Main topic:
GLAUCOMA SURGERY: TRADITIONAL AND NEW TECHNIQUES

Glaucoma Now is a continuing medical education publication. Distributed worldwide, our goal is to educate and update general ophthalmologists, glaucoma specialists and ophthalmology residents. International leaders in the field of glaucoma are invited to contribute to this journal, sharing their most recent insights.

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Core Concepts

- In the last 15 years, glaucoma filtration surgery (GFS) success and complication rates have improved due to a better understanding of functional components of the surgery as well as management of wound healing.
- The best-organized and best-known modern approach to trabeculectomy is the Moorfields Safe Surgery System (MSSS).
- Mitomycin-C (MMC) improves post-trabeculectomy IOP control significantly, but is also associated with bleb leaks or long-term hypotony. The latter issues may be minimized with appropriate surgical technique.
- Despite development of glaucoma filtration surgery (GFS) into modern trabeculectomy over the last 40 years, current methods still cannot simultaneously achieve all of low cost, high efficiency, low complication rates and high long term success rates.
- The Express implant effectively stents the sclerostomy, but adds cost without proven benefits in long-term efficacy and safety.
- Non-penetrating glaucoma surgery (NPFS) approaches have decreased complication rates, but also yield less IOP-lowering effects. YAG laser goniotomystomal puncture may be needed to create a sclerostomy.
- Bleb morphology needs to be optimized, diffuse blebs are desirable. Considering how vital bleb outcomes are in trabeculectomy, there is minimal reporting on bleb outcomes from procedure variants.
- The Moorfields Bleb Grading system is excellent for grading blebs if detailed analysis is required.

1) Introduction

Since this topic last appeared in Glaucoma Now, Glaucoma Filtration Surgery (GFS) has become more refined, and the short and medium term effects of these refinements on outcomes have started to be described. At the same time, longer term results of the Tube versus Trabeculectomy (TvT) study imply that we should consider changing our threshold for tube implant surgery, with probable inroads into the role of trabeculectomy - which remains the most commonly performed glaucoma procedure. And there are new Minimally Invasive Glaucoma Surgery (MIGS) contenders which are being promoted and tested.

GFS still lacks the high efficiency, excellent success rates, and long-term stability that we expect from cataract surgery. There are many new options for glaucoma surgery, particularly implants and machines, actively being promoted. All of these hold some hope of a better safety profile or easier or faster procedure than traditional filtering surgery.

Despite all of these new options, when faced with the need to subject their patient to an operation for glaucoma, most surgeons continue to opt for trabeculectomy most of the time. That decision is partly due to the excellent IOP control for many years that results from successful GFS. But getting to that endpoint is never guaranteed and often is not easy.

2. Technical Advances In Trabeculectomy

Readers of glaucoma surgery articles are so accustomed to that prototypical first sentence referencing Watson and Cairns’ publications that it is easy to forget their fundamental message. Modern trabeculectomy is different enough from the original early 1970s description that even the name itself is a misnomer; usually no trabeculum is excised. But the core advance of trabeculectomy, the message of ‘control outflow to improve the safety of the procedure’, became neglected frequently enough that postoperative flat anterior chambers, choroidal detachments, and hypotony complications came to be expected, and many authors published results showing that the control of IOP after surgery was poor and complications very common.

The subtle and yet substantial changes to trabeculectomy technique developed over the late 1990s, epitomized by the Moorfields Safer Surgery System (MSSS), remain the state of the art for trabeculectomy. These modifications have been adapted to fit with each surgeon’s preferred approach to surgery; even those trained in the epicentres of the MSSS have ended up developing a variety of surgical techniques while adopting the underlying principles. The MSSS emphasizes fornix-based conjunctival flap to avoid a scar tissue decimation, large area of subTenons dissection and antimetabolite treatment, careful construction of the scleral flap, maintaining IOP and the anterior chamber throughout surgery via preplaced sutures with BSS infusion (especially in high-risk cases), and understanding the use and mechanism of adjustable scleral flap sutures. Recent MSSS updates include closing the conjunctiva with interrupted sutures buried in peripheral corneal grooves, and injecting local anaesthetic into the bleb area at the end of surgery to minimise inflammation and scarring along with pain. The innovation of staining MMC with dyes has made handling and applying antimetabolites more effective and safer.

But we are still quite a long way from the ideal; the 10-10-10 target as recently proposed by Professor Sir Peng Khaw: an IOP of 10 mmHg, for 10 years, done in 10 minutes.

Speed, Economy, Quality: Pick Any Two

Trabeculectomy requires mastery; performing it well and consistently requires fastidious attention to detail and a
The trade-off for this greater control is time and effort. To get trabeculectomy right requires attention to detail and a fast procedure is less likely to be a good one. Trabeculectomy with some kind of implant (e.g. Ex-Press), may shorten the procedure slightly, but at additional cost and possibly little long-term benefit.

3. Safety And Efficacy Of Modern Trabeculectomy

While some authors still refer to trabeculectomy as having a “very high risk profile”, with “moderate long-term results at best” 18, modern publications of results suggest that trabeculectomy has made major advances 3. Publications of small series of Moorfields SSS trabeculectomy have shown very low complication rates and good short and intermediate-term success rates, with typical figures for flat anterior chambers, hyphema, and choroidal detachments of well under 5% and IOP below 18mmHg in approximately 90% of cases at 3 years 9,10.

Recently, Kirwan et al. 3 published a series of 428 procedures with more than 2 years of follow up, sourced from 9 glaucoma units with fellowship-trained glaucoma consultants. These surgeons followed a broadly similar surgical approach, including a fornix based conjunctival flap, adjustable or releasable sutures, most with antimetabolites. A subgroup analysis used inclusion and assessment criteria based on the TVT study; the unqualified success rate was 85%, with qualified success rates of 92%. In 3 patients there was vision loss of 3 or more Snellen lines (one patient declined treatment for hypotony maculopathy), 31% had cataract surgery subsequently, treatment for hypotony maculopathy), and 31% had cataract surgery subsequently, 95% of these in the first weeks after surgery. Between 6 months and the final post-surgery visit, 7.2% of cases had an IOP reading of less than 5mmHg.

The most interesting aspect of the Kirwan et al study is that post-trabeculectomy complications related to scleral flap construction and suturing were impressively low: shallow anterior chamber (AC) in 0.9%, flat AC in 0%, and choroidal detachment at any time in 5%. Both CIGTS and AGIS reported 13-15% AC after trabeculectomy.

In the TVT study 4, a large multicenter trial which published 3-year results in 2009 13, the trabeculectomy group had an average of 1+ 1.5 medications, a 31% chance of failure, 60% complications, and 27% chance of complications severe enough to warrant reoperation or result in 2 lines or more of visual loss. This study is one of the best surgical glaucoma studies ever published, but one reservation held about interpreting the results is that the outcomes and complications for the trabeculectomy group were not as good as expected. As a counterpoint, the reporting standards of randomized clinical trials (RCTs) are usually higher than that of retrospective audits, so it is possible that the TVT study better represents contemporary trabeculectomy results. Despite this, the difference in success rates compared with Kirwan’s data is substantial.

Scleral flap, Sclerostomy, and Sutures

It is the combination of the scleral flap and sutures that controls the early postoperative IOP. Using relatively simple measures and attention to detail, understanding scleral flap function, and carefully utilized adjustable sutures, early postoperative hypotony and trabeculectomy complications can be prevented.

Important factors in scleral flap construction and suture placement 3-14:

• Apposition of the scleral flap over the scleral bed that contains the sclerostomy (not apposition of the edges of the flap to the edges of the scleral bed), created by suture tension, provides resistance to flow and therefore the all-important control of perioperative IOP. Get this right and most complications can be avoided.

• If the sclerostomy is located between, or posterior to, the cut sides of the scleral flap, it can be difficult to generate enough appositional force for IOP control, and posteriorly directed flow may be harder to encourage. It is best to locate the sclerostomy anterior to a line connecting the anterior extent of the side cuts.

• If the sclerostomy is very close to the scleral flap sides, a full thickness fistula around the edge of the flap may result (Figure 2). A punch (Khaw punch or Kelly punch) makes a more discrete and controllable sclerostomy than a blade-cut sclerostomy and minimizes this risk. Ideally there would be at least 0.5mm between the flap edge and the sclerostomy edge.

• For most surgeons, depth is more controllable and it is therefore easier to produce consistent scleral flaps by starting with a scleral tunnel made with a crescent blade. In our wet-lab studies, we found that keeping the antero-posterior...
extent of the central trapdoor less than 2.5mm decreased the chance of accidentally making a flap that was irregular or lacked sufficient rigidity.

• Our recently developed understanding of the mechanisms of scleral flap function and technical aspects of flap construction has led us to a W-shaped or modified trapezoidal flap (Figure 3). This maximizes posterior flow by making resistance to posterior flow less than lateral, meets the objectives discussed above, and the <2.5mm anterior dissection distance lessens the risk of mistakes in scleral flap creation.

• Full thickness flow through the scleral flap will negate the desired effect, so choose location carefully to avoid perforating blood vessels, and avoid suture holes in the flap except near the flap edges.

• A suture that is both releasable and adjustable (Figure 4) gives the best possible control of postoperative IOP with the best range of options for manipulation. Lysis misses an opportunity for adjustability, and non-removable sutures have no option but to stay as a foreign body in the surgical site. Four throws of 10-0 Ethilon have proved to be dependable and robust, and yet remain adjustable.

• The single most important step to avoid loss of IOP control: via a paracentesis if no AC maintainer, or by turning off the AC maintainer, test the sutured scleral flap for the ability to maintain IOP before conjunctival closure - and don’t start closing the conjunctiva until adequate flow resistance and IOP control is achieved. Place more sutures if necessary, then test again. Aiming for a day 1 IOP of approximately 20 via appropriate suture tightness gives the option to lower the IOP by using adjustable sutures.

• Once the flap-suture complex controls flow adequately, use a very light touch in the area while completing the operation to avoid loosening the adjustable sutures.

Suture adjustment:

Once healing and eventual remodeling of the surgical site has occurred, adjustability of the scleral flap is lost. But prior to that, maybe extended by many weeks by antimetabolites, it is the tension of the sutures translated to scleral flap tension over the sclerostomy that controls IOP. It is easy to lower this tension, and therefore the IOP, with a high degree of fidelity in laboratory models and it is just as effective in the clinic (Figure 5).

Adjustment of these sutures is not only straightforward, it is more reliable and safer than suture lysis/release/removal, more effective than focal massage of the trapdoor region, and both more effective and immediate than digital massage by the patient. Suture adjustment can be done safely with forceps, e.g Khaw Suture Adjustment Forceps (Duckworth and Kent, http://duckworth-and-kent.com), or with a modified contact lens such as Wells Suture Adjustment Lens (Ocular Instruments, http://www.ocularinc.com)

Producing an aqueous gush, also known as ‘burping the bleb’, is likely to falsely reassure the patient and surgeon because it may take more than 30 minutes to re-establish equilibrium IOP. IOP measured in the first few minutes after aqueous release will always be low, but if the sutures have not been loosened then the IOP will return to pre-massage levels within an hour.

Sclerostomy:

The commonly available punch models are more than big enough. To cope with aqueous flow rates of up to 3.5µL/minute, even with slightly turbid aque-
Stenting the Sclerostomy

Originally the Ex-Press glaucoma implant was intended to drain directly under the conjunctiva: predictably results in a desirable flow restriction of 2.5µL/min, which is about 1/5th the diameter of the smallest available punch. Some surgeons express concern that iris or vitreous might plug the sclerostomy, and that larger might be better in this circumstance. In fact, plugging is associated with loss of anterior chamber and bulk outflow of aqueous, which is more likely if the sclerosotomy is too large and there is loss of effective scleral flap control of flow. The sclerostomy should be just anterior to the trabecular meshwork, in peripheral cornea, to avoid intraoperative hemorrhage and possible ciliary body incarceration.

The obvious modification to Ex-Press implantation, placing it under a scleral flap, was widely adopted quickly. This approach is effectively a stent to the sclerostomy, which is usually not thought of as a high-risk failure site. Several comparative studies and an excellent review comparing trabeculectomy with trabeculectomy with Ex-Press implanted beneath a scleral flap have shown possible short term advantages, especially better early anterior chamber and IOP control, but no benefit in long term outcomes. Implant exposure can occur even if the Ex-Press is implanted beneath a scleral flap and suprachoroidal hemorrhage and blebitis remain a risk. Kirwan et al’s results suggest that with due care to flap construction and adjustable/releasable sutures, the addition of this expensive implant may only bring minimal benefit, although we may yet see further refinement of technique, just as we have with trabeculectomy and GDD surgery.

Weighed against the variable but possibly improved perioperative risk profile of pain from malposition, erosion through conjunctiva and subsequent exposure, or, of greater concern, a free metal object in the anterior chamber from which endothelial cell loss could follow. Ex-Press implants may not be stable in high-power (more than 3T) magnetic fields, as found in some MRI machines.

4. Aggressive Bleb Management

A likely true maxim is that half of a successful trabeculectomy outcome is due to the operation itself and half is from the perioperative management, especially with regard to managing scarring the first months after surgery. The results reported by Kirwan et al depended on relatively intensive postsurgical management, with 27% having subconjunctival 5FU injections, 16% requiring bleb needling, and 5% having additional sutures placed. Management of bleb healing, using anti-metabolites and needling procedures as well as the routine frequent steroid eye drops, are now standard practice in many units and while extra interventions are undesirable the approach is widely accepted.

Anti-VEGF agents have been trialed and, anecdotally, in some places used as a routine adjunct for management of bleb vascularity. Although few blebologists doubt the role of vascularization in bleb failure, results from the studies of anti-VEGFs in glaucoma surgery have been mixed.

5. Interaction With Cataract Surgery

Cataract surgery results in breakdown in the blood-aqueous barrier that persists for some months. This is most apparent when a cataract procedure precipitates bleb failure after a successful trabeculectomy. Decisions regarding cataract and a need for better IOP control should be undertaken with this, and the resulting possible compromise in trabeculectomy success rates, in mind. The optimal sequence of events usually is to have the cataract surgery at least 6 months prior to trabeculectomy, if there is time to arrange this option.

6. Beyond IOP Control: Optimizing Blebs

As the safety of trabeculectomy has improved, so the next target for glaucoma surgeons and researchers should be optimization of bleb morphology, with important implications for long term surgical success and late compli-
ations such as blebitis and bleb-related endophthalmitis. Diffuse blebs without significant avascular areas are desirable (Figure 6); surgical technique as well as antimetabolites influence bleb outcomes. Thin-walled or cystic blebs are of most concern since they predispose to bleb-related endophthalmitis and late hypotony. Nowadays it is common to blame MMC for these complications; they were common after full-thickness surgical procedures that predated antimetabolite use and may be significantly minimized with changes in surgical technique.

In some centres, an alternate method of MMC application is being trialed. Instead of applying 0.2-0.4 mg/ml MMC on sponges, 10-20 micrograms of MMC is injected into the superior subconjunctival space before the peritomy. This should deliver the antimetabolite to where it is needed while eliminating wound edge contamination with MMC, avoids the risks of lost sponges and of spillage of an open MMC container with exposure of the surgeon and theatre staff to MMC. Applying MMC in this way might also contribute to more diffuse bleb formation.

Modern bleb grading systems for clinical studies, such as the Moorfields Bleb Grading System (MBGS) and the NPGS (note that the same no-bleb concept underpinned the development of trabeculectomy), are associated with better IOP control and intraocular pressure-lowering effect of NPGS may be less than with trabeculectomy. As NPGS evolves, it may be approaching trabeculectomy. YAG laser gonio-puncture is used to open a sclemm's canal, to micro-implants, to laser, surgical and stented opening of Schlemm's canal, to micro-implants, to aqueous shunts both into the subconjunctival space made in gel with no plate and also into the supra-choroidal space. So far, the highly desirable approach of a minimally traumatic and possibly bleb-less alternative to trabeculectomy, with the same success rates and reliability, range from promising but unconfirmed at best to elusive at worst.

8. Newer Approaches To Surgical Control Of IOP

Ab interno approaches, discussed in detail elsewhere in this publication, have been given a great deal of attention recently; they range from adult goniotomy to laser, surgical and stented opening of Schlemm's canal, to micro-implants, to aqueous shunts both into the subconjunctival space made in gel with no plate and also into the supra-choroidal space. So far, the highly desirable approach of a minimally traumatic and possibly bleb-less alternative to trabeculectomy, with the same success rates and reliability, range from promising but unconfirmed at best to elusive at worst.

9. Conclusion

Recently trabeculectomy success and complication rates have improved significantly, not as a result of redesigning the procedure, but as a result of understanding mechanisms and meticulous attention to detail. We know that we can avoid hypotony and manage wound healing with attendant decreases in complication rates and improved success. Remaining challenges include unpredictable wound healing responses between individuals and, despite 5FU and MMC, suboptimal tools for modulating the wound healing response.

References

7. Ashraf NN, Wells AP. Transconjunctival suture adjustment for initial intraocular pressure

Fig 6. An ideal bleb, 3 years after W-flap trabeculectomy with 0.3mg/ml Mitomycin C applied intraoperatively for 3 minutes. Bleb is diffuse and lightly vascular, asymptomatic and IOP has ranged between 9 and 12 mmHg between 2 weeks and 3 years follow-up.
What’s New

Canal & supra-choroidal surgeries

New Glaucoma surgery improving Anterior Aqueous Drainage

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Core Concepts

• Because filtering surgery with adjunctive anti-fibrosis agents which filters aqueous to the anterior subconjunctival space and tube-shunts from anterior chamber to equatorial subconjunctival space have potentially devastating complications, the search has begun for safer, effective choices.

• Newer surgeries have been introduced that seek to bypass the trabecular meshwork and/or dilate Schlemm’s canal either ab interno or ab externo. Other approaches have shunted aqueous from anterior chamber to the supraciliary (suprachoroidal) space. Generally these newer shunting procedures are safer than trabeculectomy or glaucoma drainage devices (to the equatorial subconjunctival space).

• As these newer approaches can lower intraocular pressure to the mid-teens but not much lower they may be a alternatives for patients with early to moderate glaucoma seeking to reduce or eliminate topical medications.

• Often these newer procedures are coupled with cataract surgery. Some are technically easier than others. No comparative data is available to suggest which of these is safest and/or most effective.

• Time and more extensive studies will tell which ones will become a part of the standard glaucoma armamentarium.

• The advent of these new procedures may allow surgical procedure for glaucoma to be tailored to the specific needs of individual patients.

1. Introduction

Lowering intraocular pressure consistently to levels in the low teens has been shown to slow or halt progression of glaucoma. Anti-glaucoma medicines, laser techniques and incisional surgeries all seek to lower intraocular pressure (IOP). Incisional surgery is indicated when medical treatment and/or laser surgery have failed, are likely to fail or are not available, likely to be followed or practical. In the past, the most likely surgical procedure to be attempted first was trabeculectomy (or some variation thereof e.g. ExPRESS shunt): aqueous is shunted from the anterior chamber under Tenon’s capsule and conjunctiva anteriorly. Antimetabolites markedly improved the success rate of anterior filtration but increased the potential for short and long term problems e.g hypotony, late bleb leakage and bleb-related infections. When anterior filtering surgery fails or is likely to fail such as in some secondary glaucomas, tube and plate shunts drain aqueous humor to the equatorial region of the eye under Tenon’s capsule and conjunctiva. These procedures are time-tested and generally succeed in experienced hands. Increasingly a tube-shunt operation may be the first one attempted after laser trabeculectomy. Hypotony, anterior chamber bleeding, supra-choroidal hemorrhage, serous choroidal detachments, late bleb leaks, endophthalmitis, corneal decompensation and bleb scarring occasionally (but too often) bedevil efforts to prevent vision loss with these operations. Efforts are ongoing to provide effective and safer alternatives. Holmium laser sclerostomy, viscoscanalostomy and deep sclerectomy achieved success but were limited by relative ineffectiveness, challenging surgery or unanticipated problems.

Several new approaches to improve aqueous drainage can be classified either by the approach, ab interno vs. ab externo, by the tissue compartment into which the shunted aqueous flows or by the location of the actual surgical site. I describe some of the more popular of these as well as a few that are still in their infancy, classified by the approach and the principles, as well as published results.

2. Recent approaches

Three new ab interno procedures bypass trabecular meshwork by shunting fluid from the anterior chamber either directly into Schlemm’s canal or into the supra-choroidal space.

• Trabeculectomy trabeculotomy

At its distal end, the Trabectome® has a ceramic probe that is inserted into Schlemm’s canal under gonioscopic control after being passed across the anterior chamber through a small, clear corneal limbal incision. Proximal to the ceramic tip, the trabecular mesh is ablated by a radiofrequency current across a spacer (Figure 1). About one quarter to one-third of the meshwork can be ablated through one corneal wound. Presumably this permits aqueous more easily and directly to enter Schlemm’s canal and from there directly into the scleral collector channels.

Advantages are relatively short operating time (about 10–15 minutes), IOP drop to the 15–17 mm Hg range in about 65% of eyes with Trabectome alone and 87% in eyes combined with cataract extraction, and a low rate of serious complications.3,4 Good results have been reported out to 4 years.5 The operation can be combined with cataract extraction especially clear corneal, temporal phacoemulsification.5 Early post-operative complications include an IOP spike, back bleeding from Schlemm’s canal with hyphema, Descemet’s detachment or damage, and failure to find Schlemm’s canal. In the absence of a leaking wound, hypotony is rare. There are no published long-term, prospective, controlled studies comparing Trabectome trabeculoto-
my with other techniques or comparing combined Trabectome/cataract surgery with cataract surgery alone. However, the results from long-term observational studies suggest that the combined cataract extraction/Trabectome procedure does provide longer term pressure control than cataract surgery alone. This is a relatively simple operation that can fit into the glaucoma surgical spectrum between laser trabeculoplasty and trabeculectomy or other filtration procedure.

- IStent and Hydrus Implants
  The IStent is an L-shaped titanium tube that fits into Schlemm’s canal via an ab interno insertion; it shunts fluid from the anterior chamber to the collector channels by-passing the mesh and the juxtacanalicular tissue wherein lies much of the outflow resistance. It is inserted under gonioscopic control via a 2 mm clear corneal, temporal limbal incision (Figure 2). The device increases outflow facility above baseline and even more than cataract surgery alone.7 IOP control is improved compared with cataract surgery alone.7 In a multicenter, randomized controlled trial comparing cataract surgery alone with IStent implantation, at one year, the IStent plus cataract group achieved IOP below 21mmHg without medication more often than the cataract alone group (72% vs. 50%) and, while both groups achieved approximately the same IOP, the IStent plus cataract group accomplished that IOP level with fewer medications.8,9 In both randomized trials, the complications were few and not significantly more frequent than cataract surgery alone. Implantation of two devices some degrees apart might improve outflow and IOP control over one device with excellent safety although the procedure is technically demanding and the catheter relatively expensive.10

The Trab360 and the ViscoTrab have been approved by the US FDA on the basis of substantial equivalence to existing devices. The Trab360 allows performance of a 180 degree or 360 degree trabeculotomy ab interno. The needle like tip of the device is inserted through a small clear corneal limbal incision. Under gonioscopic control, the tip is inserted into Schlemm’s canal and an enclosed nylon-like suture is advanced over 180 degrees of Schlemm’s canal (Figure 5). The device is then pulled out of the eye and the suture tears 180 degrees of trabecular meshwork. The suture can be rewound into the device and inserted in the opposite direction if desired to perform 360 degrees of trabeculotomy. No published data is available but this procedure is expected to provide similar efficacy to the Trabectome without the capital investment and with a less expensive hand piece.

The ViscoTrab device is similar to the Trab360 except that the canula threaded into Schlemm’s canal is hollow. Once 180 degrees of Schlemm’s canal has been cannulated, a slow retrieval deposits a precise, metered amount of viscoelastic into Schlemm’s canal dilating it. The effect is similar to canaloplasty (see below) but the approach is ab interno through a small corneal incision. No results have been published yet.

An excimer laser has been developed that performs multiple puncture trabeculotomies under gonioscopic control via an ab interno incision. Preliminary results with this very expensive but easy to use system have been promising.15
3. Drainage to the Suprachoroidal Space

Some aqueous normally drains into the suprachoroidal space whose pressure is negative compared with the anterior chamber. A device that shunts aqueous from the anterior chamber to the suprachoroidal space using an ab interno approach (CyPass) has been reported to lower IOP when used alone or in combination with cataract extraction. The Cypass is a tiny tube-like device made of polyimide—a bio-compatible material that is inserted into the suprachoroidal space just above the ciliary face across the anterior chamber under gonioscopic control (Figure 4).

The clear corneal, temporal corneal incision is less than 2 mm. The operation is quick; its ease depends on angle landmark identification. A large multicenter study from Europe demonstrated good efficacy with excellent safety. A large multicenter randomized, control trial in the USA has met its primary endpoints of better IOP control than cataract surgery alone but the data have not yet been published.

The following new procedures are inserted via ab externo techniques:

- **Solx**
  
The Solx device is a thin, gold micro-wafer with internal channels that carry aqueous from the anterior chamber to the suprachoroidal space. The device is implanted ab externo from the scleral side after a conjunctival incision. The device was designed with many of the microchannels unopened. These unopened channels could be opened by a titanium-sapphire laser beam aimed at the device through a gonio prism in the postoperative period to increase aqueous drainage if needed. Results have been promising and the device is being evolved further.

- **Canaloplasty**
  
In canaloplasty, through a novel, flexible microcannula (ITrack) micro-amounts of viscoelastic are injected to enlarge Schlemm’s canal via an ab externo deep sclerectomy. Then an inserted circumferential 10/0 polypropylene suture is tied to apply traction on the trabecular mesh. The cannula contains a fiberoptic bundle whose tiny light emitting diode at the tip is visible through the sclera; this helps ensure the cannula stays in Schlemm’s canal as it is threaded around the limbus. First, a one-half thickness scleral flap is dissected. Then, an inner scleral block is resected. Then, an inner scleral block is resected. Finally, the inter -nal scleral flap is excised, the external meshwork (Figure 5). Finally, the internal scleral flap is excised, the external is sutured in place and the conjunctiva closed. Initial reports were promising. A larger, multicenter study of this technique combined with cataract extraction suggests IOP in the 15 mm Hg range at one year with a low complication rate and no hypotony. Hyphema can occur. A non-randomized study comparing canaloplasty with trabeculectomy suggests that canaloplasty attains nearly equivalent IOP control with low rates of hypotony and other vision-threatening complications. Average IOP at one year was 12.3 mm Hg for trabeculectomy and 13.4 for canaloplasty. Choroidal effusions and hypotony were more frequent in the trabeculectomy group (28% to 2% and 26% to 2% respectively). If IOP rises at a later date, Nd:YAG laser goniopuncture over the cannulated and sutured trabecular meshwork can help to restore IOP control. The canaloplasty procedure is time consuming and technically challenging. The same cannula device can be used to perform an ab externo 360 degree trabeculotomy in eyes with congenital glaucoma and an ab interno trabeculotomy (see above).

### Table 1 Results of New Surgical Procedures

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<th>Procedure</th>
<th>Approach</th>
<th>Alone or with Cataract surgery</th>
<th>Number</th>
<th>Initial IOP</th>
<th>Last F/u</th>
<th>IOP @ last F/U</th>
<th>% reduction</th>
<th># Meds @ last F/U</th>
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<td>18.4</td>
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<tr>
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Table 1 Results of New Surgical Procedures.

4. Summary

How these procedures are best able to assist patient care has not been established. IOP results are summarized in Table 1 (note that the groups were probably not equivalent so drawing comparative inferences would be difficult). Several of these procedures have been adopted because of their reduced chances of profound vision loss. As more randomized, controlled studies...
are performed, the relative merits and disadvantages of these procedures will become known. Having more options in the surgical treatment of glaucoma raises the prospect of being able to tailor a procedure to the specific needs of each patient and to reduce some of the complications associated with the current standard operations.

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Clinical Issues:  
Minimising scarring after glaucoma surgery

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Core Concepts
• Scarring is the most important reason for failure of all glaucoma filtration surgery, including micro-devices draining to the subconjunctival space and suprachoroidal space. 
• Simple strategies are currently available to minimise such scarring. 
• While current anti-scarring treatments, such as the antimetabolites 5-fluorouracil (5-FU) and mitomycin-C (MMC) are effective, they are still associated with an increased risk of significant complications. 
• Improved surgical success can be achieved with simple modifications to surgical technique and to the method of application of anti-scarring agents. 
• Future therapeutic areas include anti-inflammatory agents, novel antibodies, enzyme inhibitors, RNA modifying agents, matrix metalloproteinase (MMP) inhibitors, and cytoskeletal modifiers.

1) Current Approaches
The trabeculectomy procedure is the most commonly performed glaucoma filtration surgery (GFS) and scarring is the most important reason for failure.¹ Simple but significant modifications to the original techniques have reduced the complications of surgery with anti-metabolites. These include wider surface area of treatment, and much better aqueous flow control, embodied in a system known as the Moorfields Safer Surgery System.¹ Current agents used in both the clinic and the operating theatre to minimise scarring include steroids and anti-metabolites (5-FU and MMC). However, these treatments still carry increased risks of significant complications including corneal epithelial damage, wound leak, shallow anterior chamber and cata-

Development of a combination of anti-VEGF agents with 5-FU or MMC is continuing.⁴ MMPs play a significant role throughout the entire wound healing process and results from studies of MMP inhibitors such as Ilomastat and Doxycycline have shown promise experimentally.⁵ 
Apart from antagonists to VEGF, TGF-β is a pro-fibrotic cytokine that is increased in glaucoma patients; it stimulates fibroblast migration, proliferation, collagen synthesis and myofibroblast differentiation.⁶ Therapeutic approaches to target TGF-β include antisense oligonucleotides and antibodies. The failure of a clinical trial of TGF-β2 antibody may have resulted from inadequate antibody levels (only 30 minute half life) and lack of TGF-β1 antagonist activity.

Improved antagonism of targets using other molecules such as short interfering RNA (siRNA) may offer much longer inhibition of TGF-β and other targets in the eye. Further development of new therapeutics includes modified antibodies, RNAi, gene therapy, nanoparticles and liposomes.⁷ Further developments in these areas will include combinations and optimal drug delivery approaches to minimise ocular toxicity; hopefully, this will improve prognosis in GFS.

3) Conclusions
While anti-metabolites have had a profound effect on the success of GFS, their associated complications have resulted in a search for suitable options with improved efficacy and therefore improved surgical success. There are already simple strategies that can improve outcome (Table 1) With novel targets, treatments and drug delivery methods being developed, soon we should have a number of tools to minimize scarring and ultimately to reduce the risk of
glaucoma progression for our patients through more reliable intraocular pressure (IOP) control.

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Table 1: Strategies to minimise scarring during after glaucoma surgery

- Identify high risk patients - consider appropriate actions including antimetabolite
- Reduce inflammation – non preserved drops, minimize anti-glaucoma drops, short pre-operative course of steroids topically (preferably preservative free) or systemically if extremely inflamed
- Hemostasis – apraclonidine or adrenaline to vasoconstrict. Cauterize leaking vessels
- In scarred eyes hydrodissect conjunctiva to reduce trauma and bleeding
- Use local anaesthetic in trabeculectomy area for their anti-scarring effects on fibroblasts and to stop pain – vascular leakage reflex
- Maintain blood aqueous barrier – prevent intra and post operative hypotony, consider bevacizumab in hypervascular eyes to reduce protein leakage and stimulation.
- Use anti-metabolite and apply over wide surface area to encourage diffuse non-cystic blebs
- Use steroids for at least 3 months after surgery
- Ensure early aqueous flow to prevent contact scarring/flattening of forming bleb
- If maximum grading of redness/inflammation on Moorfields bleb scale (www.blebs.net, 2-6 times risk of failure depending on time after surgery) and/or rising IOP consider sub-conjunctival (s/c) antimetabolites + steroid + local anaesthetic (for pain relief and anti-scarring). If persistent consider s/c bevacizumab, topical and oral non-steroidal anti-inflammatories and steroids.
- If needleling required and significant scarring present, consider pre-operative s/c MMC (up to 0.2mg/ml) with great care
- If persistent scarring consider post-operative s/c MMC (up to 0.2mg/ml) with great care

References
Core concepts

- Fornix-based trabeculectomy flaps appear provide more favorable bleb morphology.
- Minimizing early wound leaks is paramount for surgical success but represents one of our greatest challenges.
- Wise's suture pattern of alternating crimping with stretching of the conjunctival edge can provide robust watertight wound closure.
- A modification of Wise's technique that retains a narrow lip of anterior limbal conjunctiva as a bolster appears to reduce wound leak incidence to the lowest levels seen to date.
- Selecting a narrow profile needle with a micro-point cutting tip is critical in facilitating the technique.
- Mastering this technique will reduce early postoperative complications and improve patient outcomes.

For more than three decades the term trabeculectomy has encompassed a breadth of different techniques, each with advantages and disadvantages as well as modifications that include the implantation of the Ex-PRESS filtration device. Through its evolution limbal-based conjunctival flaps have been preferred by many surgeons because of the reported low incidence of early leakage.1-3 Closure techniques to minimize leakage have also received a breadth of different techniques, each with advantages and disadvantages as well as modifications that include the implantation of the Ex-PRESS filtration device. Through its evolution limbal-based conjunctival flaps have been preferred by many surgeons because of the reported low incidence of early leakage.1,4,5 However, has seen an increase in preference by a majority of glaucoma surgeons because of its enhanced exposure of the surgical field and resulting bleb morphology characteristics.2,3,4 Despite the utmost importance of methodical conjunctival flap closure techniques to minimize early leakage, rates of early leakage for fornix-based closure have been reported between 10% and 20% or even higher.4,5 In 1993, Wise described a running vertical mattress suture to minimize leakage with a fornix-based conjunctival flap in conjunction with Mitomycin-C6. Over the past 15 years, I have used modifications of that technique to enhance watertight closure and the resulting improved efficacy is supported by our recent report of over 500 consecutive cases.2 Two main modifications to the method described by Wise appear helpful: leaving approximately half a millimeter of limbal conjunctiva attached at the corneoscleral junction when making the peritomy along the limbus; and anchoring the suture in conjunctiva and sclera rather than clear cornea outside the confines of the conjunctival incision.

One central issue raised in regard to our technique described below is the selection and availability of the ideal needle and suture combination. Wise suggested the VAS 100-4 (Ethicon) that is readily available on 9-0 nylon. This needle has a very fine micro-cutting tip and a very slender shaft allowing for easy entry into, and steerage through corneo-scleral tissue while minimizing the perforation size of the conjunctival passes. I have used this same needle on 9-0 monofilament Vicryl (Ethicon) as a special order item (Model D-8760). This seems more resistant to breakage than nylon during suturing and does not have to be removed postoperatively. As a special order item, however, it is not readily available and is more expensive. An excellent alternative is the 8-0 braided Vicryl Model J-974 (Ethicon). It is identical in profile to the VAS 100-4, but is slightly larger. It is widely available.

A central element is Wise's suturing pattern whereby all the suture bites are LONGER than the space between any suture bites (Figure 1). The suture, however, has been an area of concern because of the potential for early wound leak. One central issue raised in regard to our technique described below is the selection and availability of the ideal needle and suture combination. Wise suggested the VAS 100-4 (Ethicon) that is readily available on 9-0 nylon. This needle has a very fine micro-cutting tip and a very slender shaft allowing for easy entry into, and steerage through corneo-scleral tissue while minimizing the perforation size of the conjunctival passes. I have used this same needle on 9-0 monofilament Vicryl (Ethicon) as a special order item (Model D-8760). This seems more resistant to breakage than nylon during suturing and does not have to be removed postoperatively. As a special order item, however, it is not readily available and is more expensive. An excellent alternative is the 8-0 braided Vicryl Model J-974 (Ethicon). It is identical in profile to the VAS 100-4, but is slightly larger. It is widely available.

A central element is Wise's suturing pattern whereby all the suture bites are LONGER than the space between any suture bites (Figure 1). The suturing starts with a solid bite incorporating sclera and conjunctiva just to the right of the extent of the conjunctival opening near the limbus (right-handed surgeon). It is anchored by tying it to itself. The next pass is down through the edge of the conjunctival flap about 3mm from the right corner of the incision (Figure 2). The needle is then placed to the far right of the incision opening and a long 3-4mm pass is made tangentially through cornea-sclera along the limbus underneath the small lip of anterior conjunctiva and as far anteriorly as possible. Note the anterior lip is NOT incorporated in any of the needle passes (Figure 3). After exiting cornea-sclera the needle is passed up through the conjunctival flap edge about 2mm from the first downward pass. Another downward conjunctival pass is then made 3-4mm further left and that is followed by a...
The pattern is repeated as needed until the needle exits the left end of the incision up through the conjunctiva beyond the confines of the incision. A final pass is made generously incorporating the redundant corner of conjunctiva and underlying sclera leaving a loop of suture so it can be tied to itself after carefully tightening the entire suture line. It is critical that the whole flap be tightly applied to the cornea-sclera under the anterior conjunctival lip. As long as the Wise suture bite architecture and length relationships are maintained, a secure closure is created with the edge of the conjunctival flap buttressed up against the small lip of limbal conjunctiva producing a tightly ‘pursed-lips’ appearance along the limbus (Figure 6). The anterior lip acts as a bolster creating robust watertight closure reducing the tendency for early leakage and helps promote rapid epithelialization at the wound. It is also important to keep any Tenon’s capsule attached to the undersurface of the conjunctiva and perform posterior sub-Tenon’s blunt dissection to enhance effective wound closure and more posterior flow.

In our retrospective review of 509 consecutive cases using this approach we found a 2.9% leak rate in the first postoperative month with a 1.6% rate of return to the operating room to resuture a persistent leak⁹. This is dramatically lower than other reported techniques including ones following Wise’s original description⁴,⁵,⁶,⁷,⁸. When meticulously performed this modified closure technique may well provide watertight closure as commonly as limbal-based techniques while producing more favorable long-term bleb morphology (Figure 7 and Figure 8).

Related Video: https://eyetube.net/video/closing-the-fornix-based-conjunctival-flap/

Fig 4. The conjunctiva beneath the suture is crimped and applied tightly against the corneosclera.

Fig 5. As the suture is pulled to the left the conjunctiva between the suture bites is stretched snugly to complete the alternating crimping/stretching effect for a robust, watertight wound.

Fig 6. The appearance of the closed incision shows the anterior and posterior conjunctival edges firmly abutting each other (arrows).

Fig 7. Four weeks postoperatively, epithelialization of the wound has been rapid.

Fig 8. One year postoperatively, a low diffuse posterior bleb with fibrosis limited to the site of the original incision is seen.

References
STATEMENT OF NEED AND PROGRAM DESCRIPTION
Recent months and years have seen significant advances in our understanding of glaucoma. Much has been learned, not only about damage mechanisms and pathogenesis, but also about diagnosis and management. Treatment options – both medical and surgical – continue to expand. This program will review this new knowledge with an emphasis on incorporating recent insights into day-to-day practice.

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