Computational Evaluation of the Role of Accommodation in Pigmentary Glaucoma

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PURPOSE. Accommodation has been proposed as the cause of the bowing of the posterior iris that occurs in eyes with pigmentary dispersion syndrome. A mathematical model of the anterior eye is needed to explore the elastohydrodynamic effects of accommodation on both the aqueous humor dynamics and the contour of the iris.

METHODS. A mathematical model of the coupled aqueous humor–iris system was used to predict the effects of accommodation on the iris position and pressure distribution in the aqueous humor.

RESULTS. The mathematical model predicts that accommodation produces a pressure reversal—the anterior chamber pressure being higher than the posterior chamber—and iris movement into a more concave configuration. Total time for accommodation, iris modulus, iris attachment point, and trabecular meshwork permeability all had little or no effect on the iris contour and pressure change. The amount of accommodation, however, had a dramatic effect on both the amount of iris curvature and especially the pressure reversal. For accommodation resulting in a 0.6-mm change in anterior chamber depth, the pressure in the anterior chamber was more than 1.0 mm Hg higher than that in the posterior chamber, compared with a pressure difference of less than 0.1 mm Hg for accommodation resulting in a 0.2-mm change in anterior chamber depth.

CONCLUSIONS. The results confirm that accommodation produces bowing of the posterior iris and the magnitude of the bowing is a strong function of the amount of accommodation. (Invest Ophthalmol Vis Sci. 2002;43:700–708)

Insight into pigmentary glaucoma (PG) has increased dramatically during the past 20 years, but the condition is still not completely understood.1 Campbell2 first proposed that rubbing of the concave iris against the zonules causes the release of pigment in eyes with pigmentary dispersion syndrome (PDS) and PG. The liberated pigment floats with the aqueous currents and is primarily deposited on the posterior cornea surface in the form of the Krukenberg spindle and on the trabecular meshwork (TM).

The cause of iris concavity in PG and PDS is not known with absolute certainty, but there is substantial evidence3 for the reverse-pupillary-block theory proposed by Karickhoff.4 Reverse pupillary block implies that aqueous humor can flow forward through the pupil under normal conditions, but if the pressure in the anterior chamber is higher than in the posterior chamber, the iris is pushed against the lens and prevents backward flow from the anterior chamber into the posterior chamber. The higher pressure in the anterior chamber applies a net force to the iris, causing it to be displaced posteriorly and assume a concave shape. The cause of the supposed pressure reversal is a fundamental question that must be answered before PG is fully understood.

There are a number of theories about how the pressure becomes elevated in the anterior chamber. When Karickhoff5 originally proposed reverse pupillary block, he also suggested that “walking, certain head positions, or eye movement could create enough of a difference in anterior- and posterior-chamber pressures to cause the ‘iris valve’ to open and close.” It is unlikely that this is the case, because of the rigidity of the cornea (modulus = 10.3 MPa6) and the near incompressibility of water.

Pavlin et al.6,7 first proposed accommodation as the cause of the pressure reversal between the anterior and posterior chambers resulting in bowing of the posterior iris. They theorized that as the lens moves forward during accommodation, the pressure in the anterior chamber is increased. The aqueous could exit through the TM, but, according to the theory of Pavlin et al., this would happen relatively slowly. The aqueous would be prevented from flowing back into the anterior chamber by reverse pupillary block, and the higher anterior chamber pressure would cause the iris to bow posteriorly. Ultrasound scans in patients with PDS show a dramatic change in iris contour before and after accommodation.7 Ultrasounds in patients with PDS after peripheral iridotomy are equally dramatic in the absence of iris contour change during accommodation.7 Similar concavity can occur after accommodation in healthy individuals,8 an observation that led Sokol et al.9 to hypothesize that the position of the iris’s insertion in combination with accommodation may determine whether PDS develops. They found that individuals with PDS had an iris insertion 0.12 mm more posterior relative to the TM than did normal individuals.

We have developed a mathematical model of passive deformation of the iris in response to aqueous humor flow.10 In this study, we used our model to analyze whether the hydrodynamic effects of accommodation contribute to the development of posterior iris curvature in PDS.

METHODS

Model Specification: Base Case

A detailed description of the two-dimensional axisymmetric model is presented in Heys et al.10 We present herein a brief review of the model’s equations and a summary of the changes for the modeling of accommodation.

Figure 1 shows schematically the region of the eye that is modeled, including the structures that correspond to various boundaries. The aqueous humor has physical properties close to those of water (see Table 1) and is modeled using the Navier-Stokes equations.
Cornea modulus (fl)

independent out

but this effect is negligibly small for all reasonable values. Pressure-
pathway conductivity to a nonzero value affects the position of the iris,
structures within the eye and are modeled with a variety of boundary
base case that the iris has a modulus of 9 kPa, based on our
been measured to our knowledge, and we therefore assumed for our

Our experiments on bovine iris13 showed that the tissue is incom-
pressible and linearly elastic under small deformations, so the incom-
pressible linear elastic equations are used to model the iris

\[ \rho \frac{Du}{Dt} = -\nabla P + \mu \nabla^2 \mathbf{u} \quad (1) \]

\[ \nabla \cdot \mathbf{u} = 0 \quad (2) \]

where \( v \) is velocity and \( P \) is pressure. The Reynolds number in the eye
is normally very small (~0.01), but the acceleration of fluid during
accommodation results in Reynolds numbers on the order of 1, requir-
ing the full Navier-Stokes equation.

Our experiments on bovine iris15 showed that the tissue is incompres-
sible and linearly elastic under small deformations, so the incompres-
sible linear elastic equations are used to model the iris

\[ -\nabla P + G \nabla^2 \mathbf{u} = 0 \quad (3) \]

\[ \nabla \cdot \mathbf{u} = 0 \quad (4) \]

where \( \mathbf{u} \) is the displacement from the rest position, which is assumed
to be planar, and \( G \) is the shear modulus (a measure of stiffness in
response to shape change). The modulus of the human iris has not
been measured to our knowledge, and we therefore assumed for our
base case that the iris has a modulus of 9 kPa, based on our findings in
bovine iris.

The boundaries of the region that is modeled represent different
structures within the eye and are modeled with a variety of boundary
conditions. The cornea is modeled as a 0.5-mm-thick elastic shell with
a modulus of 10.3 MPa.5 The TM and vitreous are modeled as porous
solids, but the hydraulic conductivity of the vitreous-retina-sclera
pathway is set to zero (i.e., no posterior outflow). The specific con-
ductivity of the TM is set to \( 2.1 \times 10^{-9} \) m/s · Pascal, which corre-
sponds to a steady state IOP of 16 mm Hg. Setting the posterior outflow
pathway conductivity to a nonzero value affects the position of the iris,
but this effect is negligibly small for all reasonable values. Pressure-
dependent outflow through the uveal scleral route is included along
the same boundary as the TM outflow. The lens is modeled as a rigid
solid with the position of the lens surface being determined by the

current accommodation level. The final boundary represents the ciliary
bodies and is modeled as a fluid source with a volumetric flow rate of
2.5 μL/min.16

Accommodation is modeled by moving the boundary that defines
the anterior surface of the lens. Three quantities are needed to model
accommodation: (1) the initial and final positions of the lens, (2) the
total time required for the lens to move between the initial and final
positions, and (3) the velocity of the lens as a function of time during
accommodation. Parameters (1) and (2) are a strong function of age,17
which may be important, because PG primarily affects younger indi-
viduals and can decline with age.

Koretz et al.18 demonstrated that the anterior lens surface position
\( y \) can be described accurately as a function of distance from the center
line \( r \) and time \( t \) by parabolas of the form

\[ y(r, t) = a(t) + c(t) \cdot r^2 \quad (5) \]

where \( a(t) \) and \( c(t) \) are functions of time determined experimentally
from ultrasound or slit lamp measurements. The change in anterior
chamber depth, which is normally measured along the symmetry axis
passing through the pupil, is highly age dependent and critical for
calculating the function \( a(t) \). Our base case assumes that the anterior
chamber depth changes by 0.2 mm during full accommodation.19,20
The second function, \( c(t) \), is calculated by assuming that a point near
the periphery of the lens remains fixed. This assumption is justified by
the fact that the human eye is focused primarily by changing the
curvature but not the position of the lens. A point approximately 4 mm
from the pupillary axis is used in the model, based on the measure-
ments of Cook and Koretz.21

The time required for full accommodation varies between the
dominant and nondominant eyes, focusing direction (far-to-near versus
near-to-far) and age. Ibi22 reported accommodation times ranging from
0.52 to 0.94 seconds. Because patients with PG tend to be younger
(i.e., accommodating over a shorter time17) our base case assumed that
accommodation requires 0.5 seconds. The velocity of the lens is
approximated as being constant and purely axial in the model. Croft et
al.17 and Ibi22 have both measured the velocity of the anterior lens
surface throughout accommodation, and, with the exception of a short
initial and final transition, the velocity is nearly constant in the
measurements.

Because the model includes only a limited region of the eye, aqueous
humor outflow equal to the change in lens volume within the
region modeled is necessary to assure conservation of mass. In other

<table>
<thead>
<tr>
<th>Parameter (Symbol)</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>AH density (( \rho ))</td>
<td>1000 kg/m³</td>
<td>11</td>
</tr>
<tr>
<td>AH viscosity (( \mu ))</td>
<td>( 7.5 \times 10^{-3} ) kg/m · sec</td>
<td>12</td>
</tr>
<tr>
<td>Iris modulus (( G ))</td>
<td>(-9 ) kPa</td>
<td>13</td>
</tr>
<tr>
<td>Trabecular meshwork permeability (( k_{\text{TM}} ))</td>
<td>( 2.1 \times 10^{-9} ) m/s · Pascal</td>
<td>14</td>
</tr>
<tr>
<td>Vitreous permeability (( k_{\text{V}} ))</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>Cornea modulus (( E ))</td>
<td>10.3 MPa</td>
<td>5</td>
</tr>
</tbody>
</table>

AH, aqueous humor.
words, as the lens in the model domain moves forward, an equal amount of fluid is forced posteriorly to reflect a constant lens volume.

In summary, the base case for accommodation has the following properties: $G_{\text{iris}} = 9$ kPa, change in anterior chamber depth $= 0.2$ mm, accommodation time $= 0.5$ seconds, and $K_{\text{TM}} = 2.1 \times 10^{-7}$ m/s \cdot Pascal. The effect of variation of each parameter will be compared with the standard case in the Results section.

Model Specification: Case Studies

Case studies serve two important purposes. First, they allow us to account for potential inaccuracy in parameter values caused by lack of reliable data or individual variation. Second, they provide a mechanism for evaluating the significance of an effect. We therefore performed a series of case studies to evaluate how different parameters affect the iris contour.

As stated earlier, the modulus of the iris in our base case ($9$ kPa) was based on our experimental results in bovine iris. In light of the importance of this parameter and the potential for interspecies and individual variation, we performed a second study with a less stiff iris, setting $G_{\text{iris}}$ at $3$ kPa.

Our base case model of accommodation assumed that the lens moves $0.2$ mm during full accommodation. Cook and Koretz,\textsuperscript{21} however, reported a change in anterior chamber depth of approximately $0.6$ mm in an 18-year-old individual. Due to the uncertainty in the change of the anterior chamber depth, we studied the case of $0.6$-mm accommodation in addition to the base case. Similarly, we consider a long accommodation time of $1.0$ seconds in contrast to our base case of $0.5$ seconds.

Finally, we considered the fact that PG patients have higher IOP and presumably lower TM conductivity, which could affect the model results. We therefore performed studies on a model with reduced TM conductivity—specifically, a reduction to $0.7 \times 10^{-9}$ m/s \cdot Pascal, corresponding to a very high steady state IOP of $42$ mm Hg.

Numerical Solution of Model Equations

The model equations were solved using the standard Galerkin finite element method, as described previously.\textsuperscript{10} The solution method was modified by allowing finite element nodes to slide along the surface of the lens to minimize element distortion.

During accommodation, the lens deforms anteriorly toward the iris and nearly comes into contact with the iris. In theory, actual contact between two smooth surfaces is impossible because of the infinite stress developed in the lubricating fluid layer on incipient contact. Inaccuracies in numerical solution, however, can cause the computed position of the iris to overlap slightly with the lens, leading to breakdown of the simulation. Various methods have been developed to combat this sort of problem, such as the use of a Lagrange multiplier to push back the nodes that have penetrated the lubrication layer.\textsuperscript{25} Our approach was to enforce a no-contact zone by introducing a stress on the iris normal to the lens. The additional stress is related to the distance between the iris and lens by the equation

$$
\sigma_{\text{iris}} = A \cdot \epsilon \cdot d \cdot n_{\text{iris}} \cdot n_{\text{lens}}
$$

where $n_{\text{iris}}$ is the vector normal to the lens surface at the nearest point on the lens surface, $A$ and $\epsilon$ are adjustable coefficients, and $d$ is the minimum distance from the iris to the lens. The coefficient $\epsilon$ corresponds to how far the no-contact zone extends into the aqueous humor, and the coefficient $A$ corresponds to how strongly the no-contact zone is enforced. The contact prevention force can affect the results if it is applied at greater distances (or equivalently greater strength), as shown in Figure 2. Based on the data in Figure 2, the maximum value of $\epsilon$ used in all studies was $3$ \textmu m. In addition to having little effect on the hydrodynamics of interest, the use of a small separation layer is consistent with the fact that the posterior iris surface is rough,\textsuperscript{24} and therefore, although some regions may contact the lens, the entire surface is unlikely to make contact.

Quantification of Model Results

We used two quantities introduced by the experimental literature to characterize our iris contour simulation results. Current high-frequency ultrasound biomicroscopy (UBM) devices are unable to resolve the gap between the iris and lens (maximum resolution of UBM is...
As a result of this limitation, many UBM researchers report an apparent iris–lens contact distance, which is the distance over which there is no resolvable space between the iris and lens. The apparent contact distance was calculated from the model solution by determining the distance over which the iris and lens are separated by less than 40–50 μm. As a result of this limitation, many UBM researchers report an apparent iris–lens contact distance, which is the distance over which there is no resolvable space between the iris and lens. The apparent contact distance was calculated from the model solution by determining the distance over which the iris and lens are separated by less than 50 μm.

The contour of the iris is significant in many forms of glaucoma, and as a result, many researchers report the curvature of the iris from UBM measurements. Iris curvature is defined as the maximum distance between the posterior surface of the iris and the line connecting the posterior iris root to the posterior surface of the iris at the pupil periphery. Thus, if the posterior iris surface were completely linear in a micrograph, the curvature would be zero. If the iris were convex, the curvature would be positive, and if the iris were concave, as in PG, the curvature would be negative. The iris curvature was calculated from the model results.

We also estimate the IOP from the model results. IOP was determined by calculating the pressure in the anterior chamber adjacent to the TM. Because there is no significant resistance to flow in the anterior chamber, the pressure is essentially uniform at the IOP throughout the anterior chamber.

RESULTS

Base Case

The results for the base case (G = 9 kPa, decrease in anterior chamber depth of 0.2 mm, and an accommodation time of 0.5 seconds) are shown in Figure 3. Before accommodation (Fig. 3a), the iris is nearly linear, but as accommodation begins, aqueous humor is displaced anteriorly by motion of the lens. At the same time, aqueous must flow posteriorly around the lens.
to because of constant lens volume (Fig. 5b). After accommodation (Fig. 3c), the iris concavity is significantly increased because of reverse pupillary block. Finally, if the eye is allowed to stay accommodated for 300 seconds (Fig. 3d), pupillary block and steady secretion of aqueous into the posterior chamber drive the iris away from the lens.

The data shown in Figure 3 are presented in quantitative form in Figure 4. Accommodation was initiated at time = 0 seconds, but the model was first run for 2 seconds to ensure that the solution was at the preaccommodation steady state. Figure 4a shows a dramatic increase in apparent contact during accommodation, but the iris drifts away from the lens during the next 300 seconds, nearly returning to the preaccommodation level of contact. The iris curvature is initially near zero, indicating an approximately linear iris (Fig. 4b). Accommodation causes the iris to be deformed into a concave configuration indicated by negative iris curvatures in Figure 4b. After accommodation, the iris returns to an approximately linear contour.

Under steady state conditions, the posterior chamber must be at a higher pressure than the anterior chamber, because the normal flow of aqueous humor is from the posterior chamber into the anterior chamber. During accommodation, however, the movement of the lens causes the pressure in the anterior chamber to be temporarily higher than the pressure in the posterior chamber (Fig. 4c). The peak pressure in the anterior chamber is approximately 0.1 mm Hg higher than that in the posterior chamber. Two minutes after accommodation, the pressure in the posterior chamber again becomes higher than that in the anterior chamber, and a steady state condition is achieved in approximately 250 seconds. The IOP increases by approximately 1 mm Hg during accommodation, because of the forcing of aqueous humor into the anterior chamber by the movement of the lens (Fig. 4d).

Case Studies

The effects of varying specific parameters from the base case were summarized by comparing the apparent contact, iris curvature, and pressure difference between chambers at three different times: (1) before accommodation (time < 0 seconds), (2) immediately after accommodation (time = 0.5 seconds or 1 second), and (3) the final steady state in the accommodated eye (time = 300 seconds).

Figure 5 summarizes the effects of reducing the iris modulus from 9 kPa to 3 kPa. The lower modulus resulted in very little change in both apparent contact and iris curvature. However, the pressure difference between chambers was significantly less immediately after accommodation. This was caused by a larger gap between the iris and lens in the low modulus case, which allowed more flow to partially equalize the pressures.

The effects of increasing accommodation time to 1.0 second from the previous value of 0.5 seconds are shown in Figure 6. The pressure difference between chambers at the end of accommodation is reduced slightly in the slower accommodation case, but there is no change in apparent iris–lens contact length or iris curvature. The reduced pressure difference is the result of the aqueous’s having more time to drain through the TM during accommodation.

Figure 7 displays the effects of two different amounts of anterior depth change on apparent contact, iris curvature, and the pressure difference between chambers. For the base case, we assumed that the anterior chamber depth decreases by 0.2 mm during accommodation, but when the depth change was increased to 0.6 mm (based on measurements in an 18-year-old man\(^2\)) the differences in the model results were dramatic. The magnitude of iris curvature at the end of accommodation was increased by approximately 200%, and the apparent contact distance was increased by more than 70%. The most significant change occurred in the pressure difference between chambers immediately after accommodation, which was more than 10 times greater than the standard case. Figure 8 shows the aqueous humor and iris regions for a decrease in anterior chamber depth of 0.6 mm at the same time points as in Figure 3. The iris curvature immediately after accommodation was significantly more concave in the case of greater anterior chamber depth change (Fig. 8c).

When the iris insertion point was moved 0.12 mm posterior to the previous position, the magnitude of the iris curvature increased before and long after accommodation, but it was nearly equal to the standard case at the maximum immediately after accommodation (Fig. 9). The posterior iris attachment causes the pressure difference between the chambers to be decreased due to pupillary block by an approximately fixed amount (0.02 mm Hg) throughout the accommodation event. This reduction in pressure difference causes the apparent contact maximum to be decreased slightly from the standard case.

Figure 10 summarizes the apparent iris–lens contact, iris curvature, and pressure difference at two different levels of TM permeability. The iris position was unaffected by the trabecular permeability, and the only significant effect of a lower permeability was an increase in the IOP before, during, and after accommodation.

![Figure 5](https://iovs.arvojournals.org/pdfaccess.ashx?url=/data/journals/iovs/933592/)
DISCUSSION

We applied a mathematical model of the eye to the study of the physical effects of accommodation on aqueous humor dynamics and iris deformation. The hypothesized relationship between accommodation and iris-lens contact observed in PDS and PG has received special attention. The most significant result is the confirmation of UBM measurements suggesting that hydrodynamic effects driven by accommodation can cause the concave iris contour observed in the PG eye. The changes in apparent contact and iris curvature were qualitatively the same as experimental measurements in eyes undergoing accommodation. The model predicts that the curvature of the iris becomes more concave as a result of accommodation, which agrees with the UBM measurements of McWhae et al. The IOP during accommodation increased by approximately 1 mm Hg, but we are not aware of any experimental evidence to support this prediction. A number of researchers have observed a decrease in IOP after accommodation, but these results are typically based on pressure measurements after 10 or 15 minutes of a near focus activity (i.e., reading). The decrease in IOP is generally attributed to an increase in outflow facility after accommodation, a phenomenon not included in the current model.

It is known from the clinical observation of aqueous humor flowing posteriorly through a hole in the iris after laser iridotomy that the pressure in the anterior chamber is transitorily higher in eyes with PG. The higher pressure in the anterior chamber must be temporary because the pigment from the iris is largely deposited throughout the anterior chamber, including the TM, indicating normal flow from the posterior chamber into the anterior chamber. The model predicts that in cases of normal accommodation (i.e., an anterior depth change of 0.2 mm) the pressure in the anterior chamber is only slightly higher than that in the posterior chamber after accommodation (~0.1 mm Hg, Fig. 4) and remains higher for approximately 120 seconds. If, however, the anterior chamber depth changes by 0.6 mm during accommodation, the anterior chamber pressure becomes significantly higher than the posterior chamber pressure (~1.0 mm Hg, Fig. 7) and remains higher for approximately 220 seconds.

FIGURE 6. Case study of time required for complete accommodation changing from base value of 0.5 seconds to 1.0 second. The change had almost no effect on the iris or aqueous humor. The pressure in the anterior chamber was slightly lower immediately after the 1.0-second accommodation, because of more extensive drainage from the anterior chamber during accommodation.

FIGURE 7. Case study of extent of accommodation, which is shown as a change in anterior chamber depth, changing from the base value of 0.2 mm to a value of 0.6 mm. Enlarging the accommodative range had a significant effect on the curvature of the iris and the pressure difference between the anterior and posterior chambers.
The model provides quantitative predictions for the iris curvature, pressure changes, and time scales involved under a variety of conditions. Greater accommodative change, increased iris modulus, and a posterior iris attachment all increase the effects of accommodation on iris curvature and apparent contact length, indicating an increased risk for mechanical rubbing between the iris and lens and potential pigment liberation. The extent of accommodative change, measured by the change in anterior chamber depth, had the greatest impact on the change in apparent contact and iris curvature after accommodation. The enhancement of accommodation effects in persons that have a larger anterior chamber depth change (i.e., younger individuals) could help explain why PDS and PG normally occur in younger persons. There are many other factors that could explain the development of PG and PDS in younger persons, including pupillary block, that prevent development in older persons.

The model predicted, as might be expected, a lower anterior–posterior pressure difference peak in eyes that accommodate more slowly (Fig. 6). Because a lower pressure difference would reduce the force pushing the iris against the lens, the possibility of iris–lens and iris–zonule contact would also be reduced. Thus, the model predicts a decrease in the potential of PDS-PG as the eye ages and accommodation time increases.

**Figure 8.** The aqueous humor–(gray) and iris–(black) based change in anterior chamber depth of 0.6 mm, using the same time points as in Figure 3. (a) Before accommodation, (b) 0.15 seconds after start of accommodation (including the flow of aqueous humor), (c) end of accommodation, and (d) steady state. The greater extent of accommodation resulted in significantly more iris curvature.

**Figure 9.** Case study of iris attachment, placed 0.12 mm posterior to the base case attachment point. The change caused little change in iris curvature and a decrease in pressure difference between the anterior and posterior chambers for the posterior iris attachment, compared with the standard case.
The effect is very small, however, and it is unlikely that slower accommodation plays any significant role in lessening the severity of the disease, so the pharmacologic slowing of accommodation cannot be considered a likely treatment option, based on the modeling results.

Posterior iris insertion led to increased pupillary block and thus decreased iris-lens contact, which in turn implies less likelihood of the loss of pigment from the iris pigment epithelium. Based on the results of the mathematical model, we conclude that posterior iris attachment increases the potential for the development of PDS and PG by a nonhydrodynamic mechanism. One possibility is that the posterior iris attachment increases the potential for contact between the concave iris and the zonules.

There are two questions that we hope to pursue in the future: What features of young male myopes lead to an increased risk of development of PDS in that group,\textsuperscript{50} and why do few eyes have PDS, even though all eyes accommodate? We have demonstrated that the large accommodative range of the young could contribute to the reverse-pupillary-block effect, but we saw reduced reverse pupillary block in cases with posterior iris insertion. Better understanding of structural and anatomic variations between patients with PDS and those without, as it becomes available, will be incorporated into the model and used to pursue these two key questions.

The focus of this study was fairly narrow. We did not consider blinking, which some have argued is responsible for the pressure reversal in PDS and PG,\textsuperscript{55} and although we are convinced by our results that accommodation must play an important role in the determination of iris contour, we cannot eliminate other effects, such as blinking, that may also be significant. We were restricted to radial symmetry in this model, forcing us to consider only symmetric effects. The relationship between pigment erosion and decreased outflow facility through the TM remains unclear.\textsuperscript{52–54} Although that relationship is beyond the scope of the present study, its understanding is clearly critical to assessing the importance of iris contour in PDS and PG.

\section*{References}


