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Modelling and simulation of radiofrequency electromagnetic field interaction with a human urogenital system

***Abstract**. This paper discusses the simulation of radiofrequency electromagnetic field thermal effects on the human urogenital system. The simulation of radiofrequency electromagnetic field thermal effects on the human urogenital system was done using a voxel model. The goal was to simulate the radiation of a mobile phone that can be placed in a person's pocket. The study involved several simulations using different antenna power values and voxel model modified only for the lumbar region. It was found that even with an increased power of the antenna, the SAR value did not exceed limit levels.*

Streszczenie.** W artykule omówiono symulację oddziaływania termicznego pola elektromagnetycznego o częstotliwości radiowej na układ moczowo-płciowy człowieka. Symulację wpływu termicznego pola elektromagnetycznego o częstotliwości radiowej na układ moczowo-płciowy człowieka przeprowadzono przy użyciu modelu woksela. Celem była symulacja promieniowania telefonu komórkowego, który można umieścić w kieszeni. W badaniach przeprowadzono kilka symulacji wykorzystujących różne wartości mocy anteny oraz model wokseli zmodyfikowany jedynie dla odcinka lędźwiowego. Stwierdzono, że nawet przy zwiększonej mocy anteny wartość SAR nie przekraczała poziomów granicznych.* (Modelowanie i symulacja oddziaływania pola elektromagnetycznego o częstotliwości radiowej z układem moczowo-płciowym człowieka*) *do Przeglądu Elektrotechnicznego***).

Keywords: radiofrequency electromagnetic field (RF EMF), human voxel model, urogenital system, SAR (Specific absorption rate),
Słowa kluczowe: pole elektromagnetyczne o częstotliwości radiowej (RF EMF), model woksela człowieka, układ moczowo-płciowy, SAR

Introduction

For the majority of people, mobile communication devices are an essential part of their everyday lives. Humans are constantly exposed to many types of electromagnetic fields (EMF) due to the world's expanding digitization, ubiquitous electronic devices, and wireless technology. As these technologies develop, both the scientific community and the general public are becoming increasingly concerned about their possible health implications, especially for vulnerable groups. Scientists have been studying the effects of radiofrequency electromagnetic fields (RF-EMF) on living tissue (Fig. 1) for a long time. Mobile phones, Wi-Fi networks, satellite communication systems, TV stations, radios, and interactive radios radiate RF-EMF. The number of these wireless communication devices that are used in daily life is increasing. When using electrical devices (such as mobile phones, laptops, microwave ovens, etc.), electromagnetic waves are produced. Concerns about the impact of electromagnetic radiation on living organisms have been brought up by studies yielding inconsistent findings. However, since mobile phone RF-EMFs were categorized by the World Health Organization (WHO)'s International Agency for Research on Cancer (IARC) as Group 2B, which is probably carcinogenic to humans, there has been an increase in public anxiety around electromagnetic exposure. [1]

Human head has been the primary focus of attention because of how cell phones are positioned and how close they are to the brain. Many possible neurological effects of exposure to electromagnetic fields (EMFs) are still being theorized. As a result, there is considerable concern about the possibility that exposure to RF-EMF could result in cancer of the cranial nerve system. Multiple investigations have established a connection between RF-EMF and brain tumours [2, 3]. Some, however, contend that brain cancer is not related to cell phone use [4], nor nearby cellular base stations are causing it [5]. Researchers are still looking into the possible health impacts of RF-EMF exposure.

The well-known effect of RF-EMF exposure is the ability to heat tissues, known as the thermal effect, where high levels of RF-EMF can cause a rise in temperature in the exposed area. The human body has natural mechanisms to dissipate heat and regulate temperature, so the impact of low RF-EMF is still the subject of scientific debate. Research is also ongoing to investigate the potential non-thermal effects of RF-EMF on living tissue. Non-thermal effects refer to biological changes that occur without a significant temperature rise. Various studies have examined genotoxicity (potential DNA damage), oxidative stress, cell function changes, and nervous system impacts.

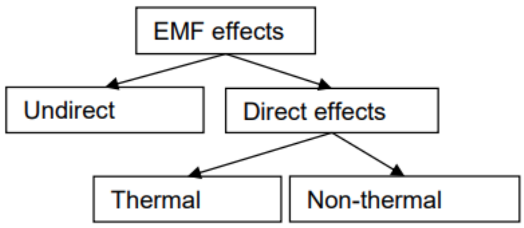


Fig.1. Basic division of EMP effects on the human body

The link between RF-EMF exposure and cancer has been extensively studied. The International Agency for Research on Cancer (IARC) of the World Health Organization has classified radiofrequency electromagnetic field (RF-EMF) as a possible carcinogen (Group 2B) based on limited evidence linking prolonged, high-level exposure to certain types of tumours, particularly brain tumours known as gliomas and acoustic neuromas. Some sufferers with electromagnetic hypersensitivity disorder report symptoms such as headaches, fatigue, and skin sensitivity when exposed to radiofrequency electromagnetic fields (RF-EMF). Nevertheless, several scientific studies could not clearly link these symptoms to exposure to RF electromagnetic fields.

To protect the public's health, regulatory agencies have established safety guidelines for RF-EMF exposure all around the world. The specific absorption rate (SAR), which determines the amount of RF-EMF radiation the body has absorbed, is one factor that is commonly taken into account in these recommendations. By following these guidelines, one can make sure that their exposure to RF-EMF stays below what is known to have detrimental thermal effects. It's crucial to remember that because this area of research is still in its early phases of development, these guidelines do not entirely address potential non-thermal consequences.

The radiation flow density |S| and the electric field strength E are used to calculate the entire amount of electromagnetic field exposure. The radiated power density |S| represents an impact wave's energy. The specific absorption rate, or SAR (W/kg), is an appropriate exposure metric to non-ionizing electromagnetic radiation at frequencies ranging from 100 kHz to 10 GHz. The *SAR* value, sometimes referred to as the absorbed power in the tissue volume, measures the energy that radiofrequency radiation energy *W* with the intensity of the electric field ***E***, absorbs by the biological tissue of volume *V* with conductivity σ and density ρ.

$$(1)\ SAR = \frac{\partial}{\partial t}\left(\frac{\partial W}{\rho \partial V}\right) = \frac{\sigma |\boldsymbol{E}|^2}{\rho}$$

The SAR value is affected by the EMF field strength, the exposed tissue's properties, and the location of the radiation-exposed body part. The public's SAR exposure limits are listed in Table I, and the International Commission on Non-Ionizing Radiation Protection recommends averaging SAR across 10 g of mass. [6, 7, 8]

Table 1. The public exposure *SAR* limits [8]

Frequency range	*SAR* * [W/kg]	*SAR* + [W/kg]	*SAR* ♣ [W/kg]
100 kHz-10 MHz	0.08	2	4
10 MHz-10 GHz	0.08	2	4
* average for whole body + local value for head and abdomen ♣ local value for extremities			

In a nutshell, the current scientific understanding indicates that normal environmental exposure levels have little consequences, regardless of the possibility of tissue heating caused by high levels of RF-EMF. There is currently no conclusive agreement regarding the possible non-thermal effects of radiofrequency electromagnetic fields (RF-EMF) on living tissue, including the possibility of cancer. More research is necessary for a more profound comprehension of RF-EMF and its possible effects on human health. The brain is often the human body's most researched sensitive tissue for apparent reasons - its close position to radiation during a phone call.

The urogenital and reproductive systems of humans are among the many other delicate bodily organs that must be considered and safeguarded. An outline of current knowledge in these body areas—crucial to humanity's survival—can be found in the following material. The interaction between electromagnetic fields (EMF) and the female reproductive system involves multiple aspects, such as fertility, menstrual cycle regulation, pregnancy outcomes, and general reproductive health. Influence on the male reproductive system and general reproductive health, including sperm quality and fertility, as well as the higher risk of urogenital tissue cancer, are also extensively studied.

Animal models are the primary source of most research due to the delicate character of the subject; many (in vitro) studies on the effects of 2.4- GHz RF-EMF on animal models and human ejaculated semen found abnormalities in sperm motility and DNA fragmentation. Concerning RF-EMF of 900 MHz and 1.7 GHz, investigations involving Cauda epididymal spermatozoa and mouse embryonic stem cells were found to have triggered DNA breakage. Since the male germ cell is tiny and stiff, EMF-induced DNA damage is considerable. The effects of an electromagnetic field (EM field) with a frequency of 900 MHz on the reproductive system of adult rats were studied by Ozguner et al. [9]. The study found no significant changes in testicular weight or the proportion of interstitial tissue to total testicular tissue. On the other hand, there was a substantial decrease in total serum testosterone levels, mean germinal epithelium height, and seminiferous tubule diameter. Higher frequencies, namely 2.45 GHz, were associated with a rise in cells positive for apoptosis and decreased Leydig cells in the rat seminiferous tubules. Because of this, exposure to 2.45 GHz RF EMF damaged and altered regions of testicular DNA. Therefore, the DNA changes of sperm or any other type of cell due to EMF may have mutagenic or tumorigenic effects [10], [11]. Using a cell phone lowers the number of sperm, motility, viability, and morphology of the semen, which may result in male infertility, according to Agarwal et al. [12]. Male infertility under the influence of oxidative stress may be caused by morphological changes in testicular tissue, decreased sperm count, increased mortality, disrupted sperm DNA integrity, or increased permeability of the blood-brain barrier along with increased mitochondrial ROS production, among other unexpected events reported thus far as a result of cell phone power density and frequency [13]. There was a substantial negative correlation between cell phone usage and sperm concentration; men who carried their phones in their pants pockets had much lower sperm concentrations than those who carried them in their waist and shirt pockets. There was no correlation between sperm concentration and the daily duration of cell phone use [14]. Houston et al. examined the known effects of RF-EMR on the male reproductive system and considered any recurring findings that would provide light on a potential mechanism. Of the 27 studies that examined the effects of RF-EMF on the male reproductive system, 21 identified adverse effects of exposure. These 21 investigations found that, in 11 of the 15 that looked at it, there were significant reductions in sperm motility; in 7 of the seven that assessed their production; and in 4 of the five that searched for it, there was increased reactive oxygen species (ROS) damage [15].

There has been research and concern over the possible impacts of electromagnetic fields (EMF) on the female reproductive system. Studies on the effects of electromagnetic field exposure (EMF) on several facets of female reproductive health have been conducted, although the field is still developing, and the results still need to be clarified. A possible connection between reproductive health and RF-EMF exposure has been studied, mainly due to the absorption of electromagnetic radiation, as radiofrequency electromagnetic fields can heat bodily tissues. Although the levels from standard devices are generally modest and considered safe, prolonged and excessive exposure may result in DNA damage and cellular stress, which may have an effect on reproductive cells. Potential effects of EMF on the female reproductive system that have been studied include fertility, impact on pregnancy outcomes, menstrual cycle, and hormonal balance. Some animal studies have linked elevated levels of RF-EMF exposure to decreased fertility, changed menstrual cycles, and impaired ovarian function. These studies have explored the association between EMF exposure and fertility issues. There is limited evidence suggesting a possible link between high levels of EMF exposure and reduced fertility, though more research is needed to establish a clear connection. Concerns have been expressed about prolonged exposure to RF-EMF during pregnancy. To learn more about its effects on prenatal development, research is still ongoing. Excessive exposure to RF-EMF has been linked to increased rates of miscarriage, abnormal fetal development, and premature delivery, according to certain studies. However, these

findings are only consistent across some studies. [16, 17, 18, 19,20]
Several studies have examined the effects of EMF exposure on the menstrual cycle and hormonal balance. There is limited evidence suggesting that EMF exposure might interfere with hormonal balance, potentially affecting the menstrual cycle. However, these findings are not well-established, and more research is necessary. In relation to changes in hormone levels, including oestrogen and progesterone, disruptions in hormonal balance could potentially affect the reproductive system, but the evidence in this area is not robust and requires further investigation. Some experts recommend taking precautions because of the uncertainty. These include preventing extended direct exposure to RF-EMF by using hands-free mobile device alternatives, avoiding placing devices near the belly, and utilizing fewer wireless technologies overall. It is noteworthy that although certain studies suggest possible issues, the entire effect of RF-EMF on the female reproductive system is still being investigated and discussed in the scientific community. There is currently insufficient data to draw a firm conclusion regarding the causal relationship between routine exposure to RF-EMF and severe harm to the reproductive health of women. [21, 22, 23, 24, 25, 26]

As seen the topic of RF EMF influence on the human tissues concerning health, fertility and well-being is still an open chapter of utmost importance. The aim of our paper is the simulation of an electromagnetic field from a mobile phone placed in the front and back trousers pocket and its absorption in close tissues with a focus on male reproductive organs. This placement might influence the male urogenital system in both direct and indirect effects, as stated in the literature.

Simulation model setup

In the CST Studio Suite environment, we use the Gustav (male) model, and Donna (female) model, which comes from the Voxel Family database, to create EM field simulations. The CST Studio Suite program contains eight models of different individuals. They differ in age, height, and weight. Model Gustav is 38 years old male, 176 cm and 69 kg, and Donna is 40 years female, 176 cm tall with weight 79 kg. The program provides the possibility of simulations on the entire human body, however, for the needs of the study, we use sections containing the urogenital tract (Fig. 2). Otherwise, the simulation of the whole human body would be time- and hardware-intensive.

The dielectric properties of biological tissues are in the models defined for frequencies in the 2.4GHZ band. In the case of the simulation's needs, the individual dielectric properties for specific frequencies are calculated using the cole-cole algorithm applying the embedded CST macro: "Home" - "Macros" -"Materials" - "Define Human Material Properties".
For the models used in simulations, we combine prepared antenna models with body cutouts in the CST Studio Suite environment. The goal is to calculate the SAR coefficient, i.e., to obtain values that show the amount of radio frequency energy absorbed by tissue in the human body. We use antenna models tuned to 2.4GHZ, which is a specific mobile service frequency.

Two types of simulation are designed for the study, using two antenna location models to investigate differences in the placement in the front and back pockets of pants. Combined simulation projects for front and back pants pocket simulation are shown in Fig. 2. Figures 3 and 4 show the area of interest of male and female model.

In all antenna positioning models is inserted the antenna tuned to a specific frequency. In this study, we focus on the 2.4 GHz frequency, representing the frequency for Wi-Fi and Bluetooth. The boundary conditions are set to "open". Then by setting the mesh general "Global properties" to number of cells to 8, we reduce the total number of cells and ensuring shorter simulation times.

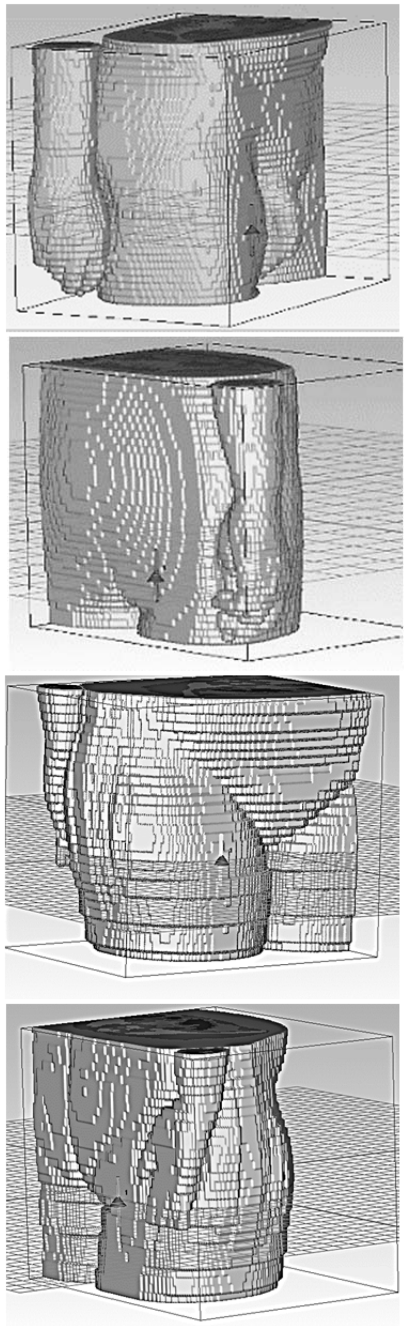
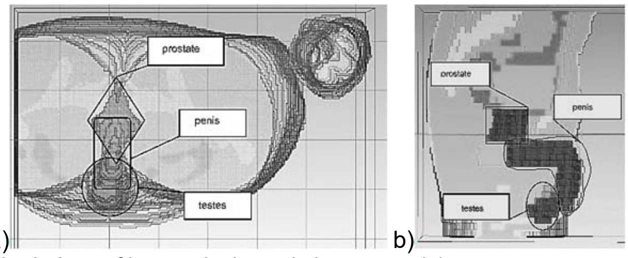

a) b) c) d)

Fig. 2. Antennae position in the human model with a) male, front pocket placement, b) male, back pocket, c) female, front pocket placement, d) female, back pocket placement.



a) b)

Fig. 3. Area of interest in the male human model.

a) b)

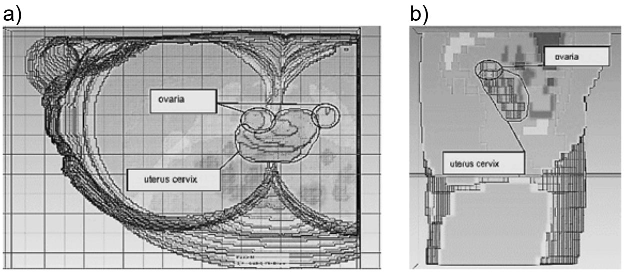


Fig. 4. Area of interest in the female human model.

In every simulation, we calculate the radiation power of our antenna set to 0.01 W, 0.1 W, and 1 W. After completing the simulation, the SAR values are calculated, which express the amount of radio frequency energy absorbed by individual tissues in the human body. In all simulations, we chose a cubic volume element of 10 g of tissue when calculating the SAR.

Simulation results

Simulations of mobile phone placement in front and back pockets provide maps of the spatial distribution of the field. We selected the values shown in the following tables from these simulation results. For exposure assessment purposes, we chose the values of electric field strength E and SAR in the areas of interest of the human body. In the case of a male, the tissues of the prostate, penis and testicles are studied; in the female model, it is the tissue of the ovaries and uterus. The maximum values of electric power E for the simulated position of the mobile phone in the front pocket and back pocket of the male and female models in the monitored tissues are shown in Tables 1 and 2. The results are shown for individual simulated radiation powers from 0.01, 0.1, and 1W respectively. The maximum field strength values E on the model's surface and power 1W are closest to the antennae, 17605.8 V/m for the male model and 18534 V/m for the female model.

Table 1. Maximum E [V/m] values in chosen male model tissues.

organ	Front pocket		
	0.01 W	0.1 W	1 W
prostate	3.988e-3	3.988e-2	3.988e-1
penis	1.9214e-2	1.9214e-1	1.9214
testes	1.211e-2	1.211e-1	1.211
organ	Back pocket		
	0.01 W	0.1 W	1 W
prostate	2.0193e-2	2.0193e-1	2.0193
penis	0.9812e-2	0.9812e-1	0.9812
testes	0.1812e-2	0.1812e-1	0.1812

Table 2. Maximum E [V/m] values in chosen female model tissues.

organ	Front pocket		
	0.01 W	0.1 W	1 W
ovaria	0.1529e-2	0.1529e-1	0.1529
uterus cervix	0.1531e-2	0.1531e-1	0.1531
organ	Back pocket		
	0.01 W	0.1 W	1 W
ovaria	0.1189e-2	0.1189e-1	0.1189
uterus cervix	0.1211e-2	0.1211e-1	0.1211

Maximum values of the field strength |**E**| for the worst case - 1W of radiated power are in the area of interest in case of front pocket placement values in the penis tissue almost 2 V/m and testes 1.2 V/m. In case of the back pocket placement, is the closes tissue prostate and it is affected by the field strength of 2.02 V/m in the areas closest to the antenna.

Similarly, the maximum surface values of the SAR value distribution results for placing the antenna in the male and female models' back and front pants pockets are 10.3868 W/kg and 9.15801 W/kg, respectively. Tables 3 and 4 show the maximum detected SAR values in the model monitored tissues of both male and female respectively.

Table 3. Maximum SAR [W/kg] values in chosen male model tissues.

organ	Front pocket		
	0.01 W	0.1 W	1 W
prostate	5.614e-6	5.614e-5	5.614e-4
penis	6.4614e-5	6.4614e-4	6.4614e-3
testes	5.214e-5	5.214e-4	5.214e-3
organ	Back pocket		
	0.01 W	0.1 W	1 W
prostate	9.5965e-6	9.5965e-5	9.5965e-4
penis	8.965e-7	8.965e-6	8.965e-5
testes	7.5965e-7	7.5965e-6	7.5965e-5

Table 4. Maximum SAR [W/kg] values in chosen female model tissues.

organ	Front pocket		
	0.01 W	0.1 W	1 W
ovaria	4.3524e-9	4.3524e-8	4.3524e-7
uterus cervix	8.1224e-7	8.1224e-6	8.1224e-5
organ	Back pocket		
	0.01 W	0.1 W	1 W
ovaria	6.676e-8	6.676e-7	5.9724e-5
uterus cervix	6.725e-7	6.725e-6	6.725e-5

The volume region of interest of the human body slice contains multiple tissues belonging to other systems of the human body, such as intestinal, cardiovascular, skeletal, muscular, fat, skin, etc., which participate in energy absorption from the mobile phone radiation. Maximum values for the SAR are therefore, indeed, in tissues closest to the antenna. The difference between the maximum values is strongly related to positioning of the antenna near the tissue and some differences among the male and female models. The distance between the area of interest – male and female urogenital tissues play the role in the maximum SAR values in Table 3 and 4. The most sensitive male tissue - testicular tissue is closer to the radiation source when the phone is situated in front pocket. The front pocket position results in higher values of SAR in penis ant testes tissue. For the back pocket placement, the tissue of prostate is affected more than two other tissues monitored because of its closeness to the antenna. The sensitive tissue of testes is further from the back pocket position, which may indicate the back pocket position as better choice.

Conclusion

Determining the precise value of critical electric strength in the tissue exposition circumstance is difficult since there isn't a widely accepted critical electric strength specifically related to mobile phone RF-EMF exposure and its direct effect on reproductive organs. Examining specific absorption rates (SAR) of RF-EMF in tissues—a measure of how quickly energy is absorbed by the body when exposed to electromagnetic fields—is a common research topic in this discipline. SAR values consider several variables, including exposure conditions, tissue properties, and frequency, when evaluating the possible health concerns connected to RF-EMF exposure.

Although specific studies suggest possible risks, there is still a lack of solid proof linking carrying a cell phone in the pocket of pants to reproductive health problems in both males and females, which is a topic of continuous investigation and discussion among experts. Extensive research, including SAR values, tissue features, and health consequences, is necessary to discover the precise threshold electric strength regarding mobile phone RF-EMF exposure and its influence on reproductive organs.

It is important to note that the genital system, particularly in men, may be subject to some thermal effects from RF

EMF due to increased exposure. Studies on the nonthermal effects of RF EMF are ongoing. The findings clearly show that the SAR value did not surpass its maximum limits, even with the antenna's increased power of 1W. The findings of research investigations that take into account nonthermal effects in the delicate tissues of the male genital area, however, caution is advised. It is appropriate to carry out this research and address other RF EMF frequencies and the effects not only on the male urogenital organs but also on other more sensitive and exposed regions, as wireless technologies are constantly improving and individuals are exposed to more EMF.

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