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Numerical Analysis of the Thermal Interaction of Cell Phone Radiation with Human Eye Tissues

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ABSTRACT

Introduction: The present study aimed to present a numerical analysis of the penetration depth, specific absorption rate (SAR), and temperature rise in various eye tissues with varying distance between radiation source and exposed human eye tissues (i.e., cornea, posterior chamber, anterior chamber, lens, sclera, vitreous humor, and iris) at frequencies of 900 and1800 MHz.

Materials and Methods: A theoretical model was proposed based on the tissue dielectric and thermal properties, Maxwell equations, Joules law of heating, and microscopic form of Ohm's law to find the realistic situation of the cell phone radiation interaction with various human eye tissues.

Results: According to the results, the anterior chamber had the highest temperature rise, compared to the vitreous, sclera, lens, cornea, and posterior chamber. By assuming the distance of 5 cm and exposure time of 30 min, the maximum rise in temperature for the anterior chamber was estimated to be 1.2°C and 2.2°C for 900 and 1,800 MHz frequencies, respectively.

Conclusion: As the findings indicated, the anterior chamber had the maximum rise in temperature, compared to other investigated tissues. This could be due to the disposal of excess heat by the perfusion of the blood in the vitreous, posterior chamber, sclera, and lens tissues and the cooling effects produced due to convection/conduction in the cornea tissue. However, the anterior chamber tissue had no such mechanism for heat disposal.

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Introduction

The absorption of electromagnetic radiations emitted from mobile phones by human tissues can result in the enhancement of the exposed tissue temperature, which is referred to as thermal effects [1]. Thermal effects are dependent upon the water content inside the tissue. The rate of absorption has been found to be higher in the tissues containing high water content as compared to those encompassing low water content [2].

Eye is one of the sensitive tissues, which contains maximum water content called aqueous humor. Therefore, the chance of radiation absorption by eye tissues are higher, compared to other human tissues. Studies available in the literature confirm the sensitivity of eye tissues towards cell phone radiations. A temperature enhancement of 3-5°C has been reported in the studies investigating the cataract formation in human and rabbit eyes [3-6]. The particular sensitivity of eye tissue is due to its high relative permittivity, non-vascularity, and limited capacity of heat dissipation [7]. Relative permittivity contributes to radiation absorption through specific absorption rate (SAR).

However, to the best of our knowledge, there is no study investigating the permittivity parameter to calculate temperature rise in the eye tissue. Regarding this, the aim of the present study was to establish a relationship between temperature enhancement and specific absorption rate by taking into consideration the permittivity parameter. In addition, the behavior of SAR by varying distance and exposure time was also studied for two different frequencies of 900 and 1800 MHz.

Materials and Methods

Figure 1 illustrates the electromagnetic field radiations from a radio frequency source kept at '*r*' distance from a human eye. Due to ethical consideration, the direct calculation of direct exposure and concerned consequences was not possible. Therefore, we opted for numerical analysis. The numerical analysis included a two-dimensional eye model comprising of cornea, anterior chamber, posterior chamber, iris, sclera, lens, and vitreous tissues (Figure 1).

Each tissue has its own thermal characteristic and dielectric properties (Table 1).

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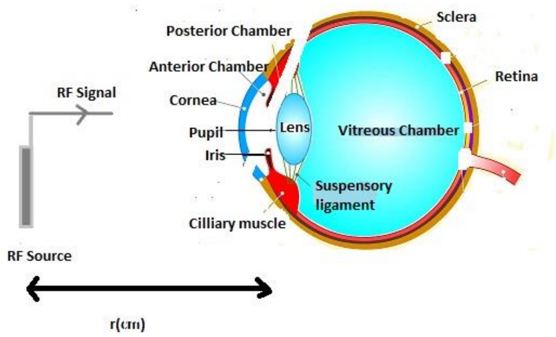

Figure 1. Anatomy of human eye

Table 1. Dielectric and thermal properties of human eye tissue [8]

Tissue	Cornea	Anterior chamber	Lens	Posterior chamber	Vitreous	Sclera	Iris
Specific heat (J/°C.Kg)	3997	3997	4178	4178	3180	3180	3000
Mass density (Kg/m^3)	1050	996	1000	996	1100	1050	1050
Permittivity ϵ_r (900 MHz)	52	73	51.3	73	74.3	52.1	52.1
Permittivity ϵ_r (1800 MHz)	55	75	41.1	75	73.7	52.7	52.7
Conductivity σ (s/m) (900 MHz)	1.85	1.97	0.89	1.97	1.97	1.22	1.22
Conductivity σ (s/m)(1800 MHz)	2.32	2.4	1.29	2.4	2.33	1.68	1.68

However, for simplification purposes, each tissue was assumed to be isotropic and homogeneous. The electromagnetic wave propagation in different tissues was calculated using the following equation [9]:

$$\frac{P}{4\pi r^2} = \frac{1}{2}\varepsilon_0 E^2 c \quad (1)$$

where ε_0 is the permittivity of free space, *E* is the electric field in air at '*r*' distance from cell phone radiation electromagnetic energy at *P* power.

Mobile phone handset generally radiates 1-2 W of power. Therefore, the power of the mobile phone for the present study was taken as 1 W. Substituting standard value of ε_o, P and c, Equation 1 can be written as:

$$E=7.746/r \quad (2)$$

Specific absorption rate facilitates the calculation of the penetration depth of electromagnetic radiation in the human body tissue. This parameter can be estimated using the Equation 3 presented as follows [10, 11]:

$$SAR = (\frac{\sigma + \omega\varepsilon_O\varepsilon_r}{\rho})E^2 \quad (3)$$

where σ represents the conductivity of biological tissue, ω displays angular frequency, ϵ_0 is the permittivity of the biological tissue, ϵ_r indicates relative permittivity of biological tissue, E^2 is induced electric field, and ρ is the density of biological tissue.

In the present study, the relationship between SAR and temperature rise was established using the following equations:

Microscopic form of ohm's law is represented by the following equation:

$$J=\sigma E \quad (4)$$

where *j* is current density (A/m^2), *σ* is conductivity (S/m), and *E* is electric field (V/m)

$$dQ= I^2 r\ dt \quad (5)$$

where *dQ* is the amount of heat generated (i.e., thermal energy when current, *I*, due to magnetic field is passing through a resistance, *r*, for *dT* time).

$$dQ=\frac{\rho\ V\ C\ dT}{\sigma + \omega\ \epsilon_O\ \epsilon_r} \quad (6)$$

Based on the above equation, the relation between SAR and thermal distribution in tissue for a period of *dt* is obtained as:

$$SAR=C.\frac{dT}{dt} \quad (7)$$

Results

The calculated SARs inside the human eye tissues exposed to the electromagnetic frequencies of 900 and 1800 MHz are displayed in Figure 2.

According to Figure 2, SAR values strongly depend on electromagnetic frequency. The SAR values were reported to be higher for 1800 MHz frequency in comparison with those for 900 MHz frequency. In addition to frequency, these values were also affected by dielectric properties, such as conductivity, relative permittivity, and linear mass density. The posterior and anterior chamber tissues had the highest SAR, while the lens tissue had the lowest SAR.

The SARs for the posterior and anterior chamber were 135.4 and 238.5 W/kg at 900 and 1800 MHz, respectively, when the phone was held at 5 cm. These rates were 82.9 and 129.6 W/Kg for the lens at the two mentioned frequencies and under the same condition (Figure 2). For the posterior and anterior chamber, relative permittivity and conductivity values were greater than those of the lens tissue; however, the order was reversed due to linear mass density. Furthermore, when the distance from the phone increased from 5 to 20 cm, SAR value was decreased by 94%.

The increase in the temperature of various eye tissues was calculated using Equation 3 and specific heat value of the investigated tissues that are mentioned in Table 1. The results are tabulated in tables 2, 3, and 4.

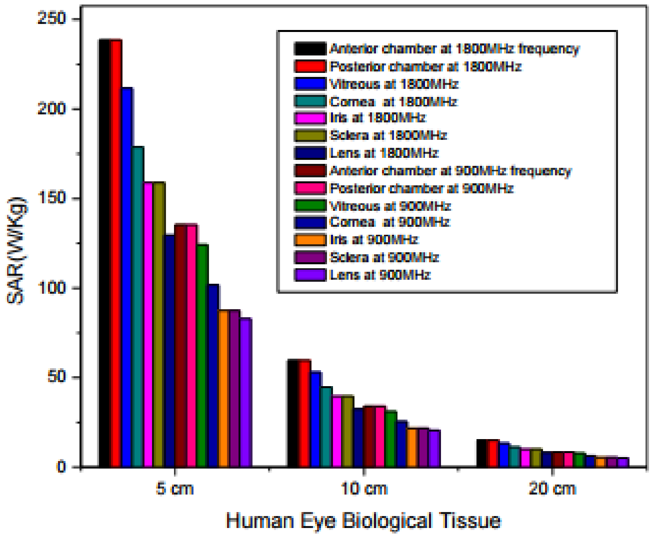

Figure 2. Comparisons of specific absorption rate with varying distance between the source of radiation and exposed human eye tissues (i.e., cornea, posterior chamber, anterior chamber, lens, sclera, vitreous humor, and Iris) for frequencies of 900 and 1800 MHz, respectively.

Table 2. Rise in temperature (°C) in various eye tissues by varying distance (cm) between cell phone device and eye at frequencies of 900 and 1800 MHz with exposure duration of 6 minutes

(a) When exposed to 900 MHz

Distance from cellphone (cm)	Rise in tissue temperature (°C) in various eye tissues						
	Anterior chamber	Posterior chamber	Vitreous	Lens	Iris	Sclera	Cornea
5	0.25	0.19	0.23	0.12	0.17	0.16	0.15
10	0.06	0.05	0.06	0.03	0.04	0.04	0.04
20	0.01	0.01	0.01	0.01	0.01	0.01	0.01

(b) When exposed to 1800 MHz

Distance from cellphone (cm)	Rise in tissue temperature (°C) in various eye tissues						
	Anterior chamber	Posterior chamber	Vitreous	Lens	Iris	Sclera	Cornea
5	0.45	0.34	0.39	0.19	0.32	0.29	0.27
10	0.11	0.08	0.09	0.05	0.08	0.07	0.07
20	0.02	0.03	0.02	0.01	0.02	0.02	0.02

Table 3. Rise in temperature (°C) inside various eye tissues by varying distance (cm) between cell phone and eye at frequencies of 900 and 1800 MHz with exposure duration of 10 minutes

(a) When exposed to 900 MHz

Distance from cell phone (cm)	Rise in tissue temperature (°C) in various eye tissues						
	Anterior chamber	Posterior chamber	Vitreous	Lens	Iris	Sclera	Cornea
5	0.42	0.32	0.39	0.19	0.29	0.27	0.25
10	0.11	0.08	0.09	0.05	0.07	0.07	0.06
20	0.03	0.02	0.02	0.01	0.02	0.02	0.01

(b) When exposed to 1800 MHz

Distance from cell phone (cm)	Rise in tissue temperature (°C) in various eye tissues						
	Anterior chamber	Posterior chamber	Vitreous	Lens	Iris	Sclera	Cornea
5	0.75	0.57	0.66	0.31	0.53	0.49	0.45
10	0.19	0.14	0.17	0.08	0.13	0.12	0.11
20	0.05	0.03	0.04	0.02	0.03	0.03	0.02

Table 4. Rise in temperature (°C) inside various eye tissues by varying distance (cm) between cell phone and eye at frequency 900 and 1800 MHz with exposure duration of 30 minutes

(a) When exposed to 900 MHz

Distance from cell phone (cm)	Rise in tissue temperature (°C) in various eye tissues						
	Anterior chamber	Posterior chamber	Vitreous	Lens	Iris	Sclera	Cornea
5	1.28	0.97	1.17	0.59	0.87	0.82	0.76
10	0.32	0.24	0.29	0.15	0.22	0.21	0.19
20	0.08	0.06	0.07	0.04	0.05	0.05	0.05

(b) When exposed to 1800 MHz

Distance from cell phone (cm)	Rise in tissue temperature (°C) in various eye tissues						
	Anterior chamber	Posterior chamber	Vitreous	Lens	Iris	Sclera	Cornea
5	2.25	1.71	1.99	0.93	1.59	1.49	1.34
10	0.56	0.43	0.49	0.23	0.39	0.37	0.33
20	0.14	0.11	0.12	0.06	0.09	0.09	0.08

Discussion

The electromagnetic waves from the radio frequency source enter into the human eye and induce thermal effects in the eye tissue. Such thermal effects can hamper the normal function of the concerned exposed tissue, and thereby lead to tissue damage and cataract formation. There are several studies indicating the adverse effects of cell phone radiations on human eye. These studies performed heat transfer analysis based on conduction model and bioheat equation based on heat diffusion mechanism and porous media model [12-14].

Such studies mainly focused on SAR for the analysis of the interaction mechanism between electromagnetic radiation exposure and eye tissue. However, despite the contribution of permittivity parameter to radiation absorption through SAR, this parameter has remained under investigated. Consequently, the present study aimed to investigate the relation between temperature rise and specific absorption rate based on the relative permittivity.

During the operational mode, people generally keep their cell phones close to the eyes and ears. As a result, the eye and ear can be considered as the transmission towers, which transmit the electric field inside the human body. However, this induced electric field does not depend on the frequencies of the radiated electromagnetic waves. The penetration of these waves in the tissue depends upon the frequency of the electromagnetic wave.

Therefore, in the present study, we evaluated SAR distribution and the corresponding temperature increase in the human eye tissues for different GSM frequencies (i.e., 900 and 1800 MHz). Temperature rise was calculated by taking two variable parameters, namely distance and exposure time. The difference in temperature distribution pattern amongst different eye tissues can be attributed to the difference in dielectric and thermal properties of the given tissue and also the induced electric field inside the eye tissue.

Radiations penetrate into the eye tissue through cornea tissue. Accordingly, cornea tissue is expected to have the highest temperature increase. However, the maximum enhancement of temperature was found in the anterior chamber instead of cornea. This might be due to the fact that excess heat generated in the cornea gets disposed via convection and radiation. The second main reason is the permittivity and conductivity values of cornea, which are lower than those of the anterior chamber.

Although vitreous tissue had a higher permittivity value, it had a lower temperature rise as compared to the anterior chamber. This is due to the presence of blood perfusion in the sclera tissue, which disposes off the excess heat from the vitreous tissue and produces a cooling effect. As indicated in tables 2, 3, and 4, the exposure time significantly affected the rise in temperature. A longer exposure time means large heat accumulation inside the tissue, and thereby higher temperature increase in the concerned tissue. It has been reported that when the exposure time increase from 6 to 30 min, the corresponding temperature of the given tissue rises up to 82.9%.

Conclusion

As the findings indicated, SAR distribution and corresponding temperature increase in human tissues depends upon various parameters, such as dielectric properties, thermal properties, blood perfusion rate, and penetration depth of the electromagnetic radiations. Therefore, the achievement of a better understanding of the realistic situation of the interaction between the electromagnetic fields and the eye requires the implementation of more in-depth studies on these parameters in the future. However, safety precautions can be taken by keeping mobile phone at the minimum distance of 20 cm from the human body and using speaker or hands free for long phone calls.

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