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Numerical simulations of fluid pressure in the human eye

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ABSTRACT

In this article we present computational results for the pressure in the human eye. Pressure computations for different flow rates of the aqueous humor, viscosity of the aqueous humor, and permeability of the trabecular meshwork are given. The fluid flow is assumed to be axisymmetric, and modeled as a coupled system of Stokes and Darcy fluid flow equations, representing the fluid flow in the anterior cavity and trabecular meshwork, respectively. Rewriting the problem in cylindrical coordinates reduces the 3-D problem to a problem in 2-D. Computations are also given for varying angles between the base of the iris and the trabecular meshwork.

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1. Introduction

In this article we numerically investigate fluid flow through the Anterior Cavity (AC) and the Trabecular Meshwork (TM) of the human eye. Of particular interest is the dependence of the pressure difference between the AC and the TM on (i) the flow rate of the aqueous humor, (ii) the viscosity of the aqueous humor, and (iii) the permeability of the TM. Our interest in modeling the pressure in the eye is due to glaucoma, the second most common cause of blindness in the United States, which in most cases is due to increased pressure in the eye [23]. An illustration of fluid flow through the eye is given in Figs. 1.1 and 1.2. In the eye fluid is generated by the ciliary muscle, located along side of, and behind, the lens. The fluid then flows through the AC and the TM before exiting through the Canal of Schlemm.

The model geometry of the eye used in our numerical simulations is shown in Fig. 2.3. We assume that the eye is positioned *looking up*, and that the eye in this orientation is symmetric about the vertical axis. Additionally we assume that the fluid flow is axisymmetric, enabling the fluid flow (through a change of variable to cylindrical coordinates) to be modeled as a 2-D problem.

There are a number of assumptions made in the construction of any computational model. Together with the symmetry assumptions mentioned in the previous paragraph, for the computations presented we assume that there is no temperature variation across the eye, the aqueous humor is a Newtonian fluid, the flow through the TM can be model using the Darcy fluid flow equations with the model parameter (the effective fluid viscosity) dependent upon the viscosity of the aqueous humor and a permeability value for the TM. The fluid flow in the AC we model using the Stokes fluid flow equations. In [12] existence and uniqueness of the discrete approximation to the coupled Stokes–Darcy fluid flow problem in an axisymmetric domain was established, together with a priori error estimates. Numerical computations on a model test problem demonstrated that the approximations satisfied the predicted error estimates. The computations presented below used the same numerical approximation algorithm as studied in [12].

Using the "lubrication theory" limit of the Navier–Stokes equations, together with the Boussinesq approximation for the buoyancy, buoyancy driven fluid flow in the AC, caused by a temperature gradient across the AC, have been

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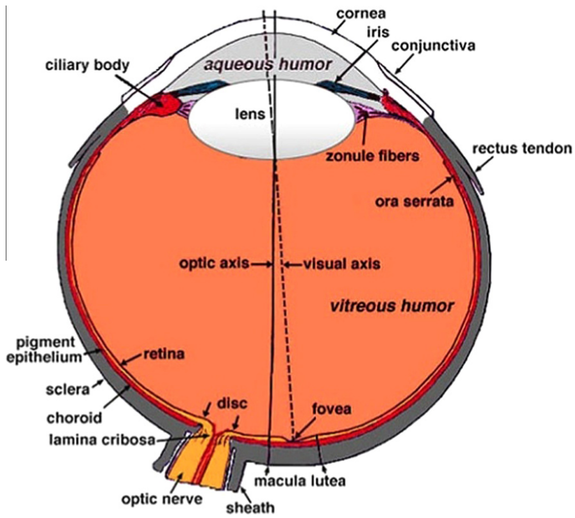

Fig. 1.1. Illustration of anatomy of an eye [19].

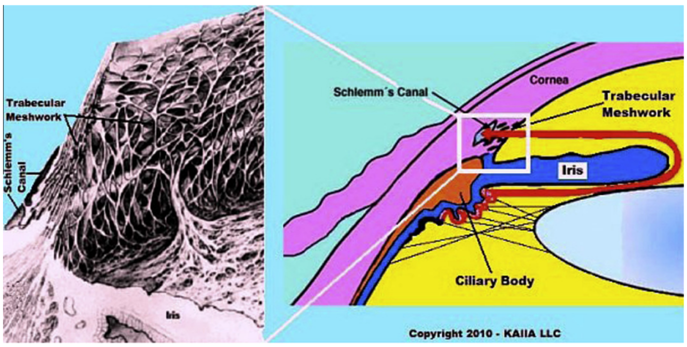

Fig. 1.2. Illustration of flow through an eye [30].

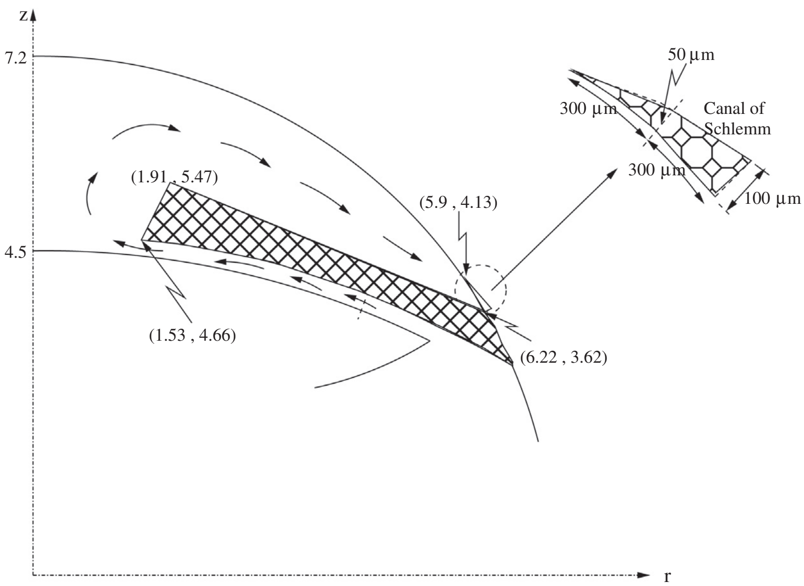

Fig. 2.3. Model for simulating fluid flow through the eye.

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