Update on aqueous shunts

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1. Introduction

Glaucoma is a disease involving impaired outflow of aqueous humor through the anterior chamber angle. The increased resistance to aqueous outflow produces intraocular pressure (IOP) elevation that damages the optic nerve. The current treatment of glaucoma is directed toward decreasing IOP to prevent progressive glaucomatous optic nerve damage. Glaucoma surgery is typically performed when adequate IOP reduction cannot be achieved with maximally tolerated medical therapy and appropriate laser treatment. Trabeculectomy and aqueous shunt surgery are the most commonly performed incisional glaucoma procedures worldwide. Both operations create an alternative route for aqueous outflow, bypassing the high resistance pathway and providing IOP lowering. Trabeculectomy creates a scleral fistula that connects the anterior chamber and subconjunctival space resulting in the formation of a paralimbal filtering bleb. Aqueous shunts are implantable devices that allow drainage of aqueous humor more posteriorly.

Aqueous shunts share a common design consisting of a silicone tube that is inserted into the eye through a scleral fistula and shunts aqueous humor to an episcleral plate that is located in the equatorial region of the globe, typically centered between (and, in the case of some devices, extending under or over) two adjacent rectus muscles. Fibrous encapsulation of the equatorial plate produces a reservoir into which aqueous humor pools. The major resistance to aqueous outflow through these devices occurs across the fibrous capsule around the equatorial plate (Minckler et al., 1987; Wilcox et al., 1994). Therefore, the final IOP that is achieved after aqueous shunt surgery is determined by capsular permeability and surface area (i.e. more permeable and larger surface-area capsules are associated with lower postoperative pressures).

Molteno pioneered the concept of wound-healing modulation to minimize the fibrous encapsulation of the equatorial explants in an effort to improve IOP control. He has advocated the combination of oral prednisone (or intramuscular methylprednisolone acetate), colchicine, and fluphenamic acid (a non-steroidal anti-inflammatory agent) with topical atropine sulfate, epinephrine hydrochloride, and dexamethasone (or betamethasone sodium phosphate), particularly for patients aged 18 months to 50 or 60 years in whom he regards the healing response most vigorous (Molteno et al., 1976; Molteno, 1980, 1987). However, because others have experienced or have been concerned about systemic side-effects, his antifibrosis regimen has not achieved widespread application (Brown and Cairns, 1983; Cairns, 1983). More recently, surgeons have attempted to minimize fibrovascular proliferation and thereby capsule thickness over the equatorial plate by applying mitomycin C (MMC), but this approach appears to be of limited benefit (Cantor et al., 1998; Costa et al., 2004). Shunts with larger equatorial plates produce greater IOP reduction, presumably by promoting a larger surface-area capsule around the plate for filtration (Heuer et al., 1992). However, there appears to be an upper limit beyond which an increase in plate size does not allow greater efficacy (Lloyd et al., 1994).

The equatorial plates of commercially-available aqueous shunts differ in the size, shape, and physical material composition. The material and surface characteristics of the equatorial plates may also influence the wound-healing response elicited by these
Advantages and disadvantages of commercially-available aqueous shunts. In rabbits, subconjunctival implantation of polypropylene induced more inflammatory reaction than silicone (Ayyala et al., 1999, 2000). Another recent study evaluated the surface topography of four commercially-available aqueous shunts and found a correlation in tissue culture to Tenon’s capsule fibroblast adhesion to surface roughness as measured by three-dimensional white-light confocal microscopy (Choritz et al., 2010).

Aqueous shunts are “valved” or “non-valved”, depending on whether a flow restriction mechanism limits aqueous humor flow. Non-valved shunts require a temporary restriction of flow by tube ligation or occlusion during surgical implantation. This maneuver allows a fibrovascular capsule to develop around the equatorial plate before aqueous humor outflow begins and reduces the risk of hypotony in the early postoperative period. Valved shunts have flow restrictors that are designed to lessen the likelihood of hypotony before plate encapsulation. Valved shunts do not require temporary flow restriction and offer the potential advantage of immediate postoperative IOP reduction. Table 1 reviews the advantages and disadvantages of commercially-available aqueous shunts (Schwartz et al., 2006).

2. Surgical trends

Medicare data and surveys of glaucoma specialists demonstrate an increase in the utilization of aqueous shunts and a concurrent decline in the popularity of trabeculectomy in recent years (Chen et al., 1997; Joshi et al., 2005; Ramulu et al., 2007). Concern about bleb-related complications, such as bleb leaks, blebitis, and bleb-related endophthalmitis (DeBry et al., 2002), has likely contributed to the expanded use of aqueous shunts as an alternative to trabeculectomy. Aqueous shunts were initially reserved for the treatment of eyes with glaucomas that had poor surgical prognoses with standard filtering surgery even with wound-healing modulation. However, an increasingly positive experience with these devices has prompted their implantation in glaucomas with better surgical prognoses (Jamil and Mills, 2007).

2.1. Medicare utilization data

Ramulu et al. (2007) examined trends in utilization of the most common glaucoma-related laser and surgical treatments for Medicare beneficiaries over the period 1995–2004. The numbers of procedures performed annually were tabulated with Current Procedural Terminology (CPT) codes. Trabeculectomies decreased by 43% and placement of aqueous shunts increased by 184% between 1995 and 2004. Commenting on those trends, Corcoran (2009) noted that in 1995, that there had been 23 times as many trabeculectomies as aqueous shunts, but by 2007 that ratio had changed to only three times more trabeculectomies.

2.2. Surveys of the American Glaucoma Society (AGS)

In late 1995, an anonymous survey of the AGS and Japanese Glaucoma Society memberships was conducted by Chen et al. (1997) to assess patterns of use of antifibrotic agents and aqueous shunts among glaucoma specialists. The survey presented ten clinical situations requiring glaucoma surgical intervention. For each clinical scenario, respondents were asked to estimate the percentage in which they would perform trabeculectomy alone, trabeculectomy with 5-fluorouracil (5-FU), trabeculectomy with MMC, or aqueous shunt implantation. Antifibrotic agents like 5-FU and MMC are routinely used as adjuncts to glaucoma filtering surgery to reduce scarring at the surgical site and increase the likelihood of surgical success. The majority of respondents preferred trabeculectomy with MMC for each of the clinical scenarios. In 2002 Joshi et al. (2005) redistributed the same survey to AGS members. Respondents still favored trabeculectomy with MMC for most clinical situations, but the percentage usage of aqueous shunts substantially increased; specifically, selection of aqueous shunts averaged 17.5% in 1995 and 29.4% in 2002.

3. Surgical results with different implants

Glaucama surgeons have questioned the superiority of the commercially-available devices with respect to safety and efficacy. Several retrospective studies failed to detect a statistically significant difference of surgical outcomes among different aqueous shunt types (Ayyala et al., 2002; Nassiri et al., 2010; Smith et al., 1995; Syed et al., 2004; Tsai et al., 2003, 2006; Wang et al., 2004). The conclusions of these studies are limited by inherent biases of retrospective investigations. Recent prospective clinical trials have provided higher level medical evidence regarding popular currently utilized aqueous shunts (Barton et al., 2011; Budenz et al., 2011; Nassiri et al., 2010). Table 2 provides a summary of key elements of these randomized clinical trials.

3.1. Ahmed Glaucoma valve implant vs Molteno implant

Nassiri et al. (2010) reported the results of a prospective randomized study that compared the Ahmed glaucoma valve implant (New World Medical, Inc., Rancho Cucamonga, California, USA) and single-plate Molteno implant (Molteno Ophthalmic Limited, Dunedin, New Zealand) in 92 patients with refractory glaucoma. The rate of surgical failure (IOP > 21 mm Hg, IOP ≤ 5 mm Hg, phthisis bulbi, loss of light perception vision, removal of the implant, reoperation for glaucoma, or any devastating intraoperative or postoperative complication) was similar for both treatment groups after 2-year follow-up (16% Molteno group vs 18% Ahmed group). The Molteno group had a greater percentage drop in IOP from baseline at 2 years (49.7% Molteno group vs 41.9% Ahmed group, p = 0.049), but the mean number of glaucoma medications
was not significantly different between the two groups (1.41 Molteno group vs 1.03 Ahmed group). Patients were censored from analysis at the time of failure, which was related to inadequate IOP reduction in all patients. Postoperative complications were comparable between the Molteno and the Ahmed groups, and no devastating complications were observed in either treatment group.

3.2. Ahmed Baerveldt Comparison (ABC) study

The ABC Study is a multicenter randomized clinical trial that was designed to compare the efficacy and safety of the Ahmed glaucoma valve implant and 350-mm² Baerveldt glaucoma implant (Abbott Medical Optics, Abbott Park, Illinois, USA) in 276 patients with refractory glaucoma (Barton et al., 2011). Mean IOP was lower after Baerveldt placement at 1 year (15.4 mm Hg Ahmed vs 13.2 mm Hg Baerveldt), use of glaucoma medications was similar between implants (1.8 Ahmed vs 1.5 Baerveldt), no significant difference in failure rates between implants (16.4% Ahmed vs 14.0% Baerveldt), and serious complications (20% Ahmed vs 34% Baerveldt) were observed. The larger equatorial plate of the Baerveldt implant likely explains the lower IOP relative to the Ahmed implant, as larger surface-area-plates are associated with greater pressure reduction (Heuer et al., 1992). The lower incidence of early postoperative and serious complications after placement of the Ahmed implant compared with the Baerveldt implant probably relates to the valve mechanism that minimizes the risk of hypotony-related complications in the immediate postoperative period.

4. Aqueous shunts versus trabeculectomy

Despite the introduction of several new incisional glaucoma procedures in recent years, trabeculectomy and aqueous shunt surgery remain the most frequently performed glaucoma operations worldwide. No clear consensus exists among glaucoma specialists regarding the best surgical approach for managing medically uncontrolled glaucoma in many clinical settings. Some surgeons favor an antifibrotic-augmented trabeculectomy, while others prefer the placement of an aqueous shunt (Chen et al., 1997; Joshi et al., 2005). Several studies have provided information comparing surgical results with aqueous shunts and trabeculectomy in specific patient groups (Gedde et al., 2005, 2007a, 2007b, 2009; Joshi et al., 2005, 2007). Table 2 offers a summary of key elements of randomized clinical trials comparing aqueous shunts and trabeculectomy.

4.1. Surgical outcomes among medicare beneficiaries

Stein et al. (2008) assessed the rates of postoperative adverse outcomes after trabeculectomy and aqueous shunt procedures...
Wilson et al. (2000, 2003) that reported similar success rates with aqueous shunt surgery after 1-year follow-up (20.0% aqueous shunt group, 0.6% trabeculectomy group, 1.3% trabeculectomy with scarring group). Before treatment, patients in the aqueous shunt group were more likely to have neovascular glaucoma ($p < 0.001$), uveitic glaucoma ($p < 0.001$), and a prior claim for a severe ($p < 0.001$) and a less severe outcome ($p < 0.001$). Controlling for these covariates reduced the differences between groups, but they remained statistically and clinically significant.

4.2. Ahmed glaucoma valve implant vs trabeculectomy

Wilson et al. (2000) compared the outcomes of the Ahmed glaucoma valve implant and trabeculectomy in a randomized clinical trial involving 117 patients. Mean IOP was lower in the trabeculectomy group at 1 year (11.4 mm Hg trabeculectomy group vs 17.2 mm Hg Ahmed group, $p = 0.01$), and the Ahmed group required more medical therapy at last follow-up (13% trabeculectomy group vs 35% Ahmed group, $p = 0.01$). The cumulative probability of success (IOP < 21 mm Hg and ≥15% reduction from baseline, IOP > 5 mm Hg, no additional glaucoma surgery, and no loss of light perception vision) was similar between the two treatment groups after 1-year follow-up (83.6% trabeculectomy group vs 88.1% Ahmed group, $p = 0.43$). The study, performed in Saudi Arabia and Sri Lanka, included patients with all glaucoma types and some eyes that had undergone previous ocular surgery. A follow-up study continued recruitment in Sri Lanka to enroll a total of 123 patients with primary open-angle glaucoma or angle-closure glaucoma without prior ocular surgery (Wilson et al., 2003). With a mean follow-up of 31 months, no significant differences between the trabeculectomy and Ahmed groups were observed with respect to the mean IOP (13.6 mm Hg trabeculectomy group vs 13.1 mm Hg Ahmed group) and mean number of glaucoma medications (0.93 medications trabeculectomy group vs 1.13 medications Ahmed group, $p = 0.34$) at final follow-up. The cumulative probability of success was also similar between treatment groups at last follow-up (68.1% trabeculectomy group vs 69.8% Ahmed group, $p = 0.86$).

Tran et al. (2009) presented a retrospective case-controlled study that compared the outcomes of Ahmed glaucoma valve implant surgery and trabeculectomy with MMC. The study included 166 patients with primary or secondary open-angle glaucoma with at least 3-year follow-up, and the two treatment groups were matched with respect to age, preoperative surgery, preoperative IOP, and preoperative medications. Four criteria were used to compare the probability of success between the two groups: (A) IOP ≤ 21 mm Hg and ≥15% reduction from baseline; (B) IOP ≤ 18 mm Hg and ≥20% reduction from baseline; (C) IOP ≤ 15 mm Hg and ≥25% reduction from baseline; and (D) IOP ≤ 12 mm Hg and ≥30% reduction from baseline. Additional criteria for success included no loss of light perception vision, no additional glaucoma surgery, and no persistent hypotony (IOP ≤ 5 mm Hg). A higher probability of success was observed with trabeculectomy with MMC compared with Ahmed implantation at 5 years, which became progressively more statistically significant as the success criteria were made more stringent. No significant difference was observed between treatment groups for criterion A (36% Ahmed group vs 48% trabeculectomy group, $p = 0.094$). This result is consistent with the randomized prospective trials by Wilson et al. (2000, 2003) that reported similar success rates with the Ahmed implant and trabeculectomy when success was defined in a manner similar to criterion A. However, a significantly higher success rate was observed with trabeculectomy with MMC for criterion B (28% Ahmed group vs 44% trabeculectomy group, $p = 0.024$), criterion C (19% Ahmed group vs 40% trabeculectomy group, $p < 0.001$), and criterion D (9% Ahmed group vs 22% trabeculectomy group, $p < 0.001$). A recent publication highlighted the degree to which surgical outcomes are affected by the criteria used to define success (Rotnshof and King, 2010), and this point is clearly illustrated by the Tran study. Twice as many patients in the trabeculectomy group required repeat glaucoma surgery (26 patients trabeculectomy group vs 13 patients Ahmed group), and more patients in the Ahmed group had penetrating keratoplasty (9 patients Ahmed group vs 2 patients trabeculectomy group).

4.3. Tube Versus Trabeculectomy (TVT) study

The TVT Study is a multicenter randomized clinical trial comparing the safety and efficacy of aqueous shunt surgery to trabeculectomy with MMC in patients with previous ocular surgery. A total of 212 patients who had prior cataract and/or glaucoma filtering surgery were randomly assigned to treatment with a 350-mm² Baerveldt glaucoma implant or trabeculectomy with MMC (Gedde et al., 2005). A higher success rate (IOP < 21 mm Hg and ≥20% reduction from baseline, IOP > 5 mm Hg, no additional glaucoma surgery, and no loss of light perception vision) was seen after aqueous shunt surgery after 3-years of follow-up (84.9% tube group vs 69.3% trabeculectomy group, $p = 0.010$ (Gedde et al., 2009). Both treatment groups had similar mean IOP (13.0 mm Hg tube group vs 13.3 mm Hg trabeculectomy group, $p = 0.78$) and mean number of glaucoma medications (1.3 medications tube group vs 1.0 medications trabeculectomy group, $p = 0.30$) at 3 years. Postoperative complications were more common after trabeculectomy with MMC during the first 3 years of the study (39% tube group vs 60% trabeculectomy group, $p = 0.004$), but no significant difference in the rate of serious complications associated with reoperation and/or vision loss of two or more Snellen lines was observed between treatment groups (22% tube group vs 27% trabeculectomy group, $p = 0.58$).

The TVT Study challenges several current concepts and other publications comparing trabeculectomy and aqueous shunt surgery. Based upon a systematic review of the medical literature on aqueous shunts, a panel of glaucoma specialists concluded that low IOP levels usually cannot be attained with these devices and the IOP typically settles in the high teens postoperatively (Minckler et al., 2008). The TVT Study contradicts these opinions, as evidenced by a mean IOP of 13.0 mm Hg and IOP of 14 mm Hg or less in 62% of patients in the tube group at 3 years (Gedde et al., 2009). Studies by Wilson et al. (2000, 2003) and Tran et al. (2009) found similar success rates with the Ahmed glaucoma valve implant and trabeculectomy. In contrast, the TVT Study found that Baerveldt implantation had a higher success rate compared with trabeculectomy with MMC (Gedde et al., 2007a, 2009). The differences in study findings may relate to differences in study populations, success and failure criteria, and retention during follow-up. Additionally, the Baerveldt glaucoma implant has an equatorial plate with a larger surface area than the Ahmed implant, and evidence suggests that shunts with larger surface-area plates are associated with greater IOP reduction (Heuer et al., 1992; Minckler et al., 2008). Stein et al. (2008) noted a higher rate of adverse outcomes after aqueous shunt surgery than trabeculectomy. The opposite observation was made in the TVT Study, with a higher rate of postoperative complications after trabeculectomy with MMC relative to aqueous surgery (Gedde et al., 2007b, 2009) Stein et al. (2008) and the accompanying Editorial (Javitt, 2008) acknowledge the limitations of data derived from Medicare claims.
including the possibility of misattributing complications from the fellow eye. Moreover, aqueous shunts have historically been reserved for patients who have failed standard filtering surgery, and there are likely differences in case severity among the Medicare beneficiaries in the Stein study who underwent aqueous shunt surgery and trabeculectomy. In contrast, patients who underwent these two glaucoma procedures in the TVT Study had similar characteristics as a result of the randomization process, and included lower risk patients than those who had undergone traditional aqueous shunt surgery (e.g., only prior clear cornea cataract extraction).

5. Complications

Aqueous shunts are associated with similar intraoperative and postoperative complications as occurs after trabeculectomy. Additionally, there are unique surgical complications that may develop postoperatively. The changes were statistically significant compared with those at baseline and those of the control eye at all time points during the study period. The superotemporal area, the site closest to the tube, showed the greatest decrease in endothelial density at 24 months (22.6% superotemporal vs 15.4% central). While this study raises concern about corneal endothelial damage with aqueous shunts, it is noteworthy that none of the study eyes experienced overt corneal edema or a decline in best-corrected visual acuity.

Mendrinos et al. (2009) assessed corneal endothelial cell loss and tube position in 10 patients who had placement of an Ahmed implant. Central and peripheral corneal endothelial density was measured with confocal microscopy, and imaging of the anterior chamber tube was performed with anterior segment optical coherence tomography (AC-OCT) at 6 months and 1 year postoperatively. Mean endothelial cell density decreased 7.9% in the central cornea and 7.5% in the peripheral cornea over the 6-month study period. No significant association between central and peripheral endothelial cell loss and tube position (intracameral tube length and distances between the tube and cornea and tube and iris). The absence of a correlation between tube position and corneal endothelial cell loss in this study does not exclude the importance of mechanical factors. Tube position relative to the cornea may change with eye rubbing and blinking (especially in eyes with low levels of IOP), and this dynamic relationship would not likely be detected with the AC-OCT measurements made in this study.

6. Surgical technique

Several modifications in surgical technique for aqueous shunt implantation have been recently described. These modifications have been directed toward improving surgical success (DeCroos et al., 2009; Sahiner et al., 2009), reducing postoperative complications (Bochmann and Azuara-Blanco, 2009; Camejo and Noecker, 2008; Prata et al., 2010), and optimizing efficiency and cost (Kahook and Noecker, 2006; Ollila et al., 2005; Rossiter-Thornton et al., 2010).

6.1. Implant enclosure in a porous membrane

DeCroos et al. (2009) developed an Ahmed glaucoma implant in which the plate was enclosed in a porous membrane of polytetrafluoroethylene, termed porous retrofitted implant with modified enclosure (PRIME-Ahmed). The PRIME-Ahmed was compared with the standard Ahmed implant in a rabbit model. Histologic analysis 6 weeks after surgical implantation demonstrated a thinner fibrous capsule around the PRIME-Ahmed (46.4 microns PRIME-Ahmed vs 94.9 control, \( p < 0.001 \)) with more vascularity near the tissue–material interface. It was suggested that a thinner fibrous capsule with enhanced vascularity may reduce aqueous outflow resistance and improve long-term aqueous shunt performance.

6.2. Drug-coated aqueous shunt

Investigators at Tulane University developed a slow-release antifibrotic drug-coated aqueous shunt (Sahiner et al., 2009). MMC was incorporated into the polymer poly (2-hydroxyethyl methacrylate), and release of the drug occurred on contact with water. This drug delivery device was attached to the Ahmed glaucoma valve and implanted in rabbits. Histologic analysis 3 months postoperatively demonstrated a significant reduction in inflammatory reaction and fibrosis of the MMC-coated Ahmed implants compared with unmodified Ahmed implants.

6.3. Tube insertion into the ciliary sulcus

Tube insertion into the anterior chamber during aqueous shunt surgery has been associated with progressive corneal endothelial cell loss. Several years after insertion, corneal endothelial cell loss and tube position in 10 patients who had placement of an Ahmed implant. Central and peripheral corneal endothelial density was measured with confocal microscopy, and imaging of the anterior chamber tube was performed with anterior segment optical coherence tomography (AC-OCT) at 6 months and 1 year postoperatively. Mean endothelial cell density decreased 7.9% in the central cornea and 7.5% in the peripheral cornea over the 6-month study period. No significant association between central and peripheral endothelial cell loss and tube position (intracameral tube length and distances between the tube and cornea and tube and iris). The absence of a correlation between tube position and corneal endothelial cell loss in this study does not exclude the importance of mechanical factors. Tube position relative to the cornea may change with eye rubbing and blinking (especially in eyes with low levels of IOP), and this dynamic relationship would not likely be detected with the AC-OCT measurements made in this study.
cell loss and corneal decompensation, especially in eyes with shallow anterior chambers, compromised corneal endothelial, or previous penetrating keratoplasty. Pars plana tube insertion maximizes the distance between the tube and cornea, but requires that a pars plana vitrectomy be performed with complete removal of the vitreous. In patients with posterior chamber intraocular lens implants, insertion of the tube into the ciliary sulcus is a surgical option that does not require a concurrent vitrectomy. Prata et al. (2010) reported encouraging midterm clinical outcomes with Baerveldt tube insertion into the ciliary sulcus. Reduction of IOP between 7 and 18 mm Hg was achieved in 82% of patients with a mean follow-up of 37.2 months. Mean IOP decreased from 28.4 ± 12.2 mm Hg to 12.1 ± 5.9 mm Hg, and the mean number of glaucoma medications was reduced from 3.4 ± 1.4 to 2.0 ± 1.4.

Camejo and Noecker (2008) reported a modified technique for ab interno sulcus placement of aqueous shunt tubes. In preparing the tube, it is trimmed longer (approximately 4 mm anterior to the limbus) with a bevel facing down. A viscoelastic agent is injected to maximalize the distance between the tube and cornea, but requires that a pars plana vitrectomy be performed with complete removal of the vitreous. In patients with posterior chamber intraocular lens implants, insertion of the tube into the ciliary sulcus is a surgical option that does not require a concurrent vitrectomy. Prata et al. (2010) reported encouraging midterm clinical outcomes with Baerveldt tube insertion into the ciliary sulcus. Reduction of IOP between 7 and 18 mm Hg was achieved in 82% of patients with a mean follow-up of 37.2 months. Mean IOP decreased from 28.4 ± 12.2 mm Hg to 12.1 ± 5.9 mm Hg, and the mean number of glaucoma medications was reduced from 3.4 ± 1.4 to 2.0 ± 1.4.

Camejo and Noecker (2008) reported a modified technique for ab interno sulcus placement of aqueous shunt tubes. In preparing the tube, it is trimmed longer (approximately 4 mm anterior to the limbus) with a bevel facing down. A viscoelastic agent is injected to expand the sulcus. A 23-gauge needle is introduced through the cornea 180° from the planned tube insertion site, advanced across the anterior chamber, and passed under the iris and out the eye through the sclera. The tube is then inserted through the needle track.

6.4. Transcameral suture to prevent tube-cornea touch

Bochmann and Azuara-Blanco (2009) described a new technique to manage tube malposition after aqueous shunt implantation. A 10–0 polypropylene suture double-armed with 3-inch long straight needles was placed transcamerally from limbus to limbus running over the tube in a patient with tube-cornea touch. The tube was depressed into an optimal position away from the corneal endothelium for 20 months follow-up.

6.5. Fibrin glue-assisted aqueous shunt surgery

Kahook and Noecker (2006) evaluated the use of fibrin glue as a suture substitute for portions of aqueous shunt implantation in a retrospective case–control study. Fourteen consecutive patients who underwent aqueous shunt placement with fibrin glue were compared with 28 consecutive patients who had aqueous shunt surgery with traditional suture material. A 250-mm² Baerveldt glaucoma implant and Tutoplast (Innovative Ophthalmic Products, Costa Mesa, CA) were used in all patients. Fibrin glue was applied to close the conjunctiva, secure the patch graft, and secure the tube to sclera with the new technique. No significant differences were observed in IOP, glaucoma medical therapy, and postoperative complications between treatment groups. Conjunctival inflammation was more pronounced in the suture group on a 0–4 scale (2.0 in the fibrin glue group vs 2.83 in the suture group, p = 0.002), and the surgical time was less for the fibrin glue group (15.0 min in fibrin glue group vs 25.9 min suture group, p < 0.001).

6.6. Graft-free tube insertion

Different techniques have been described for inserting an aqueous shunt tube through a scleral tunnel without a donor patch graft (Ollila et al., 2005; Rossiter-Thornton et al., 2010). Rossiter-Thornton et al. (2010) reported the use of a bent vitreoretinal blade introduced through a partial thickness scleral incision 5–6 mm from the limbus and guided through the superficial scleral into the anterior chamber. A consecutive case series of 34 patients with this technique for tube insertion found that only 1 patient developed tube erosion during 10 years of follow-up. Ollila et al. (2005) described another technique for graft-free tube insertion. A 6 × 4 mm partial thickness scleral flap is dissected at the limbus, as with trabeculectomy. A 6–7 mm long tunnel is developed from the equator to the limbal scleral flap with a crescent blade. Once the tube has been inserted into the scleral tunnel, an entry incision into the anterior chamber is made under the limbal scleral flap with a 23-gauge needle. A retrospective case–control study was conducted comparing this new technique in 92 patients with a traditional technique in 332 patients. A lower rate of tube erosion was observed with the new technique (0% new technique vs 4.5% traditional technique, p = 0.038) with a median follow-up of 22 months. Graft-free tube insertion offers the advantages of reduced cost and increased efficiency, as well as elimination of the risk of transmitting disease with use of a patch graft (such as prion diseases).

7. Conclusions

Aqueous shunts are being increasingly utilized in the surgical management of glaucoma as an alternative to trabeculectomy (Joshi et al., 2005; Ramulu et al., 2007). Recent studies have demonstrated comparable results with trabeculectomy and aqueous shunts in similar patient groups (Gedde et al., 2007a, 2009; Tran et al., 2009; Wilson et al., 2000, 2003). It is desirable to avoid the hypotony and bleb-related complications associated with trabeculectomy. However, aqueous shunts have their own unique set of complications, including motility disturbances (Ayyala et al., 1998; Britt et al., 1999; Dobler-Dixon et al., 1999; Harbick et al., 2006; Huang et al., 1999; Krishna et al., 2001; Lloyd et al., 1994; Rauscher et al., 2009; Roy et al., 2001; Smith et al., 1993; Tsai et al., 2003), tube exposure (Stewart et al., 2010), and corneal endothelial loss (Lee et al., 2009; Mendrinos et al., 2009). Modifications in surgical technique have been described in an attempt to improve surgical success (DeCros et al., 2009; Sahiner et al., 2009), reduce postoperative complications (Bochmann and Azuara-Blanco, 2009; Camejo and Noecker, 2008; Prata et al., 2010), and optimize efficiency and cost (Kahook and Noecker, 2006; Ollila et al., 2005; Rossiter-Thornton et al., 2010). New clinical trials data have identified differences in the safety and efficacy of the aqueous shunts in popular use (Budenz et al., 2011; Nassiri et al., 2010). This information should prove valuable to glaucoma surgeons who wish to select the safest and most effective IOP lowering procedure for each individual patient.

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