

Modeling the Effects of Increased Glucose Concentration on Intraocular Pressure

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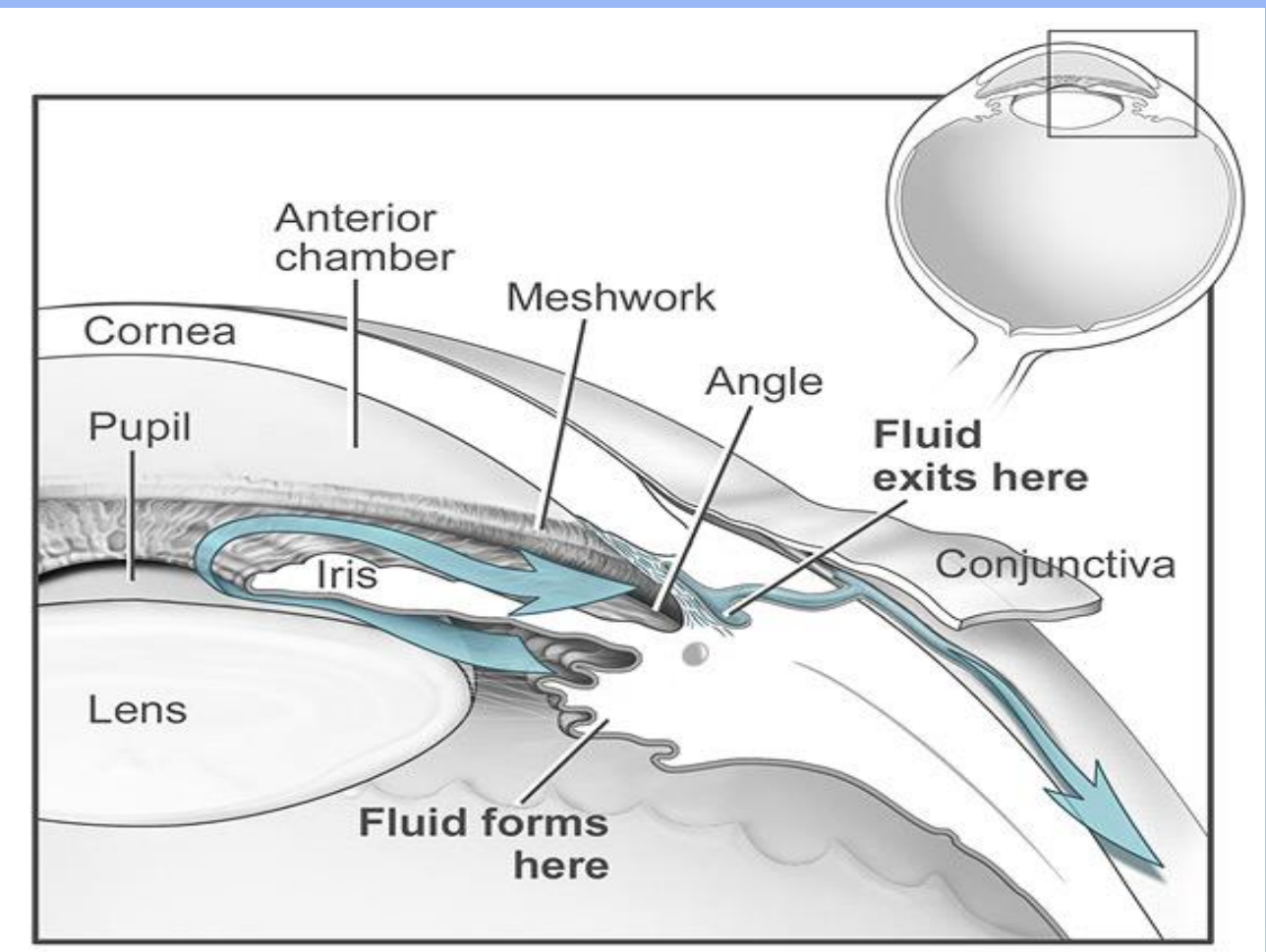


Overview

- Glaucoma: 2nd leading cause of blindness in the world / U.S.
- Open-Angle Glaucoma: most common amongst various types of glaucoma
- Risk Factor: high Intraocular Pressure (IOP), which is regulated by flow of aqueous humor in anterior chamber
- Strong correlation between those with diabetes and developing glaucoma
- Fibronectin production
 - > glucose
 - > IOP

Objective

1. Model IOP under different glucose concentrations in aqueous humor using simulation software
2. Use open-source parallel code to solve equations which produces results comparable to commercial software



http://www.lef.org/protocols/images/glaucoma_02-big.jpg

Methods

Modified Navier-Stokes equation (consider buoyancy):

$$\rho \bar{v} \cdot \nabla \bar{v} = -\nabla p + \mu \nabla^2 \bar{v} + \rho_0 \bar{g} \beta (T - T_{ref})$$

Continuity of AH for steady and incompressible flow:

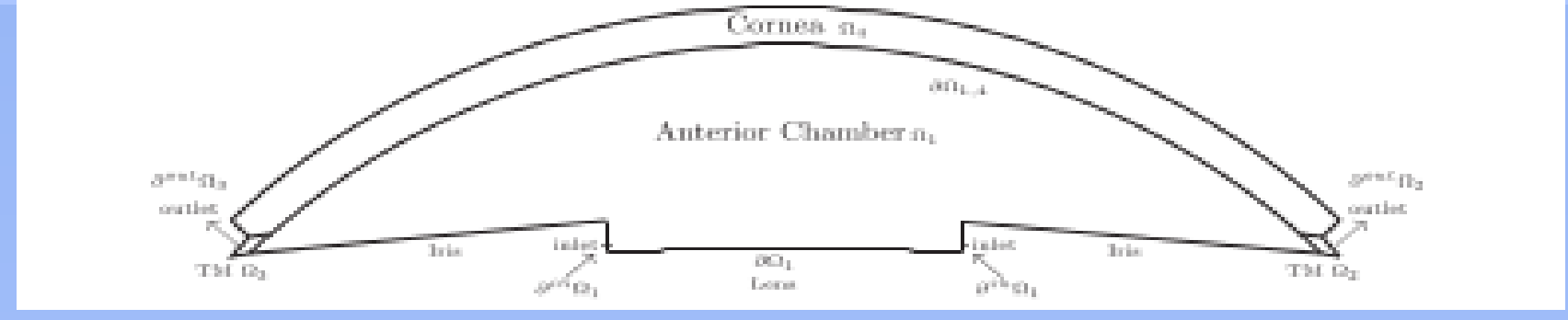
$$\nabla \cdot \bar{v} = 0$$

Convective and diffusive transport of energy:

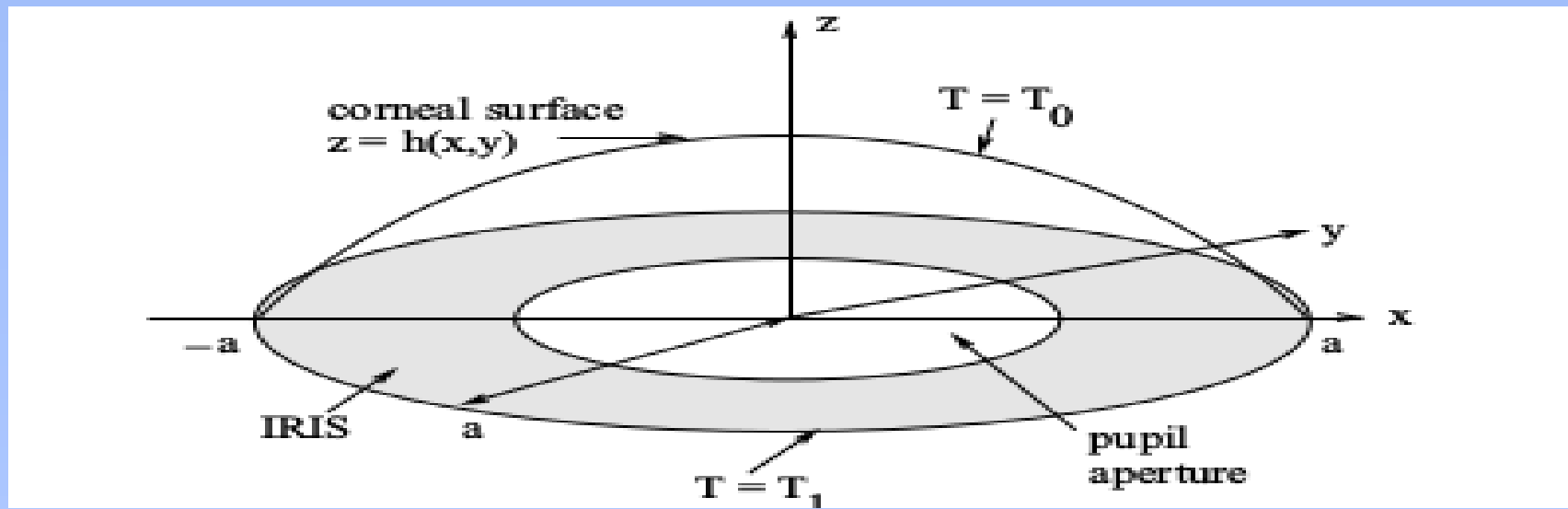
$$\rho C_p \bar{v} \cdot \nabla T = k \nabla^2 T$$

Permeability of trabecular meshwork and Schlemm's canal

$$\alpha = \frac{\mu}{\Delta p} \Delta e \bar{v} - f(g_c)$$



2D model of the human eye. (J.A. Ferreira et. al., 2014)



Fitt and Gonzalez (2006)

Tools

Hardware:	Software:
<ul style="list-style-type: none"> • Star1 (serial) • Darter (parallel) 	<ul style="list-style-type: none"> • Deal.II - FEM software library • Cubit - mesh generator • COMSOL Multiphysics Tool

Deal.II

Deal.II is a finite element software package written in C++. The package includes a Navier-Stokes example problem which was modified in order to simulate flow within the anterior chamber. The program was modified to work for both a 2D and 3D mesh generated in Cubit. Due to the computational complexity required to simulate flow in 3D, the running time of this program can last for a few hours to longer than a day.

COMSOL

COMSOL is a multi-physics tool that can perform simulations on fluid flow using modifiable pre-existing equations in

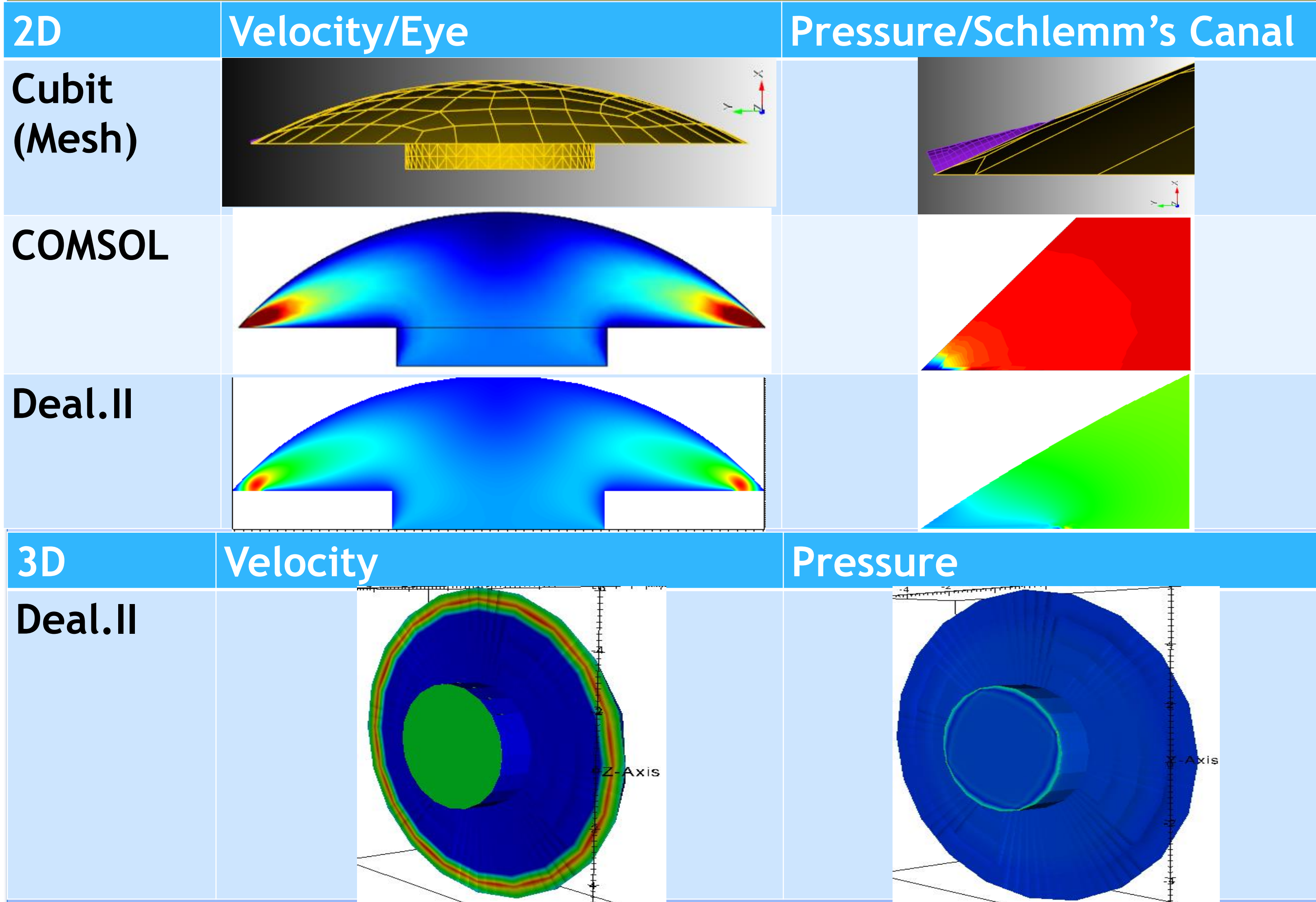
- 2D
- 2D axis-symmetry
- 3D

while allows other constraints added within designated regions of the geometry.

Analysis

The COMSOL and Deal.II velocity results appeared to be consistent for both 2D and 3D simulations. A large portion of flow in the anterior chamber had a relatively constant flow until it approached the outlet region. At this point, the velocity increased due to a large amount of fluid trying to exit into a small region. However, the pressure results seemed to vary quite a bit. After the trabecular meshwork region was added in COMSOL, the effect of Darcy's Law seemed to have little to no effect on the flow, which is inconsistent with the results found by Ferreira et al. More simulations will have to be run in order to eliminate these inconsistencies.

Results



Future Work

Once the inconsistencies have been dealt with, future simulations will incorporate the buoyancy factor in order to produce more realistic results. The final step will be to add the effects of fibronectin production on permeability of the trabecular meshwork. Other future work will include modifying the Deal.II code to run in parallel using Trilinos and MPI, allowing for faster simulations on more refined meshes. Parallel code has also been developed to solve the 1D Laplace problem in parallel. This will be expanded to the higher dimensions and then will be modified to solve the system of equations described in our model.

Acknowledgements

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References

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COMSOL:

