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Evaluation of Microwave Microdosimetry for Human Eyes with Glasses Exposed to Wireless Eyewear Devices at Phone Call State

Junqing Lan[1], Tao Hong[2], Xiao Liang[1], and Guohong Du[1, *]

Abstract—This paper evaluates the effect of glasses on the Specific Absorption Rate (SAR) and the absorbed power in the human head exposed to microwave from wireless eyewear device at phone call state. Due to the sensitivity of eyes to microwave, this paper mainly concentrates on the SAR and the absorbed power in ocular tissues. The calculated results indicate that wearing glasses can obviously increase the maximal SAR and the absorbed power in ocular tissues. Glasses has almost doubled the maximal SAR in ocular tissues. The absorbed power with glasses is about 3.1–4.5 times as big as that without glasses. Furthermore, we find that the maximal SAR and absorbed power are sensitive to the width of glass leg and the thickness of spectacle lens, while variation trends with the varying glasses size are quite different. Hypermyopia patient might suffer from higher risk of getting the oculopathy due to the larger SAR caused by the thicker spectacle lens. In conclusion, wearing glasses may pose higher health risk on eyes of wireless eyewear device user. This paper would provide valuable reference data for the future evaluation of microwave biological effect on eyes.

1. INTRODUCTION

In recent years, there has been increasing interest in wireless eyewear devices. Although these devices, currently, are just limited to wireless Bluetooth or WiFi connection with relatively lower radiation power, there is clearly a requirement for connecting to the cellular network [1]. Moreover, the radiation antenna of eyewear device is very close to the human head. Therefore, it is necessary to evaluate the possible health hazards of wireless eyewear device to the human head [2].

SAR is the common criteria for evaluating the energy absorption of biological tissue to electromagnetic fields. It is defined as the absorption rate of RF power per unit mass (W/kg) and could be obtained by [3]:

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

where $\vec{E}$ is the peak value of the electric fields strength vector (V/m). σ is the conductivity in S/m. ρ is the density in kg/m^3. Many valuable studies [2, 4–31] have been done to evaluate the SAR in the biological body caused by the wireless communication device. The results showed that SAR could be influenced by many factors including dielectric properties and size of biological tissues, electromagnetic field (radiation frequency, field source, near- or far-field pattern), exposure environment, etc.

Some of them [2, 10–16] found that the adjacent metallic object (implants, jewelry, spectacles, etc.) close to the antenna might greatly modify the SAR distributions within the human body. For instance, Copper and Hombach [10] found that the SAR for 1 g could be doubled due to the influence of metallic

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* Corresponding author: Guohong Du (jqlan@cuit.edu.cn).
[1] Chengdu University of Information Technology, Chengdu 610225, China. [2] China West Normal University, Nanchong 637002, China.

implants of resonant size in the human head. Whittow et al. [11] found that when people wear metallic jewelry of resonant size, the maximal SAR in the human head might be several times larger than that without wearing the jewelry. Stergiou et al. [12] evaluated the variation of SAR in human head upset by the metallic spectacles and found that metallic spectacles could significantly change the SAR level in the human head. Troulis et al. [13] evaluated the effects of thin metallic spectacles which could significantly alter the distribution of electromagnetic energy within the human head. Our previous researches [14] have found that the maximal SAR in ocular tissues with glasses is even eight times more than that without glasses when using the mobile phone. Among them, metallic spectacles are the most widely used and might pose a higher health risk to human body [32].

In addition, the safety standards such as IEEE C95.1:2005 [33] standards and ICNIRP [34] standard have been established to protect human health from the microwave exposures, but the doubts to their reliability still exist. This is because the present safety standards only use a peak value of the SAR to act as the safety standards for the extremely complicated biological effect of microwave. Especially, the situation of non-thermal effect of bio-microwave is insufficient. Therefore, it is highly recommended that more exposure parameters should be included in the future researches. For instance, World Health Organization [17] has taken the low-level energy absorption as one of the primary research topics of possible adverse health effects of electromagnetic fields. Dovrat et al. [18] also believe that the energy absorbed in the tissue should be paid more attention in determining the safety standards because SAR lower than the safety standard limit may also lead to the similar effect caused be the SAR higher than the safety standard.

Based on the above reasons, this paper evaluates the relative effects of metallic frame glasses on the SAR and the absorbed power in the human body under microwave exposure from wireless eyewear device at phone call state. We will mainly focus on the eyes due to its sensitivity to electromagnetic fields [18–22]. This is because eyes are close to the antenna and directly exposed to the microwave without the protection of skin and fat. Furthermore, eyes have less blood flow which could not take the heat induced by microwave timely [20]. Thirdly, ocular tissues except the cornea do not have self-renewal ability, which could never grow back once hurt by the microwave [18, 21, 22]. A three-dimensional anatomically-based human head CAD model and a pair of metallic frame glasses will be established based on the Finite Different Time Domain (FDTD) method. This head model consists of skin, fat, brain and eyes which are made of eight types of ocular tissues. A printed coupling element (CE) antenna is used as the eyewear device, which covers 0.75–0.93 GHz with a -6 dB S_{11}. The sub-gridding method is employed to improve the computational accuracy. The calculation results will provide valuable reference data for the future evaluation of microwave biological effect on eyes.

2. CALCULATION MODELS

2.1. Head Model

Compared with the traditional Visible Human Project (VHP) or Magnetic Resonance Imaging (MRI) models, the CAD model can provide a higher resolution [23]. Hence this paper establishes a three-dimensional anatomically-based human head CAD model which consists of skin, fat, brain and elaborate

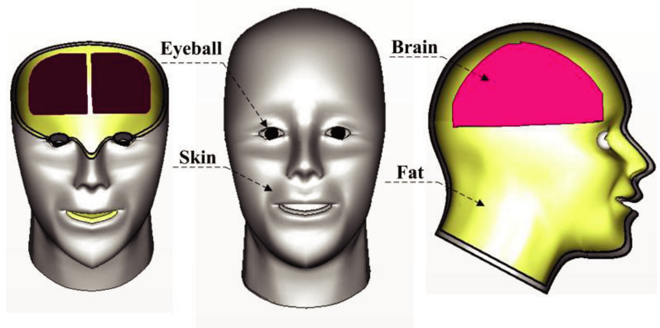

Figure 1. Human head model.

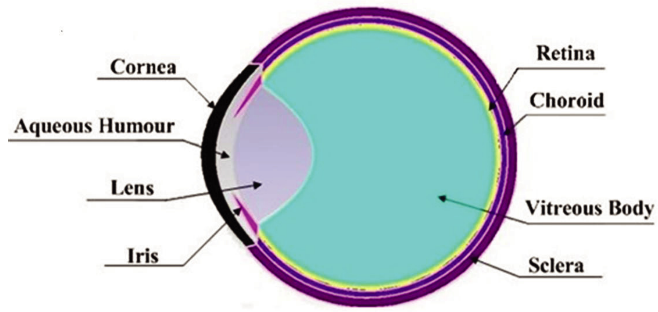

Figure 2. Cross-section of eyeball.

eyeballs (shown in Fig. 1). Fig. 2 is a two-dimensional (2D) cross-section of an eyeball. It comprises eight types of ocular tissues. In order to precisely model the configuration of eyes which comprise ultra-thin millimetre-scale membrane structures, a resolution of 0.2 mm is proposed. Table 1 [24–31, 35] presents the dielectric properties at 0.915 GHz and densities assigned to different biological materials for the following calculation. ε_r and σ represent the relative dielectric constant and conductivity, respectively.

Table 1. The dielectric properties and densities of biological materials in the human head at 0.915 GHz.

Biomaterial	ε_r	σ(S/m)	ρ(kg/m^3)
Cornea	51.5	1.9	1050
Iris	55	1.18	1040
Air	1	0	0.0016
Skin	45	0.97	1100
Choroid	55	2.3	1000
Lens	44	0.8	1150
Sclera	51	1.13	1020
Aqucous Humor	74	1.97	1010
Vitreous Body	67	1.68	1030
Retina	57	1.17	1000
Fat	15	0.35	920

2.2. Glasses Model

The glasses model used in this paper is shown in Fig. 3. Compared with the previous study [2] that only evaluate the single frame, this model consists of spectacle frame, spectacle lens and nose pad. W_1 and W_2 represent the widths of frame. The thickness of frame is 1 mm. W_3 is the thickness of spectacle lens. Glass ($\varepsilon_r = 4.82$, $\sigma = 0.0054$ S/m) and Polyimide ($\varepsilon_r = 3.5$, $\sigma = 0.03$ S/m) are used as the materials of spectacle lens and nose pad, respectively. Spectacle frames are usually made of different types of materials, and the major categories are plastic and metal. Plastic frame can be made into different colors and patterns, but it would shift and lose its form with daily use. By comparison, metal material has many advantages. For instance, Monel can be forged into different shapes without losing strength due to its high ductility. Copper has good corrosion-resistance. Titanium is extremely lightweight. Hence metallic material is more suitable for eyewear device because the spectacle frame is usually used to support the printed circuit board of the eyewear device. This paper will mainly focus on the metallic frame.

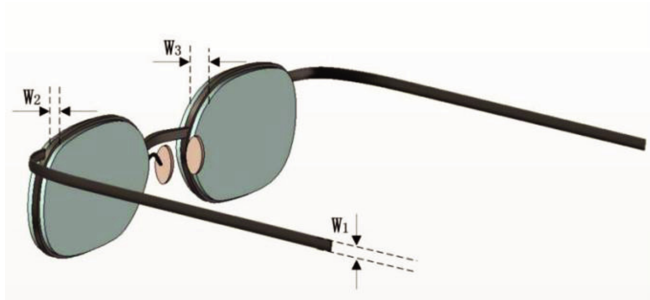

Figure 3. Model of glasses.

2.3. Antenna Model

A printed coupling element antenna designed for eyewear device [1, 2] is used in this paper. As shown in Fig. 4, the coupling element lies on one side of the FR4 printed circuit board, which is close to the eyes. The ground plane is printed on the other side of the board. A three-element matching network which consists of two series inductors and a shunt capacitor is used to feed the antenna. By adjusting the matching network, the antenna can be transformed into the desired operating band. The S_{11} of the antenna with head model (shown in Fig. 5) is displayed in Fig. 6, which covers 0.75–0.93 GHz with a -6 dB S_{11}. The input power is 0.125 W since a GSM terminal only transmits for one-eighth of the time.

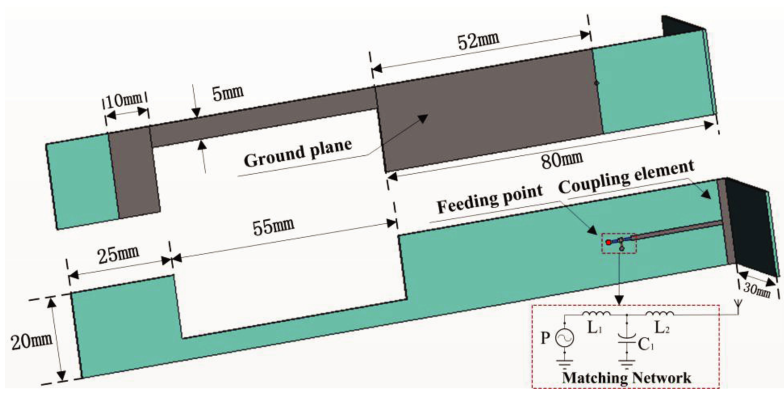

Figure 4. Antenna model for eyewear device.

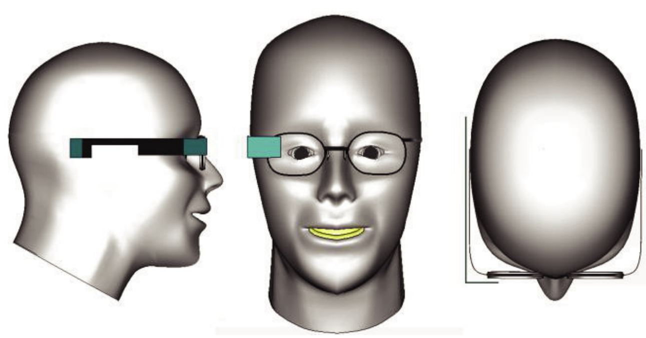

Figure 5. Model of phone call state with glasses.

3. CALCULATION RESULTS AND DISCUSSION

According to the FDTD algorithm [36–38], the whole computational space is divided by regular hexahedron grids. The size of the background grid is 2 mm. In order to obtain the finer resolution

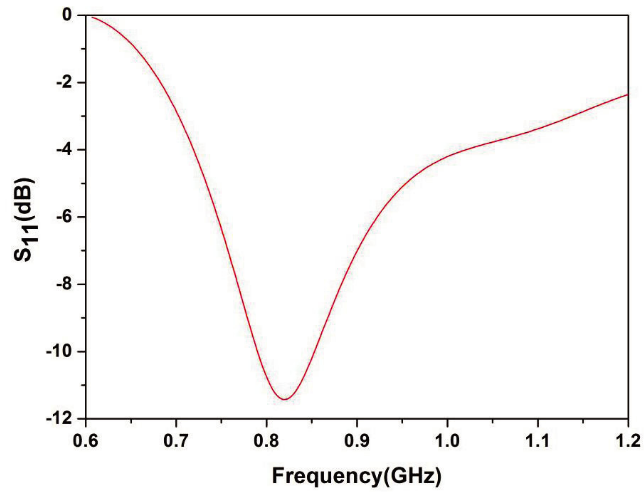

Figure 6. S_{11} of the antenna with head model ($L_1 = 9.5\,\mathrm{nH}$, $L_2 = 11\,\mathrm{nH}$, $C_1 = 0.95\,\mathrm{PF}$).

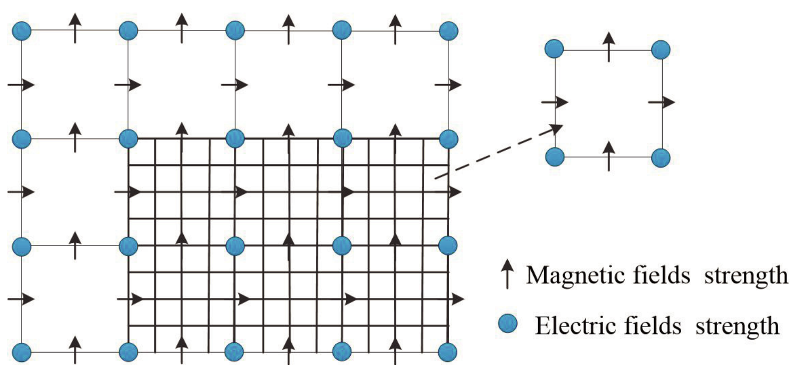

Figure 7. Sub-gridding method.

in the eyeball, the sub-gridding method is employed. As shown in Fig. 7, the sub-gridding method can inset denser uniform grids into a bigger grid. The local uniformity of the grids is crucial to keep the same stability criterion in the process of the simulation. The FDTD algorithm is also employed in the sub-gridding areas. This paper uses the grids of 0.2 and 0.5 mm to represent the eyes and other parts of the simulation model, respectively. The sub-gridding method greatly contributes to the precision of the calculated results despite that it increases the cost of calculation. The uniaxial perfectly matched layer boundary condition is used to truncate the computational domain.

The SAR for 1 g is calculated by adding the contributions of several Yee's grids to 1 g around the cube of the maximum SAR. In this paper, all SAR refers to the SAR for 1 g.

The absorbed power per ocular tissue is calculated by:

$$P = \tan(\delta)\varepsilon_0\varepsilon_r\pi f \int \left|\vec{E}\right|^2 dV \tag{2}$$

where P is the absorbed power. ε_r and ε_0 (F/m) represent the relative dielectric constant of the ocular tissue and the dielectric constant of the vacuum. $\tan(\delta)$ is the loss tangent.

Firstly, we evaluate the influence of three types of metallic frame materials on the maximal SAR and the absorbed power in ocular tissues. The conductivities of these materials (Copper, Monel and Titanium) are 5.8×10^7 S/m, 1.97×10^7 S/m and 1.80×10^6 S/m, respectively. Table 2 shows that both the maximal SAR and the absorbed power decrease with the increment of conductivity, while the maximal variation range is very small. The maximal variation of the maximal SAR and the absorbed power are only about 1.5% and 0.85%. The calculation results show that the conductivity of metallic

Table 2. The maximal SAR and the absorbed power in the ocular tissues at 0.915 GHz when people wear different kinds of metal material frame.

	The maximal SAR (W/kg)			Absorbed power (dBm)		
	Copper	Monel	Titanium	Copper	Monel	Titanium
Vitreous Body	1.21	1.20	1.19	−6.12	−6.17	−6.17
Aqueous humor	1.09	1.09	1.09	−23.09	−23.10	−23.11
Sclera	1.57	1.56	1.56	−10.23	−10.24	−10.26
Iris	0.81	0.80	0.80	−25.09	−25.16	−25.18
Cornea	1.18	1.18	1.17	−15.18	−15.32	−15.74
Lens	0.78	0.78	0.77	−17.82	−17.90	−17.92
Choroid	1.38	1.38	1.36	−15.58	−15.63	−15.64
Retina	1.31	1.30	1.29	−19.33	−19.34	−19.37

frame material has almost no influence on the maximal SAR and absorbed power. Therefore, this paper chooses Copper to act as the material of spectacle frame.

Secondly, this paper evaluates the SAR and absorbed power in the human head when people do and do not wear glasses. Fig. 8 and Fig. 9 depict the SAR distribution in the entire head and eyeballs, respectively. Calculated results indicate that wearing glasses greatly alters the magnitude and distribution of SAR in the head and eyes. This is due to the influence of secondary currents on the glasses caused by the primary sources. The maximum SAR in the human head with glasses is approximately 3.5 times as large as that without glasses. Fig. 10 and Fig. 11 show the maximal SAR and absorbed power in ocular tissues when people do and do not wear glasses. Results show that wearing glasses can increase the maximal SAR and absorbed power. To be more specific, the maximal SAR with glasses is about twice of that without glasses. The absorbed power is increased to 3.1 to 4.5 times when people wear glasses. It can be inferred from the above results that wearing glasses may possibly pose potential health risk on eyes when people use the wireless eyewear device.

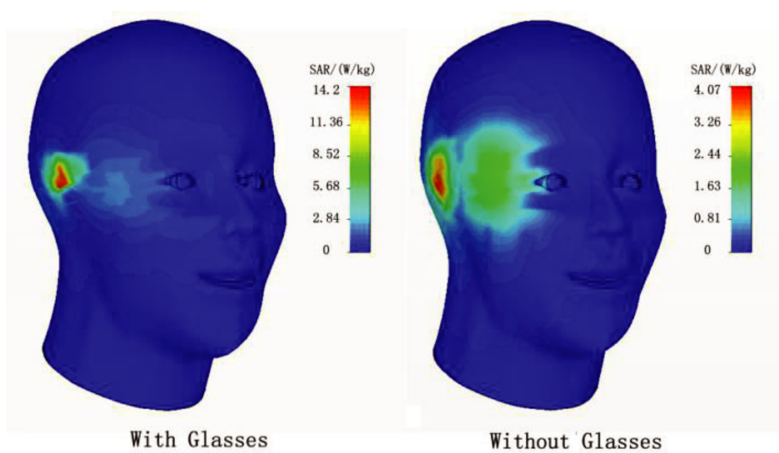

Figure 8. Distributions of the SAR in human head at 0.915 GHz.

Finally, we evaluate the effects of frame widths and thickness of spectacle lens on the maximal SAR and the absorbed power in ocular tissues. Table 3 shows that the maximal SAR decreases with the increments of $W1$, and the largest decrements has reached 12.7%. The maximal SAR, by contrast, increases with the increment of $W2$ and $W3$ except the situation in the lens which first increases and then decreases with increasing $W2$. The largest increments in both situations are 2.7% and 13.0%. The results presented in Table 4 show that the absorbed power increases with the increment of $W1$, and

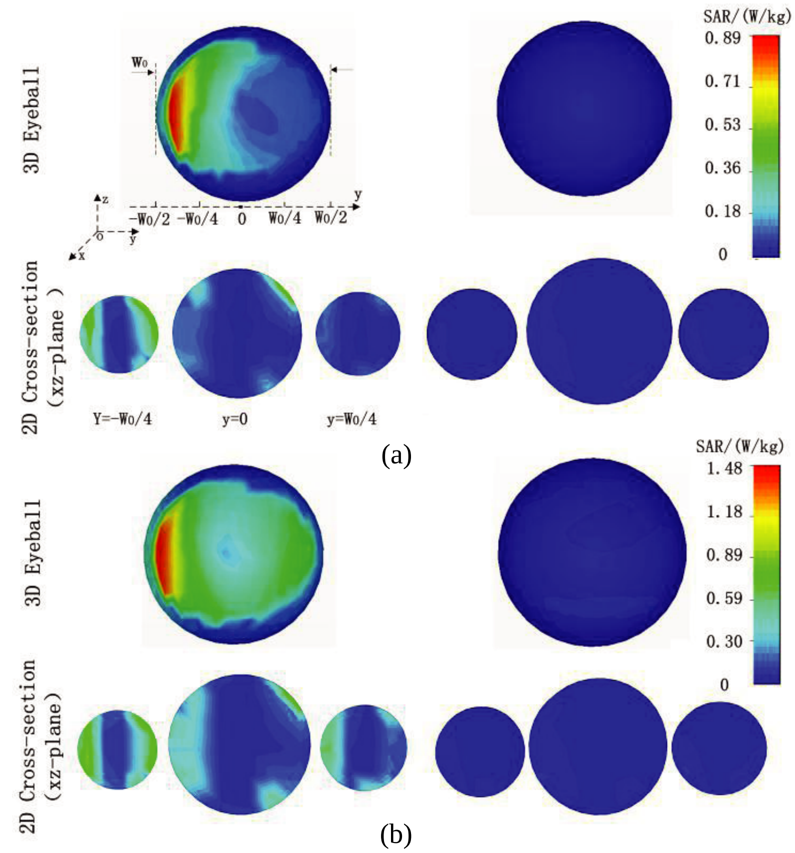

Figure 9. Distributions of the SAR in the eyeballs at 0.915 GHz. (a) Without glasses. (b) With glasses.

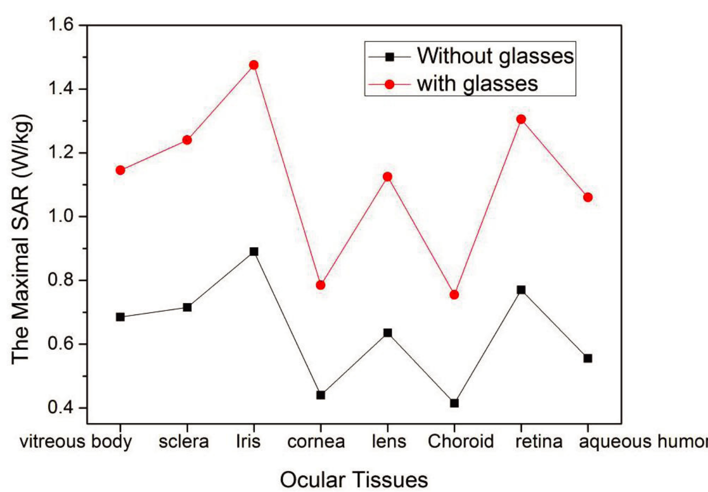

Figure 10. The maximal SAR in the ocular tissues at 0.915 GHz.

the largest increments are approximate 9.6%. With the increments of $W2$, the absorbed powers in the aqueous humor, iris and cornea increase gradually; however, that in other ocular tissues first decreases and then increases. The largest variation has reached 2.8%. The absorbed power first decreases and then increases with increasing $W3$. The largest variation is about 18.3%. From the results of Table 3 and Table 4, it can be concluded that the magnitudes of the maximal SAR and absorbed power are

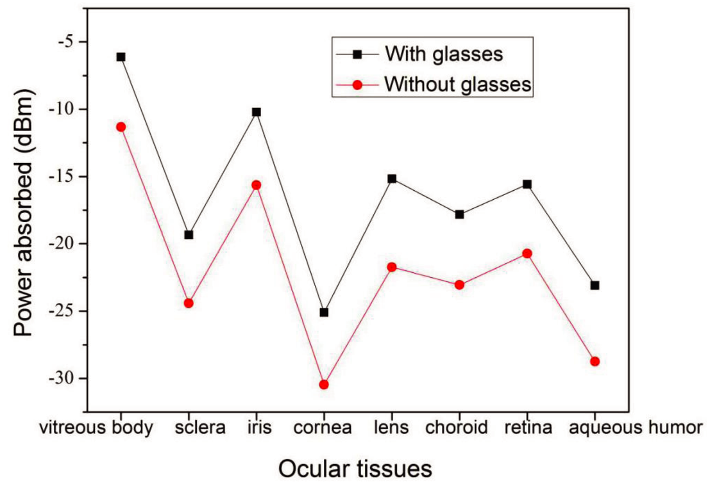

Figure 11. The absorbed power in the ocular tissues at 0.915 GHz.

Table 3. The maximal SAR in the ocular tissues at 0.915 GHz when people wear glasses with different widths of frame and thicknesses of spectacle lens.

	$W2 = 2$ mm, $W3 = 3$ mm			$W1 = 4$ mm, $W3 = 3$ mm			$W1 = 4$ mm, $W2 = 2$ mm		
	$W1$			$W2$			$W3$		
	2 mm	4 mm	6 mm	1 mm	2 mm	3 mm	3 mm	6 mm	9 mm
Vitreous Body	1.21	1.15	1.08	1.13	1.15	1.16	1.15	1.25	1.30
Aqueous humor	1.09	1.06	0.96	1.05	1.06	1.06	1.06	1.14	1.16
Sclera	1.57	1.48	1.38	1.46	1.48	1.50	1.48	1.62	1.68
Iris	0.81	0.79	0.77	0.77	0.79	0.79	0.79	0.85	0.87
Cornea	1.18	1.13	1.03	1.11	1.13	1.13	1.13	1.22	1.25
Lens	0.78	0.76	0.74	0.74	0.76	0.75	0.76	0.81	0.83
Choroid	1.38	1.31	1.22	1.29	1.31	1.32	1.31	1.43	1.47
Retina	1.31	1.24	1.17	1.23	1.24	1.26	1.24	1.36	1.40

Table 4. The absorbed power (dBm) in the ocular tissues at 0.915 GHz when people when people wear glasses with different widths of frame and thicknesses of spectacle lens.

	$W2 = 2$ mm, $W3 = 3$ mm			$W1 = 4$ mm, $W3 = 3$ mm			$W1 = 4$ mm, $W2 = 2$ mm		
	$W1$			$W2$			$W3$		
	2 mm	4 mm	6 mm	1 mm	2 mm	3 mm	3 mm	6 mm	9 mm
Vitreous Body	−6.12	−5.85	−5.79	−5.74	−5.85	−5.76	−5.85	−6.17	−5.58
Aqucous humor	−23.09	−22.75	−22.72	−22.77	−22.75	−22.68	−22.75	−23.27	−22.69
Sclrea	−10.23	−9.92	−9.86	−9.85	−9.92	−9.89	−9.92	−10.29	−9.71
Iris	−25.09	−24.77	−24.76	−24.79	−24.77	−24.69	−24.77	−25.3	−24.76
Cornea	−15.18	−14.78	−14.72	−14.82	−14.78	−14.77	−14.78	−15.19	−14.46
Lens	−17.82	−17.56	−17.55	−17.55	−17.56	−17.46	−17.56	−17.92	−17.32
Choroid	−15.58	−15.29	−15.22	−15.18	−15.29	−15.21	−15.29	−15.61	−15.08
Retina	−19.33	−19.17	−18.97	−18.92	−19.17	−18.95	−19.17	−19.32	−18.82

sensitive to the width of glass leg and the thickness of spectacle lens, while their variation trends are quite different. Therefore, the SAR and absorbed power should be taken into account simultaneously while evaluating the biological effect of microwave on eyes. Results also suggest that hyper-myopia person who wears thicker spectacle lens may have higher health risk of getting oculopathy because of the larger maximal SAR and absorbed power caused by the thicker spectacle lens.

4. CONCLUSIONS

Based on the calculated results, we find that wearing glasses can obviously increase the maximal SAR and the absorbed power in ocular tissues. The maximal SAR with glasses is almost two times as large as that without glasses. The absorbed power has even increased to 3.1 to 4.5 times. The higher SAR and absorbed power might increase the health risk to human eyes. The results also indicate that the maximal SAR and absorbed power are sensitive to the widths of glass leg and the thicknesses of spectacle lens. Hypermyopia patient might suffer from higher risk of getting the oculopathy due to the larger SAR and absorbed power caused by the thicker spectacle lens. The maximal SAR and absorbed power show quite different variation trends with the changing size of glasses. Therefore, the SAR and absorbed power should be taken into account simultaneously while evaluating the biological effect of microwave on eyes. This paper could provide valuable reference data for the future evaluation of microwave biological effect on eyes. We believe that the SAR and absorbed power might be adjusted to a moderate level by changing the size of the glasses, which could be proved by the future work. However, limited by the experimental condition, the experiment is not included. So conclusions presented in this paper are just indicative but not definitive.

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