AQUEOUS HUMOR AND IRIS MECHANICS IN APPOSITIONAL VERSUS SYNECHIAL CONTACT IN PRIMARY ANGLE-CLOSURE GLAUCOMA

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INTRODUCTION

Primary angle-closure glaucoma (PACG) is characterized by an elevated intraocular pressure (IOP) and a narrow anterior chamber angle (ACA, Figure 1). The ACA is defined by the iris insertion and the corneoscleral shell. Aqueous humor is secreted by the ciliary and exits through the trabecular meshwork. In PACG, the narrow ACA and close proximity of the iris to the trabecular meshwork obstruct aqueous outflow. Since aqueous production is nearly pressure-independent, the decrease in aqueous outflow facility results in a subsequent rise in IOP.

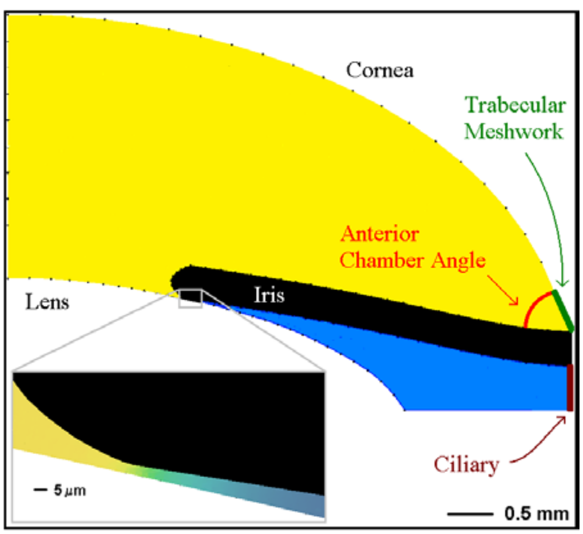


Figure 1. Model result for normal eye. The relevant ocular region is bounded by the lens and cornea. The iris is surrounded by aqueous humor, which flows from the ciliary and exits through the trabecular meshwork. Most of the pressure drop occurs at the pinch between iris and lens.

Iris obstruction of the trabecular meshwork can occur by appositional or synechial contact. In appositional contact, the iris is forced anteriorly by a persisting pressure difference between the anterior and posterior chambers resulting from pupillary block. In synechial contact, the peripheral iris is attached to the corneoscleral shell by adhesion. In both cases, the ACA is narrow and IOP is elevated. The two types are clinically distinguished through indentation gonioscopy.

We employ our previously developed mathematical model[1] of the anterior segment to evaluate the relationship between ACA and IOP for synechial closure. We also examine a possible mechanism for appositional contact.

METHODOLOGY

Aqueous humor is modeled as a Newtonian fluid and the iris as an incompressible linear elastic solid. The coupled fluid-solid system is solved using standard Galerkin finite element method with a pseudo-solid mesh[2] for the aqueous humor. The model assumes axisymmetry about the central corneal axis.

For synechial contact, we specified the degree of angle closure by imposing Dirichlet conditions on the displacement of the peripheral iris. Adhesion between the peripheral iris and cornea was simulated by moving the iris into near-contact with the cornea. In reality, synechial closure is observed to be complete contact between the peripheral iris and cornea for only part of the iris circumferentially. However, due to the axisymmetry of the model, complete contact is equivalent to total circumferential obstruction of the trabecular meshwork. Hence, as an approximation, synechial closure is modeled as near-contact instead of complete contact between the peripheral iris and cornea.

We also examined the effect of enforcing a specified pupil diameter for a normal intraocular geometry. Physiologically, the pupil size is controlled by contraction of the sphincter iridis and dilator pupillae muscles. As the sphincter contracts (shrinking the pupil), the iris is pulled into the lens, decreasing the gap between them and increasing pressure difference between the posterior and anterior chambers. This effect was modeled by imposing Dirichlet conditions on the displacement of the iris tip.

RESULTS & DISCUSSION

Figure 2 shows a typical result for modeling synechial contact. The peripheral iris adheres to the cornea, leading to a significant increase in IOP. Figure 3 shows that IOP increases as the ACA decreases (which corresponds to increasing the severity of circumferential synechial closure).

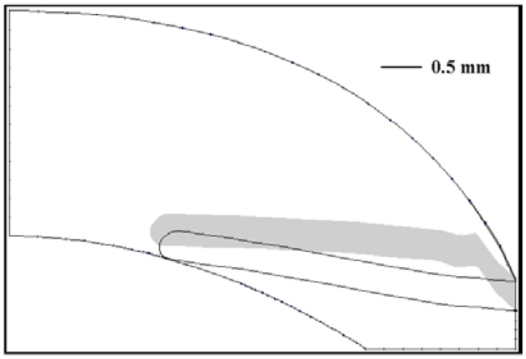


Figure 2. Model result for synechial contact (SOLID GREY). The peripheral iris is forced anteriorly toward the cornea and the central iris exhibits a flat profile. Normal iris is outlined (BLACK) for comparison.

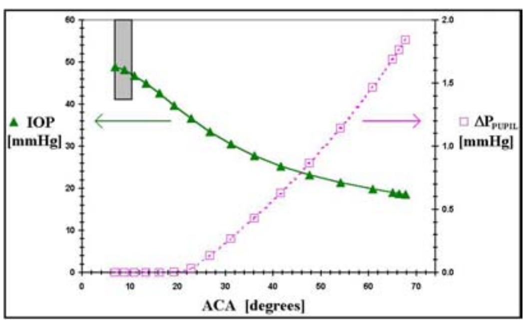


Figure 3. Model results for synechial contact. Gray area represents literature data listed in TABLE 1.

ACA (^{O})	IOP (mmHg)	REFERENCE
8.3 ± 1.3	---	[3]
---	53.4 ± 12.5	[4]
11.0	46.9	(model)
8.8	48.2	
6.8	48.9	

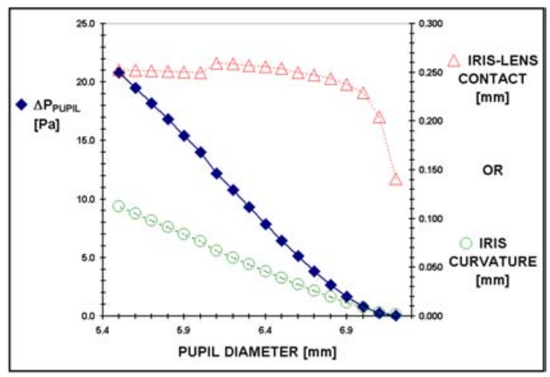
Table 1. Model results compared to literature values.

The results from modeling synechial contact are consistent with clinical observations of angle closure and IOP. For example, PACG patients exhibit a widening of ACA and a decrease in IOP after undergoing cataract extraction and subsequent intraocular lens implantation.[5] This inverse relationship between ACA and IOP is predicted by the model.

In a normal eye (Figure 1), nearly all the pressure drop occurs in the pinch region between the iris and lens. In synechial contact, the anterior position of the peripheral iris decreases the iris-lens contact distance. When the iris and lens are no longer in contact, there is no longer any significant pressure drop (ΔP_{PUPIL}) between the anterior and posterior chambers. The lack of a pressure difference across the central portion of the iris causes the iris to exhibit a flat profile. Clinically, this characteristic is termed "plateau iris configuration," one of two basic mechanisms responsible for PACG, which refers to an extremely narrow ACA coupled with a flat central iris profile.[6]

Figure 4 shows results for pupil constriction from a diameter of 7.2 mm to 5.5 mm. As pupil diameter decreases, there is an increase in the amount of contact between the iris posterior surface and the lens. The increased contact translates into higher flow resistance and the subsequent increase in ΔP_{PUPIL} causes the iris to bow anteriorly.

Clinically, flow resistance created by the narrow iris-lens gap is termed "pupillary block" – the mechanism accountable for more than 90% of angle-closure glaucoma. In pupillary block, a significant ΔP_{PUPIL} forces the iris to bow anteriorly, obstructing aqueous outflow and increasing IOP.[6] Our results indicate that anterior iris bowing may be attributed to an active mechanism where iris muscles constrict to control the pupil size.



Figures 4. Model results for pupil constriction.

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