SAR, because in addition to the electric field, its physical properties are higher than for the male gonads and the brain (See Table 3).
Regarding the SAR calculated through the measurements obtained, it was not possible to approach the data reported by the respective companies. The mobile phone that was closest to the registered value was the Huawei L23, with more than 60% of the established data, followed by the Samsung SM-G532M with almost 56%. This could have happened due to the way in which the measurements were made, since the conditions were such, there was the possibility of alteration by means external to the place, as well as the time of use of the mobiles used and perhaps they were defective. It is possible that the cause of the difference in measurements is due to the fact that the mobiles used by the companies that report the SAR are practically new or before going on the market for sale. The rules on SAR levels are also very different between those existing in the European Union and in the United States, which are not formalized in Mexico and it is not known how they could be applied here by the various existing telephone companies. In addition, it is not clearly known from which point of the world the telephones offered for sale in Mexico are exported.
Another factor that could affect the measurements is the device used. Although the PCE-EM 29 dosimeter allows to measure the electric fields emitted by mobile phones in its different modes used, it was detected that this device had a reaction time of 1 second, which probably did not allow obtaining the best data measured for the necessary calculations; quite a bit of information may have been lost over time when the experiment was performed.
Of the ten mobiles studied in this work, those with the highest electric field were Huawei L23, Samsung A310 and Samsung SM-G532M. These mobiles presented electric fields of more than 12 V/m while receiving a call and when hanging up. They are also the ones with the highest irradiance, and yet are far from approaching the maximum exposure value established by the WHO, which is 57 V/m. They are also the ones that produce the highest power in the eardrum and in the hands, but this power turns out to be in μW, so it is very far from the maximum power allowed by the WHO, which is 8.6 W/m^2. Although it is important to note that this power is an established value for the entire body and there are no limits for specific areas of the body.

5. Conclusions

From the values measured in the experiment it is possible to establish that the mobiles do not exceed the established radio frequency limit. It can be said that there is no apparent risk of the human body to the irradiance emitted by the mobile phones used here, but it is not ruled out that the excess of use generates some damage in another way.
The SAR values obtained for these phones are far from the levels reported by the manufacturers, so we can assume that the four modes studied here do not make the cell phone work at its maximum power.
Mobile phones work in the permitted radio frequency ranges, but that does not prevent us from ruling out that the amount of radiation that hits certain areas of the body causes damage. Because the mobile emits pulses of radiation, which is when the body absorbs energy, it is necessary to continue investigating the number of pulses we receive from a mobile phone per day and study how much energy could damage specific parts of the body.
It can be affirmed that the use of the mobile phone does not cause health problems immediately, however it is necessary to do long-term studies with more powerful and precise measuring equipment on the way in which it could affect health by radiation and also thermal effects, since each year cell phones appear with higher SAR levels than the previous ones, always maintaining the assumption that damage over time due to the use of mobile phones can generate an increase in radiation emission, as well as in the increase in the frequency of these when going from a 3G signal use to a 4G.

6. Acknowledgments

This research was supported by Universidad Autónoma Metropolitana (México) and partially by the Consejo Nacional de Ciencia y Tecnología (CONACyT, México).

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