International Journal of Scientific & Engineering Research, Volume 5, Issue 7, July-2014
ISSN 2229-5518

Three dimensional modelling and heat transfer study of human eye

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***Abstract*—A 3-D modelling of heat transfer is done to understand the temperature distribution inside a human eye. This study gives important results which can be used in medical field. A steady state analysis is conducted taking into account conduction and convective modes of heat transfer. A three dimensional model is used for this simulation. Blood perfusion rate is not included in this analysis. Successful thermal modeling of the human eye will assist in enabling early detections of eye abnormalities such as inflammatory. This promising simulation allows new possibility in computational methods for eye health care.**

***Keywords*—heat transfer, biomedical, human eye**

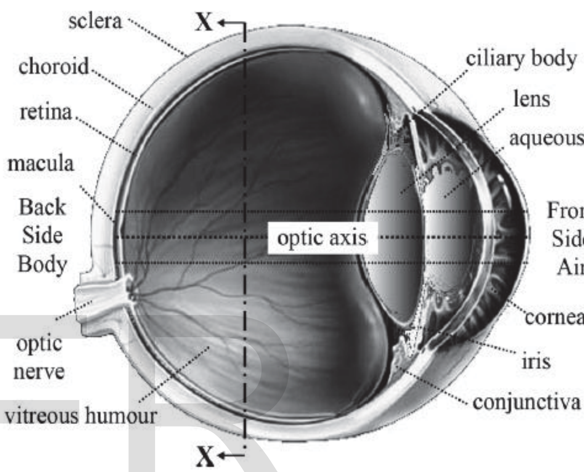
I. INTRODUCTION

In this paper a steady state analysis is conducted on a 3D human eye model. The objective of this work is, therefore, to develop a mathematical model which allows the prediction of the temperature profiles within the eye. Prior knowledge of temperature distribution in the entire region of treatment is essential to control the temperature and prevent damage to healthy tissue. Accurate experimental determination of temperature field during such live surgical process is not yet possible due to limitations in non-invasive measurement of temperature and also ethical constraints and pain tolerance of patient with invasive processes. Hence analysis and computer modeling of such bio-heat transfer process can assist ophthalmologists in prescribing safe and efficient procedures. One of the first eye models in the literature was developed by Taflove and Brodwin.

II. HUMAN EYE

A. Eye model and properties

First, In reality, the eye is a spherical ball, symmetric about the pupillary axis. However in this study, a three dimensional model of the human eye consisting of seven regions is considered for heat transfer calculations. A schematic of the 3D model is shown in Fig. 1. All dimensions and thermal properties of the various layers are shown in Table 1. Each region is assumed to be homogeneous.



B. Parts

The Human is designed considering 7 parts namely

- Cornea
- Aqueous humor
- Retina
- Sclera
- Lens
- Vitreous humor
- Choroid

OTHER PROPERTIES OF VARIOUS SUB DOMAINS IN EYE		
SUBDOMAIN	density(kg m^{-3})	c specific heat(J kg^{-1} K^{-1})
CORNEA	1050	4178
AQUEOUS HUMOR	1000	3997
RETINA	1000	4178
SCLERA	1000	4178
LENS	1050	3000
VITREOUS HUMOR	1000	4178

C. *Three dimensional modelling*

When developing mathematical models, we always aim to construct models that best resemble the actual system for the purpose of minimizing inaccuracies. However, to perfectly simulate the actual system is always impossible, largely due to limitations such as increased complexity of eye anatomy, where obtaining a unique solution is very difficult, and the limitation of current computer technology to compute the highly complex modeling equations.

Table 2

Thermal conductivities of various sub domains in eye	
subdomain	Thermal Conductivity (W $m^{-1}K^{-1}$)
cornea	0.58
aqueous humor	0.58
iris	1.0042
sclera	1.0042
lens	0.40
vitreous humor	0.603

The three dimensional modelling of eye is done in Solidworks software including all the parts mentioned in the previous section.

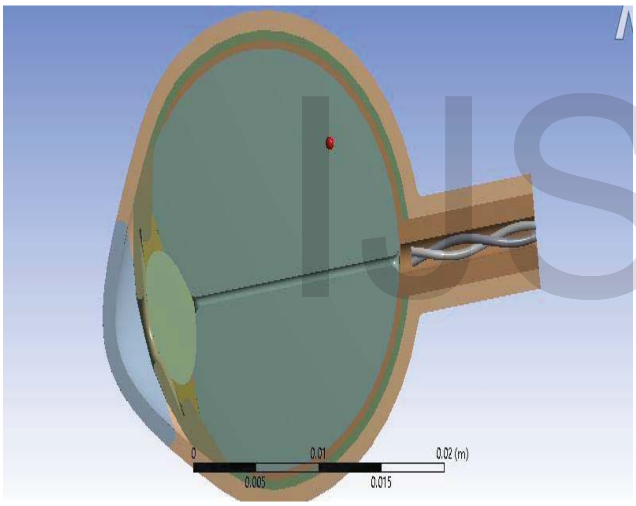


fig 2 A 3D Human eye model developed in Solidworks

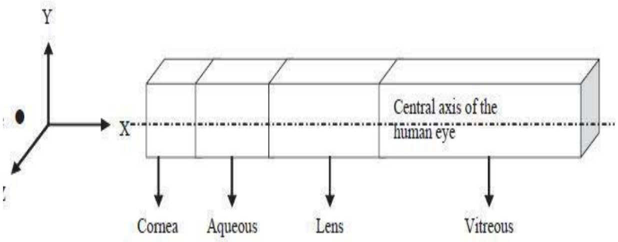


Fig 3 A schematic representation

III. Analysis

For the analysis of the model, it is imported to Ansys 14 workbench. An unstructured meshing is done.

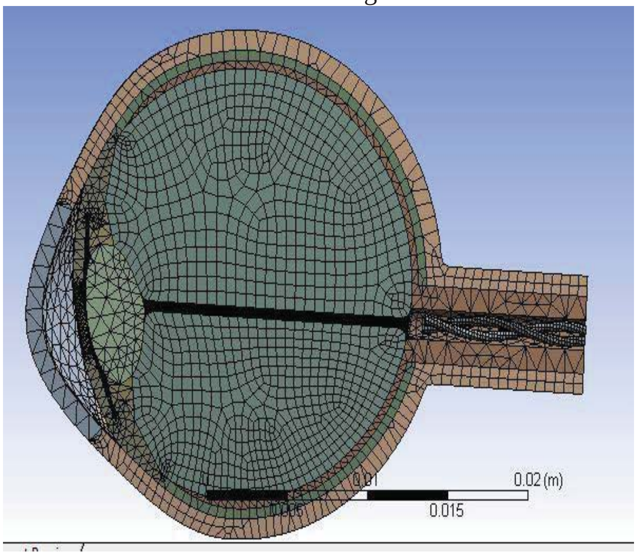


Fig. 3 Generated mesh

One of the more widely used equation for modeling transfer of heat inside biological systems is the Pennes bio heat equation which contains the metabolic heat generation and blood perfusion term. In the current study, the metabolic heat generation is neglected based on the fact that the human eye comprises mainly water. Consequently, tissues responsible for metabolic heat generation are minimal. Since the human eye is modeled as an organ isolated from the human head, we can afford to drop the blood perfusion term and account for the thermal effects of blood in the boundary condition.

A. *Governing Equations*

K	Thermal conductivity (W/mK)
h	convective heat transfer coefficient (W/m2K)
h_{amb}	ambient convective heat transfer coefficient
T	Tissue temperature (K)
T_{amb}	ambient temperature
σ	Stefan Boltzmann constant (W/m^2K^4)
ε	Emissivity
Q	Heat flux (W/m2K)
ρ	Tissue density (kg/m3)
C	Specific heat(KJ/kg K)
x	Distance along corneal axis
t	time

$$\rho c \frac{\partial T}{\partial t} = \nabla(k \nabla T) + Q$$

$$k\frac{\partial T}{\partial x} = h_{amb}(T - T_{amb}) + \sigma\varepsilon(T^4 - T_{amb}^4) + Q$$

B. *Boundary conditions*

We assume the human eye to be embedded in a homogeneous surrounding anatomy which is at body core temperature. Consequently, the transfer of heat from the surrounding to the eye may be described by a single heat transfer coefficient h_{amb}. The second boundary condition is written on the corneal surface where two heat loss mechanisms take place. These losses are the heat transfer due to convection and radiation.

Table 2

Control parameters used in present study	
control parameters	Value
blood temperature T_{bl} (^{0}C)	37
Ambient temperature T_{amb} (^{0}C)	25
ambient convection coefficient h_{amb} (W m^{-2} K^{-1})	15
emissivity of cornea	0.975
stefan–boltzmann constant, (W m^{-2} K^{-4})	5.67×10^{-8}

IV. Addition of Heat Flux

During laser surgeries a laser or a heat flux will be given to a particular part of human eye where we want to rectify the abnormality. In this paper a heat flux is given in lens of the human eye. During the addition of heat flux any change in temperature in other parts of the eye may cause serious damage. So a simulation study is conducted to understand the temperature distribution during the addition of a heat flux. The amount of heat flux given will vary according to the need.

V. Results

Geometric construction of the eye is done using solidworks. And meshing and analysis is done in Ansys workbench 14. Unstructured meshing is done. Number of elements is 10041.. We see that the heat transfer from the eye to the surroundings will result only in a temperature difference of 1 ^{0}C. The number of elements taken is 10041, and number of nodes created is 31813 which is near the convergence range when referring to reference [3]. Since the study excludes heat transfer through blood flow, the error in temperature near cornea is $3^0 C$.

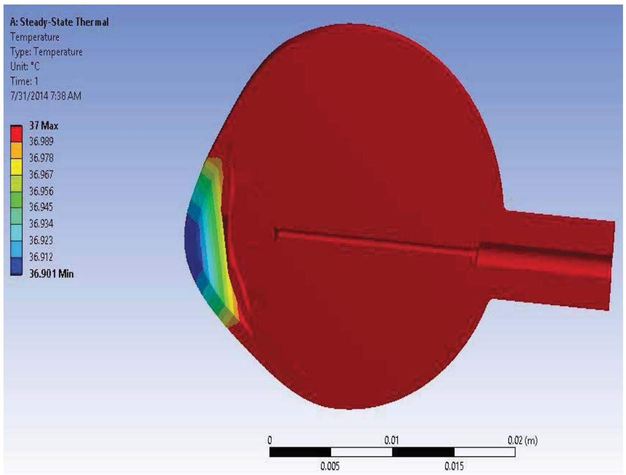


Fig 4 Temperature contour plot of human eye under normal conditions

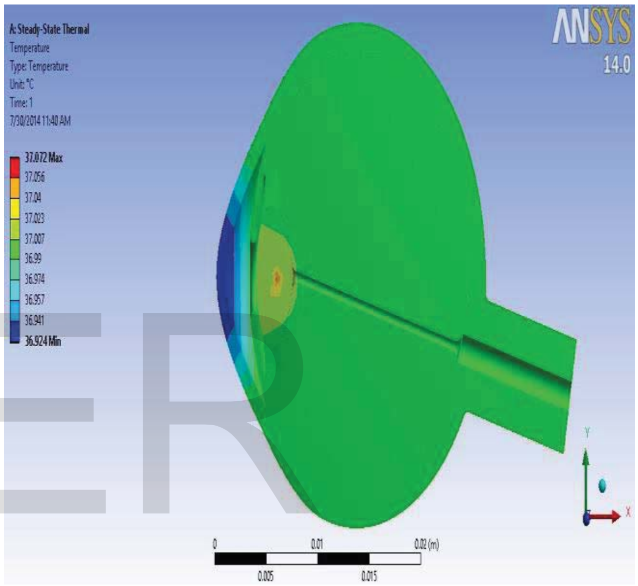


Fig5 . Temperature contour plot of human eye with heat addition of heat flux on lens

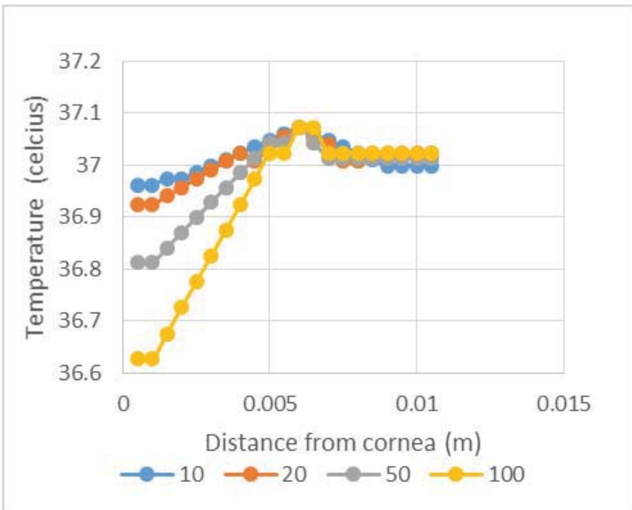


Fig6. Change in temperature inside human high for different corneal convection film coefficient.

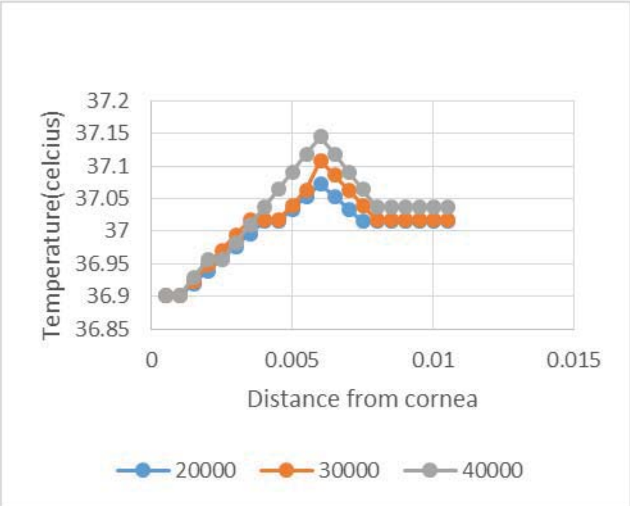


Fig.7 Change in temperature inside human for different heat flux applied on lens.

VI. Conclusion

We see that only a very small temperature variations is taking place near cornea. Further the radiation heat transfer is not included. In the future study a heat source will be given in the lens or retina assuming that laser surgery is taking place in that particular area. An increase in ambient convection coefficient will decrease the corneal surface temperature as heat transfer across the cornea surface is increased although temperatures at the inner part of the eye are not affected much. As the value of higher heat flux the temperature near to the interested area is also getting higher, so a cooler ambient condition is advised. Instead of continuous heat flux, it can be given in regular intervals of time so that eye will get cooled during the cool off period.

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