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EFFECTS OF ELECTROMAGNETIC RADIATION FROM MOBILE PHONES AND CASE STUDIES OF COMPUTATIONAL MODELS FOR CALCULATING SAR DISTRIBUTION IN HUMAN BODY

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ABSTRACT

Nowadays, the utilization of mobile wireless devices has been rapidly widespread, mobile phones in particular. The manufacturers of mobile wireless devices must ensure that the level of energy emitted from their products will not exceed the threshold frequency. This paper aims to review and introduce the effects of electromagnetic radiation and case studies of computational models for calculating SAR distribution in human body.

KEYWORDS: Effect, Electromagnetic, Mobile Phone, SAR, Human

INTRODUCTION

Based on the research work of German Mobile Telecommunication Research Programme or DMF, there were some indications concerning biological effects which encouraged people to question whether the limit value of electromagnetic fields applied at that time was adequately appropriate for preventing humans from health effects. It was almost impossible to prove whether various health effects existed were the consequence of electromagnetic fields. Meanwhile, there were also some epidemiological research studies indicating that the communication system through mobile phones may widely increase the risk of many health problems [1].

The DMF programme, therefore, gave importance to the aforementioned indications, especially to the epidemiological research study. Besides, the study and research designs were improved a lot. During the systematizing process, DMF set up new research designs or principles focusing on carrying out integrated, technical, epidemiological, and experimental researches.

The DMF programme gained the support of research capital for 54 sub projects covering many related academic branches, including biology, dosimetry, epidemiology, and risk communication with the aim to answer the following questions:

- Are there any possibilities that electromagnetic fields pose health effects on humans?
- The acceptance of risks from using high-frequency electromagnetic fields in social communication
- Developing the approach to risk assessment and mass communication

Regarding the aspect of dosimetry, the research focuses on 3 main objectives:

1. Developing the approach to measure and calculate the amount of electromagnetic fields emitted to the public

2. Analyzing the actual amount of electromagnetic fields received daily and seeking for technical solutions to the problem concerning measuring electromagnetic fields at the laboratory level

3. Classifying electromagnetic fields (exposure) appropriate for epidemiological studies

The research findings prove that daily exposure to electromagnetic fields of the population significantly fluctuated. The increasing utilization of wireless devices resulted in the increasing level of electromagnetic field released to the public as a consequence. However, such amount of electromagnetic fields released to the public throughout Germany was averagely lower than the threshold imposed. Based on this, the value of electromagnetic fields at the threshold can be measured only in case the electromagnetic source was attached to the body (for example, with regard to mobile phones, the results were not found in case the source of electromagnetic fields is a tower or base station).

Regarding the biological and epidemiological researches, there were both acute and chronic effects of electromagnetic fields found on human health. This particular research was conducted at the cellular level to analyze the effects of electromagnetic fields on the action mechanism within cells through studying several factors concerning the process of hormone production, cellular activity regulation, including cellular functions and responses which may lead to health problems. Furthermore, the effects of electromagnetic fields on vision and hearing were also studied in this particular research.

In addition, the study undertaken to analyze the immune system at the cellular level also indicated that high-frequency electromagnetic fields significantly have no biological effects on immune cells as well as retinas and the function of auditory nerve cells.

There were some changes in gene expression found in cellular models of the blood brain barrier process, but only in a single case. Therefore, it cannot be deduced that electromagnetic fields affect the changes in gene expression as a whole. Anyway, further study should be carried out to explain the reason behind such changes in the future.

With regard to the study of acute health effects, it focused on analyzing whether high-frequency electromagnetic fields posed effects on sleep qualities and the efficiency of cognition, remembrance, vision or hearing or not. From the epidemiological research, it was guaranteed that there has never been any relationship between measurable electromagnetic fields emitted from mobile phone base stations and sleep disorders, headache, general health problems, and quality of life (physically and mentally) found.

Regarding the study of chronic health effects of which the long-term studies were undertaken in laboratory animals, there has never been any possible indication showing that high-frequency electromagnetic fields pose effects on the process of blood brain barrier, development of cataracts, cancer incidence, the reproductive system, and body growth found. Moreover, the study undertaken in several generations of experimental animals found no evidence supporting the hypothesis which predicts that the cell is sensitive to high-frequency electromagnetic fields during early developmental stages. However, there is still an unanswered question on whether or not long-term effects in children is stronger than in adults, because the difference in age results children in being exposed to electromagnetic fields for a longer period of time than adults. Since this question is still left unanswered by the research of DMF, further study on this issue will be undertaken in the future.

The epidemiological study has found no increasing trend of brain tumor incidence from using mobile phones as well as uveal melanoma. Having been considered with the study of other daily electromagnetic field sources such as radios and televisions, there appears no indication to the relationships between the intensity of electromagnetic field and the increasing risk of

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uveal melanoma. However, there is still a question on long-term effects (above 10 years) left unanswered by the research of DMF.

For the study on electromagnetic hypersensitivity, there was some additional evidence supporting that there has been no relationship between electromagnetic fields and various symptoms, i.e. sleep disorders, loss of concentration or headache.

From all of GMF's researches, it is clear that the reasons were inadequate for adjusting the present standard threshold. However, there were some researches showing stronger health effects on children than adults. Therefore, long-term studies must be further undertaken to identify explicit effects on children, and the related sectors such as BfS and German Commission for Radiation Protection must implement preventive measures for harmful effects on children and adolescents.

VARIOUS ELECTROMAGNETIC RADIATION PARAMETERS FOR HUMAN TISSUES

1. SPECIFIC ABSORPTION RATE

Specific Absorption Rate (SAR) is defined as the rate at which electrical energy is delivered to human tissues and is expressed in the unit of watts per kilogram (W/ kg). SAR is the dosimetric measure generally used in measuring electromagnetic radiation in the frequency of higher than 100 kHz. For example, 1 W/ kg of the whole-body SAR from exposure to mobile phones means that 1 kilogram of the tissues of several organs will be exposed to 1 watt of radiofrequency energy while using mobile phones.

Generally, the SAR is measured from the average whole body or in small volume (1 gram or 10 grams of tissues) which is the standard rate that the producer of electric appliances or products in all corners of the world tries to reach, so as to provide the users with safety. Licensed producers must regulate to keep the rate of their products below the specified level. Regarding the measurement of SAR in USA, the Federal Commissions Commission (FCC) specified the SAR rating for the head at 1.6 W/ kg over the volume of 1 gram of tissues but 2 W/ kg over the volume of 10 grams of tissues.

2. SPECIFIC ABSORPTION RATE EQUATION

Electromagnetic radiation is composed of H: Magnetic Fields and E: Electric Fields. The result of SAR directly affects the dimension of electric fields where the relationship can be shown by the equation (1).

$$SAR = \frac{1}{\rho} Q_{ext} = \frac{\sigma}{\rho} \left| E^2 \right| \tag{1}$$

Where, SAR = Specific absorption rate of electromagnetic fields within the tissue (W/ kg)
Q_{ext} = Value of heat occurring outside the tissue (W/ m^3)
E = Intensity of electromagnetic fields (V/ m)
σ = Conductivity of the tissue (S/ m)
ρ = Specific density (kg/ m^3)

The equation (1) is the calculation of SAR which varies according to the square of the magnitude of the electromagnetic fields resulted from electromagnetic radiation. Moreover, there are other parameters: conductivity (σ) and specific density (ρ) which vary by each type of tissues. Therefore, it becomes interesting to study the level of SAR in different tissues where the study result will be used in researches so as to identify whether the level of electromagnetic fields exposed by tissues is according to the threshold given.

3. THE BIO-HEAT EQUATION

Bio-heat transfer is subjected to the physical principles. Heat transfer is mentioned as heat conduction $(\nabla.(-k\nabla T))$, for example, when we contact with hot objects, there will be conduction of heat from epidermis to the next deeper layers as well as convection of heat of which the consequence $(\rho_b C_b \omega_b (T_b - T))$ is stemmed from body fluids, for example, the blood reduces heat from contacting with hot objects. There are also thermal energy from metabolism (Q_{met}) and the result of external heat arisen from several causes. However, the aforementioned SAR level will appear in the form of external heat (Q_{ext}) by which the relationships can be demonstrated by the following bio-heat equation.

$$\rho C \frac{\partial T}{\partial t} + \nabla.(-k\nabla T) = \rho_b C_b \omega_b (T_b - T) + Q_{met} + Q_{ext} \qquad (2)$$

Where, ρ = Specific density of tissues (kg/m^3)
C = Specific heat capacity of tissues (J/kg.K)
k = Thermal conductivity of tissues (W/m.K)
h_b = Heat transfer coefficient from the blood seeping into tissues
ρ_b = Blood density (kg/m^3)
C_b = Specific heat of the blood (J/kg.K)
ω_b = Expiratory flow rate (ml/s)
T_b = Blood temperature (37 ºC)
Q_{met} = Amount of thermal energy from the metabolic process of blood (W/m^3)
Q_{ext} = Amount of external thermal energy (W/m^3)

From the result of bio-heat, it can be seen that the SAR is the factor contributing to the increase of tissue temperature. If used for a very long period of time, mobile phones will get hot. Considering from the equation, it is obvious that people using mobile phones for longer than 1 hour will feel hot around the ear on the side where the mobile phone is used. This is partly stemmed from the convection of heat from mobile phones and also the heat from electromagnetic radiation distributing into tissues from within the mobile phone, in the form of SAR.

4. DIELECTRIC PROPERTIES OF HUMAN TISSUES

The body of humans comprises a large number of organs. Each varies in electric properties due to different body structures. The electromagnetic radiation at any particular frequency will vary in its electric transmission properties among different tissues. For example, if there is an electromagnetic radiation at any particular frequency traveling through 2 types of tissues which vary in electric properties: the first type can be easily penetrated through (low attenuation rate for magnetic fields) but the other has a high resistance to electromagnetic radiation penetration, the magnitude of electromagnetic and electric fields in both tissues will be different. That is, the electromagnetic and electric fields are stronger in the low-resistant tissue compared with the high-resistant tissue. This results the SAR appearing in the first tissue type to be higher than that in the second type according to the equation (1) and will be related to the bio-heat equation (2). Therefore, this parameter is considered very important as illustrated by Table 1.

Table 1: Dielectric parameters of various tissues over different frequencies [3]

Tissue name	800 MHz		900 MHz		1800 MHz		1900 MHz		2100 MHz	
	Conductivity [S/m]	Relative permittivity	Conductivity [S/m]	Relative permittivity	Conductivity [S/m]	Relative permittivity	Conductivity [S/m]	Relative permittivity	Conductivity [S/m]	Relative permittivity
Blood	1.4956	61.7	1.5379	61.36	2.0435	59.372	2.1135	59.196	2.2614	58.851
Body Fluid	1.6083	68.926	1.6362	68.902	2.0325	68.573	2.0924	68.524	2.2218	68.418
Brain Grey Matter	0.90044	53.252	0.94227	52.725	1.3913	50.079	1.4503	49.882	1.5738	49.51
Brain White Matter	0.56067	39.251	0.59079	38.886	0.91494	37.011	0.95748	36.868	1.0466	36.6
Breast Fat	0.045417	5.4409	0.048964	5.4244	0.093586	5.2692	0.099753	5.2509	0.11269	5.2136
Cerebellum	1.218	50.151	1.2628	49.444	1.7089	46.114	1.7652	45.885	1.8822	45.462
Cerebro Spinal Fluid	2.3736	68.871	2.4126	68.638	2.9236	67.2	2.9973	67.056	3.1541	66.764
Colon	1.0341	58.48	1.0799	57.94	1.5762	55.148	1.6417	54.935	1.7787	54.531
Duodenum	1.1447	65.362	1.1867	65.062	1.698	63.227	1.7694	63.058	1.9204	62.727
Heart	1.1771	60.607	1.2298	59.893	1.7712	56.323	1.8405	56.063	1.9849	55.579
Liver	0.81402	47.343	0.85497	46.833	1.2891	44.211	1.3456	44.012	1.4637	43.638
Lung Deflated	0.82066	51.8	0.85798	51.424	1.2792	49.384	1.3359	49.219	1.4553	48.903
Lung Inflated	0.43985	22.208	0.4567	22	0.63713	20.946	0.6608	20.867	0.71038	20.717
MucousMembrane	0.80864	46.518	0.84465	46.08	1.232	43.85	1.283	43.682	1.3897	43.365
Muscle	0.90987	55.286	0.94294	55.032	1.341	53.549	1.3963	53.418	1.5135	53.163
Ovary	1.2364	51.286	1.2904	50.471	1.8178	46.396	1.8827	46.102	2.0167	45.556
Pancreas	1.001	59.924	1.0385	59.684	1.501	58.142	1.5659	57.995	1.7033	57.705
Prostate	1.1689	60.892	1.2096	60.553	1.6915	58.605	1.758	58.436	1.8984	58.107
SkinDry	0.83361	41.978	0.86674	41.405	1.1847	38.872	1.2245	38.714	1.3075	38.431
SkinWet	0.80864	46.518	0.84465	46.08	1.232	43.85	1.283	43.682	1.3897	43.365
SmallIntestine	2.1134	60.227	2.1652	59.488	2.6959	55.903	2.764	55.648	2.906	55.174
SpinalCord	0.54807	32.861	0.57369	32.531	0.8429	30.867	0.87784	30.744	0.95085	30.514
Spleen	1.2236	57.856	1.2727	57.178	1.7799	53.848	1.8452	53.607	1.9815	53.159
Stomach	1.1447	65.362	1.1867	65.062	1.698	63.227	1.7694	63.058	1.9204	62.727
Testis	1.1689	60.892	1.2096	60.553	1.6915	58.605	1.758	58.436	1.8984	58.107
Thyroid	1.001	59.924	1.0385	59.684	1.501	58.142	1.5659	57.995	1.7033	57.705
Uterus	1.2273	61.508	1.2699	61.115	1.7641	58.937	1.8317	58.754	1.9741	58.403

From Table 1, it can be seen that the property of tissues will alter when exposed to different frequencies and the aforementioned parameter can be used to identify the SAR of tissues exposed to different frequencies. In the next topic, some examples of the calculation results of SAR in the human body obtained from computer simulation models are provided. However, they are inapplicable in any particular cases.

EXAMPLES OF MODELS FOR CALCULATING SAR FROM MOBILE PHONE UTILIZATION

Nowadays, the utilization of wireless devices has been rapidly widespread, mobile phones in particular. The increasing utilization of wireless devices resulted in the increasing level of electromagnetic field released to the public as a consequence. The manufacturers of such devices must ensure that the level of energy emitted from their products will not exceed the threshold frequency, where the SAR is considered a standard indicator identifying products' standard scores.

In creating the model of SAR distribution, the distribution of SAR in various body organs such as the head and heart can be taken into consideration. The examples given are the calculation of SAR arisen from electromagnetic fields emitted by GSM mobile phones in the absence of environmental influences (room temperature and others) averaged over 1 and 10 grams of tissues respectively, based on the standard of SAM Phantom model creation of IEEE [2].

In creating the models, the standard and reliable computer program developed for calculating electromagnetic fields is used. The most widespread one is ANSYS which is capable of calculating the SAR distribution in various tissues.

1. SIMULATION MODELS OF THE HUMAN HEAD [2]

The standard for the computational simulation model for calculating the SAR marks the use of SAM Phantom models based on the IEEE's standard. It is a virtual model for measuring SAR though placing mobile phones at the head model as shown in Fig 1. Then, the energy emitted from the mobile phone antenna will be assigned (the power of energy is arbitrary).

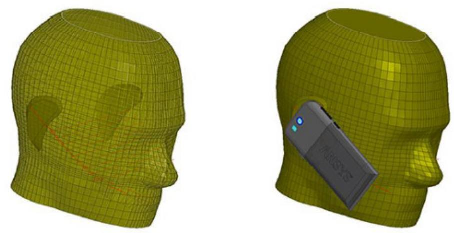

Figure 1: Computational Models of the Human Head

The comply with the safety standard, the simulation results have to be lower than the standard level at the average volume of gram (below 1.6 W/kg) restricted by USA and Canada in terms of head tissues, and in conformity with European standard averaged over the volume of 10 grams (below 2 W/kg).
From Fig. 2, the calculation results of SAR are displayed as an example, where the SAR level at the highest rate is presented in red and the SAR level at the lowest rate is presented in blue. This can be seen that, the level of SAR can greatly distribute around the area of ear, exactly where the mobile phone is used.

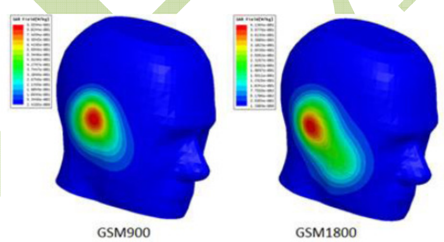

Figure 2: Calculation Results of SAR in the Head

Next, the model which closely resembles the human head will be illustrated, since only the head structure in the absence of internal organs has been taken into consideration previously. In Fig. 3, the human head model comprising the skin, skull, brain, and eyes where a mobile phone is placed at the models.

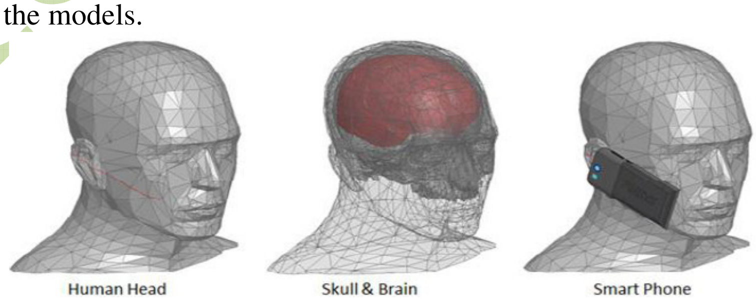

Figure 3: Computational Models of the Human Head with Internal Organs

The example results of SAR distribution induced in various organs in the head by mobile phones are illustrated as the average surface absorption rate in Fig. 4. The SAR illustrated in three-dimensional figures within the human skull and brain can point out that the distribution of SAR takes place around the ear.

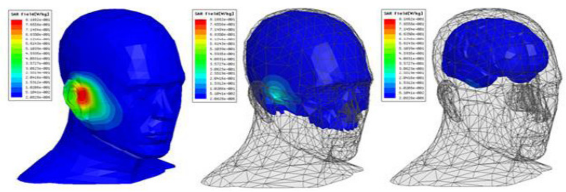

Figure 4: Calculation Results of SAR Distribution in the Brain Induced by Mobile Phones

From an example of computational models of the brain to determine the SAR in human head tissues, it is clear that the three-dimensional SAR distribution induced by mobile phones can be found around the ear used for mobile phone listening, and the SAR distribution is restricted around the tissue located not too deep from the surface.

To pass the test, the results obtained have to show that the SAR for brain models is below 1.6 W/kg according to the regulations of USA and Canada, and the average values of SAR induced by mobile phones over 1 gram and 10 grams of sample tissues are below 2 W/kg according to the European standard. It can be seen that an advantage of the models is to determine whether the SAR distribution differs from the threshold.

2. CASE STUDY OF BODY PART MODEL CONSTRUCTION TO IDENTIFY SAR DISTRIBUTION (AROUND THE WAIST AND CHEST)

Next, examples of using a computer to construct the model of standard height and size of organs will be given. It can be seen that such model is greatly beneficial to presentation and comprehension. From Fig. 5, detailed compositions of the human body such as the heart, lungs, stomach, intestine, and others are displayed. The model is designed to be placed next to a mobile phone, and an example of SAR determination is considered from two positions where the mobile phone is attached to body parts: the waist and chest. At the beginning, the SAR distribution around the waist is determined as the following.

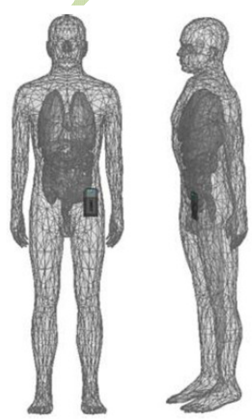

Figure 5: Computational Models of the Body Part with a Mobile Phone Attached to the Waist

Next, the evaluation to identify SAR distribution around the chest is illustrated as shown in Fig. 6. Various vital organs such as the heart and lungs are the main focus, where the SAR distribution result should be identified.

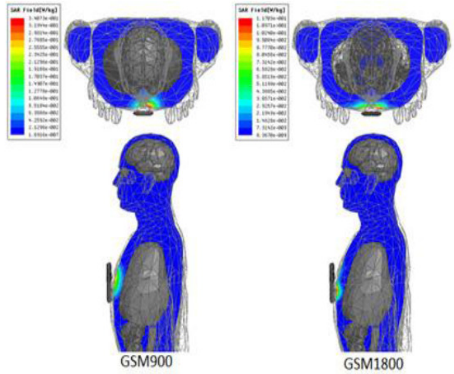

Figure 6: An example of Computational Models of Whole-body Models to Evaluate SAR of the Body Part (Chest)

CONCLUSION

The objective of this paper is to provide previous research works related to the effects of electromagnetic radiation from mobile phones and case studies of computational models for calculating SAR distribution in human body. For human safety, electric device producers must regulate to keep the rate of electromagnetic radiation from their products below the specified level. Generally, the SAR is measured from the average whole body or in small volume which is the standard rate that the producer of electric appliances or products tries to reach, so as to provide the users with safety. In this paper, several models for calculating SAR of electromagnetic radiation from mobile phone are given as examples to gain more understanding in the international safety standard. Furthermore, some examples of the calculation results of SAR in the human body obtained from computer simulation models are provided. The electromagnetic radiation at different frequencies among different human tissues is also explained in details.

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[3] The “Nello Carrara” Institute of Applied Physics (IFAC), Calculation of the Dielectric Properties of Body Tissues, can be accesses at http://niremf.ifac.cnr.it/tissprop/