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Effects of Electromagnetic Waves Emitted by Mobile Phones on Male Fertility

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Abstract: With the increase use of cell phones, there are possible interactions of electromagnetic radiation hazard on human beings and their offspring. The recent upsurges of global interest of cell phone have created a fresh impetus on the development of natural disaster, which may or may not lead to cancer or birth defects. The objective of the biological evaluation is to find out the potential of cell phone on sperm cells having some new unknown effects. While thermal effects at the present level of cell phone radiation are negligible, most of the biological interactions are attributed to non-thermal effects. Male reproductive system is highly compartmentalized and sensitive biological system that requires the integration of intrinsic and extrinsic factors to properly function. The generated electrical currents may alter the hormonal milieu and testicular microenvironment, necessary for sperm production. Additionally, sperm are electrically active cells and their exposure to cell phone electromagnetic waves and currents may affect their motility, morphology and even their count. Leaky plasma membranes, calcium depletion and oxidative stress are the postulated cellular mechanisms mediating the harmful effects of cell phones radiation on sperm and male fertility potentials. Evidences for such impacts come from designed animal and in vitro studies which may be different from in vivo human exposure. Nevertheless, the important advice is to apply strict regulations on further increase in the power density of the emitted cell phone radiation and to conduct in vivo human research to study its negative effects on fertility.

Key words: Cell phone, electromagnetic waves, male infertility, sperm.

Introduction: In today's society, modern man strives to become increasingly efficient. Our fast pace lives have
been the driving forces behind vast technological innovations such as the Internet, email, and most recently, the "Smartphone". Cell phones have become a vital part of our lives, and as the social pressures for optimal efficiency increase, so do the technological capabilities of cell phones. One, often overlooked, aspect associated with recent innovations in cell phone technology, is the impact of these devices on human health, more specifically male fertility. Recent innovations in cell phone technology may have a detrimental effect on male fertility, and maybe a growing factor contributing to male infertility. This article will focus on cell phones and dissect exactly what the recent innovations in technology mean for human reproductive health and male fertility. The essential topics of this article comprise a basic description of the cell phone technology and pathophysiological effects of the emitted radiation from cell phone devices on testicular tissues and sperm function. In addition, analysis of emerging clues from laboratory and human studies will be discussed taking into account the controversy surrounding cell phone research. Lastly, a comprehensive future look into the ensuing fertility consequences related to cell phone technology will be discussed.

General concepts of cell phone physics and biological Effects:
Cell phones emit radiofrequency electromagnetic waves (RF-EMW) to nearby relay base stations or antennas. Our bodies act as antennas that absorb the radiation and convert it into alternating eddy currents. The frequencies of these radio waves fall in the low frequency microwave range (800- 2200 MHz), therefore, this radiation is of non- ionizing type as the energy emitted is too low to break chemical bonds in biological system. On the other hand, the energy carried in extremely high frequencies (1,000,000 MHz) electromagnetic waves such as x-rays is so intense that the electromagnetic particles have sufficient power to break chemical bonds and cause serious damage to human tissue; this type of radiation is known as ionizing radiation. Our article will discuss the male fertility hazards associated with the low frequency electromagnetic waves produced by cell phone technology (1,2). When speaking into a cell phone, the

sound wave from the speaker goes through a transmitter that converts the sound into a sine wave. The transmitter then sends the signal to the antenna, which then sends it out into space in all directions. The transmitter in cell phone operates on about 0.75 to 1 watt of power, with 2 W at peak usage. This electric sine wave current running through the transmitter circuit also creates an electromagnetic field around it. As the electric current moves back and forth, the fields continue to build and collapse, forming electromagnetic radiation. Thus, cell phone radiation is generated in the transmitter, and is emitted through the antenna in the form of a radio wave (2).Modern advances in cell phone telecommunication systems are associated with an increase in signal frequency, which correlates with higher energy radiofrequency waves. The first advent of the preliminary cell phone system was the Analogue NMT (Nordic Mobile Telephone) system which operated at 902.5 MHz in the 1980s. A decade later, the GSM (global system of mobile communications) succeeded it, operating at a radiofrequency of 902.4 MHz, pulsing at 217 Hz. The most recent DCS (digital cellular system) operates at a radiofrequency of
1800 MHz and has two additional low frequency magnetic fields associated with it (3). Furthermore, specific countries differ in the frequency band at which the radio waves are transmitted. Most European and Asian countries network operates at 850/900 MHz, while the United States network operates at 1800/1900 MHz . The higher the frequency the more energy the waves carry. With increasing globalization and demand for international travel, there are now phones which can operate in multiple countries, and are therefore considered “quad-band”, receiving all signal frequencies 850/900/1800/1900 MHz. The impact of these radio frequency electromagnetic waves on the human body is measured via a standardized unit called the SAR value. The SAR (Specific Absorption Rate) is a measure of the rate of radiofrequency energy absorption in the body and is calculated as watt/kg. Device specific SAR tests are conduced with the wireless device transmitting at its highest power level in all tested frequency bands. Since 1996, the FCC (Federal Communication Commission), has required that the maximum legal SAR of any handheld mobile device should not exceed 1.6 watts per kilogram (4). From the year 2000 onwards, all cell phone manufacturers must place labels on their phones disclosing their radiation level. Although SAR is determined at a cell phones maximum power level, the actual SAR value of an operating wireless device may be less than the reported maximum. This value depends on multiple factors such as proximity to a cell site, the proximity of the wireless device to the body while in use, the mode of usage of the device (talk versus standby mode), and the use of hands-free (Bluetooth) devices (4). Lastly, every country has specific government agencies, which are responsible for the regulation of electromagnetic radiation devices. In the United States there are the American National Standards Institute (ANSI), which is part of the Institute of Electrical and Electronics Engineers (IEEE), along with the FCC and the US Environmental Protection Agency; in the United Kingdom there is the National Radiological Protection Board (NRPB), and in Brazil there is ANVISA (Agencia Nacional de Vigilancia Sanitaria). Each agency is responsible for issuing evaluation bulletins, which highlight current regulations and also provide the government’s stand on health concerns (4).

Cell Phones Have a Dual Effect on the Human Body

Electromagnetic waves (EMW) emitted from cell phones and even microwaves oven fall within the low frequency range of EMW between 300 MHz to several gigahertz. Such level is far below the high frequency EMW of X-ray and gamma rays. EMW travel through space at the speed of light, however, their energy level depends on their frequency and wavelength. The energy carried in EMW is composed of electrical and magnetic fields and it is better represented by the term power density (PD). PD is defined as the amount of power per unit area in a radiated microwave field and is usually expressed in milli- or microwatts per square centimeter (mW/cm2 or μW/cm2). Nevertheless, the level of energy in such EMW is so low that it cannot break the covalent bonds in biological molecules [116]. This type of radiation effect on molecular level is called non-ionizing radiation to differentiate it from the ionizing radiation effect of high frequency EMW. In general, the exposure to EMW from different sources is divided into two categories: “continuous” and “pulsed” according to the characteristics of the emitted waves. The biological effects of pulsed wave exposure are even more harmful than that of continuous variety from other sources. As a rule, the coupling of electrical field and magnetic field of EMW outside the biological system will no longer be

sustained inside the body due to the electrical and magnetic properties of living tissues [117]. The human body acts as parasitic antenna that receives
the EMW from external sources [116]. Specifically, both electrical fields and magnetic fields can induce electrical fields and currents inside living tissues. However, the generated internal electrical currents are of much lower strength and of different directions from the external ones. These alterations in strength and directions reflect the electrical properties of human body, such as the permittivity and conductivity. To understand these properties, human tissue is best described as lose medium with dielectric properties due to high content of water in addition to other organic molecules and ions. When living tissue is exposed to EMW the dielectric (dipole) molecules will be polarized, the extent of such polarization is called permittivity [118]. Conductivity, on the other hand, describes the conduction current density produced by an applied electrical field [116]. Essentially, the high water content renders human body poor conductor to the applied electrical field. In contrast, the applied magnetic field is easily transmitted through human body and this property is called permeability [116]. Moreover, magnetic field act as another source of induced alternating currents inside the human body. Thermal and non-thermal effects are the main mediators of EMW interaction with biological system and both the electrical and magnetic properties determine sequelae of such effects on human body. We will explain these effects with a particular emphasis on male reproductive cells.

1. Thermal effects on male reproductive organs

Testis depends mainly on surface conduction rather than blood flow for temperature control; this represents an important target for thermal effect of RF-EMW (28). Because the testis is a superficial organ, it may absorb more EMW energy than other organs. Human testes need physiological temperature 2ºC lower than body temperature for optimal spermatogenesis and an elevation of testicular temperature may be reversible detrimental factor to sperm production (35,36). Some authors have demonstrated that acute EMW exposure can have direct effect on seminiferous tubular epithelium through increase in testicular temperature (30,37,38). They exposed mice to 2.45 GHz (30 W/kg), 1.7 GHz (50 mW/cm2), and 2.45 GHz (44 W/kg) respectively and showed alteredhistology of seminiferous tubular epithelium and deranged semen parameters such as sperm count, sperm morphology. However, the EMW energy used in these studies is too high and greater than the EMW energy emitted by modern cell phones. Recent reports state that thermal effect of EMW emitted from commercial cell phones is negligible particularly at SAR < 2 Watt/kg (8,9,39). It is estimated that only a SAR value greater than 4 W/kg could result in a temperature increase of 1ºC. Yan et al. conducted an animal study on rats in which rigorous measurements of surface and core body temperature were taken by sensitive electronic temperature probes placed adjacent to the rats' faces and rectums. The authors noticed that the mean face temperature of the experimental group exposed to the full 6 hours of EMW of cell phone at SAR of 1.80 W/kg did not differ from that of the control group, and the rectal temperatures of both groups were virtually identical (9). Therefore, at this time there is no clear-cut evidence which supports the thermal effect of cell phone radiation on the human body.

2. Non-thermal effects of cell phone radiation

This effect is still under scrutiny and comprises a wide array of different metabolic pathways. The main mediator of these pathways is oxidative stress. However, direct damage of RF-EMW has been also implicated (Figure-1).

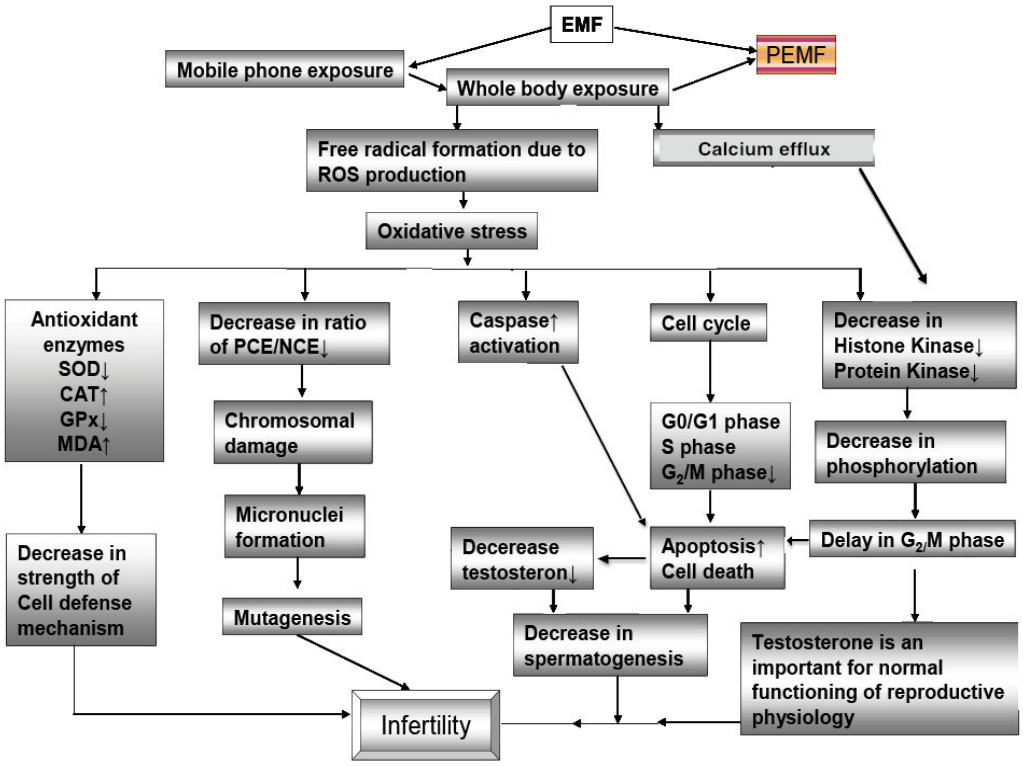

Figure 1 *- A summaries of the biological effects of RF-EMR on male reproductive pattern. This figure indicates calcium efflux and enhanced ROS due to mobile phone radiation can cause several changes at enzymatic and hormonal level, which may result infertility. Adapted from Desai 2009 (27).*

Effects of Radio-Frequency Radiation on GrossHealth

The exact underlying pathophysiologic mechanism of cell phone related health impacts is not entirely known. However, there are two proposed cell phone related biological effects on the human body. The first is termed a "thermal effect" which occurs at particularly high frequencies where the radio-frequency radiation has heating properties which may lead to an increase in tissue or body temperature. Thermal effects may cause disruption of cell function and development (5). The inflicted tissue damage in humans could occur due to the body's inability to dissipate the excessive heat. The eye and the testes are particularly vulnerable due to relative lack of blood flow to dissipate the excessive heat load (6). The second is the "non-thermal effect" which is manifested by disruption of cell membrane integrity due to passage of electrically shaking eddy current formed from body absorption of EMW, endothelial dysfunction and alterations in the blood-brain barrier, cellular signal transduction effects, immune system effects and nervous system excitability defects (7-11). More realistically, the mode of action of RF-EMW is probably a combination of the thermal and nonthermal effects. Many studies have analyzed the effects of cell phones on general human health (Figure-2). Alternation in electroencephalograph (EEG) pattern, sleep pattern and neuroendrocrine functions have been observed with increased cell phone usage (12,13). Furthermore, usage of cell phones has been associated with difficulty in concentration, fatigue, and headache (14). Cell phone exposure has also been shown to increase resting blood pressure (15). Also, EMW radiation may alter hormone secretion, such as follicle-stimulating hormone, due to deformation of

Leydig and Sertoli cells, which may lead to altered cell proliferation (16). Although it is not completely clear how the EMWs cause these changes, there is substantial evidence pointing towards a decreasein normal body function.

Cell Phone Usage & Male infertility

Proper analysis of the impact of cell phone EMW on male reproductive function comprises careful examination of the available data retrieved from different animal and human studies on cell phone related semen alteration and deranged histological testicular changes.

Gerenal Body Effects

There has been substantial development into the understanding of how cell phone radiation may alter normal bodily functions. Many studies have looked at various body tissues reaction to the radiation exposure (Fig -2). Alternations in the central nervous system, cardiovascular system, and localized tissue effects have been analyzed. Fluctuations in electroencephalograph (EEG) pattern, sleep pattern and neuroendrocrine functions have been observed with increased cell phone handling, along with decreased cognitive function and melatonin secretion (119, 120). Cell phone exposure has also been shown to increase resting blood pressure and elevate heart rate(121). Moreover, EMW radiation may alter Leydig and Sertoli cell function, leading to decreased hormone secretion which may lead to altered cell proliferation (122). Furthermore, frequent cell phone users described a difficulty concentrating, increased fatigue, and frequent headaches, coupled with a burning sensation near the ear and tingling or numbness of exposed tissue (123). Therefore, it can be seen that the effects of cell phone extend beyond that of the immediate exposure range, and that these effects if compounded, can have a substantial impact on the health and wellbeing of the user.

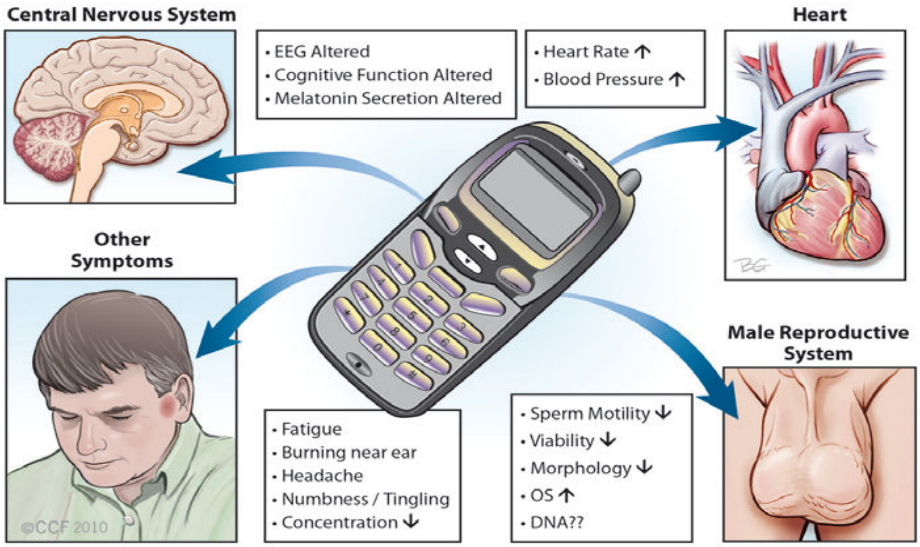

Figure 2 *- Effects of Cellular Phone Usage on the Human Body. Usage of cellular phones is associated with alterations in various body systems including the central nervous system, cardiovascular system, and male reproductive system. Adapted from Makker 2009 (115).*

Semen and male fertility effects:
The frequency associated with incoming waves and subsequent energy of transmitted waves by the cellular device can have an effect on not only the general body but more specifically on the male reproductive system. Effects on sperm motility, morphology, count, sperm functions, Leydig cells, and Sertoli cells have been studied, as well as an analysis of the pituitary gland and blood-testis barrier are frequent in studies related to cell phones.

Effects on Sperm
A. Sperm Motility
There have been several studies which have looked at the detrimental effects of cell phone on the motility characteristics of spermatozoa. Wdowiak *et al.* performed a retrospective study (304 men) noting that there was a significant decrease in the percentage of forward progressive motile sperm, correlated with the frequency of cell phone handling. In their study, 65.7% of patients who did not use cell phones had normal motility (over 50% of sperm with forward progressive motility) compared to only 17% of patients who frequently (regular phone use for more than 2 years) used cell phones (124). Furthermore, in another retrospective study involving 371 men in reproductive age, the duration of using cell phone usage and the daily transmission time correlated negatively with the proportion of rapid progressive motile sperm ($r = -0.12$ and $r = -0.19$, respectively), and shared a significantly positive correlation with the proportion of slowly progressive motile sperm ($r=0.12$ and $r=0.28$, respectively) (125). Also, in a study of 22 men with a mean age of 24 years, it was found that sperm samples exposed to high intensity EMW radiation (1.8GHz x 0.4 W/kg – 27.5 W/kg SAR) experienced a statistically significant decline in both motility and viability. Also noted, was a significant increase in the rate of mitochondrial ROS production and the level of 8-OHdG. Although the intensity of the EMW used was extremely high, this study showed that EMW radiation has the potential to cause damage not only at the morphological level but also at the molecular DNA level (126). Moreover, Agarwal *et al.* conducted a prospective *in vitro* study of 32 men, exposing the neat semen samples to RF-EMW radiation (1.46 W/kg SAR x 60 min). The authors noted a significant decrease in sperm motility and viability post exposure. Also observed was an increase in reactive oxygen species levels paired with a decrease in ROS-TAC score. It was concluded that RF-EMW emitted from cell phones may increase oxidative stress in human spermatozoa leading to decreased motility and viability characteristics (127).

B. Sperm Morphology and Count
Exposure to cell phone RF-EMW radiation has been also correlated with a decrease in normal sperm morphology and count. An observational study of 361 men was conducted to determine whether there is a correlation between cell phone usage and sperm morphology. Men were divided into four usage groups: no use, <2 h/day, 2-4 h/day, and >4 h/day. It was found a statistically significant difference in mean WHO normal morphology between the low usage group (40.32 ± 13.06) and the high usage group (18.40 ± 10.38) 9128). Wdowiak *et al.* also noted a significant increase in the percentage of sperm cells with abnormal morphology correlated with the frequency and duration of exposure to cellular phone RF-EMW emitted by GSM cell phones. 55.6% of patients without cell phones had normal morphology parameters (over 30% normal shaped sperm morphology), whereas only 16.7% of patients who frequently (regular phone use for more than 2 years) used cell phones had normal sperm morphology (129). Fejes *et al.* showed in an observational study that a significant decrease in sperm count related to cell phone handling frequency. This study analyzed 231 men over a 13- month period, and showed that for heavy users of cell phones, sperm counts were 30% lower than men who did not use a cell phone (125). Moreover, in an animal study exposed rats to cell phone RF-EMW (2 h/day x 35 days at 0.9 SAR), showed a decreased mean value of total sperm count (31.14 ± 13.6 *vs*. 61.33 ± 3.68), and an increased mean percentage of apoptotic cells (13.15 ± 1.26 *vs*. 5.93 ± 1.64 %) (130). Furthermore, Salama *et al.* conducted a study on rabbits exposed to mobile phone radiation (GSM mode, 800 MHz, standby status). RF-EMW exposure of 8 hours/day led to a significant decline in the sperm count after 8 weeks of exposure and a decrease in motility after 10 weeks of exposure (131). In contrast, other studies did not show a correlation between cell phone EMW radiation and alteration in sperm count.

DNA Integrity Defects

Deoxyribonucleic acid (DNA) contains all the genetic information that controls the vital functions of the sperm. DNA damage from external and internal sources is correlated with poor semen quality and poor fertilization rate, as well as poor pregnancy outcomes (132). Sperm have limited ability to repair single or double strand DNA breaks. DNA damage and chromatin breakage effects have been demonstrated as one of the biological interactions of cell phone EMW in different tissues. A number of studies have been performed to examine the DNA damaging effect of cell phone EMW on sperm. Aitken *et al.* reported that a 7-day exposure of male mice to RF EMFs induced significant DNA damage in both the nuclear and mitochondrial genomes of spermatozoa retrieved from the cauda epididymis (133). De Iuliis have shown the increment of sperm DNA integrity defects by TUNEL assay under cell phone EMW effect is proportional to the exposed SAR (134). In contrast, Falzone *et al.* had used TUNEL assay and did not find any significant DNA integrity defect in the examined purified sperm under EWM exposure (135) Similarly other study by Agarwal failed to show any difference with regard to EMW impact on *in vitro* sperm (136)]. The important conclusion drawn from the above studies is that DNA damage due to EMW is significant. However, this damage may be of cumulative effect of repeated exposure and it may not be revealed after short term exposure. Also, the difference in the reported results from the above mentioned studies may be attributed to differences in the frequency of applied EMW and SAR.

Ambiguity surrounding cell phone studies and their results:

The field of cell phone research, and RF-EMW radiation affecting human health, is surrounded by controversy. As shown, there have been many studies which point toward a negative correlation between cell phone and both gross human health and male reproduction. However, there are equally as many studies which conclude that the effects of RF-EMW are negligible and that there is no correlation between cell phones and semen parameters (125, 131, 137, 139). Controversy in this field stems from inadequate study design, ethics, and biological variability between individuals. The appropriate control group in a cell phone trail must be an individual who has not had any previous exposure to any form of cellular device. This, however, is hard to attain due to the technological growth occurring every day. Therefore, individuals who have “limited” exposure to cell phone RF EMW
radiation are used as a standard for *in vivo* testing. Another flaw in cell phone studies is a non-standardized testing protocol. There is a lot of variation in terms of the frequency of the radio waves, the SAR at which the phone runs, and the duration of exposure to the cells. Furthermore, there are differences in the type of cellular device used, the transmission mode at which it operates (talk *vs*. standby) and also the distance between the cells and the phone. All of these variations contribute to the ambiguity of the results present in cell phone studies. Moreover, the measured SAR varies in studies due to several parameters including frequency, intensity, polarization, and radiation source-body configuration. The exposure also depends on the cell types, shape, location, size, and electrical properties of the body. Also, animals have different body sizes and reproductive that difference in term of anatomy characteristics from human, which make the application of animal study results to humans seemingly arguable. In fact, not all the exposed men will be infertile. This notion arises from observation of inconsistent reactions of various human body system of diverse group of people to weak electromagnetic radiation and ionizing radiation. It has been estimated that 3% of people are considered electro-sensitive because they experienced a wide range of unpleasant vague symptoms such as nervousness, headache and other behavioral problems when exposed to weak non-ionizing radiation.

Contrastingly, other individuals who are electro-sensitive do not realize their problems when they are continuously exposed to this type of radiation and they report their symptoms as being perfectly normal (140)]. Theories behind electro-sensitivity include presence of thicker layer of stratum granulosum in their skin which is regarded as the leaky layer (139). Consequently, the total energy and SAR delivered to superficial organs such as the testis will be more. Others attribute this undue sensitivity to relatively low blood calcium and magnesium. Such low levels entail that fewer ions are needed to move across the plasma

membranes under EMW exposure, causing noticeable disturbance in the cells and tissues (140). Lastly, people differ in their inherited sperm characteristics such as DNA repair system and antioxidant capacity, which are the main defense mechanisms against cell phone EMW radiation. For the ethical point of view, specific considerations must be taken into account when conducting *in vivo* testing. For this reason most trials are conducted either in animal models or *in vitro* ejaculated samples. The inherent problems associated with using animal models have previously been elucidated. The complications that arise when conducting *in vitro* testing with ejaculated neat samples is determining the distance between the exposure device and the sample in order to mimic real life conditions. To solve this problem the Finite Difference Time Domain (FDTD) method was used. This computer-assisted simulation mimicked the effects of multiple tissue layers between a cell phone and the spermatozoa in the testis. The results indicated that in order to simulate *in vivo* exposure, the distance between a cell phone and an ejaculated semen sample should be 0.8 cm to 1.8 cm greater than the anticipated distance between the cell phone and the testis (141) These results can be used to construct better-designed studies in the future. No significant conclusions regarding cellular phone RF EMW radiation effects on the human body and the male reproductive system can be drawn until there is a formalized study protocol for cell phone RF-EMW exposure that takes into account an adequate control group and limits external

Conclusions:

Today's advances in technology may be associated with increasing risk to the human user. While no certain conclusions can be drawn from the evidence, a growing number of studies indicate a decrease in male fertility associated with cellular phone usage. These cellular devices emit radio frequency electromagnetic waves which may hinder spermatozoa quality as well as encumber normal bodily functions. Our review presents data which both supports and rejects these claims. The SAR in a biological body depends on several exposure parameters such as frequency, intensity, and polarization. The SAR also depends on the size, shape and electrical properties of the body. Exposure of the testis and secondary sex organs to RF-EMW's has shown a detrimental effect on spermatozoa. The exact mechanisms of how this RF-EMW may affect the spermatozoa have not yet been verified, although many feasible models have been proposed. Cellular phones are a vital part of everyday life, and additional studies are needed to evaluate the consequences of increasing usage of new-age "Smart phones." Based on the results of future studies, government may decide on new regulations to reduce the risks associated with cell phone usage.

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