2003 ME Graduate Student Conference
May 3, 2003

NUMERICAL SOLUTION OF OCULAR FLUID DYNAMICS

Satish Kumar
M.S. Candidate

Prof. Sumanta Acharya

ABSTRACT

The fluid dynamics of the aqueous humor (AH) in the anterior chamber of eye and drainage mechanisms through the Trabecular Meshwork (TM) are not fully understood. The small size of the anterior chamber and complexities of flow measurements inside the living eye makes detailed flow data difficult to obtain. Computational simulation of the flow in the anterior chamber can therefore be very useful in producing the necessary understanding of the flow mechanisms. Eye diseases such as Glaucoma are often linked to the obstruction of the outflow, which causes the fluid pressure to build up inside the eye. Increased Intra Ocular Pressure (IOP) sustained for a long time can damage the optical nerve in the eye and lead to blindness.

In the present study, numerical calculations of the aqueous humor dynamics in the anterior chamber of rabbit and human eye are presented to delineate the basic flow mechanisms. The calculations are based on a geometrical model of the eye, which represents the Trabecular mesh (TM) as a multi-layered porous zone of specified pore sizes and void fraction. The outer surface of the cornea is assumed to be at a fixed temperature (corresponding to the ambient temperature), while the iris surface is assumed to be at the core body temperature. Results are obtained for both the horizontal upward-facing orientation of the eye, and the vertical orientation of the eye. Buoyancy is observed to be the dominant driving mechanism for the convective motion in both orientations of the eye. Reducing the TM pore size does not appear to have a significant influence on the IOP until the pore size drops below 1 micron beyond which a significant increase in IOP is observed.

Many small particles of different sizes, shapes and traits circulate inside the anterior chamber in normal or pathological conditions of eye. The interaction of these particles with the ocular tissues depends on their particular characteristics and the flow field of aqueous humor inside the anterior chamber. The behavior of pigment granules, protein particles (albumin), erythrocytes and leucocytes inside the anterior chamber are of much interest for the ophthalmologists regarding their association with some specific eye diseases. Pigment Dispersion Syndrome (PDS) is a special case of defective eye with high concentration of pigment granules in the aqueous humor. This is concerned with pigment deposition on the corneal endothelium in a vertical band known as Krukenberg Spindle or heavy pigmentation of the TM. The rupture of blood vessels and bleeding inside the eye leads to accumulation of blood (erythrocytes) inside the anterior chamber and formation of Hyphema. In cases of ocular inflammation leucocytes sediment at the bottom of the anterior chamber and forms a white layered structure known as Hypopyon. Obtaining flow data and visualizing the behavior of different particles is a difficult task by present medical tools. The work is aimed to perform computational simulations inside a geometrical model of eye to get insight about the movement and deposition of particles of different characteristics and identify the mechanisms for the development of some observed structures (Krukenberg Spindle, Hyphema and Hypopyon).

Angle closure in anterior chamber occurs when the peripheral iris physically opposes the trabecular meshwork or corneal endothelium and impedes aqueous outflow. The most common etiology of angle closure is pupillary block, whereby the flow of aqueous from the posterior to anterior chamber is inhibited. Blockage of the pores of TM by iris anterior surface leads to elevation in IOP inside the anterior chamber and development of Glaucoma commonly referred in medical science as Angle Closure Glaucoma. Laser iridectomy is the treatment of choice for most cases of Angle Closure Glaucoma, which is a surgical process of making small holes in iris to enable the easy passage of AH from posterior chamber to anterior chamber. This surgery leads to diminution of pressure difference between anterior and posterior chamber; iris contours preoccupies its shape and IOP drops to the normal value. One of the objectives of the present work is to analyze the process of pupillary block and development of elevated pressure. The surgical procedures are simulated for investigating the flow and pressure distribution after opening of holes at different positions in iris disk.

Figures

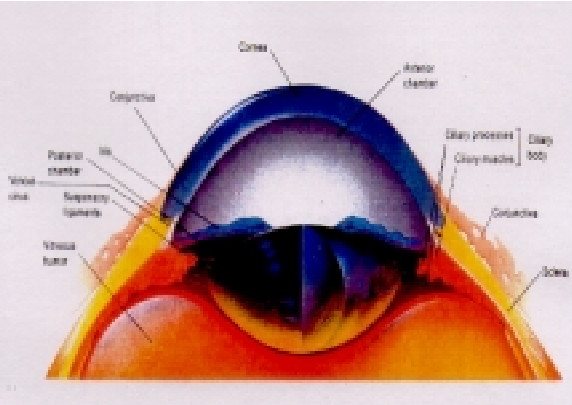

Fig 1. Schematic of the eye

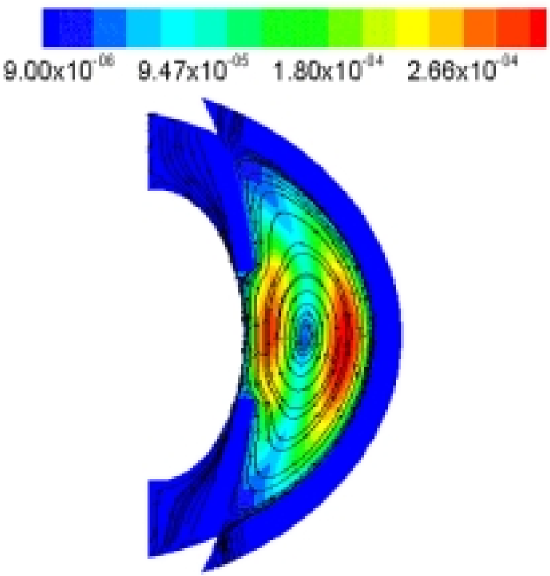

Fig 2. Streamlines and contours of velocity magnitude in vertical orientation (Standing Position), Vertical mid plane, $\Delta T = 2\,^{0}C$, Pore diameter = 0.9 μ.

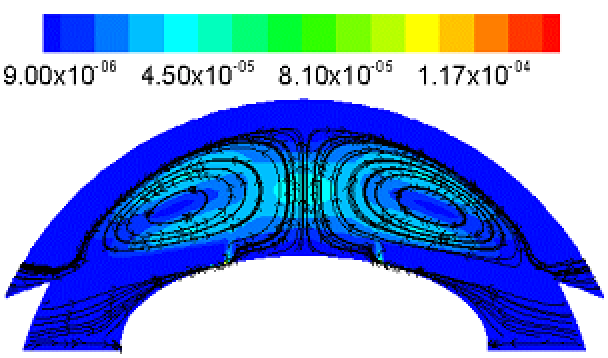

Fig 3. Streamlines and contours of velocity magnitude in horizontal orientation (Sleeping Position), Vertical mid plane, $\Delta T = 2\,^{0}C$, Pore diameter = 0.9 μ.

Fig 4. Hyphema (Blood Sedimentation)

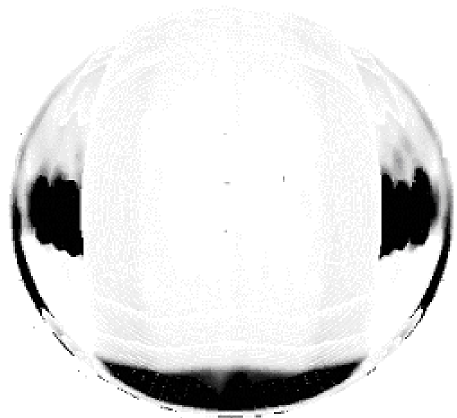

Fig 5. Deposition of RBC on corneal surface for vertical orientation of eye, Formation of Hyphema and Corneal bloodstaining.

REFERENCES

1. Kumar, S., Acharya, S., Beurman, R. and Palkama, A., "Numerical solution of Ocular Fluid Dynamics in Rabbit Eye", Journal of Biomechanical Engineering Transactions of ASME. (Under Review).
2. Heys, J. J., and Barocas, V. H., 2002, "A Boussinesq Model of Natural Convection in the Human eye and the formation of Krukenberg's Spindle," Annals of Biomedical Engineering, 30, pp. 392-401.
3. Canning, C. R., Dewynne, J. N., Fitt, A. D., and Greanny, M. J., 2000, "Fluid flow in the anterior chamber of a human eye," IMA Journal of Mathematics Applied in Medicine and Biology, pp. 1-33.
4. Kumar, S., Acharya, S., Beurman, R. and Palkama, A., "Deposition of particles on ocular tissues and formation of Krukenberg spindle and Hyphema", Journal of Biomechanical Engineering-Transactions of ASME. (Under Preparation).