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Letter to the Editor

Optimum size of iridotomy in uveitis

The failure of neodymium-doped yttrium aluminium garnet (Nd:YAG) peripheral iridotomy (PI) to prevent and relieve primary acute angle-closure glaucoma (AACG) has been well documented in the literature and has been attributed to an inadequate size of PI.[1] In cases of uveitis and iris bombe-associated AACG the failure rate is significantly greater, in the region of 40–61%.[2,3]

We present a case of a recurrence of AACG in a uveitic patient despite having a patent PI. We believe a much larger PI is required to prevent recurrent episodes of AACG in a uveitic eye. Therefore, we constructed and applied a mathematical model to determine the optimal size of iridotomy and to help understand and modify treatment options.

A 22-year-old female presented to the eye casualty with a 1 day history of a severely painful left eye, headache, nausea and vomiting. Her vision was counting fingers in the left eye and 6/6 in the right (Figs 1a,2a,2b). She attended 3 weeks go prior to this presentation with a similar episode, treated with Nd:YAG PI. She has a history of left chronic anterior uveitis resulting in raised intraocular pressure (IOP), which remained stable following insertion of Ahmed valve and cataract surgery, 5 months prior to her presentation.

Medical therapy was initiated for AACG and a further Nd:YAG laser PI was performed reducing the IOP from 58 to 28 mmHg. The PI reduced the degree of iris bombe but did not resolve the occlusion of the drainage angle (Figs 1b,2c). Therefore, the next day she underwent a left surgical iridectomy (Figs 1c,2d). Twelve months on, she has remained stable with an IOP of 12 mmHg on no anti-glaucoma medication with a visual acuity (VA) of 6/9.

A mathematical model was constructed to determine the optimal size of PI required in patients with uveitis related iris bombe and angle closure (Fig. 3a). To mimic the posterior synechiae (PS), the inner edge of the iris was assumed to be adhered to the lens, preventing the flow of aqueous between the posterior and anterior chambers. As fluid accumulates in the posterior chamber, this drives a pressure difference (ΔP) across the iris and causes it to deform. The PI formed in the iris is modelled as a small cylindrical aperture of the radius r. For the system to be in equilibrium, the liquid flow through the PI must be matched exactly by the production flow Q of aqueous. Assuming the flux of liquid through the PI can be approximated by Poiseuille's law, it emerges that the transiris pressure difference can be written as $\Delta P = 8\eta hQ/(\pi\ r^4)$, where η is the viscosity of aqueous. This formula was used to determine the optimum radius r of the PI.

Using the model parameters (Table 1), three typical examples of the iris shape for differing ΔP are shown in Figure 3b; as ΔP increases, the iris bulges

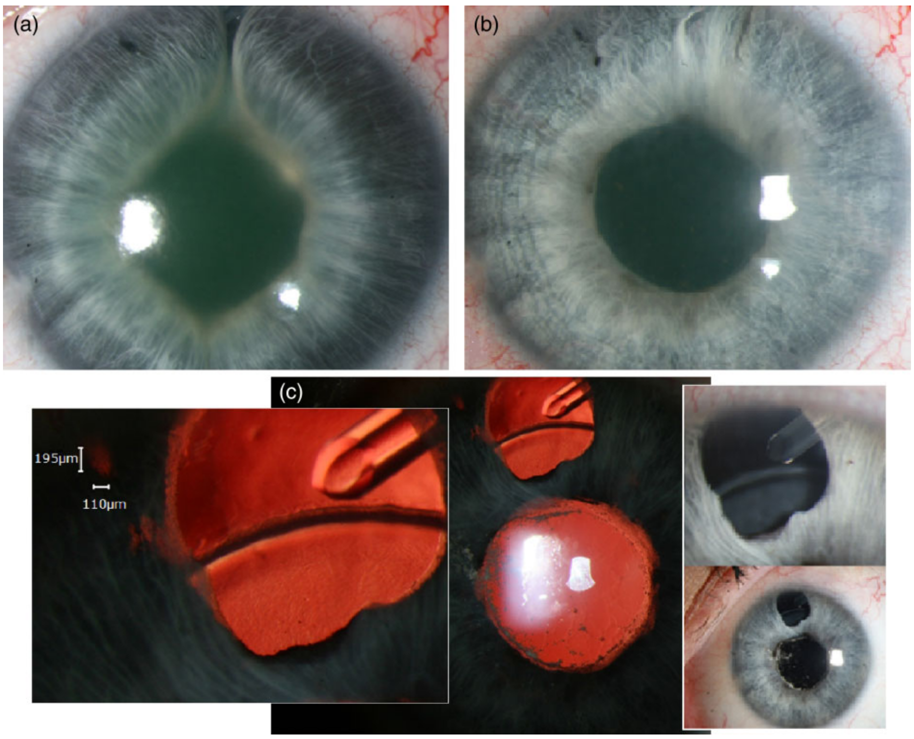

Figure 1. Left eye slit lamp photograph showing: (a) corneal oedema, iris bombe, 360° posterior synechiae, patent peripheral iridotomy (PI) and occluded Ahmed valve with intraocular pressure (IOP) of 58 mmHg. (b) Second Nd: YAG PI inferior to previous PI, occluded Ahmed valve, reduced iris bombe. (c) Broad surgical iridectomy (procedure: posterior synechiolysis, anterior vitrector used to create iridectomy at opening of the Ahmed valve with intracameral triamcinolone) and estimated size of first Nd: YAG PI (195 × 110 microns).

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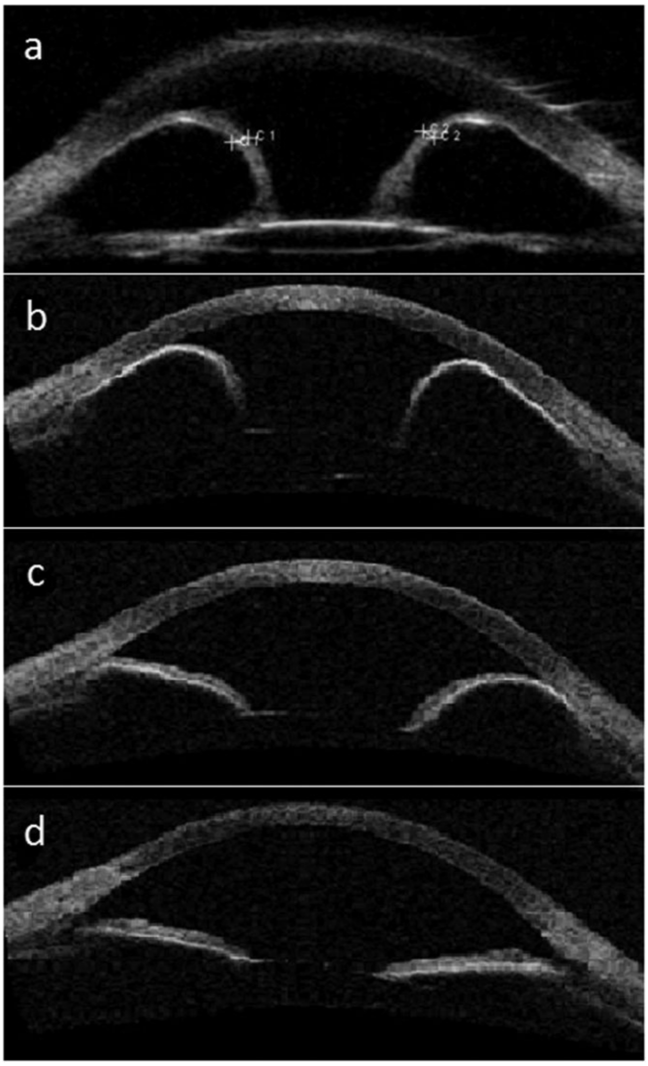

Figure 2. Imaging techniques were undertaken to investigate the mechanism of acute angle-closure glaucoma (AACG): (a) left ultrasound biomicroscopy (UBM) showed marked iris bombe with the peripheral iris in contact with the cornea in all quadrants, a very thin iris measuring approximately 0.3 mm and the drainage tube at the 1 o'clock position showed the iris pointing up in to the tip of the tube occluding it. (b) Anterior segment optical coherence tomography (AS OCT) showed iris bombe, occlusion of drainage angle. (c) AS OCT Post Nd: YAG peripheral iridotomy (PI) shows reduced iris bombe but there is still occlusion of drainage angle. (d) AS OCT Post-surgical iridectomy shows flattened iris with open angle and resolved iris bombe.

axis-symmetrically into the anterior chamber, consistent with Figure 2b–d.

The simulations show that the angle between the iris and cornea, denoted as θ, decreases as the ΔP across the iris increases, and for ΔP above a threshold, denoted ΔPc, the iris makes contact with the cornea leading to acute angle closure (Fig. 4a). For the model parameters, this critical pressure difference is calculated to be $\Delta Pc = 0.3871$ mmHg for the normal iris elastic properties. This value is slightly larger than the pressure differences assumed in other modelling studies.[1,4] Decreasing the Young's modulus by a factor of 10 ($E = 0.96$ kPa), the critical pressure difference for an atrophic/floppy iris takes a much smaller value $\Delta Pc = 0.0385$ mmHg.

The predicted curve of ΔP versus PI radius r (Fig. 4b) shows the critical pressure difference between the anterior and posterior chambers decreases as the radius of the PI increases. The predicted minimal PI radius can be as large as 32.27 μm for a normal iris. A 10-fold decrease in the Young's modulus of the iris as predicted in uveitic eyes results in the critical area of the PI increasing by approximately a factor of three, predicting the minimal PI radius to be larger at 57.47 μm. In addition, variations in the viscosity of the aqueous demonstrate an increase in the critical area of the PI (Table 2).

Uveitic glaucoma is a condition, first described in 1813 by Joseph Beer,[5] where ocular inflammation causes a persistent or recurrent elevation in IOP. It is relatively uncommon; however, in chronic uveitis, the prevalence can be as high as 46%.[6] Both secondary open angle and closure mechanisms are implicated, with a multi-factorial pathogenesis. Secondary angle closure glaucoma usually presents acutely and therefore requires immediate antiglaucoma medical therapy to reduce the IOP. If the mechanism is pupil block, the standard practice is Nd:YAG PI. During episodes of uveitis, multiple mechanisms can increase the resistance to aqueous outflow leading to an elevated IOP.

In our case, we believe multiple factors contributed to the development of AACG. She had damaged/scarred trabecular meshwork and 270° of peripheral anterior synechiae (PAS) implying she had elements of both secondary open and closed angle glaucoma prior to having tube surgery. She went on to develop AACG on two occasions despite having a functioning tube. Both were due to the formation of 360° PS causing pupil block, iris bombe and resulting in occlusion of the Ahmed valve and angle closure in a pseudophakic eye. There are other factors in this case which we believe contributed to the failure of the Nd:YAG PI. The increased viscosity of the aqueous due to the chronic uveitis, increases the resistance in the aperture of the PI, reducing the flow through it. Coupled with a floppy, atrophic iris, the pressure required to cause the iris bombe is similar to blowing up a balloon, an initial high amount of pressure is needed followed by minimal effort.

In our patient, despite a patent PI, she developed AACG. The literature reports high failure rates in uveitis;[2,3] however, the size of the PI is not determined in these studies. Furthermore, there are no reports in the literature documenting the average size of PI created by Nd:YAG, possibly as this is variable and often operator dependent.

Fleck *et al.* reported cases of primary AACG despite patent Nd:YAG PI, which have been thought to be due to inadequate size of PI.[1] To determine the optimum size of PI required to prevent AACG, Fleck *et al.* constructed a mathematical model that predicted a minimal size of iridotomy of 10–15 microns based on an estimate of the trans-iris pressure difference, which is difficult to measure *in vivo*. Their mathematical model was based on the assumptions

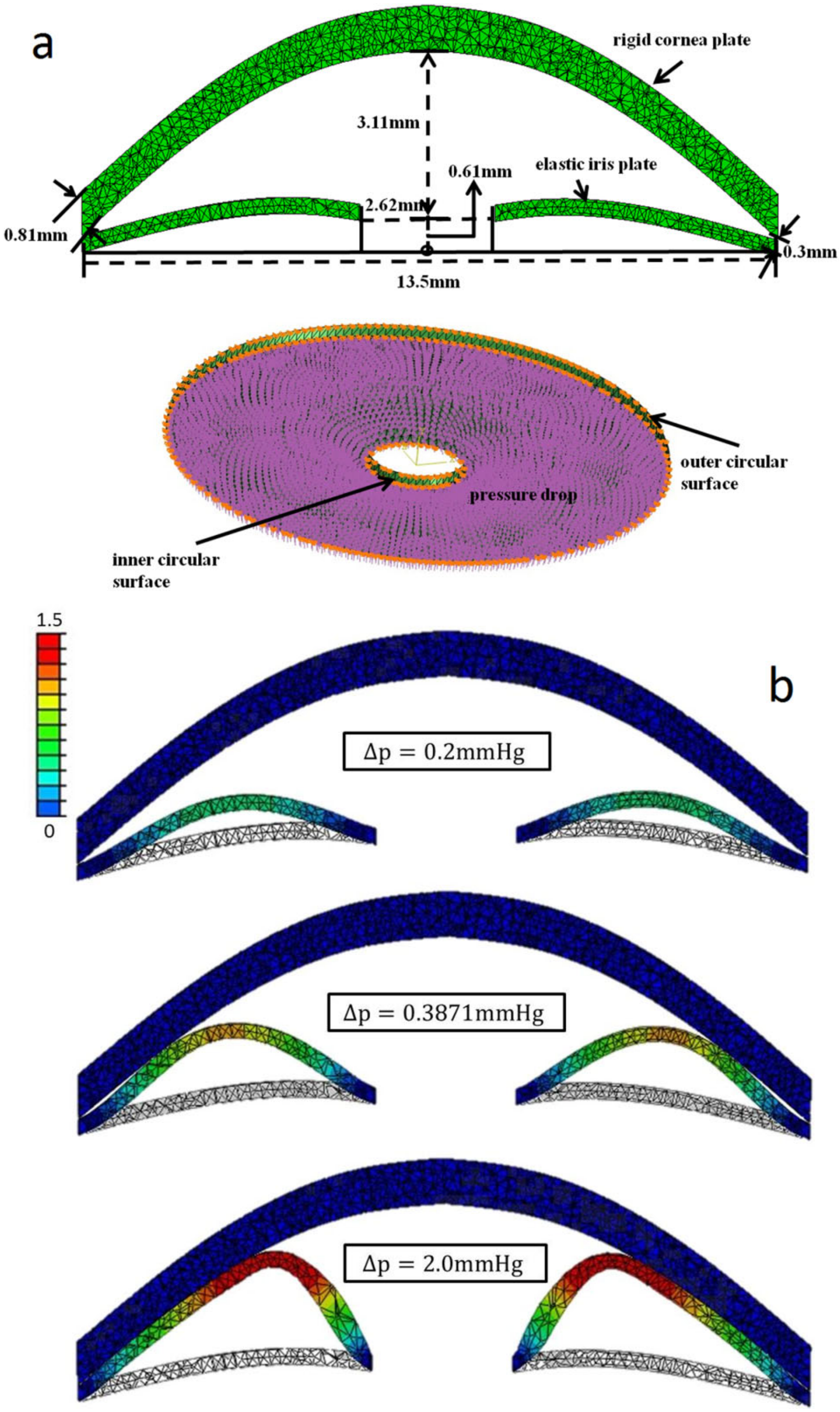

Figure 3. Mathematical model: the geometry of the model has been scaled from the UBM image (Fig. 2a): (a) the iris modelled as a deformable elasticated disc with a central circular aperture,[10] the cornea and the lens are assumed to be rigid and impermeable. (b) Computations of the iris shape as a function of trans-iris pressure difference were conducted in the Finite Element software ABAQUS 6.13 (SIMULIA, Providence, RI), assuming the iris to be of uniform initial thickness h with elastic moduli listed in Table 1. The elastic stiffness of the iris tissue is represented by its Young's modulus, E, and its compressibility by its Poisson ratio, ν. Three snapshots of the iris deformation as a function of the pressure difference ΔP. The colour shading indicates the displacement in the iris tissue.

of aqueous viscosity to be equal to the viscosity of water, aqueous flow rate = 2 µl/min and iris thickness of 50 microns. However, based on clinical cases and experience, they recommended that the minimal size iridotomy required to prevent AACG should be at least 150–200 microns in diameter, incorporating a large safety margin.

In our patient, the size of the initial Nd:YAG PI was estimated to be 195 × 110 microns (Fig. 1c), which suggests that a PI size greater than Fleck *et al.*'s recommendation of 150–200 microns is required in a uveitic eye. In our model, we improved on their approach by predicting the trans-iris pressure difference using computational solid mechanics. Assuming the viscosity of the aqueous in the eye to be the same as plasma and the iris stiffness to be comparable to a normal iris, the minimum diameter of PI predicted by our model is 64.56 microns. This critical value is significantly less than the Nd: YAG PI size used on our patient, explaining its initial success in reducing the patient's IOP. However, due to the ongoing pathology of the disease, the IOP eventually increased again, and a further surgical PI was required to control the IOP. The model demonstrates that this further increase in IOP may be attributed to a decrease in the iris stiffness and/or an increase in the aqueous viscosity.

To account for changes in viscosity, we suggest a safety factor of three from the critical size predicted for a 10-fold decrease in the iris stiffness (E = 0.96 kPa) and plasma aqueous viscosity of 1.6 mPas, predicted as a PI radius of 114.96 microns. Therefore, in order to prevent AACG in patients with uveitis-related iris bombe, we recommend a diameter of PI of at least 300–350 microns. For a PI of the size 300 microns, this would be equivalent to 10 Nd:YAG PI of similar size to that conducted on our patient

Table 1. Parameters used in the mathematical model

Parameter	Symbol	Value
Young's modulus of normal iris	E	9.6 kPa[7]
Young's modulus of atrophic/floppy iris	E	0.96 kPa
Poisson ratio of iris	ν	0.48
Thickness of iris	h	0.3 mm
Viscosity of aqueous	η	1.6 mPa s[8]
Production flux of aqueous	Q	2.75 µl/min[9]

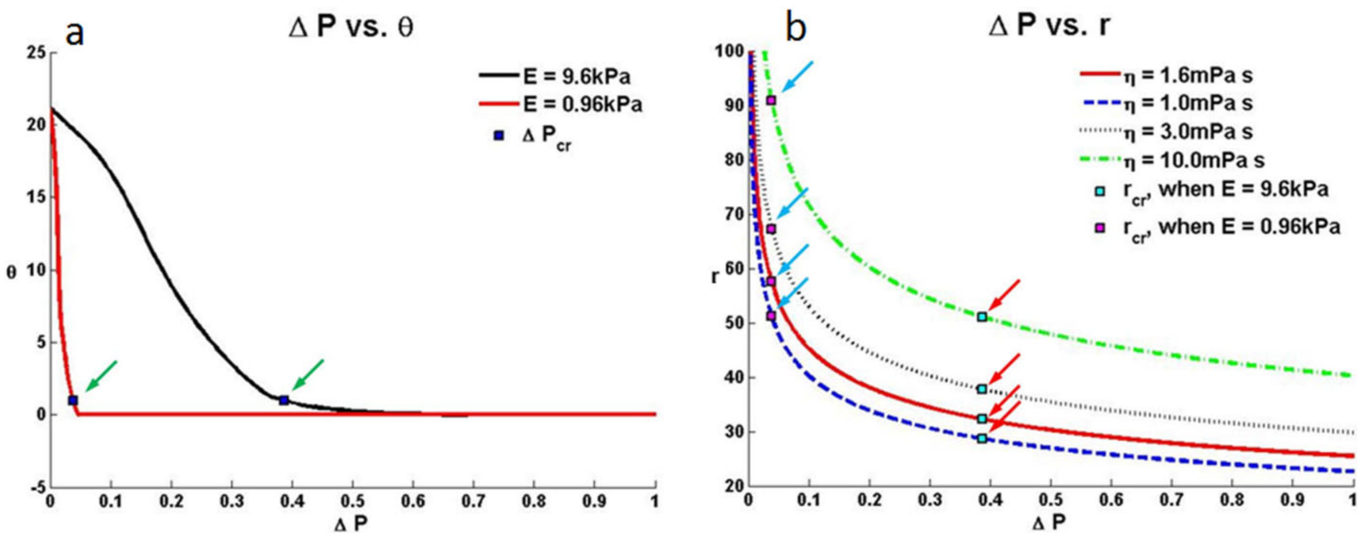

Figure 4. (a) ΔP versus θ: predicted acute angle between the cornea and the iris as a function of pressure difference for E = 9.6 kPa and E = 0.96 kPa. (b) ΔP versus r: predicted radius of peripheral iridotomy (PI) as a function of the pressure drop for E = 9.6 kPa and E = 0.96 kPa with corresponding prediction for η = 1.0 mPa s, 1.6 mPa s 3.0 mPa s and 10.0 mPa s.

Table 2. Minimal PI radius as a function of the viscosity of aqueous

Young's modulus of iris, E (kPa)	Viscosity of aqueous, η (mPa s)	Critical pressure difference, ΔPc (mmHg)	Minimal radius of PI, r (µm)	Minimal area of PI (×10^3 µm^2)
9.6	1.0	0.3871	28.69	2.58
	1.6		32.27	3.27
	3.0		37.77	4.48
	10.0		51.03	8.18
0.96	1.0	0.0385	51.10	8.20
	1.6		57.47	10.37
	3.0		67.25	14.21
	10.0		90.88	25.94

(195 × 110 microns). For a diameter of 350 microns, this would equate to 20 Nd:YAG PIs.

The mathematical model constructed is deliberately simple and has limitations, with several of the model parameters, excluding the thickness of the iris, to be based on estimated values from the literature.[7–10] Parameters such as the aqueous viscosity and the iris stiffness and thickness will be dependent on the pathology of the disease and these values can only be estimated.

This case highlights the therapeutic challenge of managing a patient with uveitic glaucoma due to the complex relationship between IOP and inflammation. The model showed the increasing aqueous viscosity and the atrophic/floppy properties of the iris, as postulated in a uveitic eye, requires a larger diameter of PI than previously recommended by Fleck *et al*. of 150–200 microns. Based on our model, we suggest a minimum diameter of PI to be 300–350 microns to prevent AACG in a uveitic eye, suggesting a surgical approach rather than Nd:YAG PI may be more beneficial for these complex patients.

Umiya Agraval MBChB,[1] Nan Qi MSc,[2] Peter Stewart PhD,[2] Xiaoyu Luo PhD,[2] Graeme Williams FRCP(Ed),[1] Alan Rotchford FRCOphth[1] and Kanna Ramaesh FRCOphth[1]
[1]Tennent Institute of Ophthalmology, Gartnavel General Hospital and [2]Department of Mathematics and Statistics, University of Glasgow, Glasgow, UK
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