

**Intraocular pressure monitoring using an intraocular sensor before and after glaucoma surgery**

Edward Saxby<sup>1</sup>, Kaweh Mansouri<sup>2,3</sup>, Andrew J. Tatham<sup>1</sup>

1. Princess Alexandra Eye Pavilion, University of Edinburgh, UK
2. Glaucoma Research Centre, Montchoisi Clinic, Swiss Visio, Lausanne, Switzerland
3. Department of Ophthalmology, University of Colorado School of Medicine, Denver, CO, USA

Corresponding Author:

Andrew J. Tatham

Princess Alexandra Eye Pavilion

45 Chalmers Street

Edinburgh EH3 9HA

Tel: 0131 536 3753

andrewjtatham@gmail.com

Disclosures:

ES: None; AJT: Consultant (Allergan, Santen, Thea); Honoraria (Allergan, Heidelberg Engineering, Santen, Glaukos, Novartis); Grant support (Allergan, Novartis); KM: Consultant (Implandata); Honoraria (Santen, Thea, Allergan)

**Précis**

The eyemate-IO sensor has been shown to be a safe, well tolerated and efficacious technology that can be implanted in patients undergoing cataract surgery and allows continual IOP monitoring before and after glaucoma surgery.

## **Abstract**

### **Purpose**

Intraocular pressure (IOP) is the only modifiable risk factor for glaucoma, with evidence from landmark randomized controlled trials demonstrating visual field preservation with IOP reduction. Over recent years, the use of remote sensors has formed an increasingly important component of the management of chronic diseases. During the COVID-19 pandemic, the ability to remotely monitor IOP proved particularly useful when public stay at home orders have been in place.

### **Patients and Methods**

This report describes the first case of glaucoma surgery in a patient who had previously received an eyemate-IO implant. The eyemate-IO (Implandata Ophthalmic Products) is an implant for intraocular pressure (IOP) monitoring placed in the ciliary sulcus during cataract surgery.

### **Results**

Remote IOP monitoring enabled the clinician to identify sustained high IOP readings and the need for glaucoma surgery. Post-operatively, response to treatment could be monitored to ensure sufficient long-term IOP control.

### **Conclusions**

The eyemate-IO implanted during cataract surgery in this patient provided valuable remote continuous IOP information that guided timely glaucoma surgical interventions for poorly controlled IOP.

### **Key words**

- Telemetry
- Monitoring
- Sensor
- Telemedicine
- Eyemate

## Introduction

Intraocular pressure (IOP) is the only modifiable risk factor for glaucoma, with evidence from landmark randomized controlled trials demonstrating visual field preservation with IOP reduction.<sup>1,2</sup> For example, the United Kingdom Glaucoma Treatment Study (UKGTS) reported a 41% lower incidence of visual field progression over 2 years in patients treated with latanoprost compared to placebo, with an average IOP reduction of 3.8 mmHg in the treatment group.<sup>1</sup> Nevertheless, conventional methods of IOP assessment have limitations, especially as they need to be performed in the office, and are influenced by biomechanical properties of the cornea. Infrequent office hour IOP measurements do not fully characterize fluctuations in IOP, which is a highly dynamic parameter, and may make it difficult to accurately determine risk of progression and response to treatment.<sup>3</sup> When treatment is instigated, any difference in IOP is often assumed to be due to treatment effect; however, due to background IOP fluctuations and measurement imprecision, it has been estimated that as much as a 7mmHg reduction in IOP is needed for 95% certainty of therapeutic effect.<sup>4</sup> More frequent IOP assessment may better characterize risk of progression and response to treatment, but can only feasibly be delivered through remote monitoring.

The use of sensors to monitor health forms an important component of the management of chronic diseases including diabetes and systemic hypertension, offering the potential for improved patient engagement with probable positive effects on treatment adherence.<sup>5</sup> Recently an implantable device for continual IOP monitoring, the eyemate-IO (Implandata Ophthalmic Products GmbH, Hannover, Germany), has been developed with affirmative safety and accuracy results reported in multicenter observational studies.<sup>6,7</sup> The eyemate-IO is a ring-shaped foldable sensor with an outer diameter of 11.3, 11.7 or 12.1 mm inserted into the ciliary sulcus during cataract surgery (Figure 1). The device houses a microelectromechanical system application specific integrated circuit (ASIC) comprising pressure and temperature sensors and a telemetry unit.<sup>8</sup> The ASIC is bonded to a gold microcoil and encapsulated in a ring of silicone rubber material with 4 haptics to provide stability in the sulcus. The eyemate-IO has a thickness of 0.5mm around the microcoil and 0.9mm at the ASIC. An external handheld reader (MESOGRAPH) provides a high frequency field wireless power supply to the implant and displays and stores IOP readings when held within 5 cm of the eye by the patient. The device can store up to 3000 IOP readings, which can be uploaded to a secure web-based platform allowing remote access by the clinician. IOP

readings from the eyemate-IO have shown strong concordance with intraocular manometry over a wide range of pressures and good agreement with Goldmann applanation tonometry.<sup>7,8</sup>

This report describes the first case of glaucoma surgery in a patient who had previously received an eyemate-IO implant. Remote IOP monitoring enabled the clinician to identify sustained high IOP readings and the need for glaucoma surgery. Post-operatively, response to treatment could be monitored to ensure sufficient long-term IOP control. The ability to remotely monitor IOP proved particularly useful during the COVID-19 pandemic, when public health stay at home orders were in place.

### **Case Report**

A 75-year-old male with glaucoma was referred to the glaucoma service in October 2019. He had originally been diagnosed with primary open angle glaucoma in 2008 with peak IOPs prior to treatment of 27 mmHg in each eye. His IOPs had initially been well controlled but he had eventually required four concurrent anti-glaucoma medications (bimatoprost, timolol, brinzolamide and brimonidine). He had undergone cataract surgery to the right eye but had been poorly adherent to treatment and lost to follow up due to non-attendance.

The main reason for him seeking a consultation was that he had noticed a large change in vision in his left eye. On examination, he had a dense cataract with visual acuity of hand movements, compared to a best corrected visual acuity of 20/20 in the right eye. He also reported having red, gritty eyes for several years due to ocular surface disease secondary to drop toxicity. IOPs were 25 mmHg in the left eye and 18 mmHg in the right, with open angles. Central corneal thicknesses were 472  $\mu\text{m}$  and 487  $\mu\text{m}$  in right and left eyes, with corneal hysteresis of 9.0 and 8.5 mmHg in right and left eyes. Due to the dense cataract and limited fundal view, reliable automated perimetry was not possible in the left eye but was normal in the right. B-scan ultrasound showed no abnormality. Axial lengths were 23.29 mm and 23.20 mm in right and left eyes.

The patient was switched to preservative free medications and urgent cataract surgery was arranged. Immediately prior to surgery, using preservative free latanoprost, timolol and brinzolamide, IOP remained suboptimal at 25 mmHg in the left eye. Consideration was given to combining cataract surgery with a subconjunctival filtering procedure or trabecular meshwork bypass procedure, but it was decided to proceed with cataract surgery alone as the visual field in the right eye was normal and the severity of glaucoma in the left eye was not certain. The possibility of simultaneous insertion of an eyemate-IO sensor was discussed to enable the patient to obtain IOP measurements at home and allow closer monitoring of treatment effect. The patient was happy to proceed and uncomplicated surgery was performed

with the EYEMATE-IO sensor placed in the ciliary sulcus (Figure 1). A 11.3 mm sensor was injected through a 3.2 mm temporal clear corneal incision.

On post-operative day one, unaided visual acuity was 20/30 in the left eye and IOP using Goldmann applanation tonometry was 19mmHg. He was confirmed to have moderate glaucoma in the left eye (Figure 2). Over subsequent weeks, the patient took daily IOP measurements using the MESOGRAPH (Figure 3). His IOP had been high prior to surgery and this continued despite ceasing postoperative topical steroids and continuing with preservative free latanoprost, timolol and brinzolamide. There was no intraocular inflammation or signs of uveal or iris chaffing from the implant and the angle remained open. Acetazolamide was prescribed and a reduction in IOP was observed with IOP fluctuating between 19 and 25mmHg (Figure 3'A'). Due to difficulties in attending the clinic due to the COVID-19 pandemic, the patient continued on acetazolamide and IOP was monitored remotely. The patient was review in May 2020, and though there was no indication of recent glaucoma progression, due to sustained high IOP, a left 0.2 mg/ml mitomycin-C trabeculectomy was performed, with 2 releasable 10-0 nylon sutures used to secure the scleral flap (Figure 3'B'). Postoperatively, the patient stopped all anti-glaucoma medication and used dexamethasone 0.1% preservative free drops 2 hourly. He was seen weekly, with the eyemate-IO enabling remote monitoring between visits. Immediately after surgery, there was a spike in IOP and so the releasable sutures were removed at week 1 and week 3 (Figure 3'C'). Though with removal of the final releasable suture, IOP fell to 11mmHg, there was an aggressive wound healing response, perhaps related to the history of ocular surface disease. Three 5-fluorouracil augmented needling procedures were performed (Figure 3'D'). Each needling produced an immediate reduction in IOP but the IOP quickly increased, with eventual failure of the trabeculectomy. The patient was restarted on anti-glaucoma medications, including oral acetazolamide and the decision was made to proceed with a glaucoma drainage device (GDD) implantation with a PAUL Glaucoma Implant (PGI, Advanced Ophthalmic Innovations, Singapore).<sup>9</sup> The PGI is a shunt manufactured from medical-grade silicone, with a plate area of 342 mm<sup>2</sup>, external tube diameter of 467 µm and internal diameter of 127 µm. Surgery was augmented with 0.4mg/ml MMC due to the aggressive wound healing response seen following trabeculectomy. The implant was sited superotemporally 10mm posterior to the limbus and inserted into the anterior chamber through a 25G needle entry track, with a 7-0 polypropylene intraluminal stent used for temporary occlusion. The intraluminal stent extended into the portion of the tube in the

anterior chamber. The limbal portion of the tube was covered with a donor patch of pericardium. No ligation suture was used.

Figure 4 shows the eyemate-IO recordings before and after GDD surgery. Following surgery and eventual removal of the intraluminal stent, IOP fell to an average of 20mmHg off medication. The eyemate-IO measurements were verified by Goldmann applanation tonometry at each face-to-face visit. Despite previous poor adherence to treatment, the patient showed a sustained high level of engagement with self IOP monitoring, recording an average of 20 IOP readings per week over the 12-month follow up period (Figure 5). Visual field and OCT examination at the most recent visit showed no evidence of significant progression despite the surgical interventions and complex postoperative course.

### **Discussion**

This case illustrates use of an intraocular IOP sensor to monitor IOP changes before and after glaucoma surgery, demonstrating the feasibility of obtaining multiple IOP readings remotely. Patients undergoing filtering glaucoma surgery require multiple visits postoperatively, and although in this case, the frequency of postoperative visits was not reduced, the ability to monitor IOP remotely allowed increases in IOP following surgery to be identified and appropriate action taken. The patient could then be contacted, and a face-to-face review arranged earlier than otherwise planned. In one instance, when high IOP was identified the patient was instructed to alter their medication, and the response to treatment change was also observable by remote monitoring.

This patient had uncontrolled IOP prior to cataract surgery and implantation of the eyemate-IO and subsequently required trabeculectomy surgery. Unfortunately, he had a complex post-operative course, with early surgical failure. The trabeculectomy failed despite augmentation with 0.2mg/ml MMC at the time of initial surgery, early removal of scleral flap sutures, and three 5-fluorouracil needling procedures.

The reasons for the failure of the trabeculectomy are uncertain, but likely related to a propensity to wound healing due to the previously noted ocular surface disease and conjunctival hyperemia due to drop toxicity. Previous studies have shown that prolonged exposure to multiple glaucoma medications produces inflammatory changes in the subepithelial conjunctiva,<sup>10</sup> while others have reported a higher rate of trabeculectomy failure associated with long-term use of multiple glaucoma medications<sup>11</sup>, perhaps due to elevated levels of inflammatory mediators or macrophage infiltration.<sup>12</sup> We withdraw preserved glaucoma medications prior to surgery but could have also used a low potency topical steroid pre-operatively.<sup>11</sup>

Though the patient in the present case had no apparent problems during cataract surgery and eyemate-IO insertion, it should be considered whether the eyemate -IO may have contributed to failure of the trabeculectomy. It is conceivable that the larger incision size, longer surgery duration, or greater iris manipulation that may occur with implantation of the eyemate-IO could increase the risk for inflammation and subsequent wound healing. Even uncomplicated cataract surgery can be associated with anterior chamber flare up to 6 months after surgery, likely reducing the chances of success of trabeculectomy surgery performed during this period.<sup>13</sup> Adverse events reported with eyemate-IO in the ARGOS-02 study included uveitis, pigment dispersion, and one case of intractable IOP increase requiring trabeculectomy.<sup>7</sup> The cause of intractable IOP increase in the ARGOS-02 study patient was not clear but it could not be ruled out that this was due to pigment dispersion due to inadvertent iris manipulation during implantation.

Though the trabeculectomy failed, the eyemate-IO allowed accurate identification of IOP reductions with each intervention and subsequent increase in IOP as the interventions failed. It also provided insight into the timing of IOP increases, for example, showing each needling procedure was associated with an increase in IOP to pre-needling levels in less than 7 days. The eyemate-IO was also able to track the successful reduction in IOP with GDD surgery and confirm a sustained IOP reduction, which with further follow up could potentially reduce the frequency of clinic visits needed.

Office visits for IOP assessment are time consuming, expensive and inconvenient for patients. The invention of newer 'smart' technologies including IOP sensors can provide abundant data, achieving a better understanding of the effects of treatment. It is also likely that self-monitoring may increase patient engagement with treatment leading to improved adherence. The COVID-19 pandemic has redefined the landscape in which glaucoma care must be delivered, prompting acceleration of development devices and applications for home glaucoma monitoring.<sup>14</sup> As has been recently described by Mansouri et al<sup>15</sup>, the use of intraocular sensors to remotely monitor IOP, during the pandemic, has been shown to be both feasible and reliable. By checking our patients IOP with GAT during clinic visits, we were able to show that the eyemate-IO device was collecting accurate pressure data. The ARGOS-2 trial<sup>7</sup> highlighted the concordance of the eyemate-IO IOP measurements with GAT IOP measurements with an overall Cronbach alpha of 0.0882 (95% confidence interval [CI] 0.835, 0.915) and an intraclass correlation coefficient ICC(3,k) of 0.783 (95% CI 0.743, 0.817). Confidence in the accuracy of the eyemate-IO data allowed us to identify a patient

who was failing medical and surgical treatments and prompting sooner recall to a face-to-face clinic.

Due to the ease of use, the patient was able to perform multiple IOP recordings per day, reducing possible IOP discrepancies due to diurnal variation, on average performing over 20 IOP readings per week. Relying on office IOP assessment alone would have provided far fewer measurements. Furthermore, the sensor identified IOP fluctuations that would have otherwise gone un-recognized that may be associated with treatment and could potentially affect ongoing management. We were interested to see a spike in IOP immediately following trabeculectomy, perhaps due to cessation of IOP-lowering medication, tight scleral flap closure, post-operative inflammation or undetected micro-hyphema. The Collaborative Initial Glaucoma Treatment Study found that an early post-trabeculectomy IOP spike of  $\geq 5$ mmHg above baseline was not associated with subsequent visual field loss but was associated with significantly higher IOP during long term follow up.<sup>16</sup> Findings such as this may well be missed with usual clinic based follow up.

The eyemate-IO sensor has been shown to be a safe, well tolerated and efficacious technology that allows continual IOP monitoring and can be simply implanted in glaucoma patients undergoing cataract surgery. The device was particularly useful to track IOP changes in this patient with poorly controlled IOP undergoing glaucoma surgery and will enable long-term monitoring to ensure the GDD remains effective.

## References

1. Garway-Heath DF, Crabb DP, Bunce C, Lascaratos G, Amalfitano F, Anand N, Azuara-Blanco A, Bourne RR, Broadway DC, Cunliffe IA, Diamond JP, Fraser SG, Ho TA, Martin KR, McNaught AI, Negi A, Patel K, Russell RA, Shah A, Spry PG, Suzuki K, White ET, Wormald RP, Xing W, Zeyen TG. Latanoprost for open-angle glaucoma (UKGTS): a randomised, multicentre, placebo-controlled trial. *Lancet*. 2015 Apr 4;385(9975):1295-304.
2. Leske MC, Heijl A, Hyman L, Bengtsson B, Dong L, Yang Z; EMGT Group. Predictors of long-term progression in the early manifest glaucoma trial. *Ophthalmology*. 2007 Nov;114(11):1965-72.
3. Aptel F, Weinreb RN, Chiquet C, Mansouri K. 24-h monitoring devices and nyctohemeral rhythms of intraocular pressure. *Prog Retin Eye Res*. 2016 Nov;55:108-148.
4. Rotchford AP, King AJ. Repeatability of measurements of effectiveness of glaucoma medication. *Br J Ophthalmol*. 2012 Dec;96(12):1494-7.
5. Beck D, Tatham AJ. Self-monitoring of intraocular pressure in glaucoma. Expert review of *Ophthalmology*. 2019.14(4-5):219-225.
6. Koutsonas A, Walter P, Roessler G, Plange N. Implantation of a novel telemetric intraocular pressure sensor in patients with glaucoma (ARGOS study): 1-year results. *Invest Ophthalmol Vis Sci*. 2015 Jan 22;56(2):1063-9.
7. Choritz L, Mansouri K, van den Bosch J, Weigel M, Dick HB, Wagner M, Thieme H; ARGOS study group. Telemetric Measurement of Intraocular Pressure via an Implantable Pressure Sensor-12-Month Results from the ARGOS-02 Trial. *Am J Ophthalmol*. 2020 Jan;209:187-196.
8. Todani A, Behlau I, Fava MA. Intraocular pressure measurement by radio wave telemetry. *Invest Ophthalmol Vis Sci*. 2011; 52: 9573–9580.
9. Koh, V, Chew P, Triolo G, Lim KS, Barton K, PAUL Glaucoma Implant Study Group. *Ophthalmology Glaucoma* 2020;3(5):350-359.
10. Broadway DC, Grierson I, O'Brien C, *et al*. Adverse effects of topical antiglaucoma medication. I. The conjunctival cell profile. *Arch Ophthalmol* 1994;112:1437–45.
11. Broadway DC, Grierson I, O'Brien C, Hitchings RA. Adverse effects of topical antiglaucoma medication. II. The outcome of filtration surgery. *Arch Ophthalmol*. 1994 Nov;112(11):1446-54.
12. Chong RS, Jiang YZ, Boey PY, Yu SJ, Htoon HM, Aung T, Khaw PT, Wong TT. Tear cytokine profile in medicated glaucoma patients: effect of monocyte chemoattractant protein 1 on early posttrabeculectomy outcome. *Ophthalmology*. 2010 Dec;117(12):2353-8.

13. Siriwardena D , Kotecha A , Minassian D , *et al.* Anterior chamber flare after trabeculectomy and after phacoemulsification. *Br J Ophthalmol* 2000;**84**:1056–7.
14. Gedde SJ, Schiffman JC, Feuer WJ, Herndon LW, Brandt JD, Budenz DL; Tube versus Trabeculectomy Study Group. Treatment outcomes in the Tube Versus Trabeculectomy (TVT) study after five years of follow-up. *Am J Ophthalmol.* 2012 May;153(5):789-803.e2.
15. Mansouri K, Kersten-Gomez I, Hoffmann EM, Szurman P, Choritz L, Weinreb RN. Intraocular Pressure Telemetry for Managing Glaucoma during the COVID-19 Pandemic. *Ophthalmol Glaucoma.* 2021 Feb 4:S2589-4196(20)30326-4.
16. Chen PP, Musch DC, Niziol LM. The effect of early post trabeculectomy intraocular pressure spike in the collaborative initial glaucoma treatment study. *J Glaucoma.* 2011;20(4):211-214.

ACCEPTED

## Figure Legends

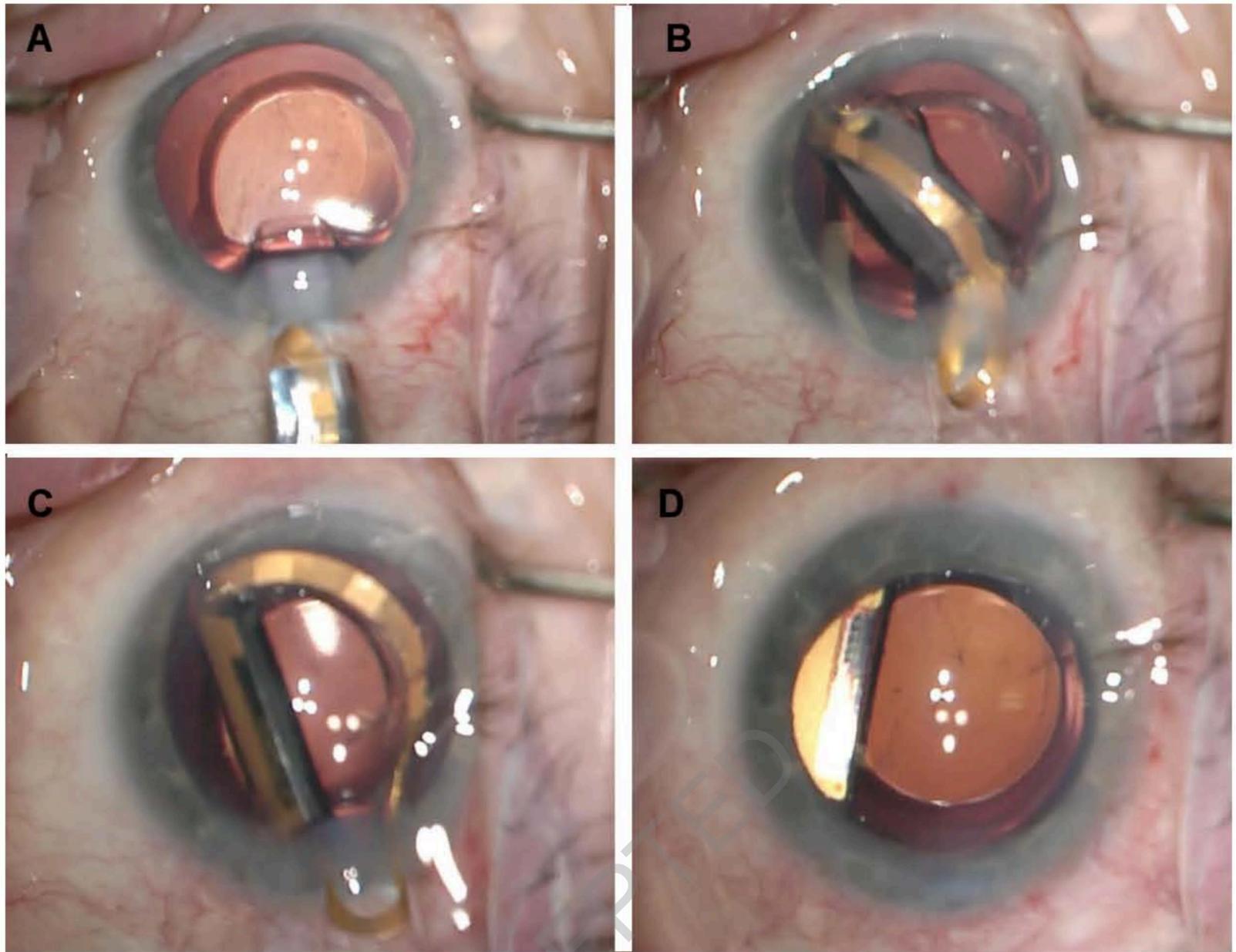
**Figure 1.** Insertion of the eyemate-IO intraocular pressure sensor in the left eye of patient at the conclusion of cataract surgery.

**Figure 2.** Standard automated perimetry (SAP) and optical coherence tomography (OCT) circumpapillary RNFL images for left eye following cataract surgery with eyemate-IO implantation. SAP mean deviation was -6.36 dB and average RNFL thickness was 60 microns.

**Figure 3.** Intraocular pressure measurements (IOP) obtained from the eyemate-IO. The patient had very high IOP so was commenced on oral acetazolamide (A), underwent trabeculectomy (B), trabeculectomy suture removal (C), and three needling procedures (D) but IOP remained high. The patient obtained 1,010 IOP measurements over an 8-month period.

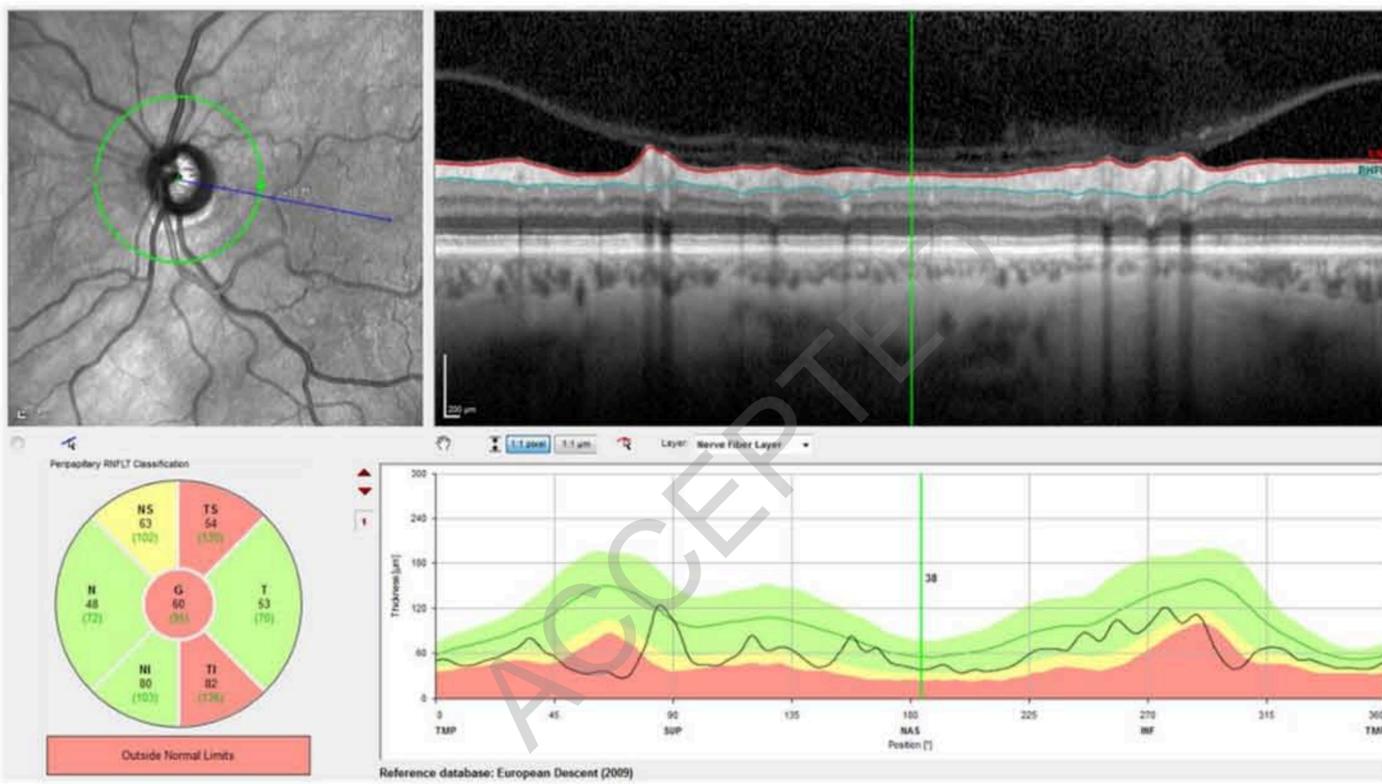
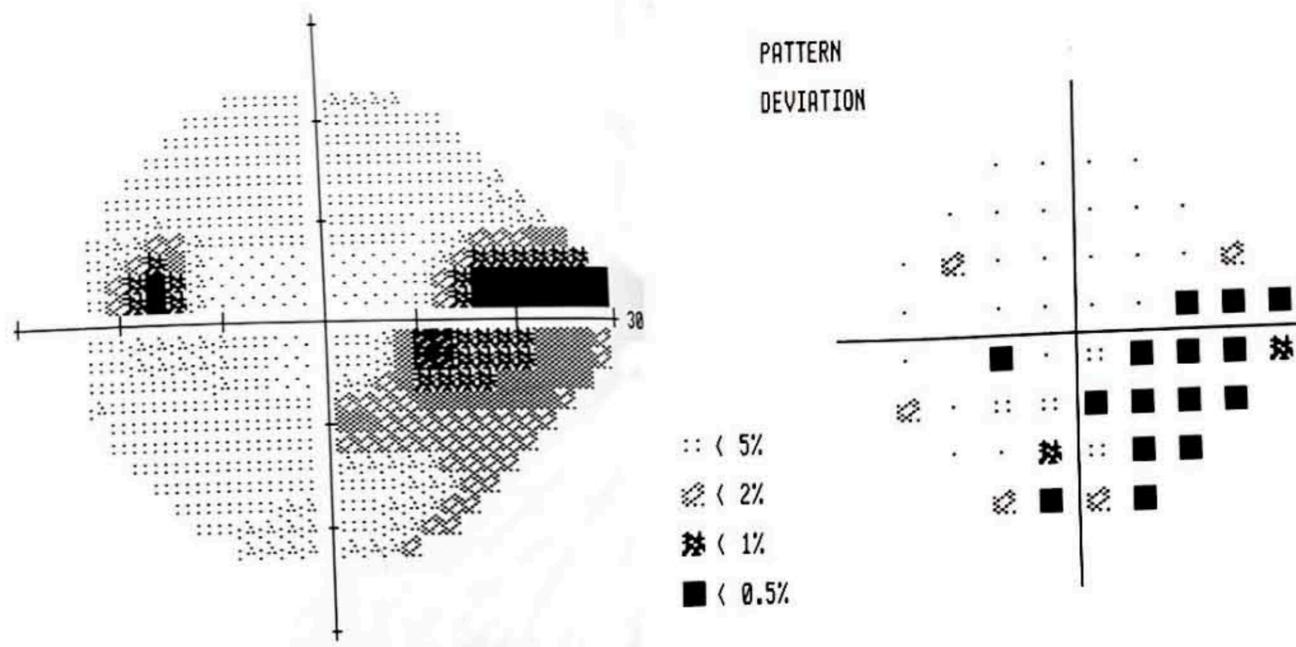
**Figure 4.** Intraocular pressure measurements (IOP) obtained from the eyemate-IO before and after glaucoma drainage device (GDD) surgery. Acetazolamide was commenced (A) but the patient was no longer able to tolerate it so GDD was performed (B). There was a dramatic reduction in IOP, which gradually increased over 6 weeks. The intraluminal stent suture was removed (C) which has resulted in a sustained IOP reduction.

**Figure 5.** Figure showing the number of IOP measurements taken by the patient using the eyemate-IO device each week for a 12-month period.



**FIGURE 1.**

ACCELERATED



**FIGURE 2.**

There are 723 measurements in the period 31.03.20 to 31.08.20. There are additionally 5 documented events.

Show events in chart

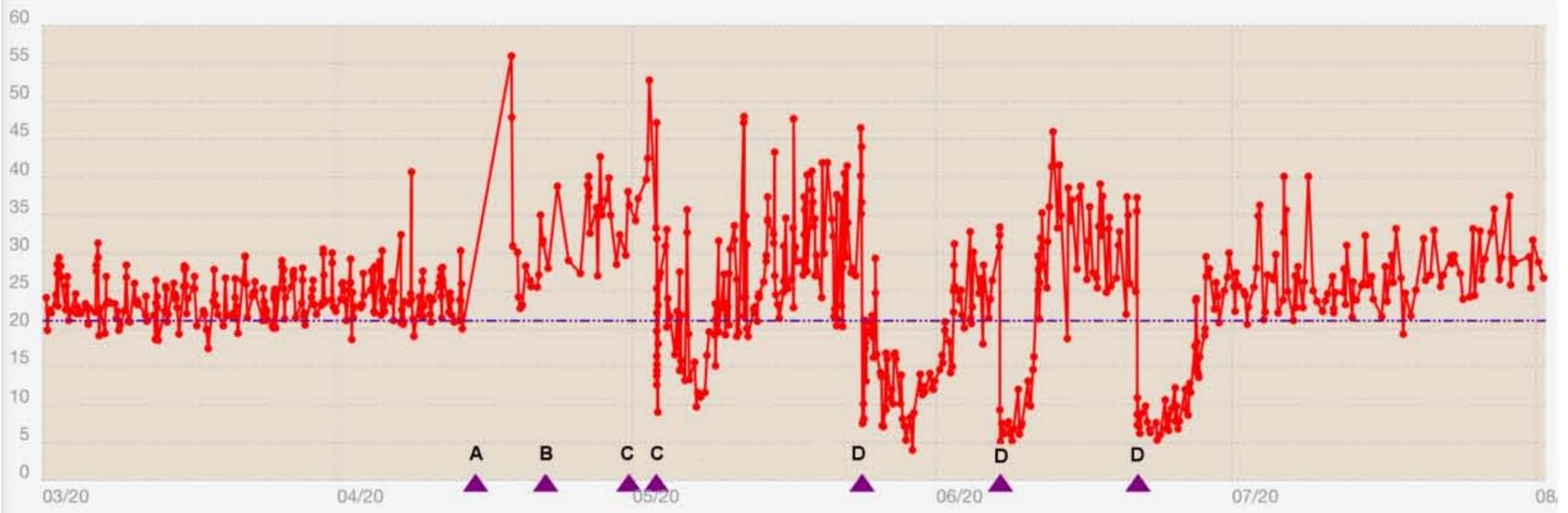


FIGURE 3.

ACCEPTED

There are 378 measurements in the period 31.08.20 to 23.01.21. There are additionally 3 documented events.

Show events in chart



**FIGURE 4.**

ACCEPTED



**FIGURE 5.**

ACCEPTED