Aqueous shunt implantation in glaucoma

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Abstract:
Aqueous shunts or glaucoma drainage devices are increasingly utilized in the management of refractory glaucoma. The general design of the most commonly-used shunts is based on the principles of the Molteno implant: i.e. a permanent sclerostomy (tube), a predetermined bleb area (plate) and diversion of aqueous humour to the equatorial region and away from the limbal subconjunctival space. These three factors make aqueous shunts more resistant to scarring as compared to trabeculectomy. The two most commonly used shunts are the Ahmed Glaucoma Valve, which contains a flow-restrictor, and the non-valved Baervedt Glaucoma Implant. While the valved implants have a lower tendency to hypotony and related complications, the non-valved implants with larger, more-biocompatible end plate design, achieve lower intraocular pressures with less encapsulation. Non-valved implants require additional suturing techniques to prevent early hypotony and a number of these methods will be described. Although serious shunt-related infection is rare, corneal decompensation and diplopia are small but significant risks.

Keywords:
Aqueous shunts, glaucoma drainage devices, glaucoma surgery, glaucoma tube shunts

Introduction
Aqueous shunts or glaucoma drainage devices (GDD) are artificial filtering devices which lower the intraocular pressure (IOP) by draining aqueous humor to the external subconjunctival space. The shunts commonly used in clinical practice are based on the design of the original Molteno implant, i.e., a silicone tube draining aqueous from inside the eye to an end plate of variable size placed on the sclera. The silicone tube may be inserted into the anterior chamber, ciliary sulcus, or vitreous cavity through the pars plana. The plate is placed over equatorial sclera, usually in the superotemporal quadrant (STQ). The advantages of a GDD over the traditional trabeculectomy include the presence of:

1. A permanent sclerostomy (the tube)
2. Aqueous drainage to the equatorial region where the potential for conjunctival scarring is less than with anterior conjunctiva at the limbus
3. A predetermined bleb area (the plate).

The use of GDD in glaucoma management has become increasingly popular. The number of GDD implantations increased 231% between 1994 and 2003 in the United States alone.[1] Today, a large proportion of glaucoma specialists routinely perform aqueous shunt surgery in managing refractory glaucoma. This review discusses the indication, surgical techniques, and complications of aqueous shunt implantation.

Aqueous Shunts Overview
Aqueous shunts differ in plate surface area, shape, thickness, material, and the presence of a flow restrictor [Table 1]. Regardless of the type of shunt, the tube part is made of silicone and of a similar size. The inner lumen of the tube is typically 0.30 mm in diameter with an outer diameter of around 0.64 mm. The Molteno implant was the first commercially available GDD, and much of our experience with aqueous shunt surgery is based on the earlier Molteno implants. Although the original is still available,
its use has been largely superseded by newer shunts. Currently, the Ahmed glaucoma valve (AGV, New World Medical Inc., Rancho Cucamonga, CA, USA) and Baerveldt glaucoma implant (BGI, Abbott Medical Optics, Abbott Park, IL, USA) are the most commonly used implants [Figure 1].

Plate size and material are two factors that determine the long-term IOP outcome. As aqueous drains to the shunt end plate, flow is eventually restricted by a capsule around the plate. Plate size predetermines the size of the capsule (bleb), and this is one of the factors that predicts the final IOP.

In an earlier study, Heuer et al. reported that 2 years after surgery, the success rate in controlling the IOP was greater with the double than single-plate Molteno (71% vs. 46%) as was the degree of IOP reduction (46% ± 33% vs. 25% ± 43%). However, hypotony-related complications such as flat anterior chamber, choroidal hemorrhage, and phthisis were higher with the double-plate implants. Britt et al. compared 350 mm² BGI implants to 500 mm² BGI implants and reported that the 500 mm² BGI achieved

| Table 1: Common valved and nonvalved glaucoma drainage devices |
|---|
| **Valved GDD** |
| **Ahmed glaucoma implants** |
| Year | Model | Plate material | Plate size (mm²) | Plate thickness (mm) | Opening IOP and comments |
| 1993 | S2 | Polypropylene | 184 | 1.6 | Closes below 8 mmHg |
| | S3 | Polypropylene | 85 | 1.6 | |
| | B1 | Polypropylene (double plate) | 364 | 1.6 | |
| | PS2 | Polypropylene | 184 | 1.6 | |
| | PS3 | Polypropylene | 85 | 1.6 | |
| | FP7 | Silicone | 102 | 2.1 | |
| | FP8 | Silicone | 364 | 2.1 | |
| | FX1 | Silicone (double plate) | 184 | 2.1 | |
| | Pars plana | Silicone | 102 | 2.1 | |
| | PC7 | Silicone | | | |
| | PC8 | Silicone | | | |
| **Krupin eye valve** | | Silicone | 184 | 1.75 | Opens above 10 mmHg |
| **Nonvalved GDD** |
| **Molteno** |
| 1973 | 1973 | Molteno | | | |
| | S1 (single plate) | Polypropylene | 133 | 1.65 | |
| | D1 (single plate with ridge) | Polypropylene | 133 | 1.65 | Ridge valve on the plate |
| | L2, R2 (double plate - left; right) | Polypropylene | 266 | 1.65 | Ridge valve on the plate |
| | DL2, DR2 (double plate with ridge - left; right) | Polypropylene | 266 | 1.65 | Ridge valve on the plate |
| | P1 (microphthalmic) | Silicone | 80 | 1.65 | |
| | Molteno 3 GS | Silicone | 175 | 0.4-1.15 | Ridge valve on the plate |
| | Molteno 3 GL | Silicone | 230 | 0.4-1.15 | Ridge valve on the plate |
| | Molteno3 S series | Silicone | 245 | 0.4-0.95 | Ridge valve on the plate |
| | M3-185 (SS) | Silicone | | | |
| | M3-245 (SL) | Silicone | | | |
| **Baerveldt** | 1992 | 101-250 | Silicone | 250 | 0.95 | Barium-impregnated silicone plate, therefore radiopaque |
| | 101-350 | Silicone | 350 | 0.95 | |
| | Pars plana | Silicone | 350 | 0.95 | |
| | 103-350 | Silicone | | | |

GDD = Glaucoma drainage devices, IOP = Intraocular pressure
lower IOP, but sight-threatening hypotony-related complications were more common leading to a lower overall success with the larger plate.\textsuperscript{3} This study was the first to demonstrate that aqueous shunts could achieve low mean IOP levels with little supplemental glaucoma medication, 5 years after implantation. In a smaller nonrandomized series, Molteno also reported that IOP control with two plates was significantly better than with one.\textsuperscript{4} In addition, the IOP control with a four-plate implant was only marginally better but at the cost of severe hypotony. In summary, larger plate size results in lower IOP. The ideal plate size should provide a balance between a safe low IOP without a significant risk of long-term hypotony.

While plate size is important, other factors including plate material, profile, and surface characteristics also influence capsule formation and long-term IOP control. Plates are commonly made from polypropylene or silicone. Silicone implants are more flexible, easier to handle, and more biocompatible due to their flexibility. Ayyala \textit{et al.} reported that silicone plates cause less inflammatory response than more rigid polypropylene plates in rabbits.\textsuperscript{5} In clinical studies comparing the polypropylene with silicone AGV, most observed lower IOP levels with less supplemental glaucoma medication and longer survival with the silicone version.\textsuperscript{6,7} However, GDD plates differ in other factors such as shape, profile, surface texture, contact area with adjacent tissues, flexibility, and micro-motion, all of which might influence the degree of encapsulation, so the observed effect is likely to result from a combination of factors.

One important feature of an aqueous shunt is the presence or absence of a fixed flow restrictor or valve. Technically, a valved device should allow only unidirectional flow with a minimum opening pressure, whereas nonvalved devices are passive and incapable of influencing either anterograde or retrograde flow. The only valved device in current use is the AGV. The Molteno and BGI are nonvalved and therefore provide no resistance to aqueous outflow in the early postoperative period before the bleb capsule develops. The only resistance to flow with nonvalved GDD is the capsule that develops over the plate around 3–6 weeks after surgery. When implanting one of these devices, the surgeon must use some form of suture to occlude the tube portion, otherwise severe early postoperative hypotony is almost inevitable.

While the valved GDD offers the advantage of avoiding immediate hypotony without surgical manipulation, many believe aqueous flow to be a disadvantage during the early postoperative period. The reason is two-fold. First, tissue contact with aqueous containing elevated transforming growth factor-beta may stimulate a greater healing response over the plate.\textsuperscript{8} Second, mechanical stretching of fibroblasts by the presence of fluid in the subconjunctival space may also stimulate fibroblast contraction and healing. Paradoxically, nonvalved devices largely avoid these effects because they are occluded in the early postoperative period.

The current clinical consensus is that valved GDD have a higher frequency of a hypertensive phase than nonvalved GDD.\textsuperscript{9} The hypertensive phase typically starts after 4–6 weeks and has been reported in 30%–80% of patients with AGV.\textsuperscript{10} Clinically, a thick capsule forms around the plate preventing aqueous absorption into the venous system. Such thick capsule formation seems to be less common with the BGI.\textsuperscript{11}

The question of whether nonvalved GDDs achieve a better long-term IOP control is addressed in two randomized controlled trials which compared the AGV model FP7 and the BGI model 101-350: the Ahmed versus Baerveldt Comparative (ABC) study and the Ahmed versus Baerveldt (AVB) study [Table 2].\textsuperscript{12,13} The definition of failure is slightly different between the two trials, rendering the percentage of surgical failure slightly higher in the AVB trial. After 3 years, the AVB study reported slightly less surgical failure, lower IOP, and less medication in the BGI group than the AGV group.\textsuperscript{14} The ABC study reported no significant difference in surgical failure in the two groups at 3 and 5 years after surgery.\textsuperscript{15,16} However, the BGI group required less medication after 3 years and had a lower IOP after 5 years. Both ABC and AVB studies reported more hypotony-related complications in the BGI groups, whereas the AGV groups more often required surgery for uncontrolled IOP.\textsuperscript{14,17} Complications in the BGI groups were more serious: persistent hypotony, explantation of the shunt, or loss of light perception. In summary, in both studies, the BGI group achieved a lower IOP on

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|}
\hline
& \textbf{1 year} & \textbf{3 year} & \textbf{5 year} \\
\hline
\textbf{AVB study} & & & \\
IOP - Baerveldt & 13.6±4.8\textsuperscript{**} & 14.4±5.1 & NA \\
IOP - Ahmed & 16.5±5.3\textsuperscript{**} & 15.7±4.8 & NA \\
Medication - Baerveldt & 1.2±1.3\textsuperscript{*} & 1.1±1.3\textsuperscript{*} & NA \\
Medication - Ahmed & 1.6±1.3\textsuperscript{*} & 1.8±1.4\textsuperscript{*} & NA \\
\hline
\textbf{ABC study} & & & \\
IOP - Baerveldt & 13.2±6.8\textsuperscript{*} & 13.1±4.5 & 12.7±4.5\textsuperscript{*} \\
IOP - Ahmed & 15.4±5.5\textsuperscript{*} & 14.3±4.7 & 14.7±4.4\textsuperscript{*} \\
Medication - Baerveldt & 1.5±1.4 & 1.5±1.4 & 1.8±1.5 \\
Medication - Ahmed & 1.8±1.3 & 2.0±1.4 & 2.2±1.4 \\
\hline
\end{tabular}
\caption{Results of Ahmed versus Baerveldt Comparison study and Ahmed versus Baerveldt study}
\end{table}

\textsuperscript{**}Difference between the two groups reached statistical significance level at \(P<0.001\). \textsuperscript{*}Difference between the two groups reached statistical significance level at \(P<0.05\). ABC = Ahmed versus Baerveldt Comparison, AVB = Ahmed versus Baerveldt, IOP = Intraocular pressure, NA = Not available
fewer glaucoma medications but at the cost of a higher rate of serious hypotony-related complications. This emphasizes the importance of preventing early hypotony in nonvalved aqueous shunts.

**Indications**

Aqueous shunts are preferred in cases where trabeculectomies are likely to fail or might be hazardous, such as in neovascular glaucoma, iridocorneal endothelial syndrome, aphakic glaucoma, Sturge–Weber syndrome, glaucoma after vitreoretinal surgery or keratoplasty, and many uveitic glaucomas. Aqueous shunts are commonly used in pediatric glaucoma because the risk of infection and the requirement for postoperative manipulation is lower than with trabeculectomy. Whether aqueous shunts are more effective than trabeculectomy in the management of primary open-angle glaucoma was addressed in the Tube versus Trabeculectomy (TVT) study. This study compared the BGI 101-350 to trabeculectomy with mitomycin-C (MMC) in patients with previously failed trabeculectomy or with previous cataract surgery over 5 years of follow-up.[18] The more recent Primary Trabeculectomy versus Tube study will compare the efficacy and safety of BGI model 101-350 and trabeculectomy in phakic patients with no previous cataract or glaucoma surgery.

The TVT study compared the efficacy of BGI model 101-350 without antimetabolite to trabeculectomy with MMC 0.4 mg/ml for 4 min. Although 80% of participants were pseudophakic, 44% had undergone cataract surgery without a previous trabeculectomy, a third of whom had undergone cataract surgery through a scleral tunnel approach.[18] After 1, 3, and 5 years, the BGI group had higher rates of success than the trabeculectomy group even though the mean IOP levels were similar.[19‑21] The rate of BGI failure averaged 5%/year compared with 9%/year for trabeculectomy. The trabeculectomy group required less medication after 1 year than the tube group, but this difference was lost after further follow-up. The complication rates were similar in the two study groups.

**Surgical Technique**

GDD surgery can be performed under local or general anesthesia. Retro- or peri-bulbar block with mixed bupivacaine and lidocaine will achieve adequate anesthesia and akinesia during the procedure. A clear cornea traction suture is placed and the globe is rotated away from the area where the GDD will be placed. With the AGV, “priming” of the tube is essential to open and wet the valve leaflets. Priming is achieved by injecting balanced salt solution (BSS) through the tube lumen using a 30-gauge cannula. Flow of BSS should be observed emerging from the end plate.

**Plate Placement**

A 3-4 clock hour peritomy with radial relaxing incisions provides good access. A limbus-based conjunctival flap (fornix-based conjunctival incision) is an alternative but has the limitation that it restricts access when inserting the tube into the anterior chamber. In addition, the presence of a wound over the tube or plate can potentially lead to dehiscence or erosion and exposure. A limbal peritomy can lead to tube exposure through conjunctival retraction, but this can be avoided by tightly securing conjunctiva at the limbus.

The GDD plate is most often placed in the STQ between the lateral and superior rectus muscles. The STQ provides the easiest access and does not contain any oblique muscle fiber. In eyes with a preexisting tube or previous surgical scar precluding STQ placement, both inferonasal quadrant and superonasal quadrant (SNQ) are alternatives. Inferiorly placed tubes have a higher exposure rate, but the SNQ placement carries a higher risk of vertical diplopia from restricting the superior oblique muscle, i.e., a pseudo-Brown’s restrictive strabismus syndrome.[22,23] In addition, aqueous shunts with a longer anteroposterior length, such as AGV, may encroach on the optic nerve when placed in the SNQ resulting in a significant injury response.[24‑26]

The ideal plate position is at least 8 mm from the limbus. The plate should be tightly secured with a nonabsorbable suture (e.g., 8-0 or 9-0 nylon or polypropylene) to prevent migration and to reduce plate micromovement which can stimulate a greater fibroblastic response and capsule formation.

While there have been a number of studies investigating the use of adjunctive antimetabolites, there is currently no evidence to support increased efficacy. Two randomized controlled trials examined the use of MMC in Molteno and AGV implants.[27,28] Neither study found a lower IOP or higher success rate in the MMC group compared to the no MMC group. The use of MMC in AGV did not reduce the rate of the hypertensive phase. Interestingly, neither study reported a higher hypotony rate in the MMC group.

**Tube Insertion**

The tube is trimmed so that it is beveled anteriorly for anterior chamber placement and posteriorly for sulcus placement to prevent iris occluding the tip. Anterior chamber positioning allows direct visualization of the tube to detect tube blockage by iris or tube retraction. The tube should be short and posteriorly placed to avoid touching the cornea as corneal decompensation is a common long-term complication of poorly positioned
aqueous shunts. Pars plana and sulcus placement minimize corneal endothelium damage but compromise visualization of the tube.\[29\] Pars plana placement requires careful vitrectomy with shaving of the vitreous base close to the tube to prevent obstruction with vitreous.\[30,31\]

A 23- or 25-gauge needle is used to create a short tunnel for insertion posterior to the surgical limbus: 1.5–2 mm from the limbus for anterior chamber and sulcus insertion or 3.5–4 mm for pars plana insertion. Both AGV and BGI offer a pars plana adaptation in the form of an elbow. The AGV pars plana clip and the BGI Hoffman elbow have a small plate at the pars plana entry site. In practice, the pars plana models are not frequently used as they are associated with a high rate of erosion, and conventional tubes without the elbow are relatively easy to insert in the pars plana.

Tubes must be covered at the limbus to prevent conjunctival erosion. Human donor sclera, cornea, or pericardium can all be used.\[32\] An alternative long intrascleral tunnel technique without patch has been described with good midterm results.\[33\]

Nonvalved aqueous shunts - intraoperative techniques to prevent hypotony

In nonvalved GDD, few techniques have been described to prevent early hypotony. The simplest is to place an external ligature such as an absorbable 7-0 polyglactin (Vicryl\[™\]) suture around the tube.\[34\] The ligation should completely occlude the tube lumen, so no aqueous flow occurs until the suture absorbs after 5–6 weeks when a capsule has formed around the plate and provided some resistance to outflow. The first problem with a complete ligation of the tube is the high IOP during the first 6 weeks. To counteract this, many surgeons will additionally fenestrate the tube proximal to the ligature (Sherwood slit).\[35\] Some even perform a trabeculectomy concomitantly with the tube implantation that is intended to mitigate against an initial high IOP and fail around the time the ligature dissolves.\[36\] The second disadvantage of using a single external ligation is the sudden IOP drop when the tube opens. Even if sufficient encapsulation has developed, the precipitous drop in eyes with larger implants may be sufficient to cause a choroidal hemorrhage in a predisposed individual.

A technique used successfully by one of the authors (KB) is an adjustable intraluminal occluding suture enhanced by a variable number of external ligatures [Figure 2].\[37\] A 3-0 nylon (Supramid Extra; S. Jackson Inc., Alexandria, VA, USA) suture is introduced internally along most of the length of the tube but not into the anterior chamber. Aqueous flow is tested at the tube aperture over the plate after insertion of the suture and the length adjusted, so only very slow flow is visible [Figure 2]. One or more 10-0 nylon ligatures are then tied around the tube over the Supramid suture to just eliminate flow completely [Figures 3 and 4]. These adjunctive ligatures can be lasered electively at the slit lamp after approximately 2–3 weeks, avoiding the risk of a sudden precipitous pressure drop. If after 3 months, the pressure is still not adequately controlled, the intraluminal suture can be withdrawn at the slit lamp through a small conjunctival entry [Figure 5]. This can also be performed in stages, again avoiding sudden decompression. The rationale of this technique is a stepwise reduction in IOP instead of a sudden drop. The disadvantage is more manipulation and more intensive follow-up than the solo ligature technique.

Complications and Management

Complications associated with GDD surgery may be classified as intraoperative, early (<3 months), and late. Intraoperative complications are infrequent. About 4%–8% of patients experienced intraoperative complications in the AVB, ABC, and TVT studies. The single most common complication is hyphema during tube insertion.\[38\] Other intraoperative complications include leakage such as inadvertent opening of a preexisting trabeculectomy bleb or persistent leakage at the insertion site. Intraoperative leakage should be addressed at the time of surgery because of the high risk of hypotony. A leaking entry site can be very difficult to suture closed but can alternatively be plugged with a small piece of tenons, pericardium, or sclera. Inadvertent opening of a bleb may require closure with a scleral or pericardial patch.

Hypotony, shallow anterior chamber, tube-corneal touch, corneal edema, uncontrolled high pressure, ptosis,
and diplopia may occur in the early postoperative period. Most complications are hypotony related and may occur with valved and nonvalved shunts. In the TVT study, the BGI group had fewer early complications than the trabeculectomy group (21% vs. 37%; \( P = 0.012 \)) although this difference is mostly due to conjunctival leakage. The incidence of severe hypotony was similar between the BGI and trabeculectomy groups. Although valved aqueous shunts are designed to prevent hypotony, hypotony may still occur if the valve fails or the entry site leaks. With a valved GDD, a small amount of viscoelastic is often left in the anterior chamber at the end of surgery, whereas with a nonvalved GDD, a tight external ligature and/or intraluminal occluding suture should be enough to prevent hypotony. A less commonly used alternative is a two-stage procedure during which the plate is implanted and the tube tucked under conjunctiva without inserting the tube into the eye. The second stage of tube insertion is usually performed 6 weeks later when the capsule has formed. If early hypotony occurs despite intraoperative precautions, sequelae from hypotony can usually be prevented in the short term by small volume anterior chamber viscoelastic injections at the slit lamp. If hypotony persists despite numerous injections, the patient needs to return to the operating room for further tube ligation.

Early ptosis and motility disturbance can be simply due to surgical manipulation and inflammation. It is advisable to wait and watch and to only intervene if the signs and symptoms persist beyond 6 months.

While short-term complications may result from surgical technique, late complications are less predictable. They include corneal edema, erosion, persistent motility disturbance, chronic iritis, tube obstruction, failure of intraocular pressure control, and rarely endophthalmitis. The TVT study found similar rates of long-term complications in the BGI and trabeculectomy groups at 5 years. Although the BGI group had a higher rate of corneal edema (16% vs. 9%) and diplopia (6% vs. 2%), the difference did not reach statistical significance. The rate of subsequent keratoplasty was similar between the two groups. In the ABC study, the corneal decompensation rate after 5 years of follow-up was similar between the AGV and BGI groups: about 20% in each group. In the TVT study, 6% of patients receiving BGI had persistent diplopia after 3 years. Some surgeons argue that proper placement of the BGI plate under the muscles will prevent diplopia. However, the ABC investigators did not observe a higher rate of diplopia in the BGI than the AGV group (11.8% vs. 12.7%; \( P = 0.81 \)). Bleb height is a likely reason for diplopia. Fortunately, diplopia was rarely experienced in the primary position of gaze. The incidence of tube erosion was 1%–3% in the AGV and BGI groups, respectively.

Endophthalmitis related to aqueous shunts is rare and much less common than after trabeculectomy. The single risk factor for GDD-related endophthalmitis is tube exposure. Therefore, exposed tubes should be revised urgently.

Suprachoroidal hemorrhage (SCH) was reported in 6% of patients in Molteno’s earlier studies. In the TVT, ABC, and AVB studies, the rate of SCH was lower and varied between 0% and 3%. The rate of SCH was similar in the tube group compared to the trabeculectomy group in the TVT study. Most of SCH occurs postoperatively instead of intraoperatively. SCH is likely to occur in...
eyes that experience a precipitous drop in IOP and aphakia.\textsuperscript{[40]}

Conclusions

Aqueous shunt implantation is an indispensable tool in the management of glaucoma, particularly in secondary glaucoma and after trabeculectomy failure. Aqueous shunts appear to have similar efficacy to trabeculectomy in lowering the IOP but require less intensive postoperative follow-up. The predictability of aqueous shunt surgery is still, at best, moderate, though probably greater than after trabeculectomy. Hypotony is always a risk but can be more predictably prevented. The factors that result in long-term corneal endothelial loss in patients implanted with aqueous shunts still remains to be clarified.

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Conflicts of interest
There are no conflicts of interest.

References

1. Arora KS, Robin AL, Corcoran KJ, Corcoran SL, Ramulu PY. Use of various glaucoma surgeries and procedures in medicare beneficiaries from 1994 to 2012. Ophthalmology 2015;122:1615-24.
2. Heuer DK, Lloyd MA, Abrams DA, Baerveldt G, Minkler DS, Lee MB, 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.
3. Britt MT, LaBree LD, Lloyd MA, Minkler DS, Heuer DK, Baerveldt G, 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.
4. Molteno AC. The optimal design of drainage implants for glaucoma. Trans Ophthalmol Soc N Z 1981;33:39-41.
5. Ayyala RS, Harman LE, Michelini-Norris B, Ondrovic LE, Haller E, Margo CE, et al. Comparison of different biomaterials for glaucoma drainage devices. Arch Ophthalmol 1999;117:233-6.
6. Ishida K, Netland PA, Costa VP, Shiroma L, Khan B, Ahmed II. Comparison of polypropylene and silicone Ahmed glaucoma valves. Ophthalmology 2006;113:1320-6.
7. Khan AO, Almobarak FA. Comparison of polypropylene and silicone Ahmed valve survival 2 years following implantation in the first 2 years of life. Br J Ophthalmol 2009;93:791-4.
8. Tripathi RC, Li J, Chan WF, Tripathi BJ. Aqueous humor in glaucomatous eyes contains an increased level of TGF-beta 2. Exp Eye Res 1994;59:723-7.
9. Won HJ, Sung KR. Hypertensive phase following silicone plate Ahmed glaucoma valve implantation. J Glaucoma 2016;25:e313-7.
10. Ayyala RS, Zurakowski D, Smith JA, Monshizadeh R, Netland PA, Richards DW, et al. A clinical study of the Ahmed glaucoma valve implant in advanced glaucoma. Ophthalmology 1998;105:1968-76.
11. 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.
12. Barton K, Gedde SJ, Budenz DL, Feuer WJ, Schiffman J, Ahmed Baerveldt Comparison Study Group. The Ahmed Baerveldt Comparison Study methodology, baseline patient characteristics, and intraoperative complications. Ophthalmology 2011;118:435-42.
13. Christakis PG, Tsai JC, Zurakowski D, Kalenak JW, Cantor LB, Ahmed II. The Ahmed versus Baerveldt study: Design, baseline patient characteristics, and intraoperative complications. Ophthalmology 2011;118:2172-9.
14. Christakis PG, Tsai JC, Kalenak JW, Zurakowski D, Cantor LB, Kammer JA, et al. The Ahmed versus Baerveldt study: Three-year treatment outcomes. Ophthalmology 2013;120:2232-40.
15. Barton K, Feuer WJ, Budenz DL, Schiffman J, Costa VP, Godfrey DG, et al. Three-year treatment outcomes in the Ahmed Baerveldt comparison study. Ophthalmology 2014;121:1547-57. e1.
16. Budenz DL, Barton K, Gedde SJ, Feuer WJ, Schiffman J, Costa VP, et al. Five-year treatment outcomes in the Ahmed Baerveldt comparison study. Ophthalmology 2015;122:308-16.
17. Budenz DL, Feuer WJ, Barton K, Schiffman J, Costa VP, Godfrey DG, et al. Postoperative complications in the Ahmed Baerveldt comparison study during five years of follow-up. Am J Ophthalmol 2016;163:75-82.e3.
18. Gedde SJ, Schiffman JC, Feuer WJ, Parrish RK 2nd, Heuer DK, Brandt JD. Tube Versus Trabeculectomy Study Group. The Tube Versus Trabeculectomy Study: Design and baseline characteristics of study patients. Am J Ophthalmol 2005;140:275-87.
19. Gedde SJ, Schiffman JC, Feuer WJ, Herndon LW, Brandt JD, Budenz DL. Treatment outcomes in the tube versus trabeculectomy study after one year of follow-up. Am J Ophthalmol 2007;143:9-22.
20. Gedde SJ, Schiffman JC, Feuer WJ, Herndon LW, Brandt JD, Budenz DL; Tube Versus Trabeculectomy Study Group. Three-year follow-up of the tube versus trabeculectomy study. Am J Ophthalmol 2009;148:670-84.

Taiwan J Ophthalmol - Volume 7, Issue 3, July-September 2017
21. Gedde SJ, Schiffman JC, Feuer WJ, Herndon LW, Brandt JD, Budenz DL; Tube versus Trabeculectomy Study Group. Treatment outcomes in the Tube Versus Trabeculectomy (TVT) study after five years of follow-up. Am J Ophthalmol 2012;153:789-803.e2.

22. Coats DK, Payse EA, Orenga-Nania S. Acquired Pseudo-Brown's syndrome immediately following Ahmed valve glaucoma implant. Ophthalmic Surg Lasers 1999;30:396-7.

23. Pakravan M, Yazdani S, Shahabi C, Yaseri M. Superior versus inferior Ahmed glaucoma valve implantation. Ophthalmology 2009;116:208-13.

24. Ayyala RS, Layden WE, Slonim CB, Margo CE. Anatomic and histopathologic findings following a failed Ahmed glaucoma valve device. Ophthalmic Surg Lasers 2001;32:248-9.

25. Ayyala RS, Parma SE, Karioglu ZA. Optic nerve changes following posterior insertion of glaucoma drainage device in rabbit model. J Glaucoma 2004;13:145-8.

26. Kahook MY, Neecker RJ, Pantcheva MB, Schuman JS. Location of glaucoma drainage devices relative to the optic nerve. Br J Ophthalmol 2006;90:1010-3.

27. Cantor L, Burgoyne J, Sanders S, Bhavnani V, Hoop J, Brizendine E. The effect of mitomycin C on Molteno implant surgery: A 1-year randomized, masked, prospective study. J Glaucoma 1998;7:240-6.

28. Costa VP, Azuara-Blanco A, Netland PA, Lesk MR, Arcieri ES. Efficacy and safety of adjunctive mitomycin C during Ahmed Glaucoma Valve implantation: A prospective randomized clinical trial. Ophthalmology 2004;111:1071-6.

29. Arroyave CP, Scott IU, Fantes FE, Feuer WJ, Murray TG. Corneal graft survival and intraocular pressure control after penetrating keratoplasty and glaucoma drainage device implantation. Ophthalmology 2001;108:1978-85.

30. Scott IU, Alexandrakis G, Flynn HW Jr, Smiddy WE, Murray TG, Schiffman J, et al. Combined pars plana vitrectomy and glaucoma drainage implant placement for refractory glaucoma. Am J Ophthalmol 2000;129:334-41.

31. Weiner Y, Faridi O, Weiner A. Clinical experience with sulcus-implanted Baerveldt glaucoma tube shunts fully concealed behind the iris in undilated pseudophakic eyes. J Glaucoma 2013;22:667-71.

32. Smith MF, Doyle JW, Tircney JW Jr. A comparison of glaucoma drainage implant tube coverage. J Glaucoma 2002;11:143-7.

33. Albis-Donado O, Gil-Carrasco F, Romero-Quijada R, Thomas R. Evaluation of Ahmed glaucoma valve implantation through a needle-generated scleral tunnel in Mexican children with glaucoma. Indian J Ophthalmol 2010;58:365-73.

34. Molteno AC, Polkinghorne PJ, Bowbye JA. The vicryl tie technique for inserting a draining implant in the treatment of secondary glaucoma. Aust N Z J Ophthalmol 1986;14:343-54.

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

36. Budenz DL, Scott IU, Nguyen QH, Feuer W, Singh K, Nicolela MT, et al. Combined Baerveldt glaucoma drainage implant and trabeculectomy with mitomycin C for refractory glaucoma. J Glaucoma 2002;11:439-45.

37. Gedde SJ, Herndon LW, Brandt JD, Budenz DL, Feuer WJ, Schiffman JC; 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.e1.

38. Molteno AC, Van Biljon G, Ancker E. Two-stage insertion of glaucoma drainage implants. Trans Ophthalmol Soc N Z 1979;31:17-26.

39. Gedde SJ, Scott IU, Tabandeh H, Luu KK, Budenz DL, Greenfield DS, et al. Late endophthalmitis associated with glaucoma drainage implants. Ophthalmology 2001;108:1323-7.

40. Tuli SS, WuDunn D, Ciulla TA, Cantor LB. Delayed suprachoroidal hemorrhage after glaucoma filtration procedures. Ophthalmology 2001;108:1808-11.