Australian Journal of Basic and Applied Sciences, 4(5): 724-730, 2010
ISSN 1991-8178

The Temperature Distribution Eximer Laser Source (193 nm) Within a Human Eye and Review on Some Side-effects

[1]S. Shahi, [2]M. Khorvash, [1]S.W.Harun, [1]H. Ahmad and [3]H.Golnabi

[1]Photonics Laboratory, Department of Physics, University of Malaya 50603 Kuala Lumpur, Malaysia
[2]Social science and humanity Faculty, Department of psychology, University of Kabensaang, Malaysia
[3]Institute of Water and Energy, Sharif University of Technology, Tehran, Iran

Abstract: A mathematical model to predict the temperature distribution within the human eye when subjected to a laser source (193nm) is presented. In this paper the thermal effects of the laser radiation on different parameters of the eye and some side-effects are discussed. The influence of parameters such as the heat conductivity, diffusivity, the scattering and refraction coefficients are compared and the damage threshold conditions for temperature distribution are estimated. Other factors such as the color of eye, the ageing factor of the human eye and anxiety are also studied in this report. The interaction of the laser sources within the eye medium is described by employing the Penne's bioheat transfer equation. Uncertainties for predicted temperatures of the eye tissues due to approximate parameters are used based on analyzing one-dimensional heat transfer subject to the boundary conditions.

Key words: Pennes equation, Bioheat transfer, Heat conductivity, 193nm, Eximer laser (ArF).

INTRODUCTION

In the area of ophthalmology, laser eye surgery has become more widespread in the last 20 years. As early as the 1960s, when lasers were first introduced in the medical field, there was a concern about the potential of incurving injury 10 the eye owing to the absorption of energy causing elevated temperatures. The between of all the different models for heat transfer in living tissue, It the different models for heat transfer in living tissue. It is the Pennes bioheat transfer equation, that allows the prediction of the temperature profiles within the eye. With regard to nonlinear boundary conditions the method of solving bioheat transfer in eye with forth power is useful too (Deng and Liu, 2001; Liu, 2001; Karra *et al.,* 2005; Zhao *et al.,* 2005; Chua *et al.,* 2005). The obtained using the Green's function method and special boundary conditions in eye summarized to one-dimension equation (Davies *et al.,* 1997). On the four different ocular tissues, the most vulnerable in the eye are the cornea and aqueous humor as the infrared radiation raises the overall temperature of the aqueous eye (Chua *et al.,* 2005). Hence, The study of interaction of heat on eye tissue is important and with having the estimating parameters will be proposed the damage conditions.

Heat Transfer Mathematical Model:

The human eye model is a solid sphere as a composite layered structure consisting of four different ocular tissue: cornea, aqueous, lens and vitreous. The tissue thermal properties for each region is homogeneous and isotropic. To simplify the problem, only half a section of the eye was simulated taking in to consideration in symmetry the problem. In this investigation, the thermal conductivity, dispersion and absorption coefficients are random and the parameters are estimated. The starting point of the model is to adopt the classic Pennes bioheat transfer equation to describe the heat transfer within a tissue that, for a three- dimensional Pennes equation is given as (Karra *et al.,* 2005; Zhao *et al.,* 2005; Chua *et al.,* 2005):

$$\rho c(\frac{\partial T}{\partial t}) = \nabla(k\nabla T)_t + \omega_b C_b \rho_b (T_a - T) + Q_s + Q_m \tag{1}$$

Corresponding Author: S. Shahi, Photonics Laboratory, Department of Physics, University of Malaya 50603 Kuala Lumpur, Malaysia
E-mail: sh_shahi08@yahoo.com and golnabi@sharif.edu

Where ρ, c and k are the density, the specific heat and the thermal conductivity of the tissue respectively. C_b is the specific heat of blood, W_b is the blood perfusion rate, T_a is the arterial temperature, and T represents the tissue temperature. Q_m and Q_s are the volumetric metabolic heat and the external spatial heating respectively. $Q^-_m = Q_m + Q_s$ and so $Q_m << Q_s$ and we neglect in the Eq. (1) (Liu, 2001; Karra *et al.,* 2005; Zhao *et al.,* 2005; Chua *et al.,* 2005).

Initial and Boundary Conditions:

For the model validation, in vitro data were used and the initial temperature of the eye was 25 °C while internal ocular temperature was assumed to be 37 °C. The boundary conditions (B.C.) are prescribed as follows:

$$(B.C.)\begin{cases} at \quad x=L, \quad T=T_c \quad ; \quad at \quad k\dfrac{\partial T}{\partial x}=h_f(T-T_f)x=0 \\ at \quad y=0 \quad k\dfrac{\partial T}{\partial y}=0 \quad ; \quad at \quad y=S_1, \quad k\dfrac{\partial T}{\partial y}=0 \\ at \quad z=0 \quad k\dfrac{\partial T}{\partial z}=0 \quad ; \quad at \quad z=S_2, \quad k\dfrac{\partial T}{\partial z}=0 \end{cases} \tag{2}$$

Where L, is the depth of the tissue domain to be analyzed in the x-direction. Here, the retina is defined at x=1, while the cornea area is at x=0. S_1 and S_2 are the widths of the eye tissue in the y and z-direction, respectively. The other parameters are T_c, the inner eye temperature which is regarded as constant, the cooling fluid (water or dilute alcohol) temperature, T_f and h_f, the convection coefficient. The initial temperature is:

At $t = 0, \qquad T(x, y, z; 0) = T_\circ(x, y, z)$ (3)

By using transformation:

$$T=\theta+T_c+(T_c-T_f)\frac{x}{k/h_f-L}=\theta=(T-T_c)-(T_c-T_f)\frac{x}{k/h_f-L} \tag{4}$$

And finally by applications of the one- dimensional analyzes (Davies *et al.,* 1997) and having the boundary conditions, we get (Liu, 2001; Karra *et al.,* 2005):

$$At\ x=0,-K\frac{\partial\theta}{\partial x}=hf\theta \quad ; \quad At\ x=L,-K\frac{\partial\theta}{\partial x}=0 \quad ; \quad \text{At t}=0\ ;\theta=\theta_0(x) \tag{5}$$

Solution:

We can also solve the (5) equation by estimating conductivity coefficients to exponential forms. That will be discussed in the results section. The analytical solutions obtained by using the Green's function method are as follows:

$$G_R(x,t,\xi,\varsigma)=\sum_{n=1}^{\infty} e^{-\alpha\beta_n^2(t-s)}\frac{2\left[\beta_n^2+(h_{f/k})^2\right]H(t-\varsigma)}{L\left[\beta_n^2+(h_{f/k})^2\right]+h_{f/k}}\times\cos\beta_n(L-x)con\beta_n(L-\xi) \tag{6}$$

;Where eigen-value β_n is the positive root of the following equation (Deng and Liu, 2001).

$$\beta_n tg(\beta_n L)=h_{f/K} \tag{7}$$

RESULTS AND DISCUSSION

By solving Eq.(1) and (6), the temperature distribution on distance is as follows :

$$T_\circ(x)=T_a+\frac{Q_m^-}{\omega_b C_b}+\frac{h_{f\circ}\left[T_{f\circ}-T_a-Q_m^-/\omega_b C_b\right]\exp(\sqrt{A}x)}{(h_{f\circ}-k\sqrt{A})+(h_{f\circ}+k\sqrt{A})\exp(2\sqrt{A}L)}+\frac{h_{f\circ}\left[T_{f\circ}-T_a-Q_m^-/\omega_b C_b\right]}{(h_{f\circ}-k\sqrt{A})\exp(2\sqrt{A}L)} \tag{8}$$

;Where $A=\frac{w_o}{k}$ and is constant for the fourth layer in the eye.

Scattering Coefficient Effect:

In the (8) equation the typical value for eye tissue properties are taken as:

$$C = C_b = 4200(J/^{\circ}Ckg)\,,\quad T_a = T_c = 37(^{\circ}C) = 310(k)$$

$$T_{f^*} = 25(^{\circ}C)\,,\ h_{fo} = h_f = h = 10(\omega/_{m^2\,^{\circ}c}) = 0.001(w/cm2^{\circ}c)\quad ,\quad \rho = 1000(Kg/_m 3) = 1(gr/cm3)$$

$$\omega_b = 0.5(Kg/m^3\,^{\circ}c) = 0.005(gr/cm3^{\circ}c)\quad ,\quad T_f \cong 25(^{\circ}C)\,,\quad \eta = 200(cm^{-1})$$

;Where η is the scattering coefficient and for the four layers in eye is close to η = 200 (L = 0.5 – 3cm). With the above parameters, we can rewrite the eq.8 that the heat conductivity for the layer in the eye considered interval 0. 2-0.5 $\left(\frac{W}{mk}\right)$. Q_s can be dealt by the present computation and the plane wave heating of the laser (or microware) approximation of Beer's law as :

$$Q_s(x,y,z;t) \equiv \eta P_o(t)\exp\left[-\eta(L-x)\right] \tag{9}$$

;Where $P_0(t)$ is the time depending heating power on cornea. Fig (1) is relative to refractive laser system (Allegratto Shahi and Golnabi, 2007) by average power of 0.64 (W).

Hence, the temperature T can be expressed as a function of the thermal parameters as:

$$T = f(K, \omega_b, Q_m, \eta, P_o) \tag{10}$$

;Where T_a is the artery temperature and it's always defined as the constant body. Suppose *ΔT* is the uncertainty of the predicted temperature due to the approximate parameters, we can write;

$$\frac{\Delta T}{T} = \sqrt{\left(\frac{\partial \ell n T}{\partial \ell n k}\frac{\Delta k}{k}\right)^2 + \left(\frac{\partial \ell n T}{\partial \ell n \omega_b}\frac{\Delta \omega_b}{\omega_b}\right)^2 + \left(\frac{\partial \ell n T}{\partial \ell n Q_m}\frac{\Delta Q_m}{Q_m}\right)^2 + \left(\frac{\partial \ell n T}{\partial \ell n \eta}\frac{\Delta \eta}{\eta}\right)^2 + \left(\frac{\partial \ell n T}{\partial \ell n P_o}\frac{\Delta P_o}{P_o}\right)^2} \tag{11}$$

The total temperature uncertainty contributed by k, wb, Q_m, η and P_o which, under this uncertain ties condition, the parameters are defined at the same level as:

$$\frac{\Delta k}{k} = \frac{\Delta \omega_b}{\omega_b} = \frac{\Delta Q_m}{Q_m} = \frac{\Delta \eta}{\eta} = \frac{\Delta P_o}{P_o} \cong \%20 \tag{12}$$

The highest $\frac{\Delta T}{T}$ occurs in the cornea and is higher than 14.5%. By increasing the temperature depth of influence, the heat scattering and thermal effect inside the eye tissue will be increase. In this research we consider the diameters of eye sphere in intervals of 0-3cm.

Effect of the Conductivity Coefficient:

In analysis of the one-dimensional Pennes equation by the symmetrical boundary condition (5), the equation changes as follows. The conductivity coefficient in different Layers in the eye is 0.2 -0.5 .$\left(\frac{W}{mk}\right)$

The changes in thermal conductivity of the lens are predominately due to an increase or decrease in water content of the lens, which is likely to have some effects on the temperature distribution within the eye. The distribution of heat decreases by increasing of the depth influences. The fourth sets of simulations were carried out at different thermal conductivity of k = 0.2 – 0.5 $\left(\frac{W}{mk}\right)$ to study the resting impact. The thermal conductivity of the human lens is estimated 0.2 $\left(\frac{W}{mk}\right)$ value, by performance experiments on rabbit that is extrapolated based on human conditions (Chua *et al.,* 2005). Figure (3) shows the temperature of each ocular tissue after the human eye was exposed to 20 minutes of laser irradiation. Increasing the thermal conductivity of the lens did not have any significant effect on the temperatures, the maximum variation was 1.3 °C in temperature, which occurred on the mid - corneal surface (Chua *et al.,* 2005).

By solving the three-dimension Pennes equation and Green's function Eq. (8), we can obtain Fig (4) for different thermal conductivity:

Figure (4) is based on the result of the Allegretto refractive system's parameters. The energy per pulse of system, pulse length and wave length of system (Eximer laser, ArF) were 16 mJ, 12ns and 193 nm, respectively. With respect to the diagram, we observed that the difference of temperatures inside the eye sphere is linear (1-3cm) because of the repetition rate is high and the time surgery is very fast but for the lower k, the difference of temperature can be decreases by increasing of the influence depth. Meanwhile, the laser threshold energy increased, the difference temperature also increased in tissue.

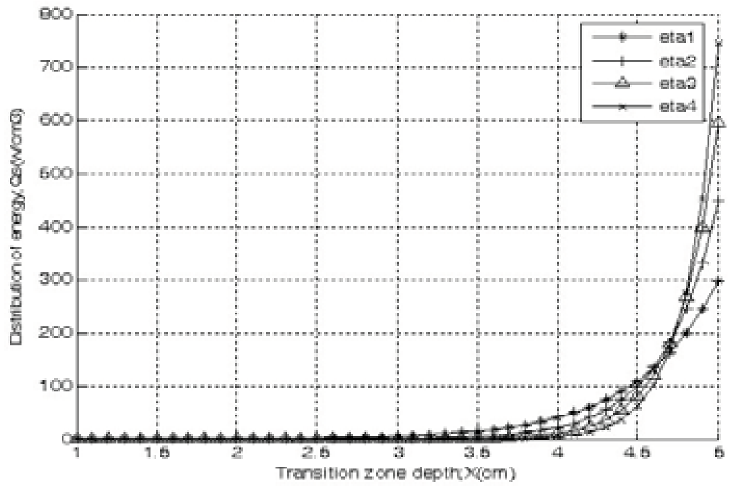

Fig. 1: Distribution of laser energy as a function of depth in terms of scattering coefficient.

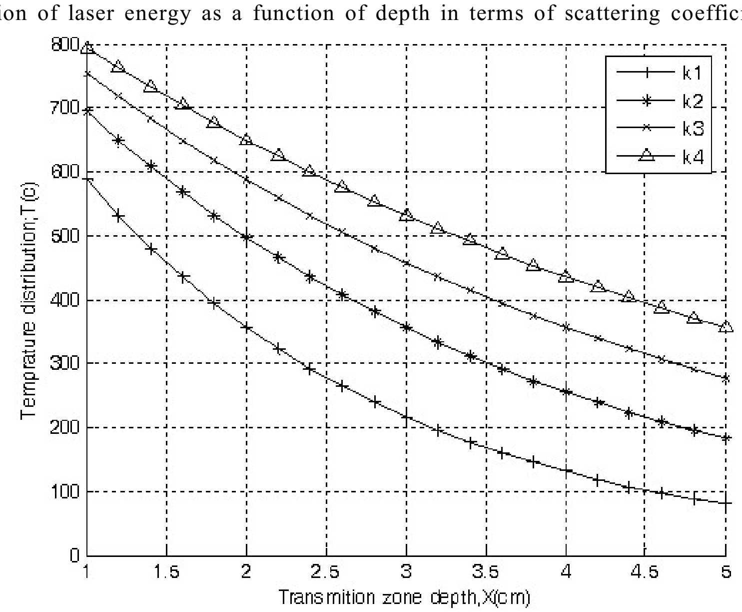

Fig. 2: The temperature distribution in eye with different conductivity coefficient (one -dimensional).

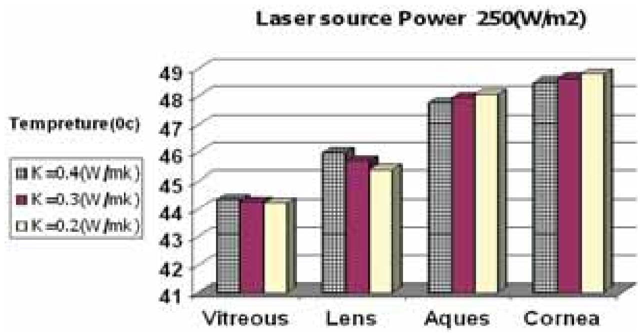

Fig. 3: The increasing of temperature in different eye layer after 20 minutes laser radiation.

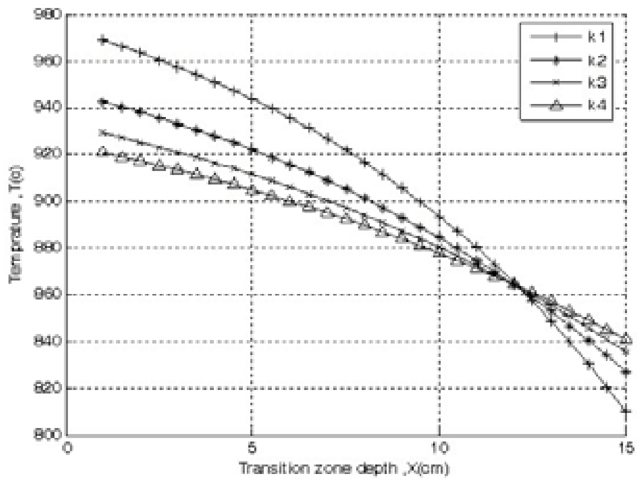

Fig. 4: The temperature distribution in eye with different conductivity coefficient (Three -dimensional).

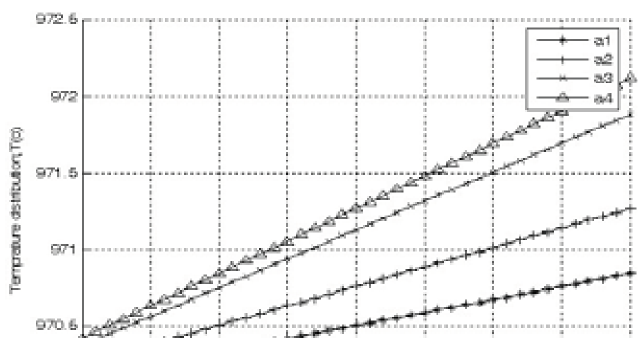

Fig. 5: The temperature exponential distribution for different diffusion coefficients in eye.

Effect of the Diffusion Coefficient:

Diagram (5) shows that the temperature distributions in terms of transition zone depth, which is useful for the effect on diffusion coefficient such as scattering investigation and led to the following exponential equation:

$$\theta_{(x)} = \theta_0 \exp(-\propto . x) \qquad (13)$$

;where ∝ is diffusion coefficient and is equal to $\propto = \frac{k}{\rho c}$ (k=0.2 – 0.5 $\left(\frac{W}{mk}\right)$).

In this diagram, with increasing of the distance from laser source variation of temperature decreased, while for the lower diffusion coefficient, temperature changes less.

Effect of the Age:

It is well known that the physical dimension of the human eye changes as a person ages. Therefore, the age of the patient impacts the degree of heat conduction within the patient's eye. As a person ages, the following physical evolution occurs within the eye: lens radii decreases, lens surface distance from the corneal decreases while the aqueous chamber thickness increases.

There was relatively more noticeable temperature effect on the lens as a person gets older and the increase in temperature in the lens was by about 0.2 ºC on average for every increase in age group. For an older person, the chamber depth decreases and thus the lens is pushed nearer to the Laser source. Therefore, as the optical interaction between laser irradiation and ocular tissues follows an exponential attention along the optical axis, a comparatively higher increase in the lens temperature was observed (Chua *et al.,* 2005).

Effect of the Refractive Index Coefficient:

By studying the four areas in the eye that is the cornea (n=1.376), vitreous (n=1.34), lens (n=1.437) and aques (n=1.336) and interaction by laser source irradiation can be understood that different environments change light ray. However, the different areas in the eye have absorption quality in optical area which change refractive coefficient (Narayanaswamy, 2006):

$$\frac{dn}{dT} = \left(\frac{\partial n}{\partial T}\right)_{\rho} + \left(\frac{\partial n}{\partial \rho}\right)\left(\frac{\partial \rho}{\partial T}\right) \quad (14)$$

These changes are due more to difference of section's density. The environments that contain liquid as usually change volume by increasing temperature and $\frac{dn}{dT}$ is going to be negative. The changes of refractive coefficient layer in eye with constant ρ depends on temperature:

$$\Delta n = \left(\frac{dn}{dT}\right)\Delta T \quad (15)$$

Thus, increasing the temperature lead to increasing the differences refractive coefficients.

Effect of the Laser's Influence:

During laser surgery, time-varying the laser's influence allows one to restrict the energy deposition on the absorbing volume so that the collateral thermal damage induced on the ocular tissues can be reduced. Thus, the effect of the laser's influence is changed if the numerical aperture (NA) of laser source is increased.

Effect of Eye's Color:

In a study on the color of the 50 patients' eye (Shahi and Golnabi, 2007), the comparison of damage rate and the side effects after surgery estimated that in the brighter color eyes absorption energy is low, therefore the patient will get high scattering of energy. As a result of investigations, after surgery brighter eye show less burn and pain due to ultraviolet irradiation absorptions or plasma in enlivenment's surgery. Besides that, they were more sensitive to light radiations because the cornea layer and refractive coefficient is changed.

Review on Some Side-effects:

The before studying (Shahi and Golnabi, 2007) compared some effects of the laser light, heat, laser operation time and the operational situation of the laser system. Some factors such as beam abbreviation, sensitivity to light, eye dryness, the regression and post operation infection were considered. Psychologists explain many causes for anxiety, such as internal emotions, uncertain situations and events (Porafkari, 1998). By using the SCL 90 scale on 50 cases (Shahi and Golnabi, 2007) which before denoted nearly 85% of people had minimum anxiety and denoted nearly 85% of people had been minimum anxiety and 15% had the most anxiety. According to Pearson's correlation statistic, meaningful relation occurs between anxiety and some side-effects. The comparison between the cases showed the patients that had more anxiety did not get the overalll visual correction after surgery. Hence, it believes that sometimes anxiety leads to increase in the temperature in the body that is perhaps one of the important factors in the quality of surgery. The study on 50 cases confirmed this matter, because the majority of patients got better results after the second eye surgery. Of course, this is an area that requires further study.

Conclusion:

With continuing "the bioheat Pennes equation" and distributions of exponential thermal laser source concluded that thermal effect decrease with increasing of distance of eye surface, that is relative to parameters such as conductivity , scattering , diffusion coefficient, age, etc. This study discusses one dimensional Pennes equation because laser irradiation effect is linear and coherence on eye tissue. The damage threshold to eye tissue estimated by diagram and graph that is useful for clinical applications. The increasing of the temperature is on the corner surface that is controlled by cooling fluid and more low temperature inside the eye. The high temperature gradient the heat conductivity and the heat power flue are efficiency on the temperature uncertainly. The variable laser power depends on the time laser is turned off. More decreasing of temperature is in the cornea. The absorption of energy on lens is greater because of the refractive coefficient of lens is higher by increasing the age.

REFERENCES

Chua, K.J., J.C. Ho, S.K. Chou and M. R. Islam, 2005. On the study of the temperature distribution within a human eye subjected to a laser source, International communications in heat and mass transfer, 32: 10571065.

Davies, C.R., G.M. Saidel and H. Harasaki, 1997. Sensivity analysis of one-dimensional heat transfer in tissue with temperature-dependent perfusion, ASME Journal of Biomechanical Engineering, 119: 77-80.

Deng, Z.S. and J. Liu, 2001. Blood perfusion-based model for characterizing the temperature fluctuation in living tissues," Statistical Mechanics and its Applications, 300: 521-530.

Karra, S., J. Zhang and F.Yang, 2005. A numerical study of a 3D bioheat transfer problem with different spatial heating, Mathematics and Computers in Simulation, 68: 375-388.

Liu, J., 2001. Uncertainty analysis for temperature prediction of biological bodies subject to randomly spatial heating, Journal of Biomechanics, 34: 1637-1642.

Narayanaswamy, O.S., 2006. A Model of Structural Relaxation in Glass, Journal of the American ceramic society, 54: 491-498.

Porafkari, N., 1998. Anxity disorders, 14: 228-231.

Shahi, S. and H. Golnabi, 2007. Comparison of different refractive laser systems for eye surgery in Iran clinics," Proc. of the 13th Iranian Conference on Biomedical Engineering, Feb 21-22, ICBM'. Sharif University of Technology, Tehran, Poster # 32, pp: 544-549.

Zhao, J.J., J.Zhang, N.Kang and F.Yang, 2005. A two level finite difference scheme for one dimensional penne's bioheat equation, Applied Mathematics and Computation, 171: 320-331.