# Flow Test to Predict Early Hypotony and Hypertensive Phase After Ahmed Glaucoma Valve (AGV) Surgical Implantation

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**Purpose:** To assess the validity of a preimplantation flow test to predict early hypotony [intraocular pressure (IOP) ≤ 5 mm Hg on 2 consecutive visits and hypertensive phase (HP) (IOP > 21 mm Hg) after Ahmed Glaucoma Valve (AGV) implantation.

**Patients and Methods:** Prospective interventional study on patients receiving an AGV. A preimplantation flow test using a gravity-driven reservoir and an open manometer was performed on all AGVs. Opening pressure (OP) and closing pressure (CP) were defined as the pressure at which fluid was seen to flow or stop flowing through the AGV, respectively. OP and CP were measured twice per AGV. Patients were followed for 12 weeks.

**Results:** In total, 20 eyes from 19 patients were enrolled. At 12 weeks the mean IOP decreased from 29.2 ± 9.1 to 16.8 ± 5.2 mm Hg ($P < 0.01$). The mean AGV OP was 17.5 ± 5.4 mm Hg and the mean CP was 6.7 ± 2.3 mm Hg. Early (within 2 wk postoperative) HP occurred in 37% and hypotony in 16% of cases. An 18 mm Hg cutoff for the OP gave a sensitivity of 0.71, specificity of 0.83, positive predictive value of 0.71, and negative predictive value of 0.83 for predicting an early HP. A 7 mm Hg cutoff for the CP yielded a sensitivity of 1.0, specificity of 0.38, positive predictive value of 0.23, and negative predictive value of 1.0 for predicting hypotony.

**Conclusions:** Preoperative OP and CP may predict early hypotony or HP and may be used as a guide as to which AGV valves to discard before implantation surgery.

**Key Words:** Ahmed glaucoma valve, glaucoma, surgery, hypotony, hypertensive phase

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The FP7 Ahmed Glaucoma Valve (AGV, New World, CA) has a valve mechanism designed to prevent hypotony in the immediate postoperative period before plate encapsulation and is thought to provide the AGV with a lower rate of early hypotony and related complications, compared with the nonvalved Baerveldt glaucoma implant.[1,2]

Despite a protective valve mechanism, the AGV has a reported hypotony rate of 9% to 13% and complications related to hypotony, such as choroidal detachment (1% to 22%), suprachoroidal hemorrhage (0% to 5%), and shallow anterior chamber (5% to 19%), have been reported.[3–6] These complications may be secondary to entry-site leakage around the tube or aqueous shutdown, but there is also evidence that they may be due to inter-valve variation.[7–10]

The hypertensive phase (HP) is described as an intraocular pressure (IOP) > 21 mm Hg during the first 3 months after glaucoma drainage device implantation.[11] This occurs more frequently with valved implants[12] and is thought to be a consequence of early exposure to inflammatory mediators,[13] but inter-valve variation is another potentially important cause.

Two studies have suggested that assessing the AGV before implantation may be predictive of early postoperative hypotony.[7,14] Both studies assessed the opening pressure (OP) (pressure at which fluid is seen to begin to flow through the AGV in vitro) and closing pressure (CP) (pressure at which fluid stops flowing through the AGV in vitro) of the AGV before implantation. However, 1 study was retrospective in nature and excluded AGV's that were deemed to be defective based on OP and CP, creating a selection bias.[7] The second study was prospective and reported that OP < 18 mm Hg had a 100% sensitivity (6/6) and 76.9% specificity (10/13) to identify low (≤ 4 mm Hg) postoperative IOP on the same day. Neither study assessed the relationship between preimplantation testing and the rate of HP.

We performed a prospective study with preimplantation AGV flow testing using a sterile lumbar puncture kit. We hypothesized that preoperative OP and CP testing are predictive of early postoperative hypertensive phase (EHP) and hypotony, respectively. We also hypothesized that such a testing protocol may predict AGV function before implantation, allowing the rejection of AGV's that may risk early hypotony or an EHP.

## PATIENTS AND METHODS

We performed a prospective interventional study on 20 eyes of 19 patients at the Toronto Western Hospital glaucoma department. All patients over the age of 18 years and scheduled for AGV were invited to participate in the study. Ethics approval was granted by the University Health Network research ethics board and all patients provided signed informed consent.

Preimplantation testing was performed on all AGVs using a modification of a technique previously described.[10] Valve priming was followed by measurement of OP and CP. This testing was performed under sterile conditions in the operating room. A disposable lumbar puncture kit (Cardinal Health, Vaughan, ON, Canada) consisting of a

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multicompartment tray, 3 mL syringe, 3-way stopcock, 2-piece 550 mm manometer, and a 5-inch extension tube was used. Each AGV was connected to a 3-way stopcock using a 30-G cannula and the 5-inch extension tube. The 2-piece manometer was attached to the vertical arm of the 3-way stopcock and the remaining arm connected to a bottle of balanced salt solution (BSS) (Fig. 1). The manometer and 3-way stopcock were held vertically with the support of the tray and 3 mL syringe. The AGV was primed using a 1 mL syringe of BSS by a 30-G cannula as per the manufacturer's instructions. Air was flushed from the experimental setup with BSS before connecting the 30-G cannula and AGV. Residual air bubbles in the system were flushed by elevating the bag above the level of the open manometer. The BSS bag was then elevated until fluid was seen to exit from the valve and the fluid level in the manometer was recorded. This was termed the OP and converted from cm $H_2O$ to mm Hg. The BSS bottle was then lowered gradually until the fluid exiting the AGV at the plate stopped; the pressure reading at this point was termed the CP. This procedure was repeated twice for each valve, resulting in 2 OP and 2 CP measurements for each AGV, which were then averaged.

The following surgical technique for AGV implantation was used: a corneal traction suture was used to stabilize the eye. The conjunctiva was incised at the limbus (G.E.T.) or 6 mm from the limbus (Y.M.B.). Tenon's was dissected and sclera was exposed. Hemostasis with cautery was performed. The primed and tested AGV was sutured 8 mm from the limbus using 8-0 silk. The trimmed AGV tube was inserted in the anterior chamber by a track made with a bent 23-G needle. Provisc (ALCON, Switzerland) was injected into the anterior chamber to stabilize the chamber. The entry site was assessed for wound leaks. Split thickness cornea was used to cover the exposed tube. Conjunctiva was closed. Postoperative medication regimen was standardized to tobramycin and dexamethasone combination drop 4 times a day and atropine 1% twice daily both for 1 week followed by prednisolone 1% 4 times a day for 1 month, then tapering down 1 drop a day per week.

The following information was collected from each patient at baseline: glaucoma diagnosis, age, sex, ethnicity, corrected visual acuity (VA), preoperative IOP, previous surgery or laser, preoperation medicines, and intraoperative complications or leakage around the tube entry site.

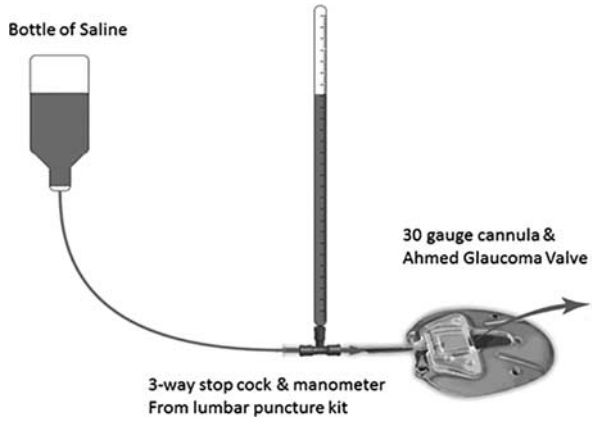


**FIGURE 1.** Schematic representation of preimplantation flow test setup.

The patients were seen at postoperative days 1 and 3 and weeks 1, 2, 4, 8, and 12. At each visit the following information was collected: VA, IOP, anterior chamber depth, tube position (iris touch, posterior 1/3, mid-AC, anterior 1/3 or corneal touch), medications, complications, and use of ocular massage. Hypotony was defined as IOP $\leq$ 5 mm Hg at 2 consecutive visits after surgery. HP was defined as an IOP > 21 mm Hg in the first 3 months, EHP was defined as IOP > 21 mm Hg within the first 2 weeks after surgery, and late hypertensive phase (LHP) was defined as IOP > 21 mm Hg between week 2 and month 3 after surgery.

Descriptive statistics and PSPP software (GNU, version 8.3) were used to analyze the data.

## RESULTS

In total, 20 eyes of 19 patients were enrolled. One patient who was lost to follow-up after 2 weeks was excluded from analysis, leaving a total of 19 eyes of 18 patients. The mean age was 64.9 ± 3.0 years, with 9 males. Eight patients were white, 5 were Asian, 4 were African Canadian, and 1 was of South Asian Indian ancestry. The mean preoperative IOP was 29.2 ± 9.1 mm Hg. Ten eyes had a preoperative logMAR (VA) of 0.3 or better and 4 patients had a VA of 1.0 or worse. Patient demographics are summarized in Table 1.

The hypotony rate (2 consecutive visits with IOP $\leq$ 5 mm Hg) was 16% (3/19) and a single visit with IOP of $\leq$ 5 mm Hg was 42% (8/19). HP occurred in 11/19 patients (58%), of which 7 occurred in the first 2 weeks (EHP) and the remaining 5 occurred between 4 and 12 weeks after surgery.

The mean 3-month postoperative IOP was 16.8 ± 5.2 mm Hg ($P < 0.01$). The mean postoperative number of medications was 1.6 ± 1.5 ($P < 0.01$). Three eyes lost 1 line of VA and the others either maintained or demonstrated a mild improvement in VA. Eleven of the

**TABLE 1.** Demographics and Baseline Patient Data

| Parameters | |
|---|---|
| Age (mean ± SD) (y) | 64.6 ± 11.24 |
| BCVA ± SD (logMAR) | 0.58 ± 0.65 |
| Presurgery IOP (mean ± SD) (mm Hg) | 29.2 ± 9.05 |
| Mean glaucoma medications ± SD | 3.95 ± 0.7 |
| History of intraocular surgery | |
| No surgery | 2 |
| Single trabeculectomy | 7 |
| Two trabeculectomies | 1 |
| One trabeculectomy and 1 AGV | 1 |
| Phacoemulsification | 12 |
| Vitrectomy | 3 |
| Descemet's stripping endotehlial keratoplasty | 2 |
| Glaucoma type | |
| POAG | 6 |
| Uveitic | 5 |
| Neovascular glaucoma | 2 |
| Pseudoexfoliation glaucoma | 2 |
| Juvenile open-angle glaucoma | 1 |
| Phemphigoid/POAG | 1 |
| Steroid | 1 |
| Axenfeld | 1 |

AGV indicates Ahmed Glaucoma Valve; BCVA, best-corrected visual acuity; IOP, intraocular pressure; POAG, primary open angle glaucoma.

19 AGV had the tube positioned in the mid-anterior chamber position; 4 were touching the iris, 2 were in the anterior one third of the anterior chamber, 1 was in the posterior one third, and 1 was in the sulcus (posterior chamber). There was no correlation between tube position and hypotony or EHP.

There was 1 intraoperative anterior chamber hyphema. The blood from this hyphema dispersed into the vitreous, causing reduced vision until the second postoperative month. In this case the IOP was well controlled until month 3, when a HP occurred. There were no other intraoperative complications, including no cases of aqueous leakage around the AGV tube.

Postoperative complications included hyphema in 3 eyes, 1 choroidal detachment, 1 ptosis, 1 transient diplopia, and 1 posterior capsular opacity that was treated with YAG laser capsulotomy. All cases of hypotony resolved by week 2, except 1 case that resolved by week 4.

### Preimplantation Testing Results

The mean AGV OP was 17.5 ± 5.4 mm Hg and the mean CP was 6.7 ± 2.3 mm Hg. The mean difference between the first and second OP and CP readings were 1.6 ± 2.9 and 0.5 ± 0.6 mm Hg, respectively.

Seven of the 19 AGV had an OP of > 18 mm Hg, of which 5/7 (71%) eyes experienced HP, all within the first 2 weeks (EHP). None of these 7 eyes developed hypotony. Of the remaining 12/19 AGV with OP < 18 mm Hg, 6/12 (50%) experienced a HP, but only 2/6 occurred in the first 2 weeks (EHP). The rest (4/6) occurred later (LHP) (Fig. 2). Therefore, AGVs with OP > 18 mm Hg were more likely to produce an EHP ($P = 0.02$) compared with AGVs with an OP < 18 mm Hg ($P = 0.02$), but were not more likely to result in any HP (both EHP or LHP) ($P = 0.36$) or LHP ($P = 0.36$).

Using 18 mm Hg as a cutoff yielded a sensitivity of 0.71, specificity of 0.83, positive predictive value of 0.71, and negative predictive value of 0.83 for predicting EHP. For predicting any HP (both EHP or LHP), the test characteristics were not robust, with a sensitivity of 0.45, specificity of 0.75, positive predictive value of 0.71, and negative predictive value of 0.50.

Of the 19 AGV implants tested, 13 had a CP of < 7 mm Hg of which 3 developed hypotony (IOP < 5 mm Hg in 2 consecutive postoperative visits) and 8 had a single postoperative IOP of < 5 mm Hg. None of the AGV's with a CP above 7 mm Hg (6/19 eyes) developed postoperative hypotony (Fig. 2). Patients receiving an AVG with a CP < 7 mm Hg were significantly more likely to have a low IOP after surgery ($P = 0.01$). Using a cutoff of CP of < 7 mm Hg, the preimplantation test had a sensitivity of 1.0 (3/3), specificity of 0.38 (6/16), positive predictive value of 0.23 (3/13), and negative predictive value of 1.0 (6/6) for predicting hypotony. For predicting a single visit of IOP < 5 mm Hg the sensitivity was 1.0 and specificity was 0.55.

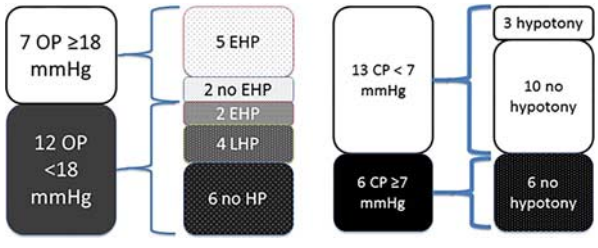


**FIGURE 2.** Graphical representation of early postoperative outcomes in Ahmed Glaucoma Valves with different opening pressures (OP) and closing pressures (CP). EHP indicates early hypertensive phase; HP, hypertensive phase; LHP, late hypertensive phase. Figure 2 can be viewed in color online at www.glaucomajournal.com.

## DISCUSSION

The AGV HP has been defined as "IOP > 21 mm Hg during the first 3 months after surgery with no evident cause."[11] It can occur between 1 and 13 weeks after implantation, and has a reported frequency of 56% to 82%.[11,15,16] The overall HP rate in our study was 58%. The HP has been attributed to inflammatory factors migrating from the anterior chamber to the bleb wall, associated with intense congestion of the bleb and elevation of IOP. It has been reported with Molteno implants,[17] less marked with the double plate Molteno implant and Baerveldt 350 implant,[18–21] suggesting that plate size or aqueous flow restriction has an impact. The HP in nonvalved implants tends to occur 4 to 6 weeks after the tube ligature is released,[13] but seen as early as 1 week with valved implants.[11,12] This suggests that other factors are involved in the EHP. Our results suggest a link between the variability of preimplantation AGV functional characteristics and the likelihood of hypotony and/or EHP, especially in the first 2 weeks after implantation.

We report a preimplantation flow test setup for the AGV using a readily available, sterile manometer to accurately assess the OP and CP of an AGV. We chose 7 and 18 mm Hg as cutoffs for CP and OP, respectively, based on other reports.[7,14] Using the method described above, this test had a 100% sensitivity to predict early hypotony and a 71% sensitivity to predict the EHP but only a 45% sensitivity to predict the LHP. The high sensitivity of the flow test to predict hypotony could possibly be explained by the fact that a low CP does not provide sufficient resistance to prevent hypotony, conversely a high OP requires a high IOP to overcome the excess valve resistance resulting in an EHP. This may explain why ocular massage can be effective in the management of HP. Manually increasing the IOP above the OP opens the valve, encouraging flow. Smith et al[22] reported that 50% of patients with HP responded to ocular massage and 50% of those remained drop free at 6 months. We speculate that ocular massage responders may have HP due to valve factors; conversely, ocular massage nonresponders may have HP due to bleb factors. Bleb-related HP would most likely occur later (LHP), be associated with an engorged encapsulated bleb, not respond to ocular massage, and respond best to management with aqueous suppressants.[16] This would be in contrast to valve-related HP, which would most likely be elevated in the early postoperative stage (EHP), with an attenuated bleb, and a better response to ocular massage. Further investigation is required to confirm this hypothesis.

Two previous studies have shown a wide inter-valve variation in AGV flow rates, OP and CP.[8,10] We report an OP range in 19 AGVs from 11 to 27 mm Hg and a CP range from 4 to 13 mm Hg. Those AGVs with a CP of < 7 mm Hg were more likely to result in hypotony ($P = 0.01$). Conversely, none of the operations using AGV with a CP above 7 mm Hg resulted in hypotony. Using a cutoff of 7 mm Hg CP, the preimplantation test had a 100% sensitivity but a low specificity (0.38) in predicting hypotony.

Our study found that EHP was much more likely to occur in valves with a high OP than low OP (71% vs. 17%, respectively, $P = 0.02$). Using a cutoff of at least 18 mm Hg, our preimplantation test had a sensitivity of 0.71 and specificity of 0.83 in predicting an EHP. Interestingly, we also showed that overall HP is more likely to occur if the AGV had a high OP (> 18 mm Hg) compared with a low OP (< 18 mm Hg) (71% vs. 58%, respectively), although with a lower correlation ($\phi$ coefficient = 0.21).

Jones and colleagues, used a similar method to assess AGVs before implantation and rejected those with an OP > 12 mm Hg and CP < 7 mm Hg. In total they rejected 4/24 AGVs (17%) and reported a 10% (2/20) hypotony rate but did not report a HP rate.[7] In our study 18/19 AGVs had an OP > 12 mm Hg. Jones and colleagues attributed 1 hypotony case to an entry-site leak and the second to a high-risk eye. Unlike our study they did not use viscoelastic in the anterior chamber.

Bochmann et al[14] reported measuring OP twice and CP once using a phacoemulsification machine setup. They reported that a second OP, or the "reopening pressure," ≤11 mm Hg, was the most helpful parameter in identifying hypotony (IOP < 5 mm Hg) in the immediate postoperative period. We did not measure any AGVs with a "reopening pressure" of < 11 mm Hg. The authors did not provide any theories as to why the OP should correlate to low postoperative IOP. They described a correlation between CP of ≤10 mm Hg with lower postoperative IOP, which is in keeping with our findings. As the CP determines when fluid no longer exits the device, logically a low CP AGV would be expected to be prone to hypotony.

Bochmann et al[14] reported a 50% incidence of single visit of IOP < 5 mm Hg which is close to our finding of 42%. In comparison Jones et al,[7] discarded AGVs with a CP of < 7 mm Hg, and had a much lower rate of hypotony of 10%. If we discarded AGVs with a CP < 7 mm Hg our rate of hypotony would have been zero; however, 10 AGVs would have been unnecessarily discarded.

The limitations of our study include a small sample size and short follow-up period and therefore this study does not demonstrate if the reported OP and CP have any long-term impact on final IOP. Provisc (Alcon, Texas) was left in the anterior chamber in each eye, which may affect the number of hypotony and EHP cases by its impact on the flow of aqueous. There are multiple causes of hypotony after AGV implantation, including entry-site leakage and ciliary body shutdown, which may also affect postoperative results. We did, however, evaluate the entry site for leakage at the time of surgery and did not note any leakage. Bleb morphology data were not collected and potentially could be used to differentiate valve versus bleb-related ocular hypertension. Our HP rate is comparable with other studies, but to our knowledge, this is the first study to suggest that a measurable variation in valve resistance may predispose to developing EHP. It is important to note that the preimplantation testing was performed in an exposed environment which is not directly comparable with the in vivo environment where there are additional factors influencing the flow and resistance. Nevertheless, our study suggests a correlation between in vitro testing and in vivo performance of the AGV.

In conclusion we report that if cutoffs for OP and CP of 18 and 7 mm Hg are used to discard AGVs then EHP and hypotony may be significantly reduced, albeit with some device wastage. If our data are confirmed we recommend the manufacturer develops quality control methods to test each AGV performance before releasing them to market so as to reduce these complications.

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