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Der Pharmacia Lettre, 2016, 8 (1):394-414
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ISSN 0975-5071
USA CODEN: DPLEB4

Simulation of the human body in different positions under radiation of radio rays

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ABSTRACT

According to development of technology, applications and uses of radioactive and frequency spectrum are being developed increasingly. The main purpose of the study is using a simple and cost-effective method (simulation) to place human body in different positions under radiation of the radioactive to measure Specific Absorption Rate (SAR).

INTRODUCTION

Frequencies of these radiations are 300 kHz to 300 GHz.

Firstly, radiations with different frequencies are studied and their features are being determined. Then, desired software is selected. CST or HFSS software is one of the most powerful programs in field of simulation. After desired designation, an adequate model is considered for body and calculations are done on the body model. Radiations can affect human health depending on the amount of radiation and applied energy. Simulation enables scientists and researchers to have features of radiation source to estimate results of electric and magnetic fields on human body.

The software programs are the most powerful programs in field of computerized simulation and include different parts, which have easily estimated designation, analysis and 3D monitoring of electromagnetic radiations. Moreover, the software can trace radiation model through solving equations. Finally, radiation model would be compared to results and reports of other studies. Data analysis has been conducted using software and after comparing the diagrams with existing values and diagrams in International Standard Organization, it could be found that can the radiations be applied in this place or not. Also, it should be noted that simulated sample of human body has been studied in various positions such as sitting, standing, lying, indoors, close to the radio waves, in conversation. In this study, adult male and female samples have been modeled.

Magnetic electric fields and their relationships

Electromagnetic fields or energies include frequencies of 1 hertz to 1 terahertz with more than 1micrometer wavelength in the air.

The wavelengths produce photon or quanta with low energy density. Hence, they can't change limitations and chemical properties of materials or stimulate electrons or ionize body cells under normal conditions.

The waves with such properties are named as low-energy or deionized waves. Application of electromagnetic radiations in medication is important. The most use of the radiations is in Magnetic Resonance Imaging (MRI) and spectroscopy. In general, equations of electromagnetic fields can be written as table 1. Electric field is presented per volt/meter and magnetic field is per ampere/meter. (1)

Table 1: summary of equations of electromagnetic fields

Field concepts
Electric intensity $\mathcal{E}$
Electric current density $\mathcal{J}$ or magnetic intensity $\mathcal{H}$
Magnetic flux density $\mathcal{B}$
Charge density q_v or electric flux density $\mathcal{D}$
Maxwell-Faraday equation $\nabla \times \mathcal{E} = -\frac{\partial \mathcal{B}}{\partial t}$
Equation of continuity $\nabla \cdot \mathcal{J}^c = -\frac{\partial q_v}{\partial t}$
Constitutive relationships (linear in the simple sense) Conductors $\mathcal{J}^c = \sigma \mathcal{E}$ Dielectrics $\mathcal{D} = \epsilon \mathcal{E}$ or $\mathcal{J}^d = \epsilon \frac{\partial \mathcal{E}}{\partial t}$ Magnetic properties $\mathcal{B} = \mu \mathcal{H}$ or $\mathcal{M}^d = \mu \frac{\partial \mathcal{H}}{\partial t}$
Power flow $\mathcal{S} = \mathcal{E} \times \mathcal{H}$
Power dissipation $p_d = \mathcal{E} \cdot \mathcal{J}^c = \sigma \mathcal{E}^2$
Electric energy $w_e = \frac{1}{2}\mathcal{D} \cdot \mathcal{E} = \frac{1}{2}\epsilon \mathcal{E}^2$
Magnetic energy $w_m = \frac{1}{2}\mathcal{B} \cdot \mathcal{H} = \frac{1}{2}\mu \mathcal{H}^2$

Non-ionizing electromagnetic radiation

Electromagnetic radiations, in which energy of photon is lower than 12.4 electron volts, have not the capacity of ionization in human body tissues. Hence, they are known as non-ionizing radiations. According to equation 1, wavelength of non-ionizing radiations is higher than 100nm and their frequency is below 15^[10]*3. Ultraviolet radiation, infrared, radio waves and frequencies lower than radio waves are considered among non-ionizing radiations.

RF and Microwave (EHF, SHF)

Microwaves can be divided to two main groups as follows:

SHF waves: frequency of the waves is from 3 to 30 GHz and their wavelength is 1-10cm. the waves would be weakened by rain and snowfall and trees and buildings can also cause scatter of these waves. Wire antenna and waveguide can be applied in them. In radars, sending data (voice and image), mobile services, satellite remote measurement and fixed satellite links would be applied.

EHF waves: frequency of these waves is 30-300 GHz and their wavelength is 1-10mm. the waves would be hardly weakened by rain and snowfall, smoke and steam and fog and also trees and buildings can also make the waves scattered. They can be sued in short distance and satellite telecommunications.

Microwaves can make fat and water molecules to vibrate and this can make materials warm. In radars, microwave ovens, remote senders with high powers would be applied and hence, they can be harmful.

Electromagnetic properties of material in equations
In a fixed material, dielectric and conductivity would be decreased and increased respectively with increase in frequency. Biologic materials, especially in fixed low frequencies, show very high dielectric response. This is because; the materials have been made of macromolecules, cells and membranes. Figure 1 illustrates this issue.

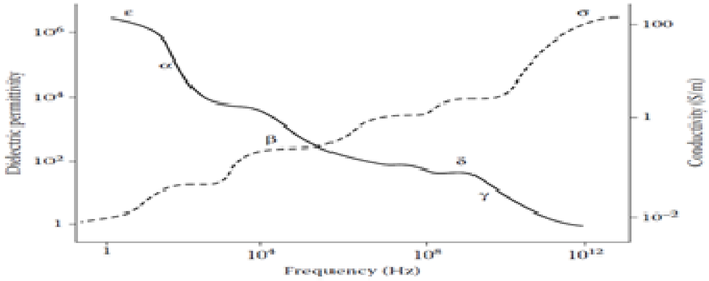

Figure 1: electric penetration and conductivity of biological material like muscle. (2)

In low frequencies or lower than 3 KHz, membrane of materials gain capacitor property and the higher frequency goes, the more conductivity of material and changes of filed would become.

Coupling in high-frequency and electromagnetic radiation
Coupling in high frequencies and electromagnetic radiation of coupling in high frequencies in form of radiation is in away or close field, in which D is antenna radios and λ is wavelength. Constant reflection and transmission for both objects would be defined for radiation wave with surface of two objects as follows:

$$R = (\eta_2 - \eta_1)/(\eta_2 + \eta_1)$$

$$T = (2\eta_2)/(\eta_2 + \eta_1)$$

The values of these constants for several materials have been presented in table 2. For example, wireless parts like Bluetooth, mobile and BTS antennas can create SAR to 0.1-1.8 w/kg (1)

Table 2: constant transmission and properties of materials in various frequencies

Frequency (MHz)	Dielectric Constant		Conductivity (S/m)		Penetration Depth (cm)		Transmission Coefficient (T)	
H_2O	High	Low	High	Low	High	Low	High	Low
27	113	20.0	0.61	0.03	14.3	77.0	0.14	0.56
40	97	14.6	0.69	0.03	11.2	58.8	0.17	0.62
433	53	5.6	1.43	0.08	3.6	18.3	0.36	0.82
915	51	5.6	1.60	0.10	2.5	12.8	0.40	0.83
2,450	47	5.5	2.21	0.16	1.7	8.1	0.43	0.84
5,800	43	5.1	4.73	0.26	0.8	4.7	0.44	0.85
10,000	40	4.5	10.3	0.44	0.3	2.6	0.45	0.87

History of investigating effects of electromagnetic radiations on human body
In order to measure the amount of absorbed power per unit weight, quantity ray source named Specific Absorption Rate (SAR) would be applied.

SAR
SAR would be defined as follows. To measure wave absorption rate per unit material (gr/kg):

$$SAR = \frac{\sigma |E|^2}{\rho}$$

σ Is electric conductivity; ρ is material density and E is effective amount of electric field. The value is simulated for an antenna, which radiates on body. The above presented formula can indicate that SAR is depended on type of material, intensity of radiated electric field to materials and its electric conductivity.

Electromagnetic radiations can be divided to two ionizing and non-ionizing types. Ionizing types have frequency higher than 3000terahertz, which include X-ray and Gamma Ray. RF and microwaves also include frequencies to 300 GHz and visible lights have also frequencies 300 GHz to terahertz.

Simulation and analysis methods

For investigation, analysis and simulation purpose, the first step is recognizing simulation or body element completely and providing a model based on measurement or simulation method. Voxel models, presented in tale 3, have been applied for absorption rate in body organs using Monte Carlo analysis for ionizing waves in radiography and radioactivity and for protective purposes.

Moreover, Voxel model, along with Finite-Difference Time-Domain (FDTD) method, would be applied to calculate SAR of non-ionizing electromagnetic fields and low-frequency magnetic fields. (3-6)

Table 3: Voxel models (anatomy) used in studies of electromagnetic radiations under various frequencies. (7)

Existing voxel tomographic computational models

Model	Images	Race	Age and sex	Subject	Comment
Child	CT	Caucasian	7-year-old female	Leukemia patient	Small for age (5 to 7-year-old)
Baby	CT	Caucasian	8-week-old female	Cadaver	
VoxelMan[a]	CT	Caucasian	Adult male	Diffuse melanoma	Head and torso
NORMAN	MRI	Caucasian	Adult male		Only 10 ribs
Golem	CT	Caucasian	38-year-old male	Leukemia patient	
ADELAIDE	CT	Caucasian	14-year-old female	Patient	Torso
VIP-man	Colour photos	Caucasian	38-year-old male	Cadaver (VHP[b])	One testicle only
Otoko	CT	Japanese	Adult male		
UF newborn	CT	Caucasian	6-day-old female	Cadaver	
UF 2 month	CT	Caucasian	6-month-old (=2) male	Cadaver	Small for age
Visible-human	CT	Caucasian	38-year-old male	Cadaver (VHP)	
Frank	CT	Caucasian	48-year-old male	Patient	Head and torso
Donna	CT	Caucasian	40-year-old female	Patient	
Helga	CT	Caucasian	26-year-old female	Patient	Legs absent below mid-thigh
Irene	CT	Caucasian	32-year-old female	Patient	
MAX[c]		Caucasian	Modified VoxelMan		Reference man dimensions
Nagaoka man	MRI	Japanese	22-year-old male	Volunteer	
Nagaoka woman	MRI	Japanese	22-year-old female	Volunteer	
KR-man	MRI	Korean	28-year-old male		
Un-named	CT		9-month-old male		Head and torso
Pregnant woman	CT		30 weeks pregnant		Part torso

[a] VoxelMan has no arms or legs but is available as MANTISSUE3–6 with VIP-man's arms (crossed in front of body) or with arms at side of body as VOXTISS8.
[b] *VHP* Visible Human Project.
[c] *MAX* is VOXTISS8 with smaller arms and legs and modified to conform to the dimensions and anatomical measurements of Reference Man.

In adopted simulations, constantly relatively careful anatomy model, along with FDTD method has been applied that has high capability in frequency sweep and simulation or analysis for these structures, compared to high frequencies. In all simulations in references, anatomy models have been derived from biophysics sources and for each organ, exact characteristics of material including all properties of material, even heat would be presented by relevant formulations.

Assessing effects of different sources on human body

Assessment of disadvantages and side effects of electromagnetic radiations in radio frequency have been emphasized since the time of production of powerful electromagnetic sources like powerful ray transmitters. The main effect of the radiations on body is thermal effect, in which body temperature and heat would be raised. (8-9)

In 20-30 MHz frequency, human body intakes energy of these radiations more than other frequencies and body temperature would is also high. However, the power is an important issue in all frequencies. For example, about people exposed to powerful rays (in range of kilowatt), if antenna is turned on in short distance as a result of mistake and a person is exposed to the radio wave, it can also cause internal burn of organs in microwave frequencies and can cause at least cataracts in lower frequencies .(10)

Moreover, the radiations should follow specific standard and be in permitted limit [14, 15].

Electromagnetic pulse effects on the body, (11)

Electromagnetic pulses from 20 to 500kv/m or higher frequencies with frequency range of 0-8 MHz would be produced by simulators of nuclear electromagnetic bombs. However, recently using Ultra WideBand (UWB) or Ultra short band electromagnetic bombs (in tile scope) have gained attentions for imaging, sensors and telecommunication uses. (12-13); The uses include medical imaging, radars on vehicles, Ground-Penetrating Radars (GPR) and telecommunication systems like handheld transceiver and private wireless networks. Figure 1 has illustrated an electromagnetic pulse with range peak of 50kv/m and half time of a microsecond. (16-17); A 10-cm sphere is exposed to it, which has simulated human head (figure 2).

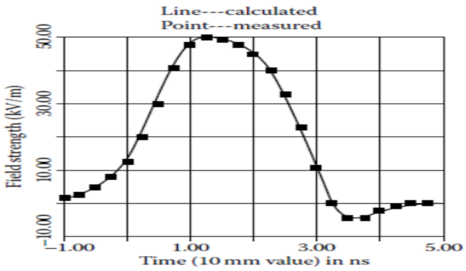

Figure 2: form of electromagnetic pulse (16)

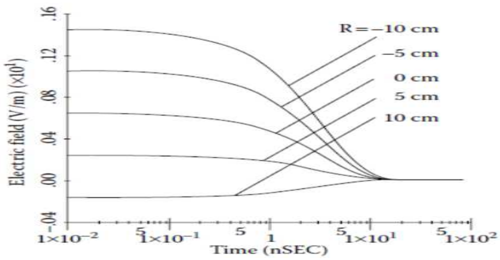

Figure 3: in-sphere electromagnetic pulse with diameter of 10cm per rime and place to simulate human head

Works and studies in different references

In references (18-19), effects of radiations and rays on head and eyes have been studied. Also, using a source like ferritic plane is suggested to overcome and decline these effects.
Electromagnetic energy absorption rate is depended on following parameters:

- Frequency and power of radiators
- exposure to radiation and the receiver (the object in the vicinity of radiation)
- Design of piece
- The size of the receiver
- distribution and the volume and type of receptor

Obtained results from calculations and simulations for head. (20-21) indicate that increase in SAR can be changed uniformly along with decline of head size. It has been demonstrated in calculations that maximum SAR for head of kids can be 60% in frequency of 1900 and 20% for frequency of 900 MHz for adults. Moreover, a reason for increase in SAR in children is their smaller ears and closer distance of cellphone to their head.

Moreover, about radiations of away field of BTS antennas, wide range studies have been adopted. In a study adopted by 2011, 5 different models of human body have been investigated. All models had resolution of 2mm and included models from 7-year old children to adults. The models could be obtained through scaling .(22) ; Following figures illustrate the mentioned models and obtained SAR value.

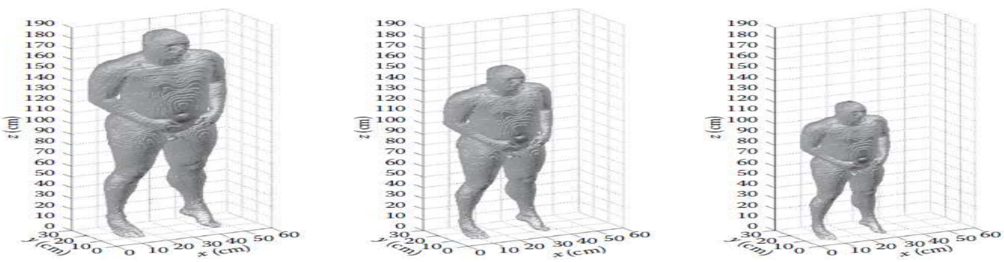

Figure 4: applied models to assess SAR in, (22)

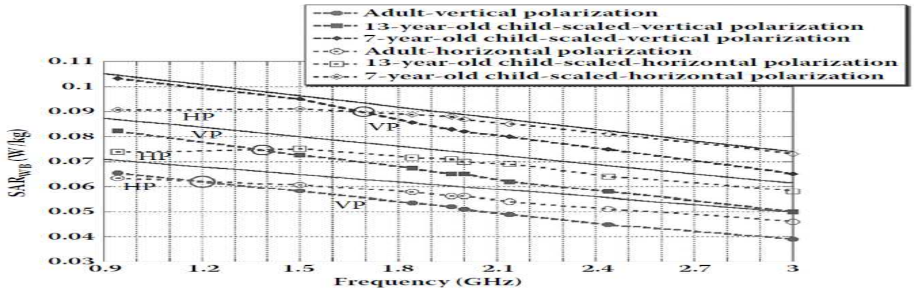

Figure 5: SAR value on entire body for radiation power of 210w/m with frequency about 900-3000 MHz ,(22)

Biologic effects

Studied biologic effects of radioactive and microwaves are as follows ,(8)

1. effects on pregnant women;
2. effects on eyes;
3. effects on neural system and
4. The increased risk for cancer.

How to check millimeter waves and their effects

- Real and imaginary parts of permittivity change from 20 to 6 and from 20 to 12.
- Fixed reflection of skin changes from 37 to 74 GHz and from 60 to 45%.
- Propagation constant is changed from 55 to 65% and from 30 to 90 GHz.
- SAR would be increased as a result on increase in frequency; although in depth of skin and with increase in frequency, the effect of radiation would be declined because of more decline of ray,(23)

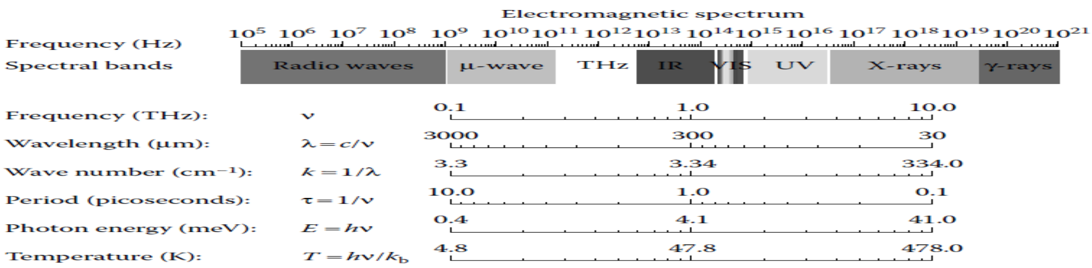

Figure 6: electromagnetic wave spectrum

Assessing anatomy of human body, models, electromagnetic features of organs for simulation

Human body has a very complicated and heterogeneous internal structure. Modeling of human body is a big challenge and various organs of a body should be considered. As a result, the model has good performance in applied programs of computer graphic such as computer games, movies, video animations and so on. However, they can't be applied for electromagnetic simulation, since modeling of a lot of internal organs and tissues is stil very difficult, (24)

Models of human anatomy and their accuracy

In this section, the aim is investigating types of models and human anatomies. In one of these models, simulated human has 84 organs as it is illustrated in figure 1 ,(25); In this figure, electromagnetic parameters of body organs have been derived from references. Moreover, Empire software can be used to gain them,(26); Similar to CST Microwave Studio, the software uses numerical method of FDTD for analysis and simulation purpose. To simulate and model human body in 3D form in,(27); the study has used,(28); which is a complete model formed of 67 parts.

The result obtained in software programs like CST under the title of CST Voxel Family includes 7 models illustrated in figure 2 (Voxel). However, the model needs separate license [i]and should be imported in software (CST Human Model Dataset). Accuracy of the models is presented in table 1.

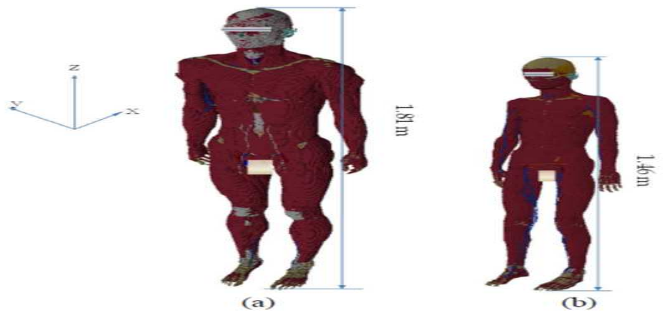

Figure 7: complete anatomy models of MRI of a man with weight of 72kg (b) and a 11-year old girl with weight of 35kg,(10)

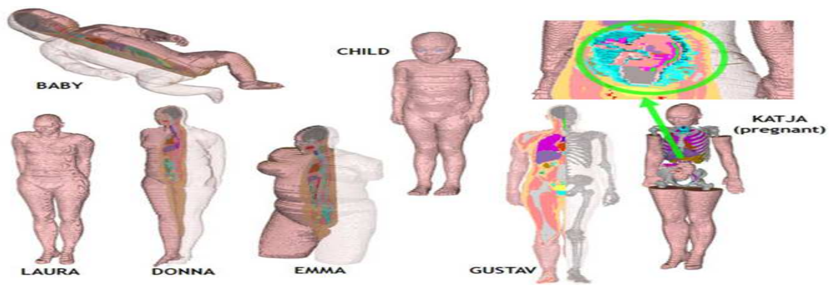

Figure 8: anatomy models in CST software, which should be imported and need separate license

Voxel models are available currently as the best human anatomy models and they have designed based on real anatomy. They would allow a close relationship between a numerical model and a studied patient. They have also flexibility to change scale in small range.

However, it should be mentioned that applied model in simulation is more complete model with major part of body organs (even vessels are simulated) among other software programs and models. Anatomy, number of organs and also comparison to CST software and physic of modeled bodies indicate this issue.

Modeling and electromagnetic characteristics of the body

The first step in regard with simulation or investigation of effects of radiation on human body is recognition of electromagnetic features of organs and its elements. Basis of these features is on examinations and reports in references. The features have been derived from experiments of living things and previous reports.

Dielectric properties of material

The properties can be obtained from mixed permittivity that has no unit: $\hat{\varepsilon}=\acute{\varepsilon}-j\varepsilon''$
In general form, electric permittivity would be measured in material based on this formula: $\sigma=\sigma_d+\sigma_i$
Obtained results from measurements indicate that ,(29)

- Dielectric properties of body organs are depended on frequency and temperature.
- The properties indicate three limitations adjusted with losses of propagation, which is from hertz to terahertz in low, mid and high frequencies (they have been named respectively as α, β and γ).
- αValue is associated with low frequency from hertz to kilohertz and related to ion diffusion phenomenon.
- Propagation area of β is associated with frequency to a few MHz and is because of polarization of cell membrane and organic macromolecules.

The member with high volume of water acts as water propagation. Frequency dependence of mixed permittivity in studied frequency range can be estimated as follows:

$$\hat{\varepsilon}(\omega) = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1+(j\omega\tau)^{1-\alpha}} + \frac{\sigma_l}{j\omega\varepsilon_0}$$

The formula is known as Cole-Cole Formula.
Obtained results from features of some body organs considered in simulation have been also illustrated in figure 4.

Frequency range	Tissues	ε' (±%)	σ (±%)
50-300 MHz	Grey Matter	1.8	4.5
	Cornea	0.8	1.5
	Long Bone	4.2	8.4
	White Matter	5.7	7.8
	Liver	1.5	2.8
	Cartilage	1.8	7.3
>300 MHz-10 GHz	Grey Matter	2.1	3.1
	Cornea	0.9	1.3
	Long Bone	4.4	5.1
	White Matter	4.5	6.3
	Liver	1.2	1.9
	Cartilage	2.0	4.5
>10-20 GHz	Grey Matter	3.0	5.9
	Cornea	1.8	2.8
	Long Bone	5.6	5.6
	White Matter	4.5	8.1
	Liver	1.8	3.4
	Cartilage	3.1	4.5

Figure 9: measured values of permittivity and conductivity for several organs in 3 frequency ranges

Measurement method mentioned din references is on this basis that a network analyst device is used to measure permittivity of material and the data would be also applied to measure electric permittivity of material. Exact analysis and investigation of measurement methods is not discussed here and they have been just applied ,(29-35)

In order to simulate body, model with high accuracy is needed, which has been presented in [36] as a 1*1*1 mm (3D model) model (figure 5).

In order to measure electromagnetic properties of body organs, software programs have been coded in format of MATLAB software that their codes are presented in appendix. Applied software for this purpose has also used Cole-Cole formula. Image of software environment is illustrated in figure 6.(36)

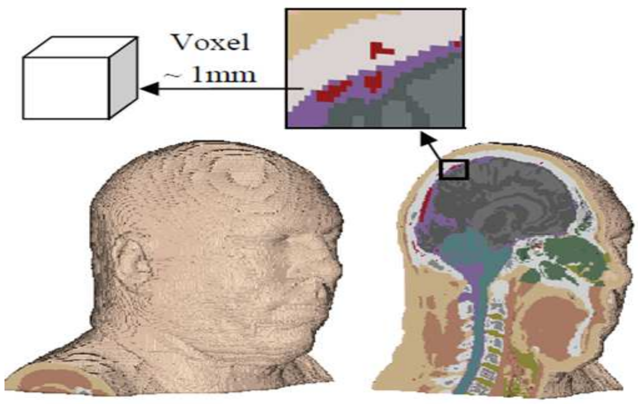

figure 10: Voxel model with accuracy of 1*1*1*mm

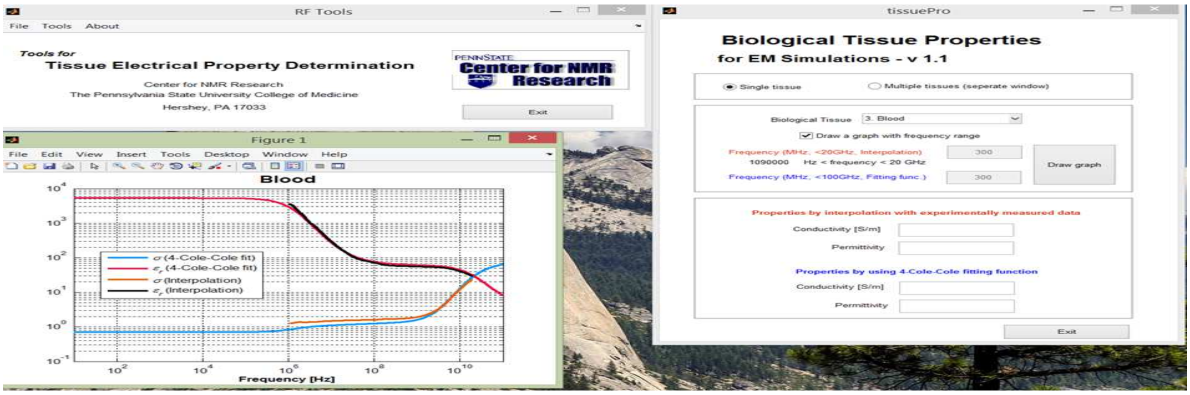

figure 11: software environment to calculate electromagnetic features of body

Applied anatomy mode and number of organs

In figures 7-10, anatomy of a woman and a man and number of their organs has been illustrated. The anatomy includes 197 organs and volume of 59 organs is equal to 900mb in format of SAT. in order to avoid complexity and also doing calculations and simulation practically in software, its number and important types should be selected. (38)

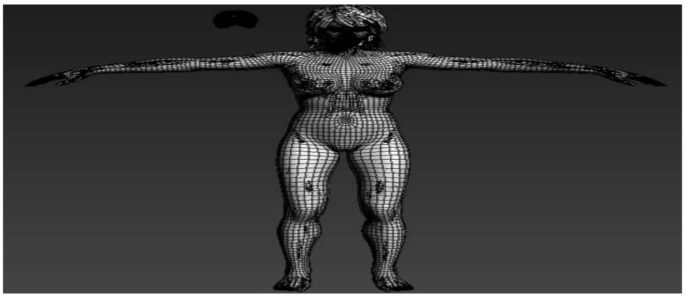

figure 12: 3D model of woman anatomy in DMAX3 software

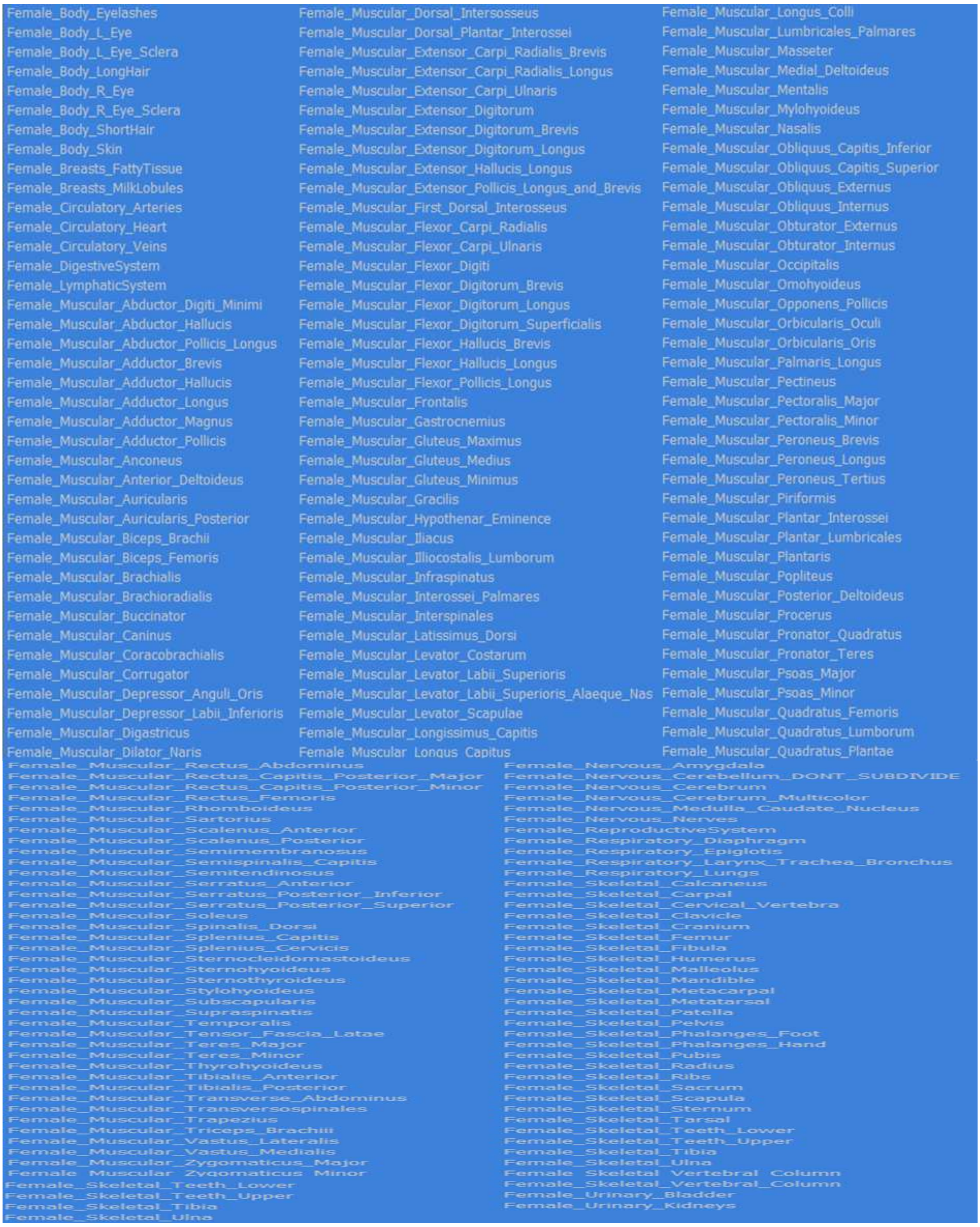

figure 13: names of 197 organs of a woman

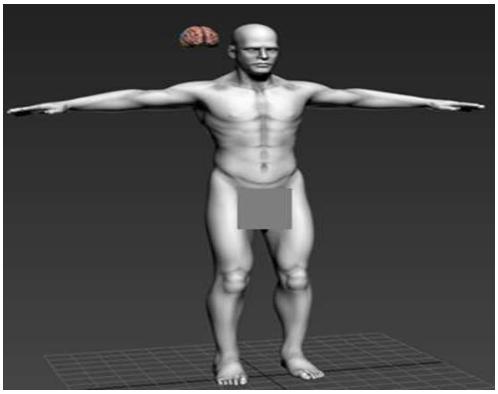

figure 14: 3D model of man anatomy in 3DMAX software

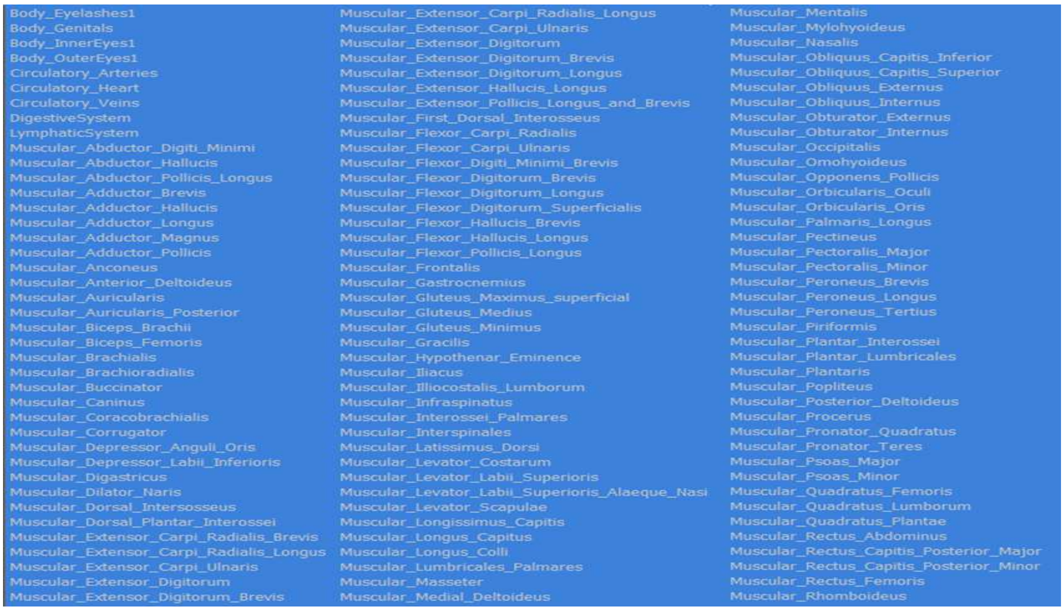

Figure 15: names of body organs of a man

Finally, according to references and investigations, least organs selected are as follows:

1- Skeleton (including at least 10 different and central members)
2- The main blood vessels (veins and arteries) and blood
3- Heart
4- Lung
5- Intestine
6- brain
7- The eye
8- Skin
9- Stomach
10-muscles (at least 10 original member)
11-Fat (at least 4)
12-pancreas
13-tendon
14-belly

SAR Simulation and measurement in different frequencies and body positions

Know how to work with 3D MAX software and VST for anatomical model;

In order to produce anatomical model in CST software, firstly a model in applicable format in CST should be created. According to figure 1, known formats for CST include SAT, OBJ and so on.

Therefore, the model of 3DMAX software is applied. The model has been derived from internet and reference ,(39-40); In 3DMAX, output file is produced in OBJ format with least accuracy (to have least volume).

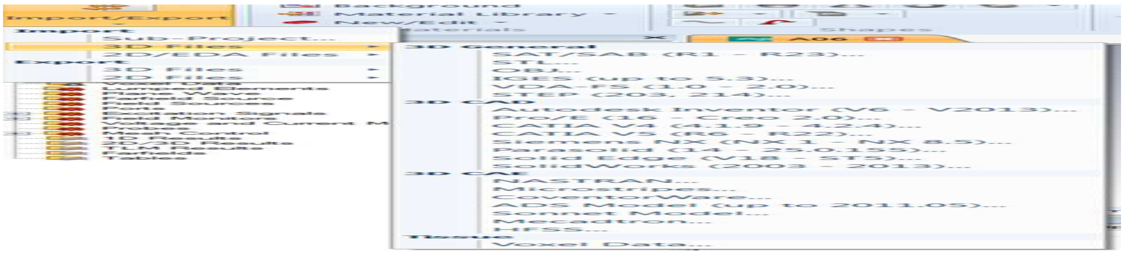

Figure 16: applicable 3D formats in CST Microwave Studio

Figures 2 and 3 indicate environment of 3DMAX. Because of high volume of output file and also the file in CST software, body organs should be limited to 40 organs. It means that 40 organs out of about 200 organs in 3DMAX software should be selected.

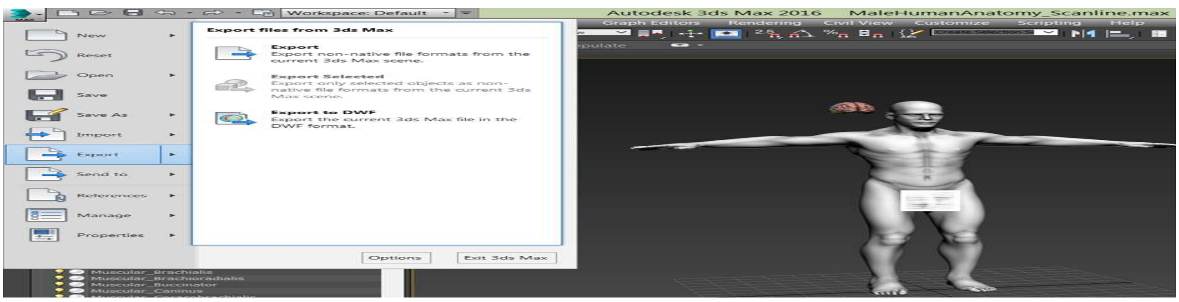

Figure 17: export style in 3DMAX

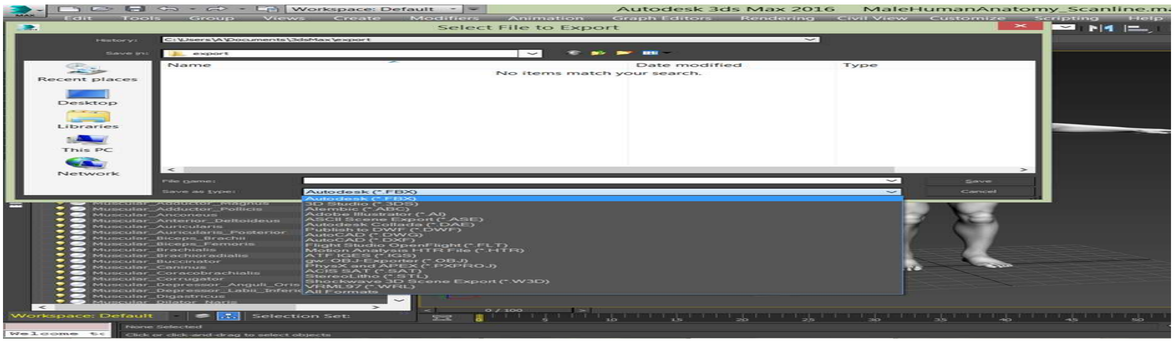

Figure 18: 3D output formats in 3DMAX

In order to exclude unnecessary organs, through maintaining Ctrl key, organs can be selected and delete key would be pressed, so that the organs can be deleted. Then, the organs should be exported to the other software.

SAR simulation and measurement by CST Microwave Studio Software

In this section, software, simulation method, analysis and results would be presented.

Numerical methods in electromagnetics of CST software

The science of electromagnetics has had considerable advancements to solve complicated problems of scattered fields as a result of radiation of rays on complicated structures.

Finite-different time-domain (FDTD) method: in this method, whole space of problem should be meshed. In this method, usually meshing is uniform and dimensions of meshes in the environment can be determined according to the smallest details in the structure, which is contrary to MOM and FEM methods ,(41-42)

The method is in time scope and is suitable for problems with transitional analysis. Similar to FEM method, the method is useful to model complicated structures and is more efficient than FEM method in regard with modeling problems with large structure. According to the mentioned characteristics, FDTD method is followed in this project. FDTD mesh is usually formed of integrated and rectangular and curved cells. FDTD method updates field values and at the same time, it changes the time in stepwise form. It also can propagate electromagnetic radiations in structure. As a result, a FDTD simulation can provide data more than an extraordinary spectrum of frequency.

FEM	FDTD
Frequency domain method	Time domain method
Tetrahedral mesh cells	Rectangular and curved conformal mesh cells
Good for high-Q structures	Good for broadband applications, physical transitions
Remote simulation and distributed frequency sweeps	Remote simulation and distributed port simulations
Fast for multi-port simulations	Each port requires additional simulation
Based on solving matrix equations; best for electrically small problems	Based on iterative time stepping; less memory intensive for electrically large problems
Multi-threaded; problems can be divided and run in parallel on multi-core CPUs	Highly multi-threaded; problems can be divided and run in parallel on multi-core CPUs and on large GPU cards

Figure 19: comparing two methods of FDTD and FEM

Profile of Members in the SCT

Figure 5 has illustrated human body and in subset of components, for example heart can be observed. Through right clicking on each organ, according to figures 6 and 7, profile of the organ can be put in software. This would be explained as follows.

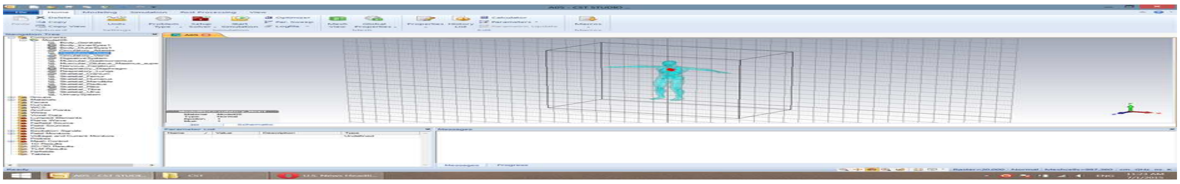

Figure 20: human body in CST and how to select organs

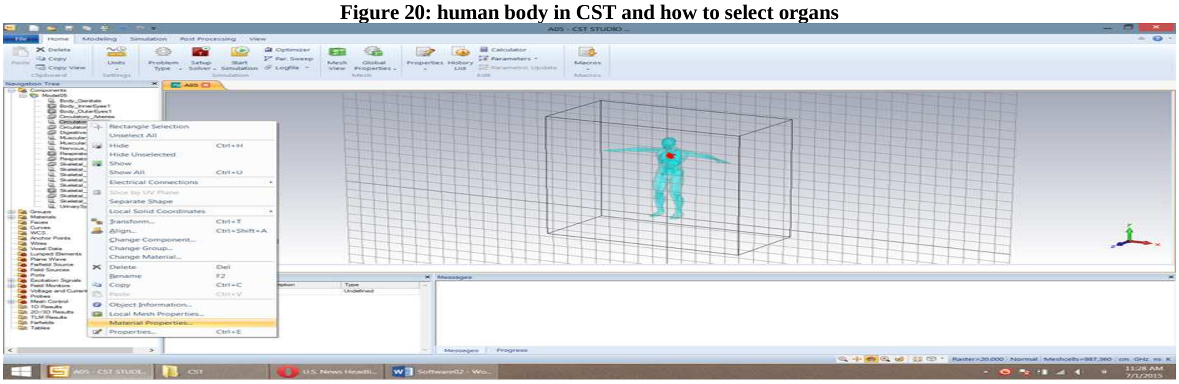

Figure 21: human body in CST and material properties

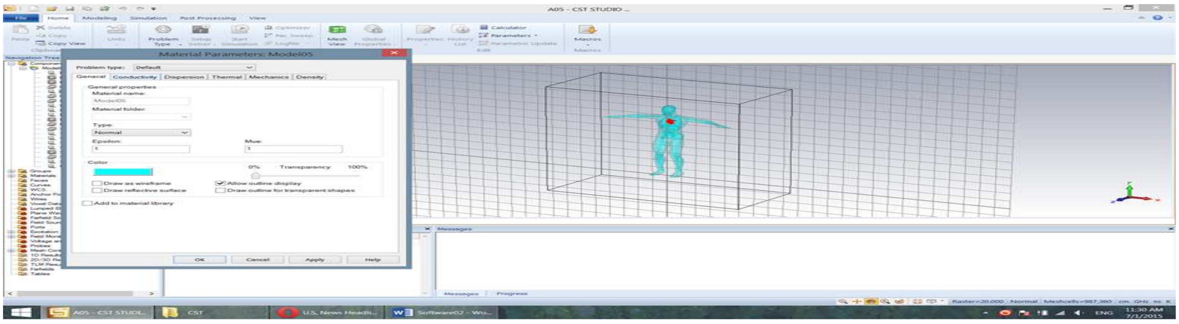

Figure 22: material and window properties

In order to simulate body similar to the software, firstly characteristics of body organs have been obtained from the site http://www.itis.ethz.ch/virtual-population/tissue-properties/database/density/ or using software.

The properties include the data presented in figure 8.

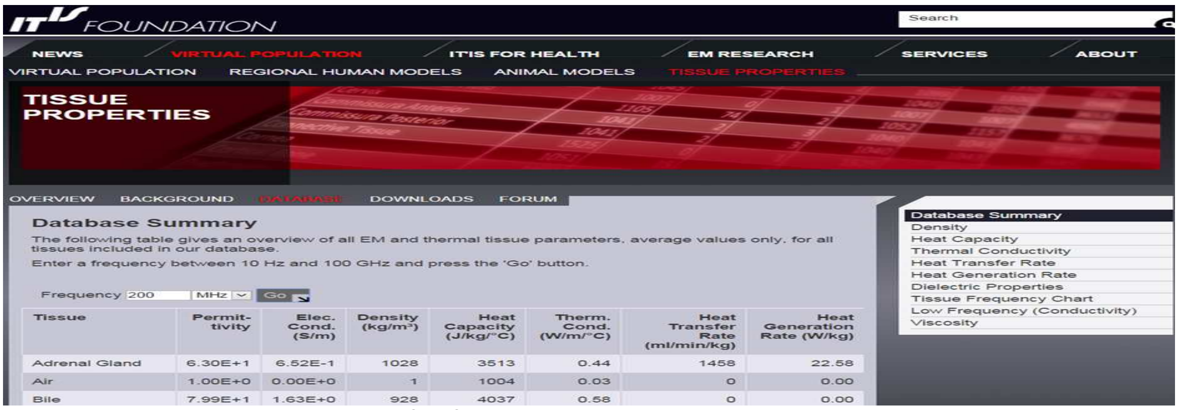

Figure 23: Full profile of the body such as density, throughput, losses and so on

Full profile is presented in table 4.

Table 4: full profile of body organs

Tissue	Permit-tivity	Elec. Cond. (S/m)	Density (kg/m³)	Heat Capacity (J/kg/°C)	Therm. Cond. (W/m/°C)	Heat Transfer Rate (ml/min/kg)	Heat Generation Rate (W/kg)
Adrenal Gland	6.30E+1	6.52E-1	1028	3513	0.44	1458	22.58
Air	1.00E+0	0.00E+0	1	1004	0.03	0	0.00
Bile	7.99E+1	1.63E+0	928	4037	0.58	0	0.00
Blood	6.85E+1	1.28E+0	1050	3617	0.52	10000	0.00
Blood Plasma	NAN	NAN	1020	3930	0.58	0	0.00
Blood Serum	NAN	NAN	1024	0	0.00	0	0.00
Blood Vessel Wall	5.11E+1	5.09E-1	1102	3306	0.46	150	2.32
Bone (Cancellous)	2.44E+1	1.96E-1	1178	2274	0.31	30	0.46
Bone (Cortical)	1.39E+1	7.41E-2	1908	1313	0.32	10	0.15
Bone Marrow (Red)	1.26E+1	1.68E-1	1029	2666	0.28	135	2.09
Bone Marrow (Yellow)	5.93E+0	2.59E-2	980	2065	0.19	30	0.46
Brain	6.71E+1	9.02E-1	1046	3630	0.51	559	11.37
Brain (Grey Matter)	6.51E+1	6.39E-1	1045	3696	0.55	764	15.54
Brain (White Matter)	4.71E+1	3.77E-1	1041	3583	0.48	212	4.32
Breast Fat	5.58E+0	3.12E-2	911	2348	0.21	47	0.73
Breast Gland	6.41E+1	8.25E-1	1041	2960	0.33	150	2.32
Bronchi	4.74E+1	5.83E-1	1102	3306	0.46	238	3.69
Bronchi lumen	1.00E+0	0.00E+0	1	1003	0.03	0	0.00
Cartilage	4.92E+1	5.18E-1	1100	3568	0.49	35	0.54
Cerebellum	6.71E+1	9.02E-1	1045	3653	0.51	770	15.67
Cerebrospinal Fluid	7.68E+1	2.19E+0	1007	4096	0.57	0	0.00
Cervix	5.44E+1	7.75E-1	1105	3676	0.53	700	10.84
Commissura Anterior	4.71E+1	3.77E-1	1041	3583	0.48	212	4.32
Commissura Posterior	4.71E+1	3.77E-1	1041	3583	0.48	212	4.32
Connective Tissue	4.94E+1	5.16E-1	1027	2372	0.39	37	0.58
Diaphragm	6.02E+1	7.43E-1	1090	3421	0.49	99	2.44
Ductus Deferens	5.11E+1	5.09E-1	1102	3306	0.46	188	2.91
Dura	5.07E+1	7.77E-1	1174	3364	0.44	380	5.89
Epididymis	6.76E+1	9.58E-1	1082	3778	0.52	200	3.09
Esophagus	7.10E+1	9.40E-1	1040	3500	0.53	190	2.94
Esophagus Lumen	1.00E+0	0.00E+0	1	1003	0.03	0	0.00
Eye (Cornea)	6.53E+1	1.10E+0	1051	3615	0.54	0	0.00
Eye (Lens)	4.00E+1	3.32E-1	1076	3133	0.43	0	0.00
Eye (Sclera)	6.12E+1	9.45E-1	1032	4200	0.58	380	5.89
Eye (Vitrous Humor)	6.90E+1	1.51E+0	1005	4047	0.59	0	0.00
Eye Lens (Cortex)	5.05E+1	6.27E-1	1076	3133	0.43	0	0.00
Eye Lens (Nucleus)	4.00E+1	3.32E-1	1076	3133	0.43	0	0.00
Fat	1.20E+1	7.26E-2	911	2348	0.21	33	0.51
Fat (Average Infiltrated)	1.20E+1	7.26E-2	911	2348	0.21	33	0.51
Fat (Not Infiltrated)	5.74E+0	3.81E-2	911	2348	0.21	0	0.00
Gallbladder	6.70E+1	1.09E+0	1071	3716	0.52	30	0.46
Heart Lumen	6.85E+1	1.28E+0	1050	3617	0.52	10000	0.00
Heart Muscle	7.52E+1	8.33E-1	1081	3686	0.56	1026	39.45
Hippocampus	6.51E+1	6.39E-1	1045	3696	0.55	764	15.54
Hypophysis	6.41E+1	8.25E-1	1053	3687	0.51	885	13.71
Hypothalamus	6.41E+1	8.25E-1	1053	3687	0.51	885	18.01
Intervertebral Disc	4.84E+1	8.81E-1	1100	3568	0.49	35	0.54
Kidney	7.80E+1	9.35E-1	1066	3763	0.53	3795	18.05
Kidney (Cortex)	7.80E+1	9.35E-1	1049	3587	0.53	3874	18.43
Kidney (Medulla)	7.80E+1	9.35E-1	1044	3745	0.54	599	2.85
Large Intestine	6.95E+1	7.56E-1	1088	3655	0.54	765	11.85
Large Intestine Lumen	6.02E+1	7.43E-1	1045	3801	0.56	0	0.00
Larynx	4.92E+1	5.18E-1	1100	3568	0.49	35	0.54
Liver	5.77E+1	5.59E-1	1079	3540	0.52	860	9.93

Lung	2.66E+1	3.35E-1	394	3886	0.39	401	6.21
Lung (Deflated)	5.92E+1	6.10E-1	1050	3886	0.39	401	6.21
Lung (Inflated)	2.66E+1	3.35E-1	394	3886	0.39	401	6.21
Lymph	NAN	NAN	1019	0	0.00	0	0.00
Lymphnode	8.23E+1	6.18E-1	1035	3739	0.46	461	7.15
Mandible	1.39E+1	7.41E-2	1908	1313	0.32	10	0.15
Medulla Oblongata	6.71E+1	9.02E-1	1046	3630	0.51	559	11.37
Meniscus	4.92E+1	5.18E-1	1100	3568	0.49	35	0.54
Midbrain	6.71E+1	9.02E-1	1046	3630	0.51	559	11.37
Mucous Membrane	6.02E+1	7.43E-1	1102	3150	0.34	594	9.19
Muscle	6.02E+1	7.43E-1	1090	3421	0.49	37	0.91
Nerve	3.97E+1	3.85E-1	1075	3613	0.49	160	2.48
Ovary	6.83E+1	8.67E-1	1048	3778	0.52	236	3.65
Pancreas	6.41E+1	8.25E-1	1087	3164	0.51	767	11.89
Penis	5.11E+1	5.09E-1	1102	3306	0.46	12	0.19
Pharynx	1.00E+0	0.00E+0	1	1003	0.03	0	0.00
Pineal Body	6.41E+1	8.25E-1	1053	3687	0.51	885	13.71
Placenta	6.85E+1	1.28E+0	995	3807	0.52	1700	26.33
Pons	6.71E+1	9.02E-1	1046	3630	0.51	559	11.37
Prostate	6.76E+1	9.58E-1	1045	3760	0.51	394	6.10
SAT (Subcutaneous Fat)	1.20E+1	7.26E-2	911	2348	0.21	33	0.51
Salivary Gland	7.87E+1	7.00E-1	1048	3760	0.51	383	5.93
Seminal vesicle	6.76E+1	9.58E-1	1045	3760	0.51	394	6.10
Skin	5.57E+1	5.82E-1	1109	3391	0.37	106	1.65
Small Intestine	7.67E+1	1.77E+0	1030	3595	0.49	1026	15.89
Small Intestine Lumen	6.02E+1	7.43E-1	1045	3801	0.56	0	0.00
Spinal Cord	3.97E+1	3.85E-1	1075	3630	0.51	160	2.48
Spleen	7.27E+1	9.01E-1	1089	3596	0.53	1557	24.11
Stomach	7.10E+1	9.40E-1	1088	3690	0.53	460	7.13
Stomach Lumen	6.02E+1	7.43E-1	1045	3801	0.56	0	0.00
Tendon\Ligament	4.94E+1	5.16E-1	1142	3432	0.47	29	0.45
Testis	6.76E+1	9.58E-1	1082	3778	0.52	200	3.09

On the other hand, because of high volume and large number of meshes, model size has been estimated to 500mb in simulation. As a result, using 3DMAX software, number of meshes would be declined according to figure 9. Firstly, full body profile is selected in 3DMAX (select all). Then, the process is Modifiers->Mesh Editing->Optimize. Afterwards, numbers 10 and 20 would be placed instead of arrangement of Face Trash and Edge Trash. Also, with the order (Modifiers->Mesh Editing->ProOptimizer) and declining Vertex percent, again accuracy and volume of meshes can be declined. It should be noted that over decline of accuracy of model and meshes can result in interference of form and losing proper structure of organs. In addition, skin and skull would be declined with numbers 4 and 20 respectively for face trash and edge trash, since they are related to more organs and need higher accuracy. Organs and their names are illustrated in figure 10.

Simulation Results in CST

Here, as the antenna should be as much as possible close to body, it has been placed near the ear and horizontally. Clearly, the more the gain of antenna is, more SAR would be obtained in direction of gain or maximum pattern. Simulation results have been presented in figures 11 and 12.

In figures 13-22, simulation results in frequencies of 900 (MGH) for man and 1800 (MHZ) for woman have been presented. This time, simulation has been conducted with flat wave and at a distance of 2 meters from the front of person.

With the increase in frequency, energy intake in human body (man and woman) would be increased. The effect in body of woman under frequency of 1.8GHz in lungs is above risk border (1.8kg/w) and can also have negative effect on heart and is in risk border. In frequency of 2.45GHz, negative effect would be on eyes in range of 1kg/w. Effects are relatively same in frequencies of 1.8GHz and 2.45GHz. Moreover, radiations can have risk effect on penis under frequency of 1.8GHz and if a person is exposed to these radiations constantly, the risk effect would be existed on the brain, eyes, penis (if man), lungs and breast. Also, in frequency of 0.9GHz, it can have no effect on organs; especially no risk effect or in risk border.

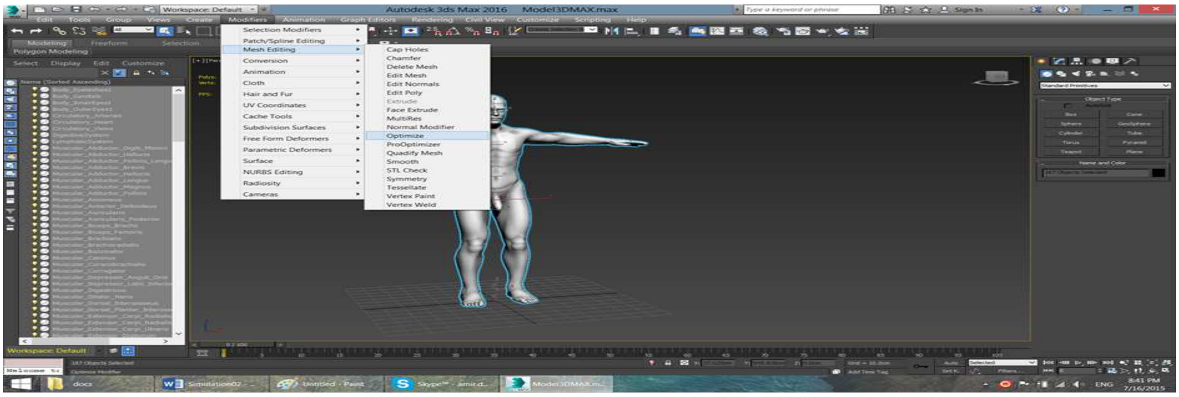

Figure 24: manner of declining number of meshes in 3DMAX

Figure 25: organs and their names simulated in CST

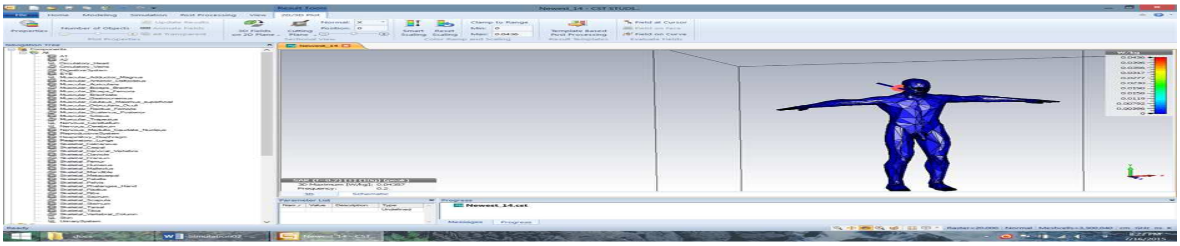

Figure 26: obtaining SAR in frequency of 200MHz, along with number and name of organs with bipolar antenna (as close as possible)

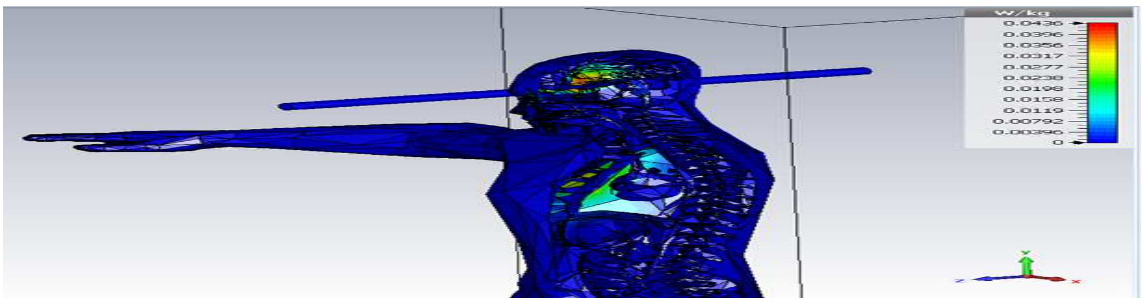

Figure 27: obtaining SAR in frequency of 200MHz with a cut of body, with bipolar antenna (as close as possible to body)

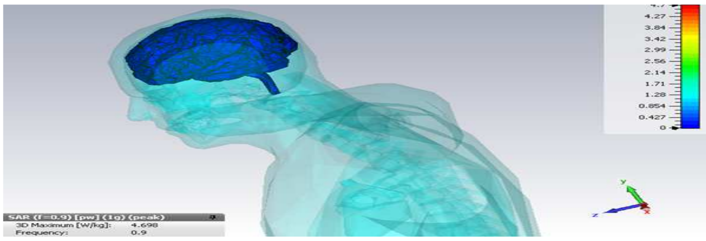

Figure 28: effect of radiation with frequency of 0.9GHz on human brain (man) in distance of 2 meter from source

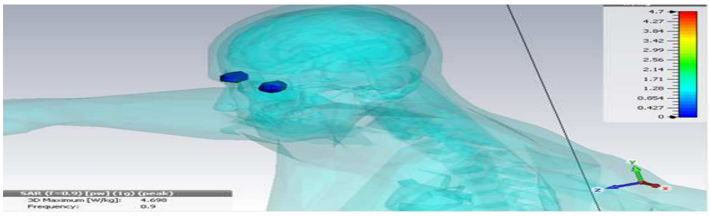

Figure 29: effect of radiation with frequency of 0.9GHz on human eyes (man) in distance of 2 meter from source

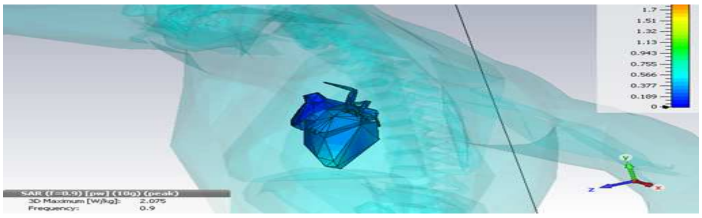

Figure 30: effect of radiation with frequency of 0.9GHz on human heart (man) in distance of 2 meter from source

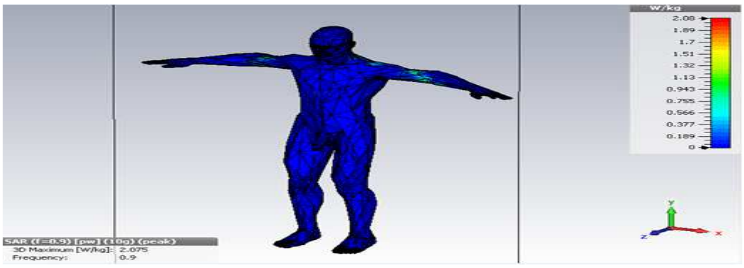

Figure 31: effect of radiation with frequency of 0.9GHz on human body (man) in distance of 2 meter from source

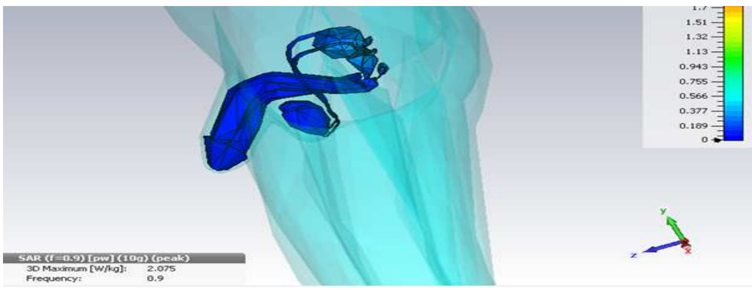

Figure 32: effect of radiation with frequency of 0.9GHz on human penis (man) in distance of 2 meter from source

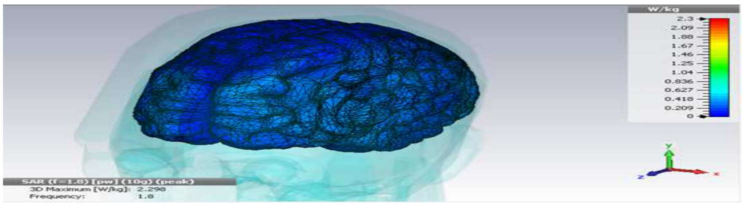

Figure 33: effect of radiation with frequency of 1.8 GHz on human brain (woman) in distance of 2 meter from source

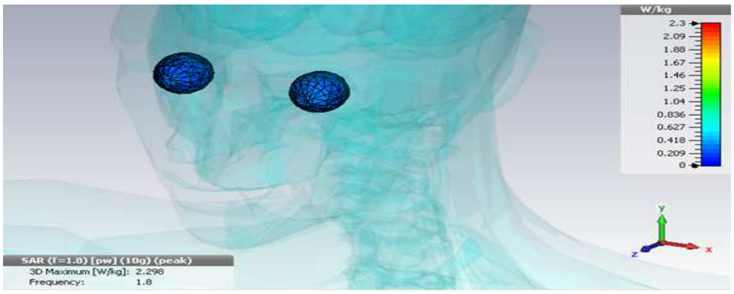

Figure 34: effect of radiation with frequency of 1.8 GHz on human eye (woman) in distance of 2 meter from source

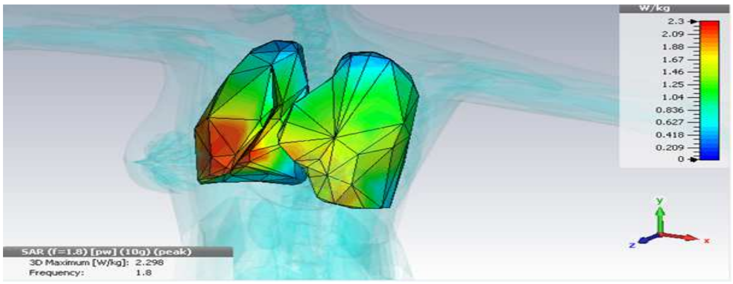

Figure 35: effect of radiation with frequency of 1.8 GHz on human lungs (woman) in distance of 2 meter from source

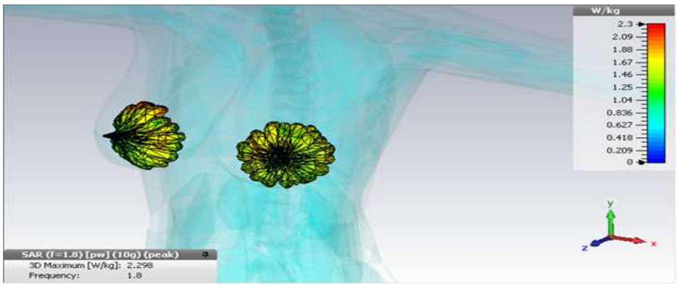

Figure 36: effect of radiation with frequency of 1.8 GHz on milk glands of woman in distance of 2 meter from source

Figure 37: effect of radiation with frequency of 1.8 GHz on female ovary in distance of 2 meter from source

CONCLUSION

In this study, the numerical and empirical techniques of SAR measurement have been discussed. The value has been obtained from previous studies in different frequencies and has been implemented and simulated for band frequency (30VHF to 300MHz) and mobile frequencies (900, 1800 and 2450 MHz) on man and woman. Moreover, conventional models and human body anatomy have been applied for evaluations. Simulations indicated that dependence parameters of SAR include distance of devise (mobile phone) from head; dielectric properties of tissue and human anatomy. As it is illustrated in figures, increase in frequency can result in increase in energy intake in human body (male and female). The effect in woman body is more than risk border in lungs in frequency of 1.8GHz (1.8 kg/w) and has also negative effect on heart and is in risk border. It has also bad effect on eyes in frequency of 2.45GHz and in range of 1kg/w.

Moreover, radiations can have risk effect on penis under frequency of 1.8GHz and if a person is exposed to these radiations constantly, the risk effect would be existed on the brain, eyes, penis (if man), lungs and breast.

Further studies:
In order to continue and expand the work, following works can be adopted:
- Simulation and Evaluation of SAR at higher frequencies including radar frequencies and the transmitter.
- Effects of simulated SAR and the child's body
- Identification and design of objects, materials or design specific structures and barriers to prevent adverse effects of SAR.
- Designing Sensors to alert SAR levels above the standard in household appliances, communications equipment, mobile and ordinary available parts.

Table 5: results of highest effects of radiation on woman and man body (distance of 2 meter from source)

organ	frequency	effect of woman's body	The maximum energy absorption in man	effect on man's body	The maximum energy absorption in woman
brain	0.9GHz	below risk border	0.3W/kg	below risk border	0.3W/kg
eyes	0.9GHz	below risk border	0.3W/kg	below risk border	0.3W/kg
penis	0.9GHz	below risk border	0.3W/kg	below risk border	0.3W/kg
breast	0.9GHz	below risk border	0.3W/kg	below risk border	1.4W/kg
heart	0.9GHz	below risk border	0.3W/kg	below risk border	0.8W/kg
overall effect	0.9GHz	risk on hands	0.3W/kg	below risk border	2W/kg
brain	1.8GHz	below risk border	1W/kg	below risk border	0.3W/kg
eyes	1.8GHz	below risk border	1.4W/kg	below risk border	0.3W/kg
penis	1.8GHz	on risk border	1.7W/kg	risk	1.5W/kg
breast	1.8GHz	on risk border	0.3W/kg	below risk border	1.5W/kg
heart	1.8GHz	below risk border	1.5W/kg	on risk border	1W/kg
overall effect	1.8GHz	below risk border	1.3W/kg	on risk border	1W/kg

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[42] K. S. Kunz and R. J. Luebbers, "The Finite Difference Time Domain Method for Electromagnetics," Boca Raton, FL: CRC Press, **1993**.

[i] The *CST Voxel Family* is a group of seven human model voxel data sets created from seven persons of different gender, age and stature. They are included in the CST STUDIO SUITE™ installation and can be imported using the Voxel Data Import, but need to be licensed additionally.