The Ahmed Versus Baerveldt Study

Three-Year Treatment Outcomes

Panos G. Christakis, MD,[1,2] James C. Tsai, MD,[2] Jeffrey W. Kalenak, MD,[3] David Zurakowski, PhD,[4] Louis B. Cantor, MD,[5] Jeffrey A. Kammer, MD,[6] Iqbal I. K. Ahmed, MD[1]

Objective: To compare 2 commonly used aqueous drainage devices for the treatment of refractory glaucoma.

Design: International, multicenter, randomized trial.

Participants: Patients aged 18 years or older with uncontrolled or high-risk glaucoma refractory to maximum medical therapy, many of whom had failed trabeculoplasty and trabeculectomy.

Methods: Eligible patients were randomized to an Ahmed-FP7 valve implant (New World Medical, Inc., Rancho Cucamonga, CA) or a Baerveldt-350 implant (Abbott Medical Optics, Inc., Santa Ana, CA) using a standardized surgical technique.

Main Outcome Measures: The primary outcome was failure, defined as intraocular pressure (IOP) outside of the target range (5−18 mmHg, with ≥20% reduction from baseline) for 2 consecutive visits after 3 months, vision-threatening complications, de novo glaucoma procedures, or loss of light perception. Secondary outcome measures include IOP, medication use, visual acuity, complications, and interventions.

Results: A total of 238 patients were enrolled and randomized; 124 received the Ahmed implant and 114 received the Baerveldt implant. Baseline characteristics were similar in both groups. Half the study group had secondary glaucoma, and 37% had previously failed trabeculectomy. The mean preoperative IOP was 31.4±10.8 mmHg on 3.1±1.0 glaucoma medications. Median baseline Snellen visual acuity was 20/100. At 3 years, the cumulative probability of failure was 51% in the Ahmed group and 34% in the Baerveldt group ($P = 0.03$). Mean IOP was 15.7±4.8 mmHg in the Ahmed group (49% reduction) and 14.4±5.1 mmHg in the Baerveldt group (55% reduction; $P = 0.09$). Mean number of glaucoma medications was 1.8±1.4 in the Ahmed group (42% reduction) and 1.1±1.3 in the Baerveldt group (65% reduction; $P = 0.002$). There was a moderate but similar decrease in visual acuity in both groups ($P < 0.001$). The 2 groups had similar complication rates (52% Ahmed, 62% Baerveldt; $P = 0.12$); however, the Baerveldt group had a higher rate of hypotony-related vision-threatening complications (0% Ahmed, 6% Baerveldt; $P = 0.005$). More interventions were required in the Baerveldt group, although the difference did not reach statistical significance (38% Ahmed, 50% Baerveldt; $P = 0.07$). Most complications were transient, and most interventions were slit-lamp procedures.

Conclusions: Both devices were effective in reducing IOP and glaucoma medications. The Baerveldt group had a lower failure rate and required fewer medications than the Ahmed group after 3 years, but it experienced more hypotony-related vision-threatening complications.

Financial Disclosure(s): The author(s) have no proprietary or commercial interest in any materials discussed in this article. *Ophthalmology 2013;120:2232-2240 © 2013 by the American Academy of Ophthalmology.*

Glaucoma refractory to maximum tolerated medical therapy and laser trabeculoplasty often requires surgery to lower intraocular pressure (IOP) and prevent vision loss. The most common procedure is trabeculectomy, which removes a block of limbal tissue to establish a fistula leading to a bleb that facilitates aqueous outflow. However, high rates of complications have been reported in trabeculectomy, and 5-year failure rates approach 50%.[1−3] Patients who fail trabeculectomy or who have high-risk disease (e.g., neovascular or uveitic glaucoma) may benefit from aqueous drainage devices, which are being used more frequently.[4−7] A Cochrane review in 2006 comparing trabeculectomy with various aqueous drainage devices found no evidence of superiority of one procedure over another.[8] More recently, however, the Tube Versus Trabeculectomy Study found the Baerveldt implant to have a higher success rate than trabeculectomy with mitomycin C at 5 years, with fewer early postoperative complications.[1,3] This has initiated discussion as to the role of aqueous drainage devices as a first-line surgical treatment for glaucoma, and the Primary Tube Versus Trabeculectomy Study is under way to explore this question.[9]

Two of the most commonly implanted aqueous drainage devices are the Ahmed valve and the Baerveldt implant. These devices shunt aqueous humor via a long tube to an equatorial subconjunctival end plate. The Ahmed implant features a Venturi-based flow restrictor designed to reduce postoperative hypotony and its complications.[10] However, it has been associated with high rates of encapsulation and

ISSN 0161-6420/13/$ - see front matter
http://dx.doi.org/10.1016/j.ophtha.2013.04.018

inadequate IOP reduction, often requiring postoperative glaucoma medications.[10–14] The Baerveldt implant is a nonvalved device that requires intraoperative mechanical flow restriction to allow adequate time for a bleb to form at the end plate. This has been reported to cause early postoperative IOP volatility, including both ocular hypertension and hypotony-related complications.[15,16] However, once the end plate is functional, the Baerveldt implant has been associated with better IOP control, fewer glaucoma medications, and less encapsulation in the long term.[12,13,17] This may be a result of its larger end plate (350 vs. 184 mm^2) and lack of valve-induced resistance.[5,17–19] There have been 4 retrospective studies to compare the Ahmed valve with the Baerveldt implant; however, they have been small-scale, nonrandomized, and compared different device models and patient populations, which made drawing conclusions difficult.[12,13,17,20,21]

Currently, selecting an aqueous drainage device currently is largely driven by surgeon preference, which is influenced by personal experience and clinical center precedent. The Ahmed Versus Baerveldt (AVB) Study is a prospective, international, multicenter, randomized trial designed to compare the long-term efficacy of the Ahmed valve with the Baerveldt implant in patients with refractory or high-risk glaucoma.

Methods

The AVB Study design and baseline data have been reported in detail elsewhere[22] and will be briefly summarized here. Patients were recruited from 6 international clinical centers and operated on by 9 surgeons (Appendix 1; available at http://aaojournal.org). Institutional review board approval was obtained at each clinical center, and the study protocol was in accordance with the principles of the Declaration of Helsinki. Eligibility required patients to be older than 18 years of age; to have inadequately controlled glaucoma refractory to maximum medical therapy; and to be willing and able to provide informed consent and adhere to the study requirements, including implant randomization and follow-up. Patients who previously failed antimetabolite trabeculectomy and patients at highrisk of failing trabeculectomy (e.g., neovascular glaucoma, conjunctival scarring) were included in the study. One eye per patient was eligible for enrollment, and no additional procedures (e.g., phacoemulsification) were performed at the time of device implantation.

A total of 238 eligible patients were randomized to receive an Ahmed-FP7 valve or a Baerveldt-350 implant using a standardized surgical technique.[22] Baerveldt implants were ligated intraoperatively using a releasable suture, and tube fenestrations were placed in patients with glaucoma requiring an immediate IOP reduction. Patients had regular scheduled study follow-up, including 9 appointments in the first postoperative year, 2 appointments the second year, and annual appointments until 5 years. At each visit, IOP, visual acuity, glaucoma medications, complications, and interventions related to the implant were recorded, and a treatment outcome was assigned (complete success, qualified success, or failure).

Outcome Measures

The primary outcome measure was failure, defined as any of the following: IOP outside of the target range (5–18 mmHg, with ≥20% reduction from baseline) for 2 consecutive visits after 3 months, vision-threatening complications, de novo glaucoma procedures, or loss of light perception (Table 1, available at http://aaojournal.org). Success was considered the absence of failure and classified as complete or qualified. Complete success required patients to have IOP within the target range at all visits after 3 months without the use of glaucoma medications and without significant vision loss (>2 Snellen lines), vision-threatening complications, or surgical interventions required. Qualified success allowed nonconsecutive visits outside of the target IOP range and allowed the use of medications and surgical interventions provided that they were not for vision-threatening complications. Success was also analyzed using 2 alternative IOP criteria (≤14 and ≤21 mmHg), as recommended by the World Glaucoma

Table 2. Baseline Demographic and Ocular Characteristics

	Overall (n=238)	Ahmed (n=124)	Baerveldt (n=114)	P Value
Age, mean ± SD	66±16	65±17	67±15	0.29*
Sex: female	132 (55)	59 (48)	73 (64)	0.011†
Ethnicity: white	170 (71)	91 (73)	79 (69)	0.90†
Glaucoma diagnosis				0.82†
Open-angle	119 (50)	64 (52)	55 (48)	
Neovascular	50 (21)	28 (23)	22 (19)	
Uveitic	23 (10)	10 (8)	13 (11)	
Other	46 (19)	22 (18)	24 (21)	
IOP (mmHg), mean ± SD	31.4±10.8	31.1±10.5	31.7±11.1	0.71*
Glaucoma medications, mean ± SD	3.1±1.0	3.1±1.0	3.1±1.1	0.60*
Previous surgery, mean ± SD	1.7±1.2	1.8±1.3	1.6±1.1	0.35*
Cataract surgery	172 (72)	90 (73)	82 (72)	0.91†
Trabeculectomy	89 (37)	41 (33)	48 (42)	0.15†
Previous lasers, mean ± SD	0.9±1.1	0.8±1.1	1.0±1.1	0.17*
Trabeculoplasty	60 (25)	27 (22)	33 (29)	0.20†
Visual acuity, median Snellen	20/100	20/100	20/100	0.67‡

Values are n (%) unless otherwise indicated.
IOP = intraocular pressure; SD = standard deviation.
*Student *t* test.
†Pearson chi-square test.
‡Mann–Whitney *U* test.

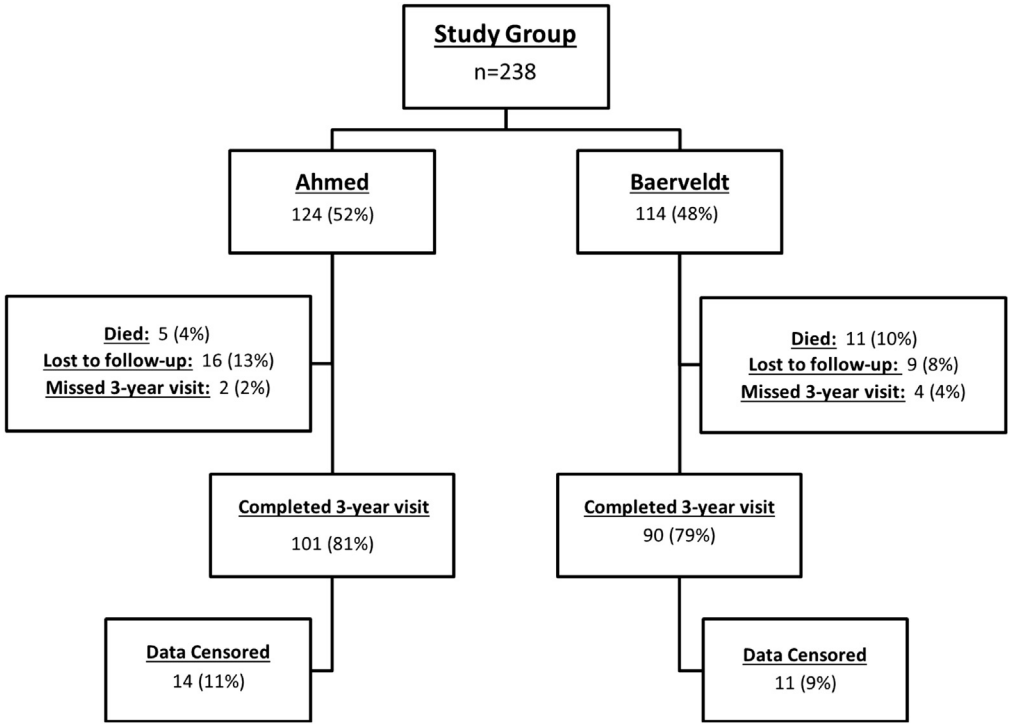

Figure 1. Retention rates at 3 years.

Association.[23] Secondary outcome analyses compared groups on the basis of IOP, medication use, visual acuity, complications of surgery, and interventions required.

Data Censoring

Patients meeting the criteria for failure are included in secondary analyses, except those who underwent de novo glaucoma surgery (e.g., cyclodestruction, second drainage device) or who experienced vision-threatening complications that altered treatment goals (e.g., progression to no light perception). In these cases, IOP and medication use were censored to prevent confounding, but visual outcomes and additional complications or interventions related to the initial surgery were included. The relative rate of censoring and status at the time of censoring was compared between groups.

Statistical Analysis

Statistical analysis was performed using SPSS 16.0 (SPSS Inc., Chicago, IL) using intention-to-treat analysis. All statistical tests were 2-sided, and significance was defined as $P \leq 0.05$. Continuous and quantitative variables were analyzed between groups using the Student *t* test or Mann–Whitney *U* test, and discrete and qualitative variables were analyzed using a Pearson chi-square test or Fisher exact test. Snellen visual acuity was converted to logarithm of the minimum angle of resolution (logMAR) for analysis. Analysis of variance was used to compare change in quantitative variables from baseline over time. Kaplan–Meier analysis was used to compare failure rates between groups using the log-rank test (Mantel-Cox).

Results

A total of 238 patients were randomized: 124 to the Ahmed-FP7 valve implant and 114 to the Baerveldt-350 implant. Baseline demographic and ocular characteristics were similar between groups and are presented in Table 2. The study population was predominately white and had an average age of 66 years, and 55% were female (greater proportion in the Baerveldt group). Disease was refractory to maximum tolerated medical therapy, with a mean IOP of 31.4±10.8 mmHg on 3.1±1.0 classes of medications. Baseline vision was poor, with a median Snellen acuity of 20/100. Half the study population had secondary glaucoma; 21% had neovascular glaucoma, and 10% had uveitic glaucoma. Many patients had failed laser and surgical therapy; 25% had previously undergone laser trabeculoplasty, and 37% had failed trabeculectomy with antimetabolite.

All patients received the implant to which they were randomized, and there were few intraoperative complications (4% in each

Table 3. Reasons for Failure during Three Years of Follow-up

	Ahmed (n=124)	Baerveldt (n=114)
Success	61 (49%)	75 (66%)
Complete*	5 (4%)	13 (11%)
Failure†	63 (51%)	39 (34%)
High IOP (>18 mmHg for consecutive visits)	50 (40%)	21 (18%)
Requiring additional glaucoma surgery	14 (11%)	7 (6%)
Volatile IOP or inadequate reduction‡	9 (7%)	8 (7%)
Progression to NLP	2 (2%)	4 (4%)
Devastating complications	2 (2%)	6 (5%)

IOP = intraocular pressure; NLP = no light perception.
*$P = 0.047$ (Fisher exact test).
†$P = 0.013$ (Fisher exact test).
‡Consecutive visits in which IOP >18 or <5 mmHg or <20% reduction from baseline.

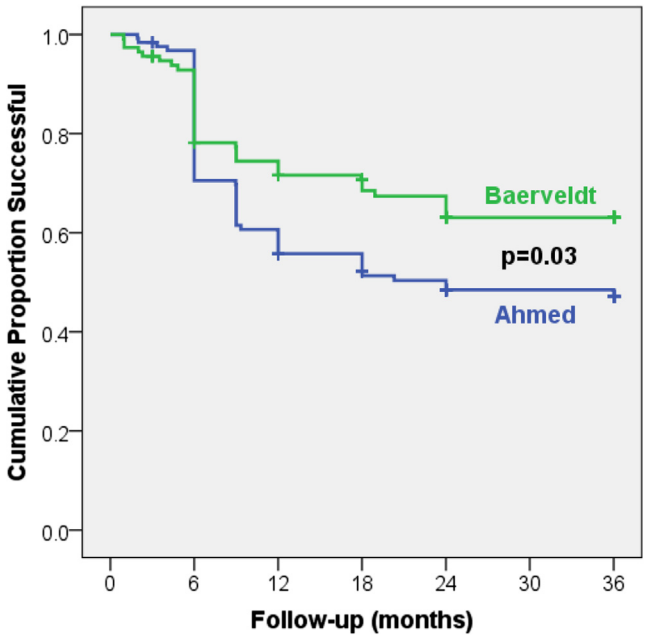

Figure 2. Kaplan–Meier analysis using the primary outcome criteria (5 mmHg ≤ intraocular pressure ≤ 18 mmHg). Censoring is denoted by *hash marks*.

group).[22] Retention rates were high in both groups after 3 years (Fig 1); only 16 patients (13%) in the Ahmed group and 9 patients (8%) in the Baerveldt group were lost to follow-up (P = 0.29, Fisher exact test).

Treatment Outcomes

After 3 years of follow-up, failure had occurred in 63 patients (51%) in the Ahmed group and 39 patients (34%) in the Baerveldt group (P = 0.013). The most common reason for failure in both groups was high IOP, and many of these patients required a de novo glaucoma procedure (Table 3). Complete success required patients to have IOP in range at all visits after 3 months without any medications, significant loss of vision, or additional procedures: only 5 patients (4%) in the Ahmed group and 13 patients (11%) in the Baerveldt group met these criteria (P = 0.047). Kaplan–Meier analysis comparing the cumulative probability of failure at 3 years showed that the Baerveldt group had less failure than the Ahmed group (P = 0.03) (Fig 2). Alternative IOP criteria were analyzed to determine their effect on failure. When a less rigid IOP target of ≤21 mmHg was used, the 2 groups had similar failure rates (39% Ahmed, 29% Baerveldt; P = 0.16). When a strict IOP criteria of ≤14 mmHg was used, failure rates were high in both groups (76% Ahmed, 66% Baerveldt; P = 0.19).

Intraocular Pressure

The mean IOP at each postoperative visit is presented in Figure 3 and Table 4 (available at http://aaojournal.com). The Ahmed group had a lower mean IOP at the 1-day (P < 0.001), 1-week (P < 0.001), and 2-week (P = 0.029) follow-up visits.[24] Seven patients (6%) in the Baerveldt group had vision-threatening hypotony-related complications (3 developed suprachoroidal hemorrhage, 3 had retinal/choroidal detachments, and 1 had refractory hypotony requiring explantation) compared with zero patients in the Ahmed group (P = 0.005). From 1 month onward, the Baerveldt group had a lower IOP than the Ahmed group, which reached statistical significance at the 12-month and 18-month visits (P < 0.001). The mean IOP at 3 years was 15.7±4.8 mmHg in the Ahmed group (49% reduction from baseline, P < 0.001) and 14.4±5.1 mmHg in the Baerveldt group (55% reduction from baseline, P < 0.001; comparison between groups, P = 0.09).

Glaucoma Medication Use

The mean number of glaucoma medications required at each postoperative visit is shown in Figure 4 and Table 4 (available at http://aaojournal.com). The Ahmed group required fewer glaucoma medications at the 1-day, 1-week, and 2-week follow-up visits (P < 0.05).[24] From 2 months onward, the Baerveldt group required fewer glaucoma medications than the Ahmed

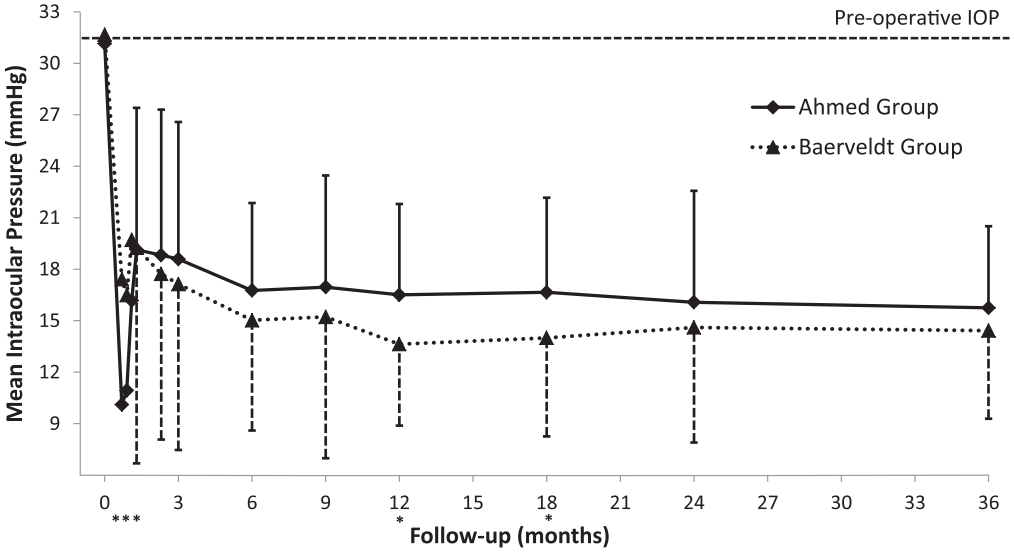

Figure 3. Mean intraocular pressure (IOP) during the 3 years after surgery. Error bars represent standard deviation. *Corresponds to a statistically significant difference between groups.

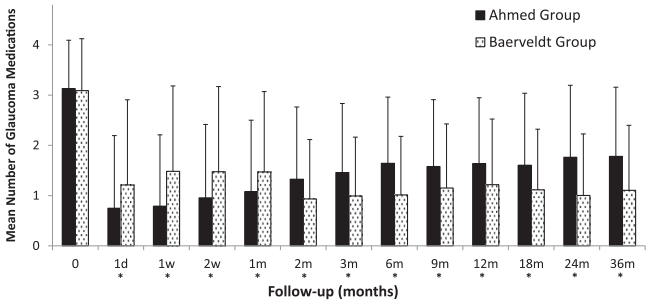

Figure 4. Mean number of glaucoma medications during the 3 years after surgery. Error bars represent standard deviation. *Corresponds to a statistically significant difference between the groups.

group ($P < 0.05$). The mean number of glaucoma medications required at 3 years was 1.8±1.4 in the Ahmed group (42% reduction from baseline, $P < 0.001$) and 1.1±1.3 in the Baerveldt group (65% reduction from baseline, $P < 0.001$; comparison between groups, $P = 0.002$). At the 3-year visit, 25% of the Ahmed group and 50% of the Baerveldt group required no medications ($P < 0.001$).

Visual Outcomes

Change in visual acuity between preoperative values and those at the 3-year visit are shown in Figure 5. The 2 devices had comparable visual acuities at each postoperative visit. At the 3-year follow-up visit, the mean logMAR acuity was 1.6±1.2 in both groups ($P = 0.79$), corresponding to a median Snellen acuity of 20/200. Comparison of the logMAR acuity of patients at their 3-year visit with their preoperative value showed a moderate but similar decrease in visual acuity in both groups (1.3±1.1 to 1.6±1.2; $P < 0.001$). Eleven patients (5%) progressed to no light perception: 5 (4%) in the Ahmed group and 6 (5%) in the Baerveldt group ($P = 0.76$). Seven (64%) of these patients had neovascular glaucoma.

De Novo Glaucoma Procedures

De novo glaucoma surgery was performed in patients in whom IOP could not be adequately controlled with medications or in whom there was progression of disease. Twenty-one patients (9%) required additional glaucoma surgery: 14 patients (11%) in the Ahmed group and 7 patients (6%) in the Baerveldt group ($P = 0.25$). The choice of glaucoma surgery was at the discretion of the surgeon. Cyclodestruction was performed in 6 patients in the Ahmed group and 2 patients in the Baerveldt group. A Gold Micro Shunt (SOLX Ltd., Boston, MA) was placed in 1 patient in the Ahmed group and 3 patients in the Baerveldt group. A Baerveldt device was implanted in 5 patients in the Ahmed group and 1 patient in the Baerveldt group, and an Ahmed device was implanted in 1 patient in the Baerveldt group. The average IOP at the time of reoperation was 25.6±16.0 mmHg in the Ahmed group and 24.5±14.5 mmHg in the Baerveldt group ($P = 0.86$). Patients who underwent de novo glaucoma procedures had their IOP and medication data censored from secondary analyses at the time of reoperation.

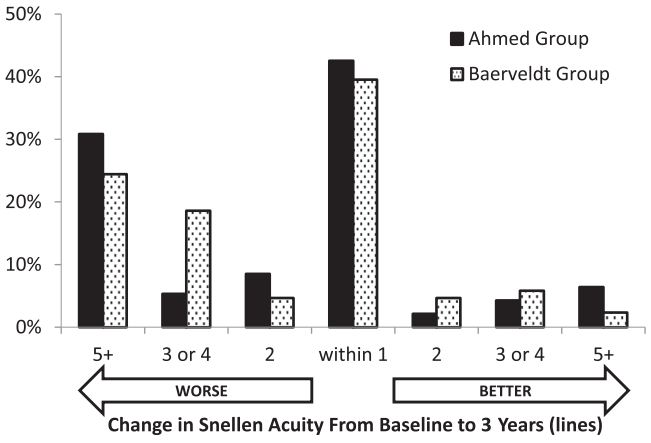

Figure 5. Distribution of change in visual acuity from baseline to 3 years.

Postoperative Complications

In the first 3 years after surgery, 64 patients (52%) in the Ahmed group and 71 patients (52%) in the Baerveldt group experienced complications ($P = 0.12$) (Table 5). The most common complications were shallow anterior chamber (15% Ahmed, 17% Baerveldt; $P = 0.72$), choroidal effusion (13% Ahmed, 14% Baerveldt; $P = 0.85$), persistent corneal edema (7% Ahmed, 14% Baerveldt; $P = 0.09$), persistent iritis (6% Ahmed, 10% Baerveldt; $P = 0.33$), encapsulated bleb (11% Ahmed, 3% Baerveldt; $P = 0.01$), and tube-related complications (15% Ahmed, 16% Baerveldt; $P = 0.86$).

Postoperative Interventions

In the first 3 years after surgery, 47 patients (38%) in the Ahmed group and 57 patients (50%) in the Baerveldt group required interventions ($P = 0.068$) (Table 6). The most common interventions were anterior chamber reformation (11% Ahmed, 13% Baerveldt $P = 0.35$), paracentesis (4% Ahmed, 14% Baerveldt, $P = 0.010$), phacoemulsification (7% Ahmed, 10% Baerveldt, $P = 0.45$), tube-related interventions (6% Ahmed, 14% Baerveldt, $P = 0.046$), bleb needling (4% in each group, $P = 1.0$), and pars plana vitrectomy (3% Ahmed, 4% Baerveldt, $P = 1.0$).

Discussion

The AVB Study randomized 238 patients with glaucoma refractory to conventional treatment to receive an Ahmed-FP7 valve or a Baerveldt-350 implant. Patients had uncontrolled IOP at the time of surgery despite maximum tolerated medical therapy, and many had previously failed trabeculectomy. There were high rates of secondary glaucoma, and baseline vision was poor because of concomitant ocular pathology. Given the advanced and refractory nature of disease, we set our IOP target to ≤18 mmHg, which is more stringent than previous studies comparing these devices.[8] This was based on evidence that an IOP target of ≤21 mmHg may be insufficient to prevent disease progression in patients with advanced glaucoma.[25] Our patients required on average a 40% reduction in IOP from baseline to achieve their target pressure. We did not consider interventions required to correct complications of surgery, including operating room procedures, to constitute failure unless the IOP or visual acuity criteria were not met. However, patients who experienced vision-threatening complications or who required de novo glaucoma

Table 5. Postoperative Complications during 3 Years of Follow-up

	Ahmed (n=124)	Baerveldt (n=114)	P Value*
Shallow anterior chamber	18 (15%)	19 (17%)	0.72
Choroidal effusion	16 (13%)	16 (14%)	0.85
Persistent Iritis	7 (6%)	11 (10%)	0.33
Persistent corneal edema	9 (7%)	16 (14%)	0.095
Encapsulated bleb	14 (11%)	3 (3%)	0.011
Tube complications†	18 (15%)	18 (16%)	0.86
Cataract progression‡	7 (6%)	10 (9%)	0.45
Motility disorder	7 (6%)	3 (3%)	0.34
Persistent hyphema	4 (3%)	6 (5%)	0.53
No light perception	5 (4%)	6 (5%)	0.76
Malignant glaucoma	2 (2%)	2 (2%)	1.00
Suprachoroidal hemorrhage	0 (0%)	3 (3%)	0.11
Retinal/choroidal detachment	1 (1%)	3 (3%)	0.35
Endophthalmitis/episcleritis	2 (2%)	0 (0%)	0.50
Patients with complications	64 (52%)	71 (62%)	0.12

*Fisher exact test.
†Includes tube obstruction, malposition, and erosion.
‡Corrected for the number of phakic patients.

procedures were considered failures and censored at the time of reoperation to minimize confounding.

At 3 years, the failure rate was 51% in the Ahmed group and 34% in the Baerveldt group ($P = 0.03$). The main reason for failure in both groups was high IOP (>18 mmHg), and the majority of failures occurred in the first year after surgery. These rates of failure are higher than in previous retrospective comparisons, in which Ahmed implantation had a failure rate of 33% to 38% and Baerveldt implantation had a failure rate of 15% to 36%.[12,13,17,20,21] However, these studies used an IOP target of ≤21 mmHg and patients had less severe disease at baseline. When we used an IOP target of ≤21 mmHg, the failure rate was 39% in the Ahmed group and 29% in the Baerveldt group ($P = 0.20$). Our results are comparable to the 10% failure per year quoted by the American Academy of Ophthalmology report on aqueous drainage devices.[5] In addition, our failure rates are similar to those in the Ahmed Baerveldt Comparison (ABC) Study, a concurrent multicenter study that reported 30% failure rates in both groups at 3 years (Budenz DL, Barton K, Feuer WJ, et al. Invest Ophthalmol Vis Sci 2012;53:ARVO E-Abstract 6355). When we used an IOP target of ≤14 mmHg, failure rates were exceptionally high in both groups. Overall, the Baerveldt group had a lower failure rate using all criteria, but statistical significance was reached only when using the prospectively defined IOP target for which our study was powered.[22]

Table 6. Postoperative Interventions during 3 Years of Follow-up

	Ahmed (n=124)	Baerveldt (n=114)	P Value*
Anterior chamber reformation	13 (11%)	14 (13%)	0.35
Paracentesis	5 (4%)	16 (14%)	0.010
Phacoemulsification†	7 (24%)	10 (34%)	0.45
Tube interventions‡	7 (6%)	16 (14%)	0.046
Bleb needling	5 (4%)	4 (4%)	1.00
Pars plana vitrectomy	4 (3%)	5 (4%)	0.74
Iris sweep	1 (1%)	4 (4%)	0.20
Laser peripheral iridotomy	2 (2%)	2 (2%)	1.00
DSEK/PKP	5 (4%)	5 (4%)	1.00
YAG capsulotomy	4 (3%)	3 (3%)	1.00
Drainage of SCH	0 (0%)	2 (2%)	0.23
Additional glaucoma surgery	14 (11%)	7 (6%)	0.25
Explant or enucleation	4 (3%)	3 (3%)	1.00
Patients requiring interventions	47 (38%)	57 (50%)	0.068

DSEK = Descemet's stripping endothelial keratoplasty; PKP = penetrating keratoplasty; SCH = suprachoroidal hemorrhage; YAG = yttrium aluminum garnet.
*Fisher exact test.
†Corrected for number of phakic patients.
‡Includes tube irrigation, ligation, revision, reposition, or laser for obstruction.

Treatment success was subdivided into complete and qualified success. Complete success required IOP to be in range at all visits after 3 months without the use of glaucoma medications and without any significant loss of vision or additional surgical procedures required. Although 49% of the Ahmed group and 66% of the Baerveldt group were considered successes at 3 years, only 4% of patients in the Ahmed group and 11% of patients in the Baerveldt group were complete successes ($P = 0.04$). This reflects the complicated postoperative course of aqueous drainage devices, including IOP volatility, the need for glaucoma medications, and complications requiring additional surgeries. This is compounded by the poor baseline prognosis of our study population because of the high rates of neovascular and uveitic glaucoma. Retrospective studies of patients with neovascular glaucoma undergoing aqueous drainage device implantation report failure rates between 44% and 79%, with progression to no light perception occurring in 24% to 31% of patients.[26,27] Many of these patients' had disease progression despite their IOP being within target range, suggesting that failure may reflect the natural course of disease rather than device failure. This may contribute to the high rates of failure observed in our study population.

Despite high rates of failure in both groups, both devices were effective in reducing IOP and the need for glaucoma medications ($P < 0.001$). At the 3-year visit, the Ahmed group had a mean IOP of 15.7±4.8 mmHg (49% reduction from baseline) compared with 14.4±5.1 mmHg (55% reduction) in the Baerveldt group ($P = 0.09$). The Ahmed group required an average of 1.8±1.4 medications (42% reduction) compared with 1.1±1.3 medications (65% reduction) in the Baerveldt group ($P < 0.01$). Twice as many patients in the Baerveldt group required no medications compared with patients in the Ahmed group (25% in the Ahmed group, 50% in the Baerveldt group; $P < 0.001$). Medication use may reflect device efficacy because it is often used to titrate IOP to meet clinical targets. Our results were again similar to those of the ABC Study, which reported lower IOP in the Baerveldt group at 3 years (Ahmed 14.3±4.9 mmHg, Baerveldt 12.9±4.4 mmHg; $P = 0.049$) and fewer glaucoma medications (Ahmed 1.9±1.4, Baerveldt 1.5±1.4; $P = 0.048$) (Budenz DL, Barton K, Feuer

WJ, et al. Invest Ophthalmol Vis Sci 2012;53:ARVO E-Abstract 6355).

In the first month after surgery, the Baerveldt group required a greater number of medications and interventions such as paracentesis to treat volatile IOP. It has been postulated that aggressive treatment of postoperative elevated IOP in patients with severe glaucomatous disease is necessary to prevent visual loss.[28] For this reason, many surgeons prefer flow-restrictive aqueous drainage devices because they provide an immediate IOP reduction. In our study, patients in the Baerveldt group requiring an early IOP reduction had tube fenestrations placed anterior to the ligature to provide some early aqueous outflow until the end plate bleb was formed.

Transient postoperative hypotony was seen in both groups, with 13% of the Ahmed group and 14% of the Baerveldt group experiencing choroidal effusions. This is similar to the ABC study, in which 15% of Ahmed valves and 10% of Baerveldt implants experienced postoperative choroidal effusions.[29] Hypotony in Ahmed implants may result from a defective valve, destruction during priming, or excessive peritubular filtration at the anterior chamber insertion site.[30,31] In Baerveldt implants, the lack of flow restriction predisposes to severe hypotony if there is ligature malfunction or excessive filtration through the tube fenestrations.[30,31] In our study, 7 patients (6%) in the Baerveldt group experienced vision-threatening hypotony-related complications compared with zero patients in the Ahmed group ($P = 0.005$).

The majority of complications and interventions occurred in the first 3 months in both groups. Similar to previous retrospective studies, our study found that the Ahmed valve had a higher rate of encapsulation than the Baerveldt implant (11% vs. 4%; $P = 0.01$).[12] Several theories have been postulated to explain this finding, including differences in early flow rates and exposure to inflammatory mediators, as well as differences in end plate materials and topography.[13,32–34] Early exposure of the Ahmed bleb to mechanical compression from aqueous flow and exposure to surgery-induced inflammatory cytokines may stimulate fibroproliferative encapsulation.[32,33] Furthermore, electron microscopy comparing the Ahmed-FP7 end plate with the Baerveldt-350 implant found that it had a root-mean-square roughness 10-fold greater, resulting in increased in vitro tenon fibroblast adhesion.[34] Antimetabolites have been trialed in aqueous drainage device implantation to prevent encapsulation but failed to show improved IOP and had a higher incidence of hypotony and graft melt.[5,8,32] Bleb histology has been cited as an important factor in the long-term success of aqueous drainage devices, with encapsulation reducing filtration and increasing the need for medications.[12] In our study, the medication requirement of the Ahmed group increased steadily beginning at 4 weeks, in contrast to the Baerveldt group, whose requirement for medications decreased over time. Nine patients (4%) underwent bleb needling, of whom 4 regained significant function of the bleb. De novo glaucoma procedures were performed in patients whose IOP could not be adequately controlled with medications or device revision. Twenty-one patients (9%), including 14 patients (11%) in the Ahmed group and 7 patients (6%) in the Baerveldt group, underwent de novo glaucoma procedures. Thirteen patients (5%) had a second glaucoma device implanted, and 3% of patients underwent a ciliary body destructive procedure. These rates are similar to those in a large-scale retrospective case series that reported a device revision rate of 4% and additional device placement rate of 7%.[35]

The most common long-term complication was corneal edema, which affected 7% of patients in the Ahmed group and 14% of patients in the Baerveldt group at 3 years ($P = 0.08$). This is similar to the Tube Versus Trabeculectomy Study, which reported a persistent corneal edema rate of 16% in the Baerveldt group at 5-years.[3] Hypothesized causes include accelerated damage to the endothelium as a result of hypotony, postoperative IOP fluctuations, and anterior chamber tube placement.[3,5,36] This is compounded by the poor preoperative corneal health of patients receiving aqueous drainage devices as a result of long-term glaucoma and multiple previous surgeries.[32] The higher rate of corneal edema in the Baerveldt group also was reported in the ABC Study and may be a result of greater IOP volatility in the early postoperative period.[29]

There was a moderate but similar worsening of visual acuity in both groups. However, determining whether the cause of vision loss was a result of glaucomatous progression, complications of the surgery, or concomitant ocular pathology is difficult. Five patients (4%) in the Ahmed group and 6 patients (5%) in the Baerveldt group progressed to no light perception, the majority of whom had neovascular glaucoma.

Study Limitations

The AVB Study has several limitations that should guide how the results are interpreted. First, the patients recruited had advanced glaucoma refractory to maximum tolerated medical therapy and were at a high risk of surgical failure. In recent years, aqueous drainage devices have become more frequently used early in the course of disease, and our results cannot be applied to this patient population. Second, although preservation of visual function through the prevention of optic nerve damage is the main goal in glaucoma therapy, our study used IOP as a surrogate measure of success. Glaucoma trials use IOP as the main outcome measure because it is quantifiable, reproducible, and the only clinically modifiable risk factor to prevent disease progression. However, structural changes to the optic nerve and visual field data may better assess disease progression and functional outcomes. Unfortunately, the poor baseline vision of our study population precluded standard visual field testing, and ocular coherence tomography was not readily available when the study commenced. Thus, they were not formal outcome criteria but were used to monitor disease progression and guide management. Finally, our results may be influenced by our surgeon's relative skill and experience implanting each device. To minimize this bias, only surgeons who had extensive experience in implanting both devices participated in the study, as determined by the senior author (I.I.K.A.).

Intraoperative complication rates were low in both groups and similar in number and severity.

In conclusion, the results of the AVB Study demonstrate that both the Ahmed-FP7 valve implant and the Baerveldt-350 implant were effective in lowering IOP and reducing the need for glaucoma medications in a population of patients with refractory glaucoma. When comparing the devices, the Baerveldt group had a lower failure rate and required fewer medications than the Ahmed group after 3 years of follow-up, but it experienced more hypotony-related, vision-threatening complications. Other factors must be considered when selecting a device, including surgeon skill and experience with each operation, as well as patient risk factors for failure, medication compliance, and goals of therapy. Additional follow-up is required before drawing conclusions about the relative efficacy of these devices because studies that have followed patients with aqueous drainage devices over the long term have reported failure until 5 years after surgery.[1,13]

References

1. Gedde SJ, Schiffman JC, Feuer WJ, et al, Tube versus Trabeculectomy Study Group. Treatment outcomes in the Tube Versus Trabeculectomy (TVT) Study after five years of follow-up. Am J Ophthalmol 2012;153:789–803.
2. Fluorouracil Filtering Surgery Study Group. Five-year follow-up of the Fluorouracil Filtering Surgery Study. Am J Ophthalmol 1996;121:349–66.
3. Gedde SJ, Herndon LW, Brandt JD, et al, Tube versus Trabeculectomy Study Group. Postoperative complications in the Tube Versus Trabeculectomy (TVT) study during five years of follow-up. Am J Ophthalmol 2012;153:804–14.
4. Boyle JW IV, Netland PA. Incisional therapies: shunts and valved implants. In: Schacknow PN, Samples JR, eds. The Glaucoma Book: A Practical, Evidence-Based Approach to Patient Care. New York: Springer; 2010:813–30.
5. Minckler DS, Francis BA, Hodapp EA, et al. Aqueous shunts in glaucoma: a report by the American Academy of Ophthalmology. Ophthalmology 2008;115:1089–98.
6. Wilson MR, Mendis U, Paliwal A, Haynatzka V. Long-term follow-up of primary glaucoma surgery with Ahmed glaucoma valve implant versus trabeculectomy. Am J Ophthalmol 2003;136:464–70.
7. Ramulu PY, Corcoran KJ, Corcoran SL, Robin AL. Utilization of various glaucoma surgeries and procedures in Medicare beneficiaries from 1995 to 2004. Ophthalmology 2007;114:2265–70.
8. Minckler DS, Vedula SS, Li TJ, et al. Aqueous shunts for glaucoma. Cochrane Database Syst Rev 2006;(2):CD004918.
9. Nguyen QH. Primary surgical management refractory glaucoma: tubes as initial surgery. Curr Opin Ophthalmol 2009;20:122–5.
10. Huang MC, Netland PA, Coleman AL, et al. Intermediate-term clinical experience with the Ahmed Glaucoma Valve implant. Am J Ophthalmol 1999;127:27–33.
11. Nouri-Mahdavi K, Caprioli J. Evaluation of the hypertensive phase after insertion of the Ahmed Glaucoma Valve. Am J Ophthalmol 2003;136:1001–8.
12. Tsai JC, Johnson CC, Dietrich MS. The Ahmed shunt versus the Baerveldt shunt for refractory glaucoma: a single-surgeon comparison of outcome. Ophthalmology 2003;110:1814–21.
13. Tsai JC, Johnson CC, Kammer JA, Dietrich MS. The Ahmed shunt versus the Baerveldt shunt for refractory glaucoma II: longer-term outcomes from a single surgeon. Ophthalmology 2006;113:913–7.
14. Ayyala RS, Zurakowski D, Smith JA, et al. A clinical study of the Ahmed glaucoma valve implant in advanced glaucoma. Ophthalmology 1998;105:1968–76.
15. Krishna R, Godfrey DG, Budenz DL, et al. Intermediate-term outcomes of 350-mm(2) Baerveldt glaucoma implants. Ophthalmology 2001;108:621–6.
16. Britt MT, LaBree LD, Lloyd MA, et al. Randomized clinical trial of the 350-mm2 versus the 500-mm2 Baerveldt implant: longer term results: is bigger better? Ophthalmology 1999;106:2312–8.
17. Goulet RJ III, Phan AD, Cantor LB, WuDunn D. Efficacy of the Ahmed S2 glaucoma valve compared with the Baerveldt 250-mm2 glaucoma implant. Ophthalmology 2008;115:1141–7.
18. Heuer DK, Lloyd MA, Abrams DA, et al. Which is better? One or two? A randomized clinical trial of single-plate versus double-plate Molteno implantation for glaucomas in aphakia and pseudophakia. Ophthalmology 1992;99:1512–9.
19. Pan T, Stay MS, Barocas VH, et al. Modeling and characterization of a valved glaucoma drainage device with implications for enhanced therapeutic efficacy. IEEE Trans Biomed Eng 2005;52:948–51.
20. Syed HM, Law SK, Nam SH, et al. Baerveldt-350 implant versus Ahmed valve for refractory glaucoma: a case-controlled comparison. J Glaucoma 2004;13:38–45.
21. Wang JC, See JL, Chew PT. Experience with the use of Baerveldt and Ahmed glaucoma drainage implants in an Asian population. Ophthalmology 2004;111:1383–8.
22. Christakis PG, Tsai JC, Zurakowski D, et al. The Ahmed Versus Baerveldt Study: design, baseline patient characteristics, and intraoperative complications. Ophthalmology 2011;118:2172–9.
23. Heuer DK, Barton K, Grehn F, et al. Consensus on definitions of success. In: Shaarawy TM, Sherwood MB, Grehn F, eds. WGA Guidelines on Design and Reporting of Glaucoma Surgical Trials. Amsterdam, The Netherlands: Kugler; 2008:15–24. Available at: www.worldglaucoma.org/Download/dl_files.php?id=1. Accessed April 2, 2013.
24. Christakis PG, Kalenak JW, Zurakowski D, et al. The Ahmed Versus Baerveldt study: one-year treatment outcomes. Ophthalmology 2011;118:2180–9.
25. AGIS Investigators. The Advanced Glaucoma Intervention Study (AGIS): 7. The relationship between control of intraocular pressure and visual field deterioration. Am J Ophthalmol 2000;130:429–40.
26. Netland PA, Ishida K, Boyle JW. The Ahmed glaucoma valve in patients with and without neovascular glaucoma. J Glaucoma 2010;19:581–6.
27. Sidoti PA, Dunphy TR, Baerveldt G, et al. Experience with the Baerveldt glaucoma implant in treating neovascular glaucoma. Ophthalmology 1995;102:1107–18.
28. Tranos P, Bhar G, Little B. Postoperative intraocular pressure spikes: the need to treat. Eye (Lond) 2004;18:673–9.
29. Budenz DL, Barton K, Feuer WJ, et al, Ahmed Baerveldt Comparison Study Group. Treatment outcomes in the Ahmed Baerveldt Comparison Study after 1 year of follow-up. Ophthalmology 2011;118:443–52.
30. Schwartz KS, Lee RK, Gedde SJ. Glaucoma drainage implants: a critical comparison of types. Curr Opin Ophthalmol 2006;17:181–9.

31. Stein JD, McCoy AN, Asrani S, et al. Surgical management of hypotony owing to overfiltration in eyes receiving glaucoma drainage devices. J Glaucoma 2009;18:638–41.
32. Hong CH, Arosemena A, Zurakowski D, Ayyala RS. Glaucoma drainage devices: a systematic literature review and current controversies. Surv Ophthalmol 2005;50:48–60.
33. Molteno AC, Fucik M, Dempster AG, Bevin TH. Otago Glaucoma Surgery Outcome Study: factors controlling capsule fibrosis around Molteno implants with histopathological correlation. Ophthalmology 2003;110:2198–206.
34. Choritz L, Koynov K, Renieri G, et al. Surface topographies of glaucoma drainage devices and their influence on human tenon fibroblast adhesion. Invest Ophthalmol Vis Sci 2010;51:4047–53.
35. Shah AA, WuDunn D, Cantor LB. Shunt revision versus additional tube shunt implantation after failed tube shunt surgery in refractory glaucoma. Am J Ophthalmol 2000;129:455–60.
36. Lee EK, Yun YJ, Lee JE, et al. Changes in corneal endothelial cells after Ahmed glaucoma valve implantation: 2-year follow-up. Am J Ophthalmol 2009;148:361–7.

Footnotes and Financial Disclosures

Originally received: November 16, 2012.
Final revision: April 14, 2013.
Accepted: April 17, 2013.
Available online: June 24, 2013. Manuscript no. 2012-1728.

[1] Department of Ophthalmology and Vision Sciences, University of Toronto Faculty of Medicine, Toronto, Canada.

[2] Department of Ophthalmology and Visual Science, Yale School of Medicine, New Haven, Connecticut.

[3] Drs. Massaro & Kalenak SC, Milwaukee, Wisconsin.

[4] Department of Anesthesiology, Children's Hospital Boston, Harvard Medical School, Boston, Massachusetts.

[5] Eugene and Marilyn Glick Eye Institute, Indiana University School of Medicine, Indianapolis, Indiana.

[6] Department of Ophthalmology and Visual Sciences, Vanderbilt University School of Medicine, Nashville, Tennessee.

Presented at: the American Academy of Ophthalmology, October 22–25, 2011, Orlando, Florida, and November 10–13, 2012, Chicago, Illinois; the American Glaucoma Society, March 1–4, 2012, New York, New York; and as a poster at: the Canadian Ophthalmological Society, June 26–30, 2012, Toronto, Canada.

Financial Disclosure(s):
The author(s) have no proprietary or commercial interest in any materials discussed in this article. The AVB Study has not received any funding or support from New World Medical, Inc., or Abbott Medical Optics, Inc.

The AVB Study is supported by a research grant from the Glaucoma Research Society of Canada, Toronto, Canada (I.I.K.A., P.G.C.), and a departmental challenge grant from Research to Prevent Blindness, Inc., New York, New York (J.C.T.). The research funding sponsors had no role in the design or conduct of the study. Dr. Ahmed has received speaker's honoraria from Abbott Medical Optics, Inc., and New World Medical, Inc.; Dr. Cantor has been a consultant for Abbott Medical Optics, Inc.

Correspondence:
Iqbal I. K. Ahmed, MD, 3200 Erin Mills Parkway, Mississauga, Ontario, L5L 1W8. E-mail: ike.ahmed@utoronto.ca.