Minimally Invasive Glaucoma Surgery: Trabeculectomy Ab Interno

16

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Introduction

Trabeculectomy ab interno with the trabectome (Neomedix, Tustin, CA) was FDA approved in 2004 [1]. It was originally described as using electrocautery to ablate trabecular meshwork (TM), unroofing the nasal Schlemm's canal over 30–60°. A first series of 37 patients was highly successful demonstrating a mean 42 % decrease in intraocular pressure (IOP) from a baseline of 28 mmHg after 1 year [1]. There were no cases of postoperative flat anterior chambers, hypotony, infection, wound leak, bleb formation, choroidal effusion, or loss of two lines of Snellen visual acuity.

The introduction of ab interno trabeculectomy with the trabectome at a time when trabeculectomy was considered the gold standard evokes memories of when cataract surgeons started to realize the benefits of phacoemulsification over extracapsular cataract extraction (ECCE). Trabectome surgery is similar to phacoemulsification in that it requires advanced equipment, is standardized, uses a small incision, and is very safe. In contrast, both ECCE and trabeculectomy require only simple instruments, feature a large incision, cannot be standardized, and produce a wide range of outcomes and complications, both early and late ones.

The aim of this chapter is to discuss the indications, to detail the techniques that the authors have adopted, and to review the results and complications of trabectome surgery.

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Indications

Trabectome was first described for use in glaucomas with an angle open by at least 20° or grade 2 on the Shaffer scale and an IOP level likely causing progression while on maximally tolerated medical therapy [1]. Exclusion criteria were angles with poor visibility of the trabecular meshwork and neovascular glaucoma. In our experience with more than 500 trabectome surgeries, we have found that a wide range of glaucoma types and stages can be operated on using a modified surgical technique described below. We find that only active neovascular glaucoma, elevated episcleral venous pressure, moderately active uveitis, and angle dysgenesis represent true contraindications. The patient has to be able to rotate the neck by more than 30°, or a microscope is available with a large tilt angle to compensate for the limitation. The cornea must be sufficiently free of opacities in the form of peripheral scars, deposits, vascular pannus, or arcus lipoides.

Surgical Technique

Glaucoma surgeons do not typically learn trabectome surgery as their first glaucoma surgery but often begin with drainage device implantations and trabeculectomies. As a result, it is not surprising that more delicate microsurgery of the angle initially seems overwhelming with its requirement for higher magnification and excellent depth perception to strictly avoid structures that are only a few 100 μm apart from each other: distal to ablation, the outer wall of Schlemm's canal with collector channel intakes, posteriorly the more vascularized scleral spur, iris and ciliary body, and anteriorly the corneal endothelium.

While the beginning surgeon becomes comfortable with the goniolens relatively quickly, a considerable learning curve follows before great results can be achieved. We find that indications can be broadened, and lower target pressures, higher success rates, and earlier visual recovery

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can be achieved when careful attention is paid to six key elements:

1. Excellent visualization using a xenon light microscope with large tilt capabilities
2. No viscoelastic injection before or during ablation
3. Creation of a corneal incision that is 2 mm anterior to the limbus and flared on the inside
4. Avoidance of outward push applied during ablation
5. Ablation of a long, near 180° ablation arc
6. Swift tamponade of the unroofed canal with viscoelastic before and after cataract extraction

We will discuss these key elements in detail in the following.

Angle Visualization: Xenon Light and Large Tilt Angle

The impact of an outstanding microscope with excellent optics and blue-white illumination using xenon light (e.g., Zeiss Lumera, Carl Zeiss Meditec, Jena, Germany) cannot be overestimated to visualize the target of ablation, the lacy, delicate, 50-μm-thick trabecular meshwork.

Preoperative considerations pertaining to anesthesia are minimal. Adequate anesthesia can be achieved with intracameral 1 % preservative-free lidocaine [1]. The surgeon sits temporally. For patients who will face significant difficulty rotating the neck, the microscope tilt can be increased. If the patient is unable to rotate the neck, then the superior axial core may be rotated by placing blankets underneath the half of the patient's back and shoulder on the side closest to the surgeon. Preoperative pilocarpine is not necessary, and when trabectome surgery is combined with phacoemulsification, routine dilation can be used. The intact lens of a young patient should be protected by preoperative pilocarpine or intracameral carbachol.

No Viscoelastic Prior to or During Trabectome Ablation

The paracentesis is fashioned as for phacoemulsification. As is common practice for goniotomy for pediatric glaucoma, no viscoelastic should be used because it interferes with optimal visualization from different optical densities and interfaces, traps ablation gas bubbles, and can bake into the tip during ablation.

Incision 2 mm Anterior to Limbus, Slight Flare of Innermost Aspect

The main incision is positioned at the standard clock hour position as for phacoemulsification. The size is only 1.6 mm wide, and the incision should be made 2 mm anterior to the limbus and parallel to the iris (Fig. 16.1). The more anterior

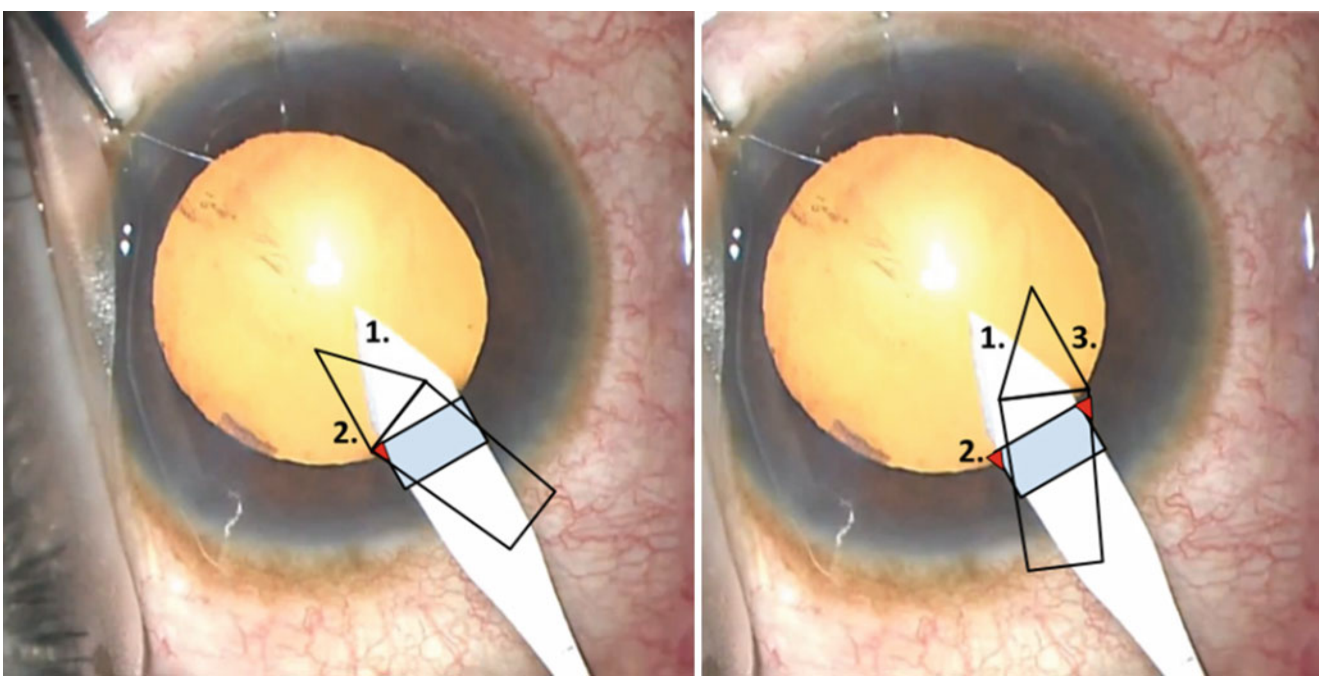

Fig. 16.1 Main incision for trabectome surgery into the anterior chamber filled with 1 % lidocaine solution. (*1*) Entry is made 2 mm anterior to limbus and parallel to the iris in the left and right photos. Line diagrams showing how to position the blade for internal enlargement to the left (*2*) and to the right (*3*), allowing for better trabectome range without striae can be achieved by nicking Descemet's membrane and slightly flaring the incision

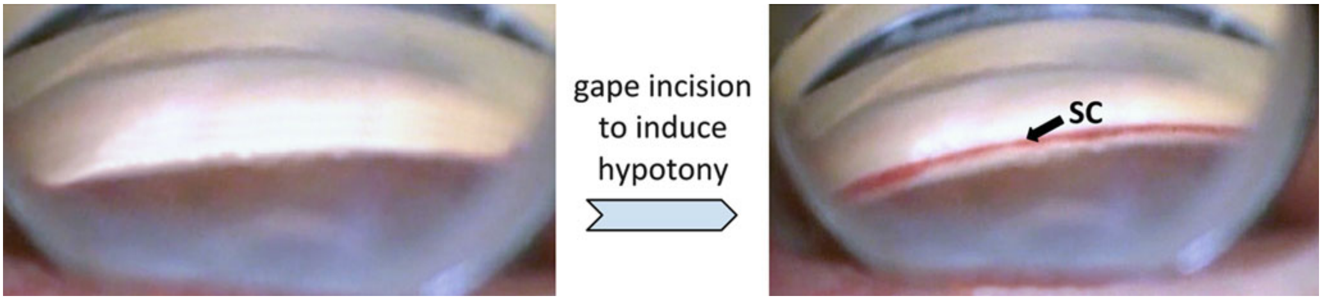

Fig. 16.2 Schlemm's canal (SC, *right*) can be easily identified by gaping the main incision to induce hypotony and blood reflux from the collector channels. This is useful in nonpigmented TM but more generally to differentiate angle landmarks that may look similar (e.g., Sampaolesi's line, TM, ciliary body band)

incision and planar orientation – compared with a regular incision for phacoemulsification – will greatly reduce striae during manipulation of the handpiece and prevent iris prolapse. Following full entry, after only partially retracting the blade in the initial incision, a slight forward cut is made to the left and to the right, pointing toward the anticipated end of the ablation arc, flaring the incision. Only the innermost 25 % of the wound needs to be flared for the first-generation handpiece. This prevents the metal irrigation sleeve from getting caught at the level of Descemet's membrane and reduces corneal striae that can reduce visibility when the incision is torqued at the end of large ablation arcs. The redesigned second-generation tip has a sloped irrigation sleeve and allows for a much smoother insertion.

The anterior chamber will not collapse as long as the keratome is kept parallel to the incision plane and no viscoelastic is needed for insertion. A small amount of fluid egress can induce temporary hypotony. This will allow blood to reflux into Schlemm's canal and clearly outline the target structure (Fig. 16.2). Oftentimes the trabecular meshwork may not be pigmented or other pigmented structures are confusing. Misidentification and ablation of the wrong structure by beginning surgeons is the primary reason for arterial bleeding. Since the correct structure was not unroofed, the hyphema cannot exit the anterior chamber and the high persistent IOP will ensue.

Following the main incision, the patient's head is rotated about 30° away from the surgeon, while the microscope headpiece is tilted approximately 45° toward the surgeon. A direct Swan-Jacobs gonioscopy lens with proper handedness (Ocular Instruments, Bellingham, Washington) is placed to assure an adequate view of the trabecular meshwork after adjusting zoom and focus. The trabectome handpiece is then inspected under the microscope to assure the integrity of the tip. Continuous irrigation should be activated on the foot pedal but without activating electroablation which can damage the tip.

The irrigation bottle should be raised to near maximum height to deepen the angle and improve the view. The impact on visibility is manifold: surge is prevented, the iris root and peripheral iris are maximally displaced posteriorly resulting in an immediately apparent angle opening, and the cornea is forced into a stable spherical shape without striae. This also prevents reflux from the collector channels, while any pigment or bubbles are swiftly washed out through the main incision. The trabectome handpiece is inserted through the main wound. If the shoulder of the handpiece (19 gauge) cannot be inserted easily through the wound, a twisting motion with rotation along the long axis can be used as gentle but increasing pressure is applied at the wound. If this is inadequate, the upper lip of the corneal wound can be grasped and pulled anteriorly with forceps to offer less resistance to insertion. The insertion should be done quickly to avoid excess aqueous egress and anterior chamber collapse. The handpiece tip should be advanced to the center of the pupil before the goniolens is placed back onto the cornea. With the modified Swan-Jacobs lens, no coupling fluid is needed other than balanced salt solution (BSS). The goniolens should only gently touch the cornea: if striae are noted (first seen at the most superior aspect of the view), then too much downward pressure is being applied.

Identifying and Engaging Schlemm's Canal, No Outward Pressure During Ablation

Without certain identification of Schlemm's canal, this procedure can produce either no IOP effect when ablation occurs in the cornea or create arterial bleeding with large hyphemas and dangerous postoperative IOP. If the TM is nonpigmented, then induction of hypotony by wound gape is an effective means to visualize the TM (Fig. 16.2).

Under gonioscopic view, the trabectome tip is moved toward the trabecular meshwork (TM). It is easier to initiate ablation at a point that is more toward the left than exactly at the opposite site of the chamber. This offers a better angle of engagement because the tip is now pointed toward, and not parallel to, the TM (Fig. 16.3).

The TM is approached with the tip at a 45° angle aimed upward (Fig. 16.4), from just inferior to the TM at the scleral

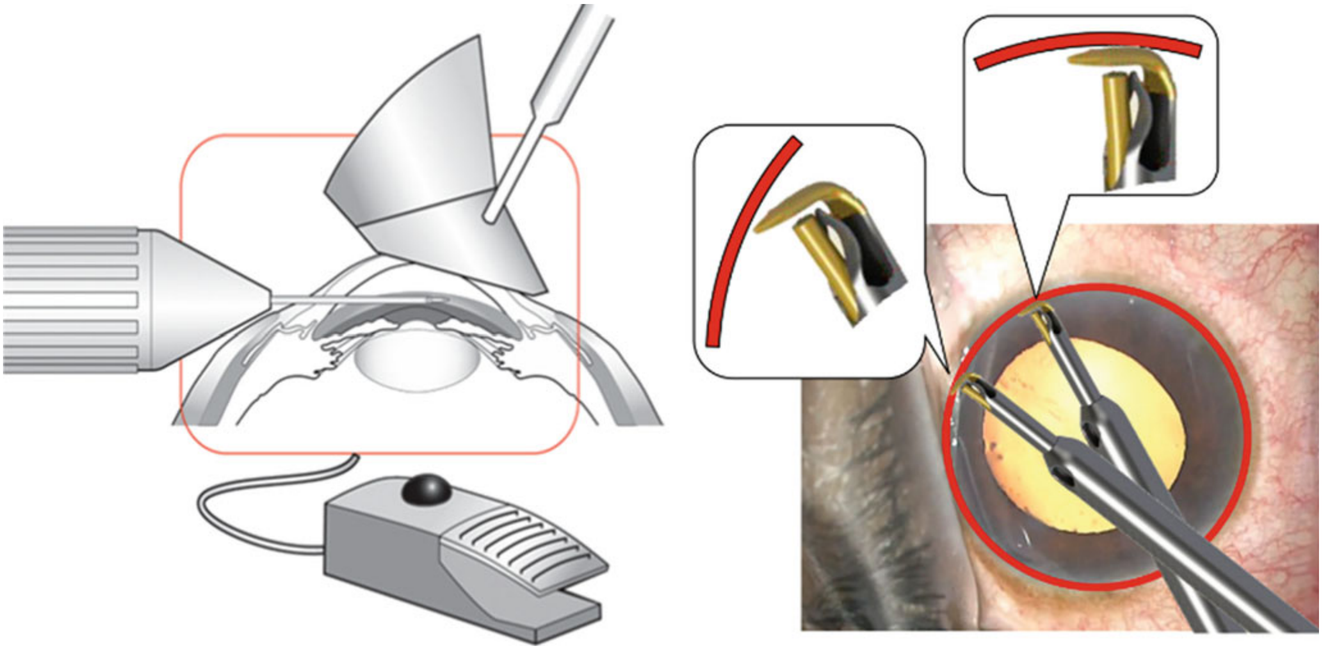

Fig. 16.3 *Left*: Sketch of trabectome, lens and eye. *Right*: If entry of Schlemm's canal opposite of the main incision is difficult, the tip should be moved toward the left to allow a more pointed encounter

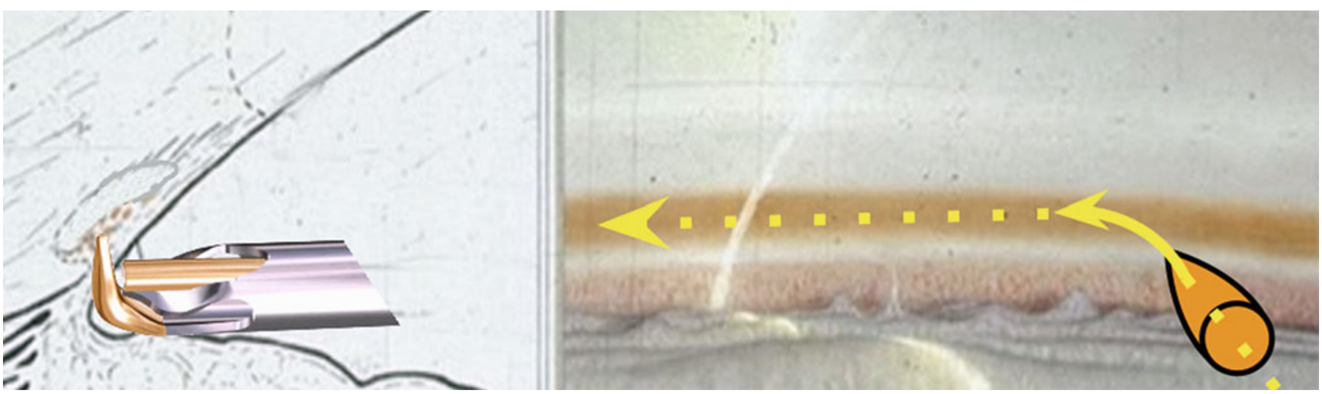

Fig. 16.4 Entry of Schlemm's canal with the trabectome is easiest directly anterior to the scleral spur in a 45° angle because the space is maintained by it. If the trabectome is held parallel to the trabecular meshwork, Schlemm's canal collapses

spur. The spur will keep the space open and resist collapse of Schlemm's canal which occurs when the trabectome tip is held parallel and pushed outward when engagement is attempted directly across from the incision. Once the footplate is behind the TM, a slight inward pull should be exerted to counteract the tendency to push outward. This tenting of the TM changes the visibility of the ablation tip and confirms proper insertion. Ablation is started toward the surgeon's nondominant hand.

Ablation can be carried out starting at 0.8 mW and titrated up. Power should be decreased if visible blackening of the upper and lower edges of the TM occurs. This is possible although heat transfer through the footplate to the outer wall is only 1.2°C. As discussed, the bottle height should be at maximum. The trabectome foot pedal can be tapped (black ball switch) for continuous, gravity-fed irrigation, then depressed to position 1 for continuous, nonlinear aspiration and position 2 for continuous and constant ablation power. Aspiration has a maximum flow rate of 10 ml/min [2].

During ablation, it is pertinent to avoid any outward pressure, ideally preventing touching the outer wall entirely. The outer wall of Schlemm's canal is lined with 50-μm orifices of the collector system that easily scar over when the lining endothelium is damaged (Fig. 16.5). Yet because beginning surgeons are focused on trying to enter Schlemm's canal and engaging the TM, this mistake is extremely common leading to disappointing pressure results either early on or after several weeks as a response to endothelial damage.

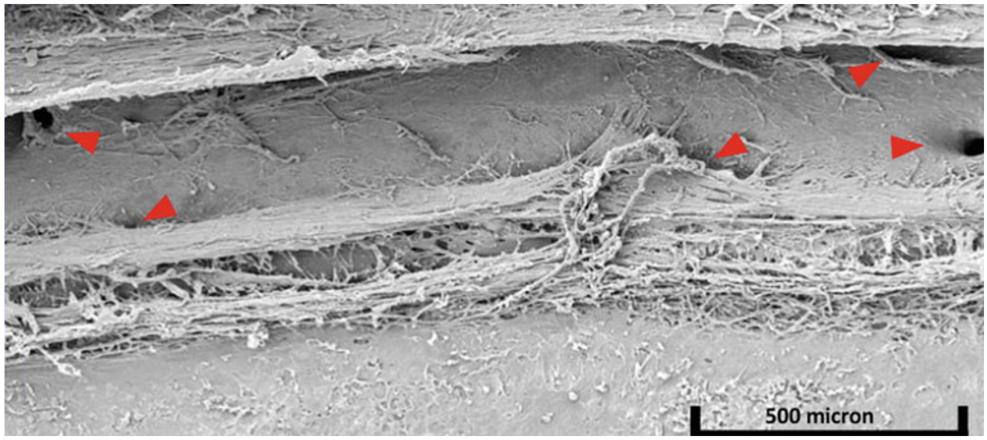

Fig. 16.5 Location of collector channel orifices. Many intakes are close to the upper (anatomic anterior) and lower (anatomic posterior) portion of Schlemm's canal, providing a possible explanation why removal of TM with the trabectome might be superior to goniotomy which merely incises the TM allowing the remaining lips to roll inward and occlude those

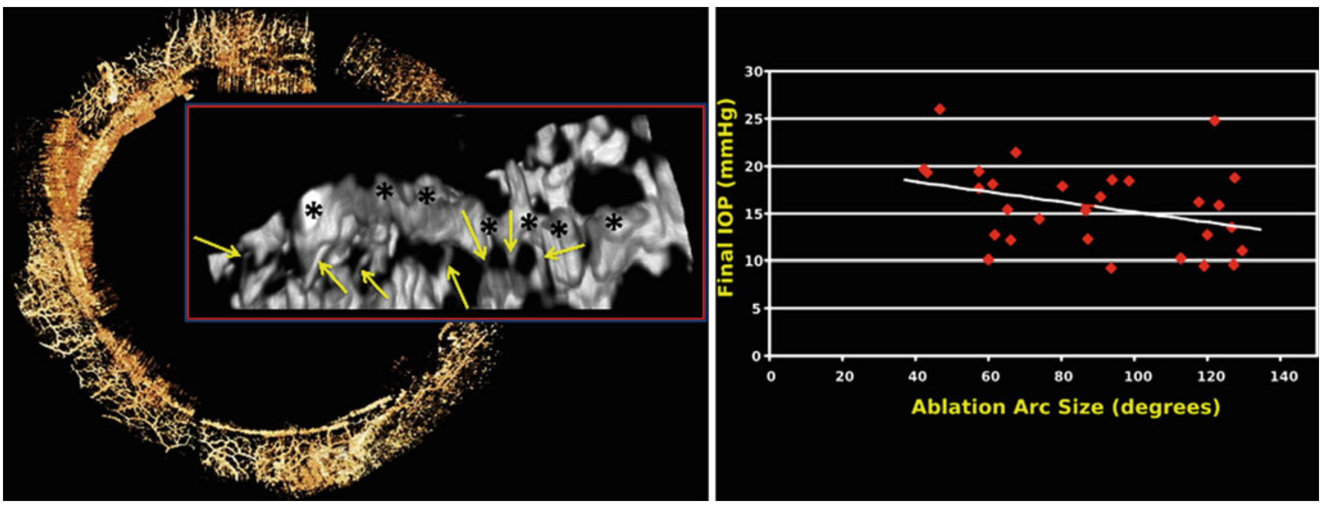

Fig. 16.6 *Left*: In vivo, Schlemm's canal is often not contiguous and may have duplications (After Kagemann et al. [3]; *asterisks*: Schlemm's canal, *yellow arrows*: collector channels). *Right*: ablation arc length correlates with final IOP (After Sit et al. [4])

Achieve 180° of Ablation

Aiming to ablate 180° of trabecular meshwork increases the chance of obtaining successful access to viable collector channels. Contrary to common belief, aqueous flow is not circumferential (Fig. 16.6). Studies ranging from injecting intracameral tracer [5] to anterior segment optical coherence tomography (OCT) [6] have shown that aqueous outflow through Schlemm's canal is segmental, increasing near collector channels. For instance, Schlemm's canal was shown to be 33 % wider nasally than temporally [7], and actual septae have been imaged in 2-μm resolution 3d micro-computerized tomography scans [8]. Adequate ablation can be confirmed by the white appearance of the outer wall of Schlemm's canal. The first 60° can usually be ablated continuously without many adjustments. As visualization is turned to the remaining 30°, the goniolens is rotated in the same direction the ablation is occurring, and the eye is tilted closer to the endpoints to increase visibility (Fig. 16.7).

Although the goal should be to ablate a full 90°, the final 10–15° cannot always be visualized for ablation. Once the full extent of visualization is reached, the tip is retracted from Schlemm's canal by pulling inward. It is rotated with one hand and under continuous gonioscopic view, tip down, by a full 180° and reinserted into Schlemm's canal where the original ablation was started.

The handpiece is rotated between the index finger, ring finger, and thumb while the wrist is increasingly pronated during the ablation of the remaining 90° (Fig. 16.8). The metal sleeve of the trabectome can be rested firmly against the proximal, straight edge of the goniolens during the 180° rotation into the opposite direction. Visualization of the wall of Schlemm's canal is confirmed as ablation continues. It is advisable not to force the tip ahead but instead stop and retract the tip. This will unwrinkle the TM or retract the tip from the outer wall and collector openings, and then ablation can be continued. After ablation is complete, the handpiece is withdrawn completely from the TM. The handpiece can then be removed from the eye.

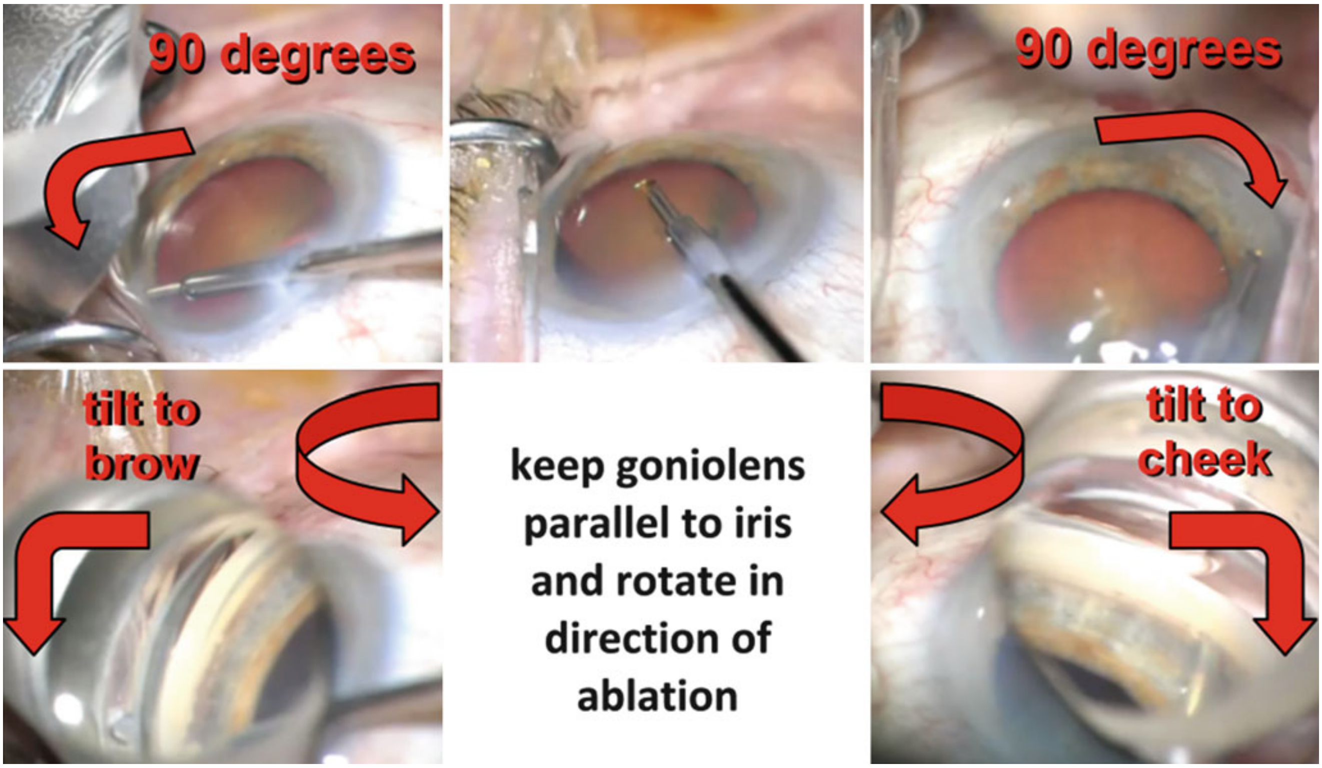

Fig. 16.7 A modified Swan-Jacob goniolens designed for trabectome surgery is placed on the cornea without compressing it. It is held parallel to the iris and rotated into the direction of ablation. The eye can be tilted upward or downward by lifting the trabectome up in the incision to increase visibility of the superior and inferior chamber angle and maximize the ablation arc to achieve near 180°. Gonioscopic prism power and angle view at these ablation endpoints is increased by lifting the distal part of the lens off the cornea to float in the pool of saline that forms during the procedure (*lower left* and *right*)

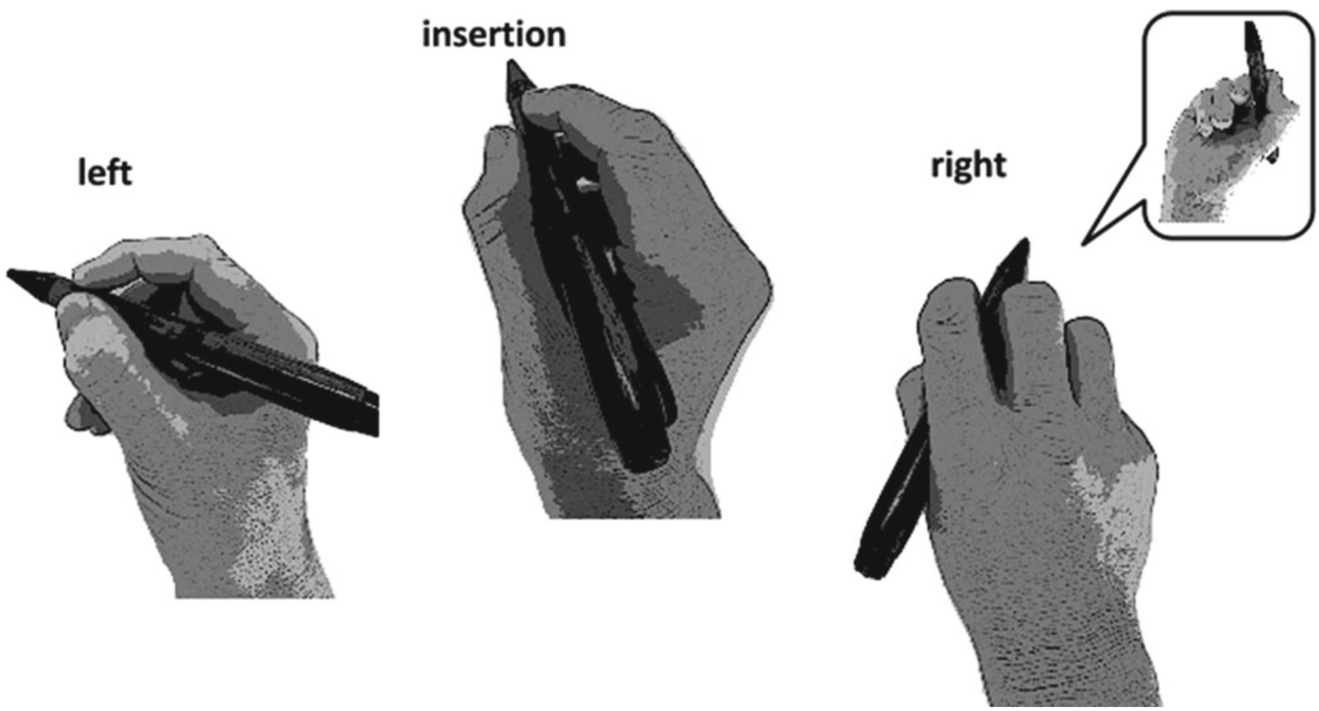

Fig. 16.8 Hand position during trabectome surgery. The trabectome handpiece is held like with phacoemulsification during insertion with the tip pointing toward the left (*middle*). As ablation continues toward the nondominant hand, the hand is increasingly supinated and more held like a pen (*left*). The handpiece is then rotated 180° under gonioscopic view and ablation continued toward the right while the hand is increasingly pronated (*right*; *inset*: finger position from *below*). The tip is rolled between the thumb, index finger, and ring finger to keep it parallel to Schlemm's canal

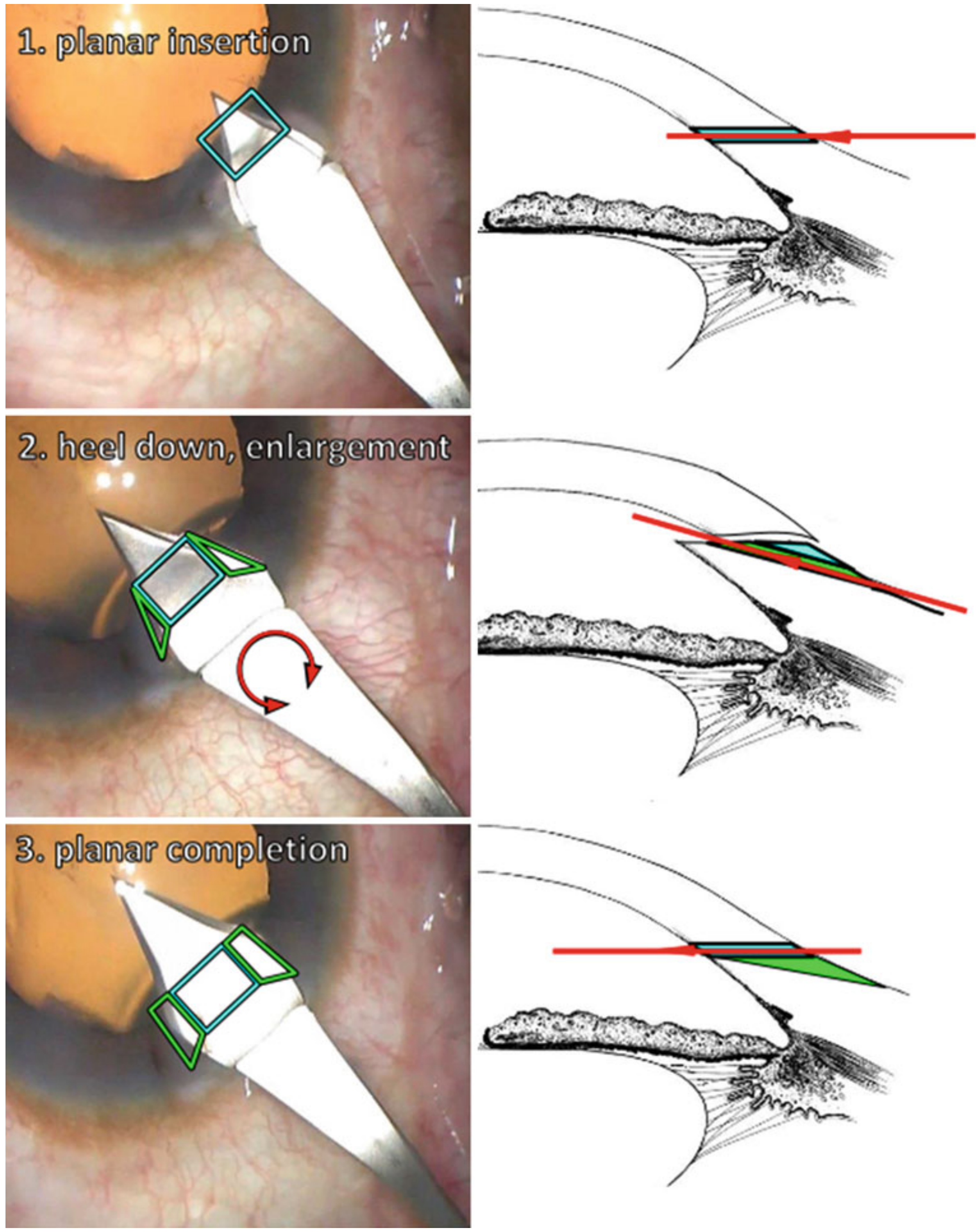

Fig. 16.9 Enlargement of the main incision (*blue*) to prepare for cataract surgery; tri-planar wings (*green*) are fashioned that allow a single self-sealing incision. This requires that in step 2 the heel of the keratome be almost flush on the conjunctiva while the keratome is gradually advanced with careful rotations. The *red arrow* in the drawing on the right represents the base of the keratome's triangular blade

Immediate Viscoelastic Tamponade of Ablated Canal, Chamber Pressurization

Once the ablation is complete, viscoelastic is injected directly along the ablation arc at the root of the iris. This will displace non-coagulated as well as coagulated blood and tamponade Schlemm's canal and collector channels. We compared five different viscoelastic substances for this purpose and recommend a premixed viscoelastic with both cohesive and dispersive agents in one syringe (e.g., DiscoVisc, Alcon, Fort Worth, TX). The dispersive properties allow the viscoelastic to flow easily into the chamber angle including the orifices of the collector channels, while the cohesive properties allow to maintain the space and prevent displacement. The entire anterior chamber can be pressurized while the patient's head is still rotated, or the head can be rotated back and the chamber then fully filled and pressurized with the remaining viscoelastic. The patient and microscope are now rotated back until they are again perpendicular to the floor.

To continue with cataract surgery, a standard keratome is partially inserted planar to the iris into the main incision (Fig. 16.9), the tip is carefully advanced past the inner lip of Descemet's membrane, and then the heel is moved all the way down against the conjunctiva before the keratome is carefully inserted further, aided by small rotating movements around the axis of the handle if necessary. This will create a partial tri-planar incision that has a slight inverted U-shape like a scleral tunnel in ECCE and provide self-sealing features on the left and right aspects of the smaller, initial trabectome keratome incision. To conclude the enlargement of the incision, the blade is now held parallel to the iris again and the keratome moved forward to complete the incision.

Capsulorrhexis and the remaining phacoemulsification steps are done in standard fashion. Just before lens insertion, viscoelastic is injected again to prepare the capsule for implantation, and a second viscoelastic crescent is injected directly along the root of the iris again with the goal to tamponade and displace refluxing blood. Following lens implantation, viscoelastic can be partially removed and the incision is hydrated. We recommend retaining at least 30 % of viscoelastic in the eye to create a positive pressure gradient from the anterior chamber to the outflow system. This will avoid postoperative hypotony and hyphema with better vision early on, and may also provide better early pressures by reducing the phacocytotic load on the remaining trabecular meshwork from red blood cells while minimizing blood clotting along the unroofed canal. It is especially important to maintain postoperative IOP because evidence suggests that fluctuations in IOP, even the brief hypotony induced following a blink, can lead to flow from the ocular surface through the clear corneal incision and into the anterior chamber [9, 10]. OCT has shown full-thickness gaping of a clear corneal wound when the IOP was at 5 mmHg [11]. The wound is hydrated but a suture is not needed and may in fact cause gaping hypotony and instant hyphema. Although the viscoelastic mentioned above has a tendency to cause considerable postoperative hypertension after regular cataract surgery if not carefully removed, the unroofing of Schlemm's canal in trabectome surgery will allow for improved evacuation similar to glaucoma drainage device surgery.

The patient is seen the following day, at 1 week, at 1 month, and finally at 3 months. All glaucoma medications are discontinued the day of surgery. The postoperative regimen for the first week consists of a fourth-generation fluoroquinolone, prednisolone acetate 1 %, and pilocarpine 1 or 2 %, all of which are started four times daily on the day of surgery. The fluoroquinolone is continued for 7 days. The prednisolone is tapered weekly by one drop for a 4-week course. Pilocarpine is usually maintained at 4 times daily for about 4 weeks, then three times per day 4 more weeks. Flattening the iris out using pilocarpine is thought to reduce the chance of forming peripheral anterior synechiae [12]. If trabectome surgery is combined with phacoemulsification, then a proper refraction cannot be obtained until pilocarpine is stopped.

Results

The steps described above are designed to maximize visibility, facilitate identification of the correct structure, maximize the area that gains access to the outflow system, and reduce or eliminate hyphema. Our own results with this evolved technique in 192 trabectome surgeries that consisted of open-angle glaucomas and approximately one third of patients with uveitic, traumatic, angle-closure, or low-pressure glaucomas suggest that a 30 % IOP drop can be achieved from a relatively low preoperative IOP of 20 ± 8 to 14 ± 4 mmHg at year 1. The incision technique described above produces predictable astigmatism as any standard cataract incision which allows to implant toric lenses in the same session and deliver high quality of vision and satisfaction to glaucoma patients undergoing combined procedures.

The first retrospective series of 37 patients by Minckler et al., which were stand-alone trabectome cases, demonstrated a 42 % decrease in mean IOP, lowering the baseline IOP from 28 to 16 mmHg at 12 months. The series was later extended to 101 patients [1]. The larger series still demonstrated a 40 % IOP decrease. Eleven of those patients had follow-up for 30 months, and that group sustained a 33 % mean IOP decrease. A further report revealed a mean IOP decrease of 42 % after 36 months, although only five patients were still available at that time [13]. A series of 1,127 patients was composed of 738 patients who underwent stand-alone trabectome in addition to 366 cases combined with phacoemulsification [14]. This study retrospectively followed patients for up to 5 years and defined failure as either final IOP over 21 mmHg or demonstrating less than a 20 % decrease from baseline IOP and found a 55 % failure rate after 4 years. The published results of trabectome surgery are divided into stand-alone trabectome cases below in Table 16.1 and combined trabectome-phacoemulsification in Table 16.2. There are no published randomized trials involving trabectome. Longer follow-up is needed to elucidate the long-term success rates. The largest case series dating back to the first trabectome cases had 1,878 trabectome cases (alone or with phacoemulsification) recorded as of 2010 [20]. There was data on five patients who had been evaluated a full 6 years after the procedure and still maintained a 38 % mean IOP decrease.

Only a few studies have identified risk factors for failure. Studies that stratified their results by baseline IOP suggest that trabectome lowers the IOP significantly more starting from a higher baseline IOP. In one study, when the baseline IOP was below 20 mmHg, the IOP reduction at 1 year was only 0.2 % versus a 28 % decrease when baseline IOP was 20–25 mmHg, and a 45 % decrease when baseline IOP was over 25 mmHg (absolute values were not reported, only percentages) [2]. A prospective study of 1,401 cases came to similar conclusions [21]. From a baseline IOP below 17 mmHg, the decrease in IOP was only 7 % versus a 33 % decrease from a baseline IOP between 23 and 29. One study reported on risk factor analysis and found that younger age and lower baseline IOP were significant risk factors after multivariate analysis [16].

Table 16.1 Review of published results with trabectome-only cases

Authors	Type of study	Number of patients	Mean baseline IOP	Mean or final % decrease IOP	Mean # decrease in medication	Length of study
Minckler et al. [1]	Prospective	37	28	40	0.9	13 months
Minckler et al. [1]	Prospective	101	28	40	Not reported	30 months
Minckler et al. [14]	Retrospective	738	26	35	1.1	5 years
Ting et al. (POAG patients only) [15]	Prospective	450	26	34	0.6	12 months
Ting et al. (PXG patients only) [15]	Prospective	67	29	44	0.9	12 months
Jea et al. [16]	Retrospective	115	28	41	1	30 months
Minckler et al. [17]	Retrospective	1,151	26	36	1.7	60 months
Mosaed et al. [18]	Retrospective	538	26	31	0.8	12 months

PDG pigmentary dispersion glaucoma, *POAG* primary open-angle glaucoma, *PXG* pseudoexfoliation glaucoma

Table 16.2 Review of published results with combined phacoemulsification and trabectome cases

Authors	Type of study	Number of patients	Mean baseline IOP	Mean or final % decrease IOP	Mean # decrease in medication	Length of study
Minckler et al. [14]	Retrospective	366	20	20	1.2	5 years
Francis et al. [2]	Prospective	304	20	25	1.2	21 months
Francis and Winarko [19]	Prospective	89	22	27	1	12 months
Ting et al. (POAG patients only) [15]	Prospective	263	20	22	0.7	12 months
Ting et al. (PXG patients only) [15]	Prospective	45	22	35	0.9	12 months
Minckler et al. [14]	Retrospective	681	20	21	0.9	36 months
Mosaed et al. [18]	Retrospective	290	20	18	0.8	12 months

JRA juvenile rheumatoid arthritis, *PDG* pigmentary dispersion glaucoma, *POAG* primary open-angle glaucoma, *PXG* pseudoexfoliation glaucoma

Table 16.3 Reported failure rate defined as IOP >21 or less than 20 % IOP decrease

Study	Length of time analyzed	Failure rate for trabectome only	Failure rate for combined phaco/trabectome
Minckler et al. [14]	4 years	45 % (only one value reported for both stand-alone and combined cases)	45 % (only one value reported for both stand-alone and combined cases)
Francis and Winarko [19]	1 year	Not studied	5 %
Ting et al. [15]	1 year	27 % for POAG, 21 % for PXG	9 % for POAG, 13 % for PXG
Jea et al. [16]	2 years	78 %	Not studied

POAG primary open-angle glaucoma, *PXG* pseudoexfoliation glaucoma

There was some concern that damage to the outflow pathway by laser trabeculoplasty could lead to downstream scarring which would lower the efficacy of the trabectome procedure [22]. The issue was examined in a retrospective review of 1,345 trabectome patients, 493 of whom had previous laser trabeculoplasty (there was no differentiation between micropulse diode, Nd:YAG or argon laser). Despite starting from a very similar baseline IOP, there was actually a larger mean decrease in IOP at 36 months in the group who had previously undergone laser trabeculoplasty (39 % decrease versus 32 %), though the difference was not statistically significant. There was also no statistically significant difference in the complication rate between the two groups.

The various studies reporting on the success of the trabectome procedure have used different definitions of success, from a multitude of absolute and relative change in IOP to just demonstrating a decrease in medication [2]. The wide range of definitions makes it difficult to compare the results. Using a less stringent definition of a decrease in medications (all patients in this group had a baseline IOP ≤21 mmHg) yielded a success rate just over 70 % at 18 months. There were four studies [14–16, 19] which reported a similar definition of failure being IOP >21 or demonstrating less than a 20 % IOP decrease from baseline (see Table 16.3). For stand-alone trabectome cases, the failure rate using this definition ranged from 21 to 78 %. For cases combined with phacoemulsification, the failure rate ranged from 5 to 45 %. The longest study to analyze failure rates reported on 1,415 patients and followed them for as long as 6 years [23]. The main definition of failure used was needing any further glaucoma surgery. The failure rate (given for all cases, stand alone and combined) with this definition was 10 % at 5 years. Using another less stringent definition of failure being IOP >21 and less than 20 % IOP decrease, the failure rate was about 5 % for combined cases (reported out to 3 years) and about 48 % for the stand-alone trabectome cases after 6 years.

Since combined cataract surgery and trabectome has not been compared with trabectome as a stand-alone procedure in a randomized controlled fashion, it is not possible to conclude that cataract surgery added to trabectome surgery increases the success rate as outcomes might simply be a consequence of eyes with different disease status. However, it is possible that reduced incidence of peripheral anterior synechiae (PAS) does improve the success rate [24]. Cataract surgery might have an IOP-lowering effect from ultrasound-mediated trabeculoplasty of the remaining trabecular meshwork [25], but there was no regression of the success rate toward trabectome alone over time in a single-surgeon prospective study [2]. The average IOP decrease after 2 years was 7 mmHg in the stand-alone trabectome group versus only 2 mmHg in the stand-alone phacoemulsification group.

Surgical Failure

A study examining the timing of 100 failed trabectome procedures [14] found that only 12 occurred by 2 weeks but 76 by 6 months, and 95 by 18 months. This could suggest that the majority of failures will be seen by the 6-month visit. This was corroborated in a study on failed trabectome surgeries which went on to need a trabeculectomy [26]. The range of time to trabeculectomy was 3 days to 18 months, with an average of 4.9 months. Possible reasons for failure to reach the target IOP following an apparently successful procedure may be inferred from a preclinical study of the trabectome handpiece on donor corneoscleral rims [27]. One specimen still had an intact TM after the procedure, and the authors suggest that the footplate never entered into Schlemm's canal. Another specimen revealed damage only to the superficial TM, suggesting that although the footplate may have come into contact with the TM, it was not properly positioned entirely in Schlemm's canal with the TM engaged between the footplate and the electrodes. At least two specimens did show successful ablation of TM, but the edges had re-approximated. Long-term studies are needed to evaluate the time course and rate of possible re-approximation of the ablated edges. One study reports on neodymium-doped yttrium aluminum garnet (Nd:YAG) goniopuncture intervention for eight patients with post-trabectome IOP elevation 33 % above baseline [12]. Four of the eight patients had visible peripheral anterior synechiae (PAS) lysis during the laser, while the other four were seen to have cleft closure which was considered reopened upon blood reflux into the AC. An average of 10.5 months following goniopuncture, the IOP had been lowered again to 21 % below baseline. The settings used were 0.2–0.6 mJ for 3–15 shots. Supporting the use of postoperative pilocarpine to reduce formation of synechiae, none of the patients in that study received any pilocarpine.

If trabectome surgery does not lower pressure sufficiently, every conventional treatment can be attempted, including SLT, trabeculectomy ab externo, Express shunts, aqueous shunts, endocyclophotocoagulation,and external cyclophotocoagulation [21]. Outcomes of subsequent glaucoma procedures involving the conjunctiva such as glaucoma drainage devices are not affected by trabectome that uses a clear corneal incision. One study examined the effect of trabectome on subsequent trabeculectomy [26]. A retrospective review of 34 patients who failed trabectome surgery was compared to 42 patients who underwent primary trabeculectomy. Starting from a baseline IOP of 28 mmHg in the failed trabectome group and 29 in the primary trabeculectomy group, the mean IOP was 11 in both groups after 24 months, with no statistically significant difference in IOP between the two groups at any time point. Kaplan-Meier survival curve analysis also confirmed no statistically significant difference in success rates, indicating that a failed trabectome does not increase the risk of failure of a subsequent trabeculectomy. There was also no statistically significant difference in rates of complication between the two groups, with 6 % of the primary trabectome group and 7 % of the primary trabeculectomy group going on to need further surgery. The benefit of repeating trabectome, for instance, by operating across the nose and unroofing the temporal Schlemm's canal, remains unclear at this time. Although it has certainly been reported [20], there is no subgroup analysis or any specific reports on the efficacy.

Results with Various Subtypes of Glaucoma

Although many secondary open-angle glaucomas have been reported to be treated with trabectome, the results often do not detail subgroup success rates. Out of the 1,127 cases reviewed by Minckler, the second largest group (after POAG) was pseudoexfoliation with 109 cases [14]. Only one study analyzed glaucoma subtypes: the study by Ting et al. compared a group of patients with POAG to those with PXG [15]. With both stand-alone trabectome and trabectome-phacoemulsification combined procedures, the PXG group started with a higher mean baseline IOP and showed a greater IOP decrease as compared to POAG. There was a 5 mmHg further decrease in IOP for PXG patients versus POAG patients with trabectome only and a 3 mmHg further decrease from the combined procedure. Other types of glaucoma reported to be treated with trabectome but without subgroup success rate analysis include: pigmentary, uveitic, steroid-induced, and chronic angle-closure glaucoma (that still offered a view of nasal TM with or without goniosynechialysis).

Complications

Table 16.4 summarizes the complications reported following trabectome surgery. The most common complication is hyphema, occurring in up to 100 % of cases, depending on

Table 16.4 Complications reported after trabectome

Hyphema
PAS
Corneal injury
Transient IOP spike
Cyclodialysis cleft [16]
Transient hypotony (it has not been reported past 30 days)
Iris injury
Lens injury
Aqueous misdirection [20]
Choroidal hemorrhage [20]

the definition of hyphema versus microhyphema [16]. In our experience, visual acuities of 20/30 can be expected if the anterior chamber is properly pressurized and maintained as described above. Given that blood refluxes into Schlemm's canal when episcleral pressure exceeds IOP, and Schlemm's canal is unroofed during this procedure, this can be an expected occurrence. There is only one published case detailing surgical intervention for hyphema associated with an IOP spike [28]. The vast majority are cleared by 1 week. As described in the technique section above, using a crescent of viscoelastic to tamponade the unroofed area limits the extent of postoperative hyphema. It is especially important to forewarn patients about this common occurrence.

A case series of 12 patients who complained of transient decrease in vision between 2 and 31 months following trabectome demonstrated a spontaneous rebleed associated with a mean IOP 12 mmHg higher than the preceding visit [28]. Six of them reported the episode occurring four or more times, and ten of them awoke with the blurring. Only three of them had a visible hyphema. Knape and Smith reported on a patient with an intraoperative hyphema during a trabeculectomy done 11 months after a failed trabectome surgery [29]. When the sclerostomy was made, the authors noted reflux bleeding from the nasal angle. This led the authors to suggest using viscoelastic and releasable sutures to avoid hypotony during second surgeries following a trabectome, a practice that we employ already during primary trabectome surgery for the same reason. In the study by Jea et al. comparing trabeculectomy after failed trabectome to primary trabeculectomy, there was a higher incidence of postoperative hyphema in the group who had a previous trabectome surgery (20 % versus 7 %), but this difference was not statistically significant ($p=0.1$) [26].

In one study, the second-most common complication was PAS, which was found in 24 % of patients [1]. Transient postoperative IOP spikes of at least 10 mmHg may be seen in 4 [19]–10 % [15]. It occurred in 6 % of a series with 1,127 cases [14]. One study examined the time course of these postoperative IOP spikes and found that while 9 % had an IOP spike over 10 mmHg on post-op day 1, only 2 % still had an IOP spike at post-op day 7 [2]. Liu et al. found that IOP spikes after post-op day 7 resolved after stopping or switching to a less potent steroid [30].

Comparison to Other Glaucoma Surgeries

One of the main benefits of performing trabectome is that there is no bleb formation with the perpetual increased risk of infection nor is there any hardware left in the eye to erode or become infected. The conjunctiva is spared in case further surgery is needed. The main disadvantage is that trabectome should not be relied upon when the target IOP is in the low teens. The success rate of trabectome performed alone however, without same session or prior phacoemulsification, is lower. Even after failed trabeculectomy or tube shunt surgery, trabectome surgery can have a success rate of 70 % at year one ($n=107$, success definition = IOP less than 21 mmHg and 20 % decrease and no need for another surgery; Loewen et al., unpublished data).

Two studies compared the trabectome to trabeculectomy with mitomycin C but neither was randomized. The first was a prospective study that showed at 1-year trabeculectomy lowered the IOP by 52 % versus a 30 % decrease following trabectome [19]. Using the stringent success criteria (like the Tube versus Trabeculectomy Study) [31] of final IOP <21 mmHg and maintaining a 20 % IOP decrease while avoiding persistent hypotony and reoperation, the 12-month success rates were statistically similar at 95 % for trabectome and 83 % for trabeculectomy, $p=0.1$. The second, retrospective study followed 217 patients for 2.5 years [16]. The final IOP decrease was 41 % with stand-alone trabectome and 62 % for trabeculectomy. Despite a 41 % mean decrease in IOP, the reported success rate of trabectome after 2 years ranged from 10 to 43 % versus 66–76 % with trabeculectomy, depending on which IOP cutoff was chosen. Excluding hyphema (none of which required treatment), the complication rate was only 4 % with trabectome versus 35 % with trabeculectomy.

As suggested by the American Academy of Ophthalmology report on Novel Glaucoma Procedures [32], trabectome is meant to augment conventional outflow rather than offer an alternative route such as with an aqueous shunt. The report points out that at this time, the goal with minimally invasive glaucoma surgery may be more to reduce the amount of glaucoma medications needed while maintaining a lower risk of devastating complications as compared to traditional, incisional glaucoma surgery. Given the improved side effect profile (as in the study by Jea et al. with a 4 % complication rate with trabectome versus 35 % with trabeculectomy), trabectome may be offered earlier in the course of glaucomatous nerve damage. One of the goals of this minimally invasive glaucoma surgery is to avoid devastating complications. As of October 2012, there are no published cases of postoperative flat anterior chambers, hypotony past 1 month, wound leak, bleb formation, or choroidal effusion.

Conclusion

Trabeculectomy ab interno with the trabectome is a mature surgery that was first reported in 2004. By maximizing visibility, identifying and ablating the correct structures, enlarging the ablation, and reducing hyphema through generous use of viscoelastic, the range of indications can be extended and outcomes can be improved. The average IOP reduction is 30–40 %. Longer-term studies indicate a failure rate that may be favorable to trabeculectomy. It is a fast procedure that can easily be combined with phacoemulsification, thus making it an excellent option to provide improved quality of life in glaucoma patients. No randomized controlled trials currently exist comparing trabectome surgery with trabeculectomy or glaucoma drainage devices. IOP reductions in the low teens are uncommon. No long-term complications occur.

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