TITLE: Systematic occlusion of shunts: control of early postoperative IOP and hypotony-related complications following glaucoma shunt surgery.

Eamon Sharkawi MD MRCP FRCOphth,[1] Justyna D Oleszczuk MD,[1] Cyrielle Bela MD,[1] Farid Achache MD,[1] Paul H Artes PhD[1,2] Keith Barton MD FRCP FRCS FRCOphth,[3] and Ciara Bergin PhD[1]

[1]Glaucoma unit, Jules-Gonin Eye Hospital, University of Lausanne, Switzerland.

[2]Ophthalmology and Visual Sciences, Dalhousie University

[3]Glaucoma Service and NIHR Biomedical Research Centre for Ophthalmology, Moorfields Eye Hospital NHS Foundation Trust and UCL Institute of Ophthalmology, London, UK

Data was presented in part, in the new ideas oral session, European Glaucoma Society, Copenhagen, June 2012.

Financial support: Unrestricted grant from: Fondation asile des aveugles, Switzerland.

No conflicting relationships exist for any author.

Running head: Systematic occlusion of shunts (SOS) study.

Corresponding author:

Dr Eamon Sharkawi MD MRCP FRCOphth

Address: Glaucoma unit, Jules Gonin Eye Hospital, Ave de France 15, Lausanne 1004, Switzerland

Tel: +41 21 626 8578, Fax: +41 21 626 8246

Email: eamon.sharkawi@fa2.ch

ABSTRACT

Objective

Evaluation of a protocol of total intraluminal occlusion of Baerveldt shunts and its effects on early postoperative IOP control and hypotony related complications.

Design

Non-comparative, prospective, interventional study.

Participants

Glaucoma patients were recruited to undergo Baerveldt shunt surgery. A total of 116 eyes of 112 patients were enrolled.

Intervention

During shunt implantation, aqueous outflow was restricted using an intraluminal occluding stent inserted through the entire tube length, with and without external ligation, to halt aqueous flow. Postoperatively, eyes underwent ligature laser suture lysis and partial or complete stent removals, at predetermined time intervals.

Main outcome measure

Loss of postoperative IOP control, categorized as transient or persistent hypotony (IOP≤5 mmHg) or hypertony (IOP>21 mmHg). Patients were followed up for one year.

Results

Preoperatively median IOP was 23 mmHg (mean 26 mmHg, SD 12 mmHg), median number of glaucoma medications was 3.0 (mean 3.0, SD 1.2). During year one, laser suture lysis was

performed in 30 eyes (26%) and stent removal in 93 eyes (80%), (23 partial; 70 complete). There was one case of transient hypotony, no cases of persistent hypotony, 10 of transient hypertony and three of persistent hypertony. Nine eyes had IOP ≤5 mmHg at one or more time points and hypotony related complications occurred in 8 eyes (7%). At one year, median IOP was 12 mmHg (mean 13 mmHg, SD 4 mmHg) with a median of 1.0 glaucoma medications (mean 1.1, SD 1.3). The cumulative probability of failure during the first 12 months follow-up was 6% (n=7). Overall postoperative complications occurred in 11 eyes (9%).

Conclusion

The surgical and postoperative protocol resulted in controlled, step-wise reductions of IOP with low rates of hypotony and related complications.

INTRODUCTION

Traditionally, aqueous shunts have been reserved for patients with recalcitrant glaucoma or for those in whom previous filtration surgery had failed.[1,2] The Tube Versus Trabeculectomy (TVT) study highlighted the greater efficacy of shunt implantation compared with trabeculectomy in eyes with previous surgery (although mean IOP was similar, significantly lower failure rates were found with Baerveldt tubes at years 1, 3 and 5).[3,4] The primary TVT study is currently investigating the role of shunts as first line glaucoma surgery.[5] These reports support a larger role of aqueous shunts in glaucoma surgery.[3,5,6]

However, postoperative complication rates with shunts remain high.[4-29] Most early complications commence with postoperative hypotony resulting in choroidal effusions and/or haemorrhages, shallow or flat anterior chambers (AC) with or without induced aqueous misdirection, or maculopathy. With non-valved implants, hypotony usually results from the failure to adequately restrict aqueous outflow, and several surgical techniques have been introduced to reduce hypotony-related complications (HRCs). These include two-stage surgery,[7] dissolvable ligation sutures[7-11] with or without tube fenestration,[8,10,12,13] intraluminal rip cord (partial-length),[14-16] and intracameral C3F8 gas injection.[16-20]

In this paper, we demonstrate a technique of Baerveldt shunt implantation in which an occluding stent is inserted throughout the entire length of the silicone tube, with or without an external ligature. Postoperatively, the intraluminal outflow resistance can then be systematically adjusted according to a standardized protocol. We investigated whether this technique can improve control of intra-ocular pressure (IOP) and reduce the rates of hypotony and hypotony-related complications. We compared the data to those from the large multi-centre tube-shunt studies[4,18,19] as a benchmark of expected outcomes.[7,8,10,12-20,40]

METHODS

This was a prospective study of 116 eyes of consecutive patients enrolled between January 2009 and January 2011 from the Glaucoma Unit at Jules-Gonin Eye Hospital, Lausanne, Switzerland. The surgical methods of Baerveldt (350mm^2) tube implantation were standardized prior to enrolment, and performed by a single experienced glaucoma surgeon (ES). The 3.0 Supramid® suture (S. Jackson Inc. Alexandria, VA, USA) was used as an intraluminal occluding stent inserted through the full length of the silicone tube to halt aqueous flow. Postoperatively, outflow was increased using argon laser suture lysis (if a ligature had been applied intraoperatively) and through the staged removal of the intraluminal occlusive stent. The postoperative visits and interventions were determined by a predefined protocol, outlined below. All eyes underwent slit lamp biomicroscopy, visual acuity (VA), IOP measurements using Goldmann applanation tonometry, gonioscopy, and dilated fundus examination. Patients with previous aqueous shunt surgery or encircling band retinal surgery were excluded. Ethical approval was granted by Commission Cantonale d'Éthique, Vaud, Switzerland and all patients provided written informed consent.

Surgical Procedure

Baerveldt shunts were placed superotemporally using a 3-clock-hour conjunctival peritomy. The tube plate was placed under the bellies of the superior and temporal recti and secured to the sclera with 9.0 prolene sutures. The Supramid was inserted through the silicone tube until it reached the distal end, which was trimmed in a bevel up configuration. The stented distal tube was inserted into the AC through a tight scleral canal, created using a 25-gauge-needle, posterior to the limbus (figure 1A). Tubes were routinely left unligated. However, if aqueous was seen to exit at the shunt plate, a 10.0 nylon ligature suture was tied around the proximal stented tube to halt aqueous flow as a precautionary measure (figure 1A). Processed human pericardium

(Tutoplast® Pericardium, IOP Ophthalmics, Costa Mesa, USA) was used to cover the tube and a square 4x4 mm window was created over the proximal portion of the silicone tube, enabling argon laser suture lysis postoperatively (figures 1B, 1C). The free end of the Supramid was looped forward, away from the tube plate, tucked under the anterior end of the pericardial patch and sutured to the sclera using 10.0 nylon to ensure easy access of the occlusive stent post-operatively (figure 1B). Finally the conjunctiva was closed with 8.0 vicryl sutures, and subconjunctival cefuroxime and beclamethasone were administered. No viscoelastics were injected into the AC.

Postoperative protocol

Postoperative examinations were performed during study visits on day 1, week 1, 3, 6, month 3, 6 and 12, or more frequently if clinically indicated. Postoperative medications included unpreserved topical dexamethasone (Dexafree® UD 0.1%) 8 times daily and tapered over 6 weeks and ofloxacin (Floxal® UD, Bausch and Lomb, Zug, Switzerland) 4 times daily.

Postoperative adjustments to reduce intraluminal outflow resistance and IOP were performed according to the following time points:

- ≥ 4 weeks postoperatively: argon laser suture lysis (LSL) of the nylon ligature suture (when present), using a Hoskins lens.
- 6-12 weeks postoperatively: partial stent removal (P-SR), the occluding stent was retracted by 5 mm. This was only performed if IOP remained uncontrolled despite maximal medications.
- ≥12weeks postoperatively: complete stent removal (C-SR) was performed. In cases of neovascular glaucoma, uveitis or previous cyclodestructive procedures (risk factors for hypotony) P-SR was performed as a first procedure and followed by C-SR if required
- Stent removals were not performed when IOP dropped to ≤10 mmHg without glaucoma medications.

Occlusive stent removal

While occlusive stent removal (SR) can be performed at the slit lamp, all study SRs were performed under topical anaesthesia in the operating room. During this procedure, the anterior conjunctiva was incised over the Supramid 3.0 suture, which was then either retracted 5.0 mm and re-sutured to the anterior sclera (P-SR) or completely removed (C-SR). Balanced salt solution was injected into the AC in eyes with all SRs. Viscoelastic (0.05-0.1mls) was routinely injected into the AC of eyes undergoing C-SRs. The conjunctiva was sutured using 8.0 vicryl. Tobradex® (tobramycin, dexamethasone; Alcon, Switzerland) was prescribed 4 times daily and tapered over 4 weeks. IOP was measured at day 1, weeks 1 and 4, following stent removals.

Primary and secondary outcomes

Primary outcomes:

Loss of IOP control, occurring at any time points throughout follow up, was classified as:
Transient hypotony: IOP ≤5 mmHg on two consecutive visits ≥3 weeks and < 6 weeks apart.
Persistent hypotony: IOP ≤5 mmHg on two consecutive visits ≥6 weeks apart.
Transient hypertony: IOP >21 mmHg on two consecutive visits, ≥3 weeks and < 6 weeks apart.
Persistent hypertony: IOP >21 mmHg on two consecutive visits ≥6 weeks apart.

Secondary outcomes:

Failure was defined as: inadequate IOP control (IOP ≤5 mmHg OR >21 mmHg OR <20% reduction from baseline on 2 consecutive study visits after stent removal (or after 3 months – where stents were not removed before 6 months, reoperation for glaucoma, loss of light perception vision, or removal of the implant.

Success was defined as IOPs ≤21 mmHg and ≥5 mmHg and >20% reduction in IOP from baseline on 2 consecutive study visits after stent removal (or after 3 months - where stents were not removed before 6 months). Reoperation for glaucoma was defined as additional glaucoma surgery, such as an additional aqueous shunt or cyclodestruction. Post-operative interventions such as stent removal, needling procedures or laser suture lysis, were not considered glaucoma reoperations, whether performed in the OR or at the slit lamp.

Complications

Macroscopic hyphema was considered present when >1 mm blood was seen in the AC. Hypotony related complications were classified as: choroidal effusions/haemorrhage, shallow/flat AC and hypotony maculopathy. The presence of choroidal effusions and maculopathy were assessed by routine dilated fundus examination.

Statistical analysis

Analysis was performed using R version 2.15.1. Patients lost to follow-up were censored at their last visit. Missing data was assumed to occur at random, and the complete case approach was adopted. Since some of the variables reported here (e.g. IOP and VA) were not normally distributed, median and inter-quartile ranges (IQR) were reported. Mean and standard deviation (SD) were also included to allow comparison with previous studies.

RESULTS

A total of 116 eyes of 112 patients underwent Baerveldt shunt implantation, of these 104 eyes (90%) completed one-year of follow-up. Of the 12 patients who missed the one-year appointment, 4 attended later visits and 8 were lost to follow-up (figure 2). Fewer than 15% of follow-up appointments were missed.

Patient demographics and surgical outcomes are shown in table 1. Details of postoperative IOP throughout follow-up are presented in figure 3. The median preoperative IOP was 23 mmHg (mean 27 mmHg). A marked IOP reduction was noted at all time points after week 1 (figure 3). The median IOP at 12 months was 12 mmHg (mean 13 mmHg). None of the eyes had IOP ≤5 mmHg on postoperative day 1. Nine eyes (8%) experienced a postoperative IOP ≤5 mmHg at any study time point. This comprised of one patient with transient hypotony (lasting 3 weeks), and 8 patients with IOP ≤5 mmHg lasting between 2 and 8 days. Almost all eyes had a gradual and controlled reduction in IOP (figure 3). None of the eyes developed persistent hypotony. Ten eyes (9%) had transient hypertony (IOP >21 mmHg), and 3 eyes (3%) had persistent hypertony.

Of the 116 eyes, 38 eyes (33%) underwent tube ligation during shunt implantation. In 8 eyes the nylon sutures could not be located postoperatively because Tenon's capsule was too thick. The remaining 30 eyes underwent LSL on average 6.8 ± 3.1 weeks postoperatively. The median IOP prior to LSL was 26 mmHg [IQR 19-33 mmHg], which dropped significantly to 14 mmHg [IQR 11-21 mmHg], one week later and remained lower one month later (19 mmHg [IQR 14-22 mmHg]). There were no cases of hypotony or HRCs following LSL. Of the 30 eyes that underwent LSL, subsequent stent removal was necessary in 25 eyes (8 P-SR; 17 C-SR). Details of postoperative IOP following LSL, P-SR and C-SR are summarised in table 2 and figure 4. There were no significant differences between the preoperative and final postoperative IOP of the ligature stent group versus non-ligature stent group ($p=0.60$ and $p=0.40$, respectively).

Stent removals were required in 80% of eyes (n=93). Prior to SR the median IOP was 19 mmHg [IQR 14-26 mmHg], which reduced to 14 mmHg [IQR 11-20 mmHg] one week later and remained low after one month (16 mmHg [IQR 12-20 mmHg]). Both C-SR (n=70) and P-SR (n=23) resulted in significant IOP reduction. Following stent removal 5% (n=5) of eyes required an increase in medications; only 2 eyes experienced both an increase in IOP and an increase in glaucoma medications (figure 4). There was no significant difference between IOP reduction

following C-SR and IOP reduction following P-SR at one week (p=0.65) however at one month IOP after C-SR was significantly lower than IOP after P-SR (p<0.01). P-SRs did not result in any HRCs. Early P-SR (3 and 5 weeks) was required in 2 eyes with uncontrolled elevated IOP despite maximal tolerated medications. One eye required viscoelastic injection into the AC due to low IOP following C-SR (lasting 2 days). Two eyes required reinsertion of the Supramid stent (via AC).

The median number of glaucoma medications reduced from 3 [IQR 2-4] preoperatively to 1 [0-2] postoperatively at year one (figure 3). A significant drop in medications was observed following SRs, which persisted throughout all subsequent visits. Prior to stent removal the mean number of glaucoma medications was 3.6 ± 1.5, which reduced to 0.5 ± 1.2 one week later and remained significantly reduced one month after SR (0.9 ± 1.3). The IOP reduction following stent removal was not significantly associated with the reduction in number of medications between pre-removal and one-month post-removal (p=0.16, 2 way ANOVA).

Failure occurred in 7 eyes (6%) due to inadequate IOP reduction. However, there were no cases of persistent hypotony, glaucoma re-operation, or loss of light perception. In the eyes considered as surgical failure, one eye was lost to follow-up. In the remaining 6 eyes, median pre-operative IOP was 15mmHg and postoperatively 13mmHg and mean pre-operative glaucoma medications was 3.3 and postoperatively 1.2. At month 12, qualified success (with or without medications) was achieved in 94% (n=98) of eyes and complete success in 32% (n=33) of eyes.

Intraoperative hyphema was observed in 2 patients, and no other intraoperative complications were observed. Postoperative complications occurred in 11 eyes (9%) and were non-sight threatening: hyphema (n=1), transient diplopia (n=1), Descemet's membrane detachment (n=1); HRCs occurred in 8 eyes: transient hypotony (n=1), shallow AC (n=2) and transient choroidal

effusions (n=5) (table 3). There were no tube blockages, retractions, erosions or cases of endophthalmitis.

DISCUSSION

The importance of early flow control following non-valved shunt implantation has previously been highlighted.[8-10,14-16,21,23] This is the first study of aqueous shunts to report IOP data following full-length intraluminal occlusion and stepwise reductions of flow restriction using laser suture lysis and partial/complete stent removals, according to requirements (some eyes did not require stent removal). Complete stent removals were delayed until after 12 weeks of bleb maturation,[7,8,12,32,36] which is in contrast to the traditional use of a rapidly dissolving tie, where maximal outflow occurs indiscriminately as early as three to six weeks after surgery. The staged approach in this study resulted in low rates of hypotony (1%) and overall HRCs (7%), and consequently the total complication rate was 9%. To our knowledge these are amongst the lowest reported in the literature (table 3, figure 5).[3,8,10,12,13,18-20,22,24,29]

In vitro, unligated partial-length Supramid occlusion of Baerveldt shunts does not always provide sufficient intraluminal resistance to prevent hypotony.[23] The full-length occluded shunts used in our protocol offer additional outflow resistance due both to increased Supramid length and its passage through the tight intrascleral canal (which obviated the need for ligation in two thirds of tubes). Postoperatively, scleral squeeze around the stented tube is likely to have gradually relaxed, allowing aqueous flow into a relatively mature bleb (suggested by the lowering of IOP prior to stent removal). This delayed and gradual increase in flow may circumvent inflammatory bleb wall thickening associated with copious early flow, [7,8,12,32,36] and could explain why a hypertensive phase following removal of flow restriction[8,10,12,19,24,32,36] was not observed in study eyes. Further studies are required to establish whether final IOP is affected by delaying aqueous flow into the maturing bleb.

On post-operative day one, none of the study eyes had IOP below 6 mmHg. This lack of immediate hypotony compares favourably with other techniques.[3,8-29] Intraoperative viscoelastic AC injections were never required during tube implantation. These can cause erratic IOPs in occluded shunts.[3,4,32] Since flow control was central to this protocol, LSL was preferred over a dissolving tie as this enabled the clinician to determine the need and the timing of resistance reduction.[3,5,8,10,13,18-20] Similarly, partial stent retractions provided an intermediate stage of resistance reduction when complete removal posed a risk of HRCs (for example in patients with uveitis, previous cyclodiode, and small eyes). Neither LSL nor P-SR resulted in hypotony related events. A total of 16% of eyes achieved sufficiently low IOP without requiring stent removal. Removal of these stents may have resulted in hypotony. [8,12,20,22] Emerick et al reported hypotony in 25% of eyes following ligature autolysis, where no occluding stent was present.[12]

Early post-operative complications (predominantly HRCs) using non-valved shunts are largely preventable using surgical and post-operative strategies,[7,19,27] and are not necessarily associated with surgeon experience.[18] The case-mix, prospective protocol and analysis methods of this study are not unlike those of the ABC study, [18,25] yet here the complication rate was markedly lower (9% versus 58%); (54% in AVB[19]; 34% in TVT [3]; table 3, figure 5). A major confounder is that the detection of and reporting of complications varies between studies – not all previous studies report all complications (figure 5; table 3). However, the mean of each reported HRC was calculated separately in order to estimate a cumulative HRC rate of 35%[3,8,10,12,13,18-20,22,24,29] (table 3; figure 5). This is substantially greater than the 7% reported here. Transient hypotony (12-25%)[8,12,20,22] and persistent hypotony (0-5%)[12,18,19,29] were also markedly lower in this study (1% and 0% respectively).

There were no occurrences of new onset corneal decompensation in this cohort during the first year of follow-up. Care was taken to leave the intracameral tube short and position it away from the cornea, and this may have helped to reduce corneal endothelial cell loss. However corneal

decompensation following prolonged endothelial cell loss is a recognized late-onset complication of shunt implantation and as such is more likely to feature in reports with longer follow-up.

In contrast to complication rates, the success and failure rates at year one (which are predominantly IOP determined), were similar to previous studies that included Baerveldt shunts (figure 6). This supports the notion that given similar ocular characteristics, it is implant type[18,19,29,32,33] and surface area,[30,31] rather than surgical technique, that principally determine the mature bleb characteristics and therefore final IOP.[30,31,34,35] At year one, failure rates (6%) were not dissimilar to those reported with Baerveldt shunts in the TVT and ABC studies (4%[3] and 14%[18] respectively). The recent large shunt studies report failure using different IOP criteria, making it difficult to compare, and therefore we have given the full range of outcomes for the cumulative probability of failure at month 12 (figure 6). Here the most frequently reported failure criterion of IOP and ≤20% reduction from baseline is shown (figure 6). To facilitate comparison, the three failure rates at month 12 of the TVT, ABC and AVB studies have been superimposed.

Notably in the 6 eyes that failed within the first year of follow-up, there were no re-operations for glaucoma. In this subgroup mean IOP reduced by 8% from baseline and there was a 64% reduction in medications. The reduction in the number of medications due to drug intolerance was an important preoperative consideration in these patients.

One of the drawbacks of non-valved shunt surgery is the delay in IOP lowering due to flow restriction. During the early postoperative period (prior to stent removals) the delayed IOP lowering was not regarded as surgical failure. We therefore presented IOP values and glaucoma medications for all eyes at all study time points in figure 3 (strip plot). During the first 3 months, according to clinical requirements, medications were frequently altered, LSL and/or stent removals were preformed, and hence IOP values across subsequent time points rarely correspond to the same eye. This prompted the stratification of hypertony (IOP>21mmHg) into

transient and persistent. Ten eyes (9%) experienced transient hypertony (3-6 weeks) and a further 3 eyes had persistent hypertony (>6 weeks). Thus it is apparent that prolonged periods of high pressure were a rare phenomenon with this systematic approach.

During stent removals a small incision is made in the anterior conjunctiva to access the free end of the stent. This added step does increase healthcare costs, but the lower complication rates may make this approach more acceptable. When resources are scarce, this approach could be reserved for monocular patients or eyes with advanced disease, vulnerable to visual damage ensuing from hypotony and its complications.[1,10,32] In patients unsuitable for a second postoperative intervention (e.g, geographical location, expenses, medical reasons) suture removal may be carried out at the slit lamp.

The outlined surgical methods and postoperative protocol have been described in a manner to facilitate reproducibility. This method resulted in low rates of hypotony and its related complications and prevented persistent hypotony in all study eyes. Given the rising rates of aqueous shunt implantation, continued development of safer implantation techniques and postoperative treatment strategies are essential.

Acknowledgments/Disclosures:

We would like to thank Dr Lorenzo Franscini and Dr Aleksandra Petrovic for data validation.

Financial support:

This study was funded by an unrestricted grant from: Fondation Asile des Aveugles, Switzerland.

REFERENCES

1. Reinthal EK, Rohrbach JM, Grisanti S. Glaukom-Drainage chirurgie Glaucoma Drainage Implants. Klin Monbl Augenheilkd 2010;227:49-55.

2. Mosaed S, Minckler DS. Aqueous shunts in the treatment of glaucoma. Expert Rev Med Devices 2010;7:661-666.

3. Gedde S, Schiffman J, Feuer W, et al. Treatment outcomes in the tube versus trabeculectomy study after one year of follow-up. Am J Ophthalmol 2007;143:9-22.

4. Gedde S, Herndon L, Brandt J, et al. Surgical complications in the Tube Versus Trabeculectomy Study during the first year of follow-up. Am J Ophthalmol 2007;143:23-31.

5. Gedde SJ, Heuer DK, Parrish RK. Review of results from the Tube Versus Trabeculectomy Study. Current Opinion in Ophthalmology 2010;21:123-128.

6. Minckler DS, Francis BA, Hodapp EA, et al. Aqueous Shunts in Glaucoma: A Report by the American Academy of Ophthalmology. Ophthalmology 2008;115:1089-1098.

7. Molteno AC, Van Biljon G, Ancker E. Two-stage insertion of glaucoma drainage implants. Trans Ophthalmol Soc NZ1979;31:17-26.

8. Kansal S, Moster MR, Kim D, Schmidt Jr CM, Wilson RP, Katz LJ. Effectiveness of nonocclusive ligature and fenestration used in Baerveldt aqueous shunts for early postoperative intraocular pressure control. J Glaucoma 2002;11:65-70.

9. Rose GE, Lavin MJ, Hitchings RA. Silicone tubes in glaucoma surgery: the effect of technical modifications on early postoperative intraocular pressures and complications. Eye 1989;3:553-561.

10. Trible JR, Brown DB. Occlusive ligature and standardized fenestration of a Baerveldt tube with and without antimetabolites for early postoperative intraocular pressure control. Ophthalmology 1998;105:2243-2250.

11. Molteno ACB, Polkinghorne PJ, Bowbyes JA. The vicryl tie technique for inserting a draining implant in the treatment of secondary glaucoma. Aus NZ J Ophthalmol 1986;14:343-354.

12. Emerick GT, Gedde SJ, Budenz DL. Tube fenestrations in Baerveldt glaucoma implant surgery: 1-year results compared with standard implant surgery. J Glaucoma 2002;11:340-346.

13. Harbick KH, Sidoti PA, Budenz DL, et al. Outcomes of inferonasal Baerveldt glaucoma drainage implant surgery. J Glaucoma. 2006;15(1):7-12

14. Sherwood MB, Smith MF. Prevention of early hypotony associated with Molteno implants by a new occluding stent technique. Ophthalmology 1993;100:85-90.

15. Breckenridge RR, Bartholomew LR, Crosson CE, Craig E, Kent A. Outflow resistance of the Baerveldt glaucoma drainage implant and modifications for early postoperative intraocular pressure control. J Glaucoma 2004;13:396-399.

16. Lim K, Bufidis T, Eslah E, Murdoch IE, Khaw PT, Barton K. Early flow control in a non-valved glaucoma drainage device: Intraluminal stent suture in isolation [abstract]. Invest Ophthalmol Vis Sci 2002;43:3357.

17. Wishart PK, Choudhary A, Wong D. Ahmed glaucoma valves in refractory glaucoma: a 7-year audit. Br J Ophthalmol 2010;94:1174-1179.

18. Budenz DL, Barton K, Feuer WJ, et al. Treatment outcomes in the Ahmed Baerveldt comparison study after 1 Year of Follow-up. Ophthalmology 2011;118(3):443-452.

19. Christakis PG, Kalenak JW, Zurakowski D et al. The Ahmed versus Baerveldt Study: One-Year Treatment outcomes. Ophthalmology 2011; 118(11): 2180-2189

20. Syed HM, Law SK, Nam SH, Li G, Caproli J, Coleman A. Baerveldt-350 implant versus Ahmed valve for refractory glaucoma: a case-controlled comparison. J Glaucoma 2004;13:38-45.

21. Barton K. A Modified Stenting Technique Without External Ligation for Early Flow Control With the Baerveldt Glaucoma Drainage Device [abstract]. Invest Ophthalmol Vis Sci 2005;46:86.

22. Nguyen QH, Budenz DL, Parrish RK. Complications of Baerveldt glaucoma drainage implants. Arch Ophthalmol 1998;116:571-575.

23. Gilbert DD, Bond B. Intraluminal Pressure Response in Baerveldt Tube Shunts: A Comparison of Modification Techniques. J Glaucoma 2007;16:62-67.

24. Krishna R, Godfrey DG, Budenz DL, et al. Intermediate-term outcomes of 350-mm2 Baerveldt glaucoma implants. Ophthalmology 2001;108:621-626.

25. Barton K, Gedde SJ, Budenz DL, Feuer WJ, Schiffman J, the Ahmed Baerveldt Comparison Study Group. The Ahmed Baerveldt Comparison Study: Methodology, Baseline Patient Characteristics, and Intraoperative Complications. Ophthalmology 2011;118(3):435-442.

26. Assaad MH, Baerveldt GM, Rockwood EJ. Glaucoma drainage devices: pros and cons. Curr Opin Ophthalmol 1999;10(2):147-153

27. Nguyen QH. Avoiding and managing complications of glaucoma drainage implants. Curr Opin Ophthalmol 2004;15(2):147-150

28. Siegner SW, Netland PA, Urban RC Jr, et al. Clinical experience with Baerveldt glaucoma drainage implant. Ophthalmology 1995;102(9);1298-307

29. Goulet 3rd RJ, Phan ADT, Cantor LB, WuDunn D. Efficacy of the Ahmed S2 glaucoma valve compared with the Baerveldt 250-mm2 glaucoma implant. Ophthalmology 2008;115:1141-1147.

30. Hwang JM, Kee C. The Effect of Surface Area Expansion with Pericardial Membrane (Preclude (R)) in Ahmed Glaucoma Valve Implant Surgery. J Glaucoma 2004;13:335-339.

31. Heurer DK, Llyod MA, Abrams DA et al. Which is better ? One or two ? A randomized trial of single-plate versus double-plate Molteno implantation for glaucoma in aphakia and pseudophakia. Ophthalmology 1992;99(10):1512-9

32. Ayyala RS, Zurakowski D, Smith JA, et al. A clinical study of the Ahmed glaucoma valve implant in advanced glaucoma. Ophthalmology 1998;105:1968-1976.

33. Schwartz KS, Lee RK, Gedde SJ. Glaucoma drainage implants: a critical comparison of types. Curr Opin Ophthalmol 2006;17:181-189.

34. Wilcox MJ, Minckler DS, Ogden TE. Pathophysiology of artificial aqueous drainage in primate eyes with Molteno implants. J Glaucoma 1994;3:140-151.

391 35. Minckler DS, Shammas A, Wilcox M, Ogden TE. Experimental studies of aqueous
392 filtration using the Molteno implant. Trans Am Ophthalmol Soc. 1987;85: 368-392.

393 36. Nouri-Mahdavi K, Caprioli J. Evaluation of the hypertensive phase after insertion of the
394 Ahmed Glaucoma Valve. Am J Ophthalmol 2003;136:1001-1008.

395 37. Tsai JC, Johnson CC, Kammer JA, Dietrich MS. The Ahmed shunt versus the Baerveldt
396 shunt for refractory glaucoma II, Ophthalmology. 2004;113(6):913-91

397 40. Caprioli, J. The tube versus trabeculectomy study: why its findings may not change
398 clinical practice? Am J Ophthalmol 2011; 151(5):742-744

399

400

401 **Table legends**

General	
Eyes, n	116
Sex M/F, n (%)	63 (54%) / 53 (46%)
Ethnicity • Caucasian • Black • Latin American • Asian • Other	 • 95 • 9 • 4 • 2 • 6
Mean age, years (± SD)	62.3 years (±22.1)
Primary glaucoma diagnosis **n (%)** • Open angle • Angle closure • Pseudoexfoliation • Aphakic • Neovascular • Congenital • Pigmentary dispersion • Traumatic • Uveitic	 • 39 (34) • 18 (16) • 17 (15) • 5 (4) • 11 (9) • 8 (7) • 7 (6) • 6 (5) • 4 (3)
Previous incisional surgery, **n (%)** • IOP implantation • Deep Sclerectomy • Trabeculectomy • Express tube • Viscocanalostomy • Tube	 • 93 (80) • 48 (41) • 32 (28) • 10 (9) • 3 (3) • 1 (1)
Pre-operative measures, Median [IQR] (mean± SD)	
IOP mmHg	23 [18,32] (26.9 ± 11.6)
Glaucoma medications	3.0 [2,4] (3.0 ±1.2)
Visual acuity LogMAR	0.5 [0.2,1.0] (0.9 ±1.0)
Post-operative measures Median [IQR] (mean± SD) **– month 12**	
IOP mmHg	12 [10,15] (12.8 ±3.7)
Glaucoma medications	1 [0,2] (1.1 ±1.3)
Visual acuity LogMAR	0.4 [0.2,1] (0.7 ±0.7)

402

403 Table 1. Summary of the patient demographics and surgical outcomes. (POAG, primary open
404 angle glaucoma; PEXG, pseudoexfoliation glaucoma; ACG, angle closure glaucoma; PDG,
405 pigmentary dispersion glaucoma.)
406

Type of postoperative adjustment	IOP before adjustment Median [IQR]	IOP 1-week later Median [IQR]	IOP 1-month later Median [IQR]
Ligature laser suture lysis (LSL) only	21 [15, 26]	16 [11, 18]	17.5 [12, 20]
Partial stent removal	21 [16.5, 30]	14 [11.5, 18.5]	20 [13, 23.5]
Complete stent removal	19 [14, 24.5]	15 [11, 20]	15 [12, 18.75]
All stent removals	19 [14, 26]	14 [11, 20]	16 [12, 20]
Stent removal (without prior LSL)	19 [14.25, 26]	14 [10.25, 20]	16 [12, 20]
Stent removal (underwent prior LSL)	21 [14.75, 26.5]	16 [11.75, 18.5]	18 [12, 21]

Table 2. Intraocular Pressure (IOP) before and after postoperative adjustments.

411

Complication type	Systematized Occlusion of Shunts (%)	Studies of Baerveldt shunts: Reported complication rates (%) publication reference
Overall complication rates	9	34,[4] 38,[13] 58,[18]54 [19]
Shallow AC	2	11,[4] 20,[18] 14,[19] 14[24]
Choroidal effusions	4	16,[4] 3-9,[8] 22,[10] 17-18,[12] 10,[18] 13,[19] 19,[22] 23[24]
Choroidal haemorrhage	0	2 ,[4] 1,[10] 0-1,[12] 2,[13] 2,[18] 3,[19] 3,[20]4,[22]2[29]
Hypotonous maculopathy	0	1,[4] 2,[18] 5[24]
Transient Hypotony	1	14-23,[8] 24-26,[12] 38,[20] 20[22]
Persistent Hypotony	0	2,[4] 2,[18] 2[29]
Descemet detachment	1	1,[4] 0,[10] 1,[13] 1,[19] 1,[22] 3,[24] 3[29]
Hyphema	1	2,[4] 14,[10] 6-7,[12] 2,[13] 6,[18] 20[24]
Diplopia	1	5,[4] 1-5,[12] 2,[13] 5,[18] 6,[19] 3[24]
Macular edema	0	3,[4] 4,[13] 2,[18] 9[24]
Requirements for AC reformation	0	1,[4] 0[10]
Endophthalmitis	0	1,[4] 0,[10] 0-1,[12] 1,[13] 1,[18] 0,[19] 3,[22] 3[24]
Tube related complications	0	11 [19]
Occlusion	0	2,[4] 2,[10] 0-1,[12] 4,[13] 9,[18] 10,[19] 3,[20] 5[22]8[24]
Malposition	0	1-2,[12] 1,[13] 6,[18] 2,[19] 3[24]
Erosion	0	3-5,[12] 3,[13] 1,[18] 3,[19] 2,[20] 2[22]

412

413 Table 3. List of complications reported with Baerveldt shunts.

414

Figure legends

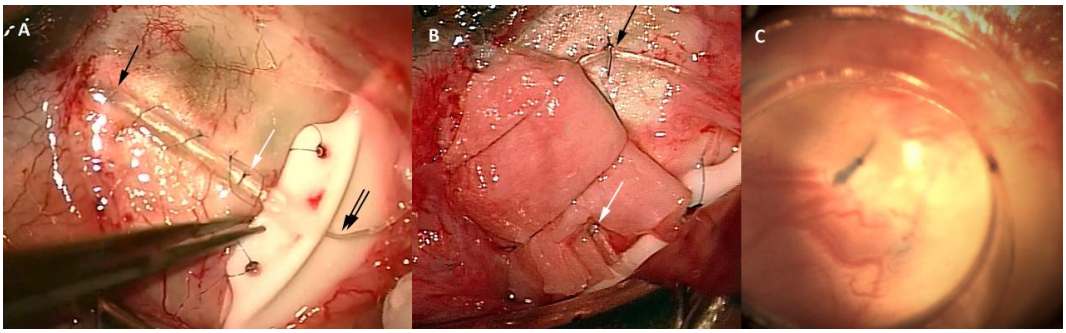


Figure 1. (A) Intraoperative photograph of fully-stented Baerveldt tube entering the AC through a tight intrascleral canal (black arrow). Supramid occluding stent can be seen at tube plate (double black arrow). The 10.0 nylon ligation suture (white arrow) is tied around proximal tube to halt aqueous egress if detected at tube plate. (B) A photo showing pericardial patch covering tube, with a posterior window enabling postoperative laser suture lysis (white arrow). The free end of the Supramid is sutured with 10.0 nylon (black arrow) and tucked under the pericardial patch near the limbus, to facilitate retraction/removals post-operatively (C) The 10.0 nylon ligation suture seen through Hoskins lens prior to laser suture lysis

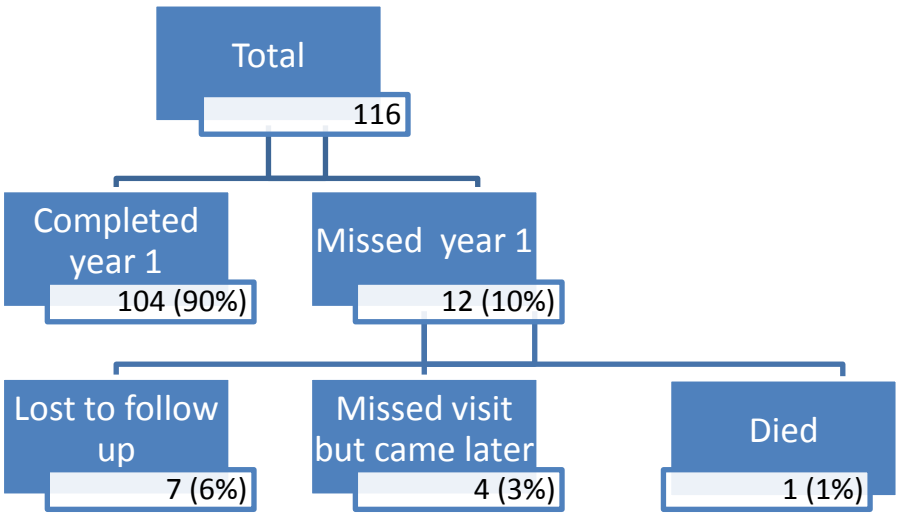


Figure 2. Flow chart of follow-up achieved at year 1.

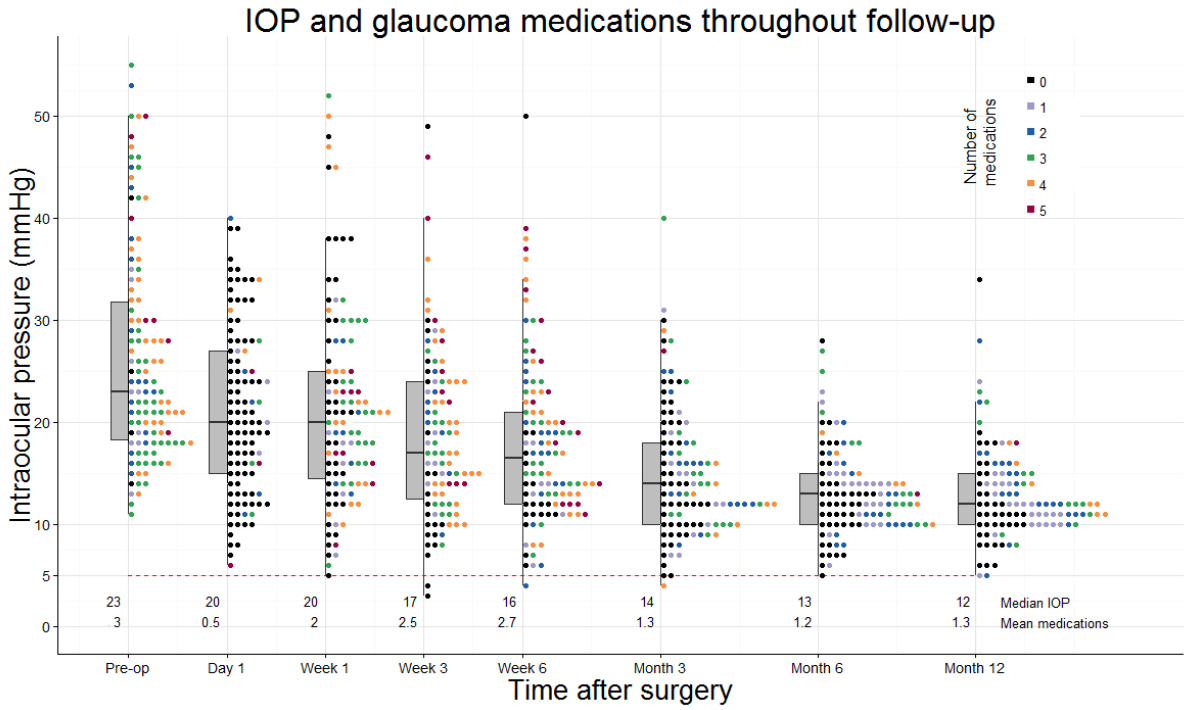
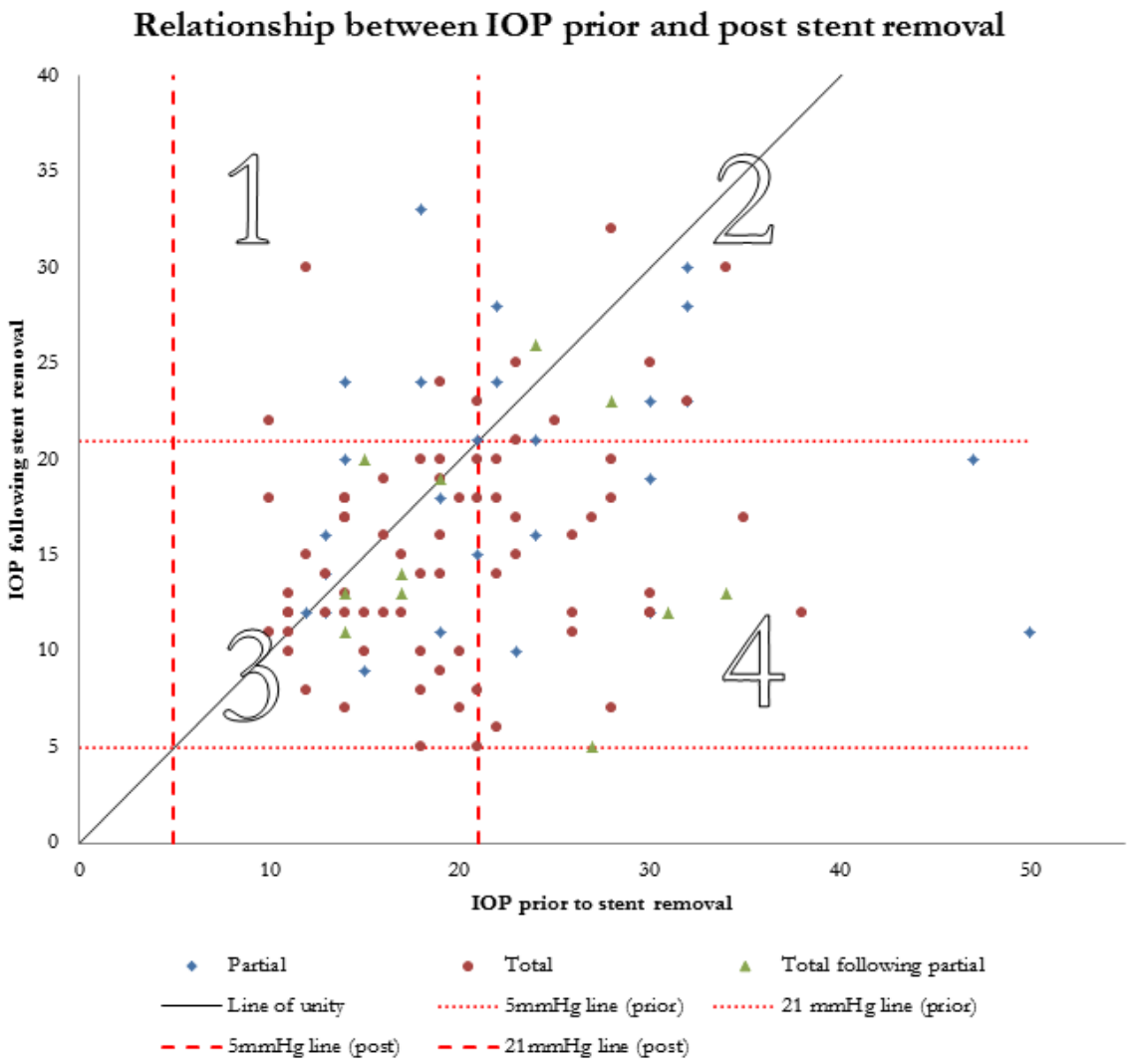


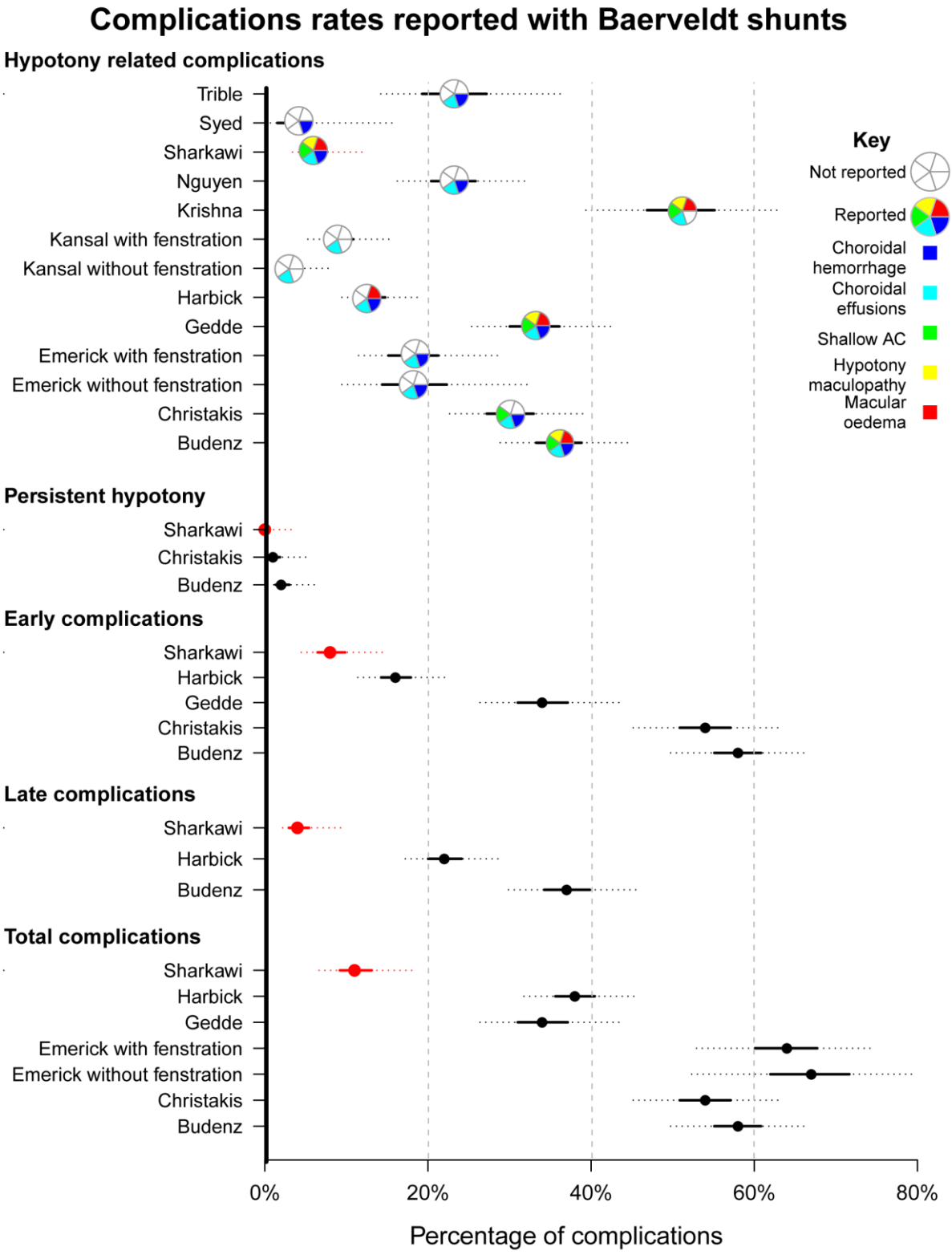
Figure 3. Summary of postoperative intraocular pressure (IOP) measurements and number of glaucoma medications throughout follow up. A box and whisker plot summarises IOP values recorded at each time point, the height of the box represents lower and upper inter-quartile range (50% of the range), the ends of the whiskers extend to 95% of the range (2.5%-97.5%). The line bisecting each box represents the median IOP. Additionally to the right of each box a strip plot is shown, here with each marker denoting an individuals' IOP value. These markers are colour coded where the colour denotes the number of medications. Please note: in strip plots, the same location at subsequent study points is highly unlikely to correspond to the same eye. The horizontal red dashed line marks the lower IOP limit associated with hypotony (≤5 mmHg). The mean IOP and number of medications are also shown beneath this line, at each time point.



439

440 Figure 4. Summary of the relationship between intraocular pressure (IOP) measures prior to stent
441 removal (SR) and IOP recorded at 1 month following partial SR (circle) and complete SR
442 (triangle). The dashed and dotted red lines represent the lower and upper IOP limits defining
443 hypotony (5mmHg) and hypertony (21mmHg) prior to and following SR. The (solid black) line
444 of unity representing no change in IOP. Each marker has been colour coded to denote the
445 change in glaucoma medications following stent removal, with green denoting no change, red
446 indicates an increase in medications and blue indicates decrease, and the intensity of the colour
447 denoting the amount of change.

448



449

450 Figure 5. Summary of the complication rates reported in studies of Baerveldt (350) shunts. The
451 percentage rates of hypotony related complications, persistent hypotony, early, late, and total
452 number of complications for each study are illustrated. Hypotony related complications include

choroidal haemorrhage, choroidal effusion, shallow anterior chamber, hypotony malculopathy and macular oedema. However since not all studies report all hypotony related complications, a coloured key has been added to denote which complications are reported in each study.

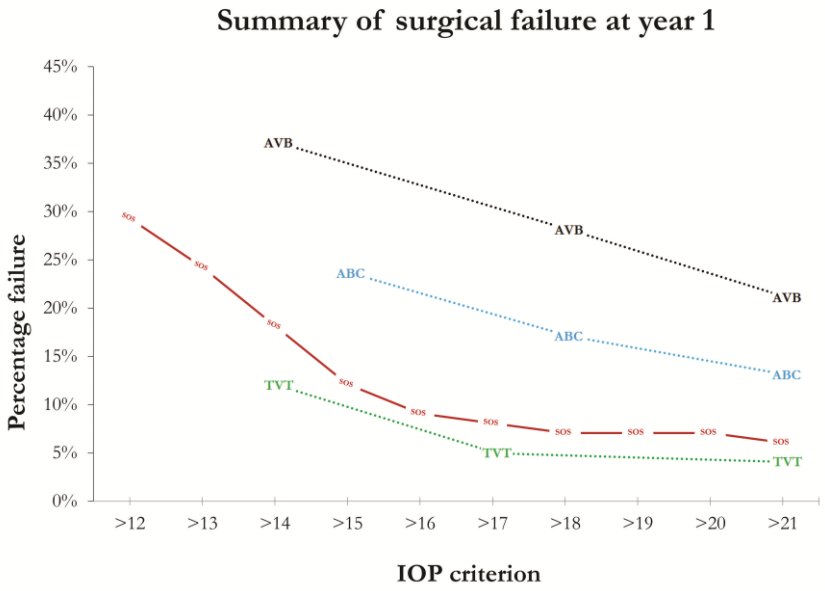


Figure 6. Failure as a function of intraocular pressure (IOP): a summary of the cumulative probability of failure, at 12 months from this study, is given for 10 different criteria in 1 continuous graph labelled with "SOS". The three failure rates at month 12 reported in recent ABC, AVB and TVT studies using Baerveldt shunts have been superimposed. A dotted line has been used to connect the reported values