Advances in Glaucoma Surgery

Arushi Garg, Rishika Jain, Usha Yadava
Glaucoma Services, Guru Nanak Eye Centre, Maulana Azad Medical College, New Delhi

Abstract
Currently popular glaucoma filtration surgeries which include trabeculectomy and glaucoma drainage devices have their share of vision-threatening complications. Lately less invasive and safer devices have been developed to be used alone or in conjunction with cataract surgery for lowering the intraocular pressure. These microscopic implants utilize the trabecular pathway, suprachoroidal pathway or subconjunctival route for drainage. The term ‘Micro-Invasive Glaucoma Surgery’ includes surgical procedures that use an ab-interno approach, such as iStent, Trabectome, Hydrus Scaffold shunt, Excimer laser trabeculotomy and CyPass suprachoroidal shunt. Implants which utilize ab-externo approach are canaloplasty with microcatheter, Ex-PRESS glaucoma microshunts, SOLX Gold shunt and Aquashunt. Studies are ongoing to evaluate their efficacy alone or in combination with phacoemulsification and have found encouraging results in early to moderate glaucoma.

Keywords: Micro-Invasive Glaucoma Surgery, microshunts, suprachoroidal shunt, ab-interno glaucoma surgery

From the time of its inception by Cairns in 1968, trabeculectomy remains the standard surgical procedure for achieving control of intraocular pressure (IOP) in medically uncontrolled glaucoma patients, with or without anti-fibrotic augmentation. Recently, glaucoma drainage devices have gained considerable mileage and popularity in both high-risk as well as primary glaucoma cases. Long term follow up has shown favourable results with trabeculectomy, as well as drainage devices, although not without their share of complications. Most notable complications include accelerated cataract formation, choroidal effusion, wound leak, hyphaema, hypotensive maculopathy, late bleb leak, bleb encapsulation, corneal decompensation, bleb-related endophthalmitis and tube-related complications (with drainage devices). The past decade has shown a growing interest in alternative surgeries which are less invasive.

The term ‘Micro-invasive Glaucoma Surgery’ (MIGS) encompasses the group of glaucoma surgeries that share five preferred qualities:
1. They have an ab-interno micro-incisional approach contrary to conventional trabeculectomy, which is an ab-externo procedure. MIGS through a clear corneal incision spare the conjunctiva. They allow direct visualization of internal anatomical landmarks and can be combined with cataract surgery also. They also allow maintenance of the anterior chamber by virtue of being micro incisional, along with causing little anatomical distortion, refractive change and hence, have increased safety.
2. They cause minimal trauma to the target tissue, anatomically and physiologically. These devices exhibit a high degree of biocompatibility.
3. The surgical procedure shows at least a modest efficacy initially.
4. They are required to have a high safety profile and avoid the serious complications seen with conventional surgical procedures.
5. The procedure has rapid recovery and should minimally impact the patients’ quality of life. Ease of use and a steep learning curve are also desirable features in MIGS.

There are three mechanisms by which the newer glaucoma implants can lower IOP (Figure 1): (1) increase outflow by creating a new drainage channel into the subconjunctival space by forming an external bleb such as Ex-PRESS glaucoma implant, Fugo blade transcleraly filtration, (2) increase the conventional trabecular outflow pathway into the Schlemm’s canal as with trabecular micro-bypass stent (Glaukos iStent), trabectome, Excimer laser trabeculotomy (ELT), canaloplasty and Fugo Blade goniotomy, or (3) increase the uveoscleral outflow into the suprachoroidal space (CyPass Shunt, SOLX Gold shunt).

A. Increasing Trabecular Outflow
1. Ab Interno Procedures
Glaukos iStent (Glaukos Corporation, Laguna Hills, CA, USA)
This is a 1 x 0.3 mm heparin coated titanium implant for insertion through the trabecular meshwork (TM) into Schlemm’s canal (SC). It is an L-shaped device with a pointed tip that penetrates the TM, a 1 mm long trough that rests in the Schlemm’s canal, and a “snorkel” that faces the anterior chamber and allows the aqueous to drain from the anterior chamber (AC) to the canal. The trough has arches facing the TM to make it self-retaining (Figure 2). It is implanted with the use of a disposable inserter via gonioscopic guided approach from a paracentesis site. It can be combined with cataract surgery in open-angle glaucoma (OAG), with good IOP reduction postoperatively. Multiple iStents can also be implanted at once and have shown good efficacy (Synergy Trial). The advantage of the stent is the maintenance of the bypass patency by virtue of its heparin coating. Common associated complications are mild hyphaema from the Schlemm’s canal, transient IOP spike, corneal edema, stent malposition, lumen obstruction by blood clot or iris, inability to implant the stent, vitreous incarceration, and need for second surgery. Studies conducted on iStent have
shown greater number of subjects achieving ≥20% IOP reduction with iStent combined with cataract extraction versus cataract surgery alone in patients of open angle glaucoma.\textsuperscript{5,7} It has been approved by US-FDA for usage in patients of OAG with phacoemulsification. Glaukos has now developed second generation iStent (iStent inject) made of heparin-coated titanium in a conical design. A third generation iStent (iStent Supra) has been developed for placement in the suprachoroidal space.

**Trabectome (NeoMedix, Inc., Tustin, CA):**
It is a 19.5-gauge electrocautery device with a disposable hand piece connected to a console, with irrigation and aspiration controlled by a foot pedal. Under gonioscopic guidance, 90 -120 degrees of the trabecular meshwork and inner walls of schlemm’s canal is cauterised and stripped to create a direct communication between the anterior chamber of the eye and Schlemm’s canal (Figure 3). Studies have reported significant IOP reduction with Trabectome, similar to trabeculectomy\textsuperscript{8,9} either alone or in combination with phacoemulsification\textsuperscript{10} in open angle glaucoma. Intraoperative blood reflux is seen in almost 100% of cases. Other typical complications of Trabectome trabeculotomy are goniosynechiae formation and membrane growth both of which may lead to IOP elevation. Trabectome surgery generally achieves a postoperative IOP in range of low to mid-teens, mean reduction approximating 30% over a 6-month follow up.\textsuperscript{9} It is to note that the higher the IOP was before surgery, the greater the IOP reduction.
**Excimer Laser Trabeculotomy** (AIDA, Glautec AG, Nurnberg, Germany)

Ab interno excimer laser trabeculotomy (ELT) utilizes the energy of a xenon chloride pulsed excimer laser (308 nm wavelength) connected to a quartz fiber-optic probe. It is aimed at creating multiple microperforations in the TM and inner wall of SC to increase aqueous outflow. The probe tip is bevelled at 65 degrees to aid the placement of the tip against the angle. Eight to ten laser punctures spaced over 90 degrees are created under gonioscopic or endoscopic visualization. It delivers a mean energy of 1.2 mJ over 80 ns duration with each pulse. Whitening of the TM followed by blood reflux from the laser site following laser ablation is taken to be the end-point. However the lack of circumferential flow in the SC may limit its efficacy, as well as the theoretical possibility of closure of these microholes. It has not yet been cleared for marketing in the United States.

**Hydrus Microstent** (Ivantis, Inc., Irvine, CA, USA)

It is an “intracanalicular scaffold”, 8 mm long device made of a highly elastic biocompatible material called nitinol, having three windows along its length and is open on its posterior surface (Figure 4). It is inserted into Schlemm’s canal across the TM during cataract surgery. It acts like an intracanalicular stent, dilating approximately one quadrant of the SC, thus increasing aqueous outflow from the anterior chamber to SC by bypassing the TM and by dilating the canal. It is inserted into the SC via an ab-interno gonioscopy-guided approach, leaving the proximal 1 mm inlet of the microstent outside the SC, facing the anterior chamber to bypass the TM.

Camras et al reported significant reduction in outflow facility in human eyes after implantation of Hydrus device.11 Pfeiffer et al12 in their recently published 2-year results on Hydrus microstent reported that combined Hydrus with phacoemulsification surgery reduced IOP by 20% in 80% of OAG patients (from 26.3±4.4 mmHg to 16.9±3.3 mmHg) as compared to 46% of OAG patients in phacoemulsification alone group (from 26.6±4.2 mmHg to 19.2±4.7 mmHg). It can cause subconjunctival hemorrhage, hyphema, and focal peripheral anterior synechiae. The scaffold device is available only for investigational use in the United States but has received CE-mark in Europe.

2. Ab Externo Implants

**Canaloplasty**

It is a non-penetrating and bleb-independent procedure in which aqueous outflow is enhanced by circumferential 360 distention of the Schlemm’s canal done with viscous material like Healon GV through a microcatheter. This procedure also establishes circumferential flow within the SC and stretches the TM. It bears conceptual similarities to viscocanalostomy, with the addition of a catheter-aided dilatation, placement of a permanent suture in the SC under tension and creation of a filtering intrascleral “lake”. The microcatheter (iTrack, iScience International, Menlo Park, CA, USA) is 200 µm in diameter and has an optical fibre illuminated beacon tip to assist in guidance. After deroofing the Schlemm’s canal and creating a trabeculo-descemetic window, the microcatheter is advanced into the Schlemm’s canal and the full length of the canal is visco-dilated. Following this, a 10-0 polypropylene suture is sutured to the distal tip of the microcatheter and looped through the canal. The suture is then tightened to ensure that it stretches the Schlemm’s canal and TM circumferentially. Intraoperative high resolution ultra-biomicroscopy can confirm the placement of this suture.

This procedure is US-FDA approved. It is a technically more difficult, expensive and time-consuming procedure and its efficacy is limited by the resistance of SC and episcleral venous pressure. Complications include microhyphema, elevated IOP and descemets detachment. Another disadvantage is conjunctival scarring caused by the procedure and bleb formation in few patients. Evidence shows that canaloplasty lowers IOP to lower-to-mid-teens alone or when combined with cataract surgery in...
open angle glaucoma, with a percentage IOP reduction of 30-65%.

Phacoemulsification combined with canoloplasty gives superior results over canoloplasty alone. The Stegmann Canal Expander (Ophthalmos GmbH, Schaffhausen, Switzerland)
The Stegmann Canal Expander (SCE) is a 9.0 mm long stent made of polyimide and placed into Schlemm’s canal to create a permanent distension of the TM. Each stent occupies one quadrant of the SC circumference. Due to its fenestrated nature SCE is patent to aqueous humor. They are placed in a similar fashion as canoloplasty. After viscodilation of the SC, the microcatheter is withdrawn and SCE replaces the suture stent, thus making canoloplasty easy and avoiding ‘cheesewiring’ of the suture under tension. The superficial scleral flap is sutured very tightly as in canoloplasty to prevent bleb formation and to force the aqueous humour leaving through the physiological drainage system. Complications such as descemets tear, postoperative IOP spike, hyphema and iris prolapsed have been noted with SCE also. Clinical trial are ongoing and are encouraging.

B. Subconjunctival Implants

EX-PRESS Glaucoma Filtration Device (Alcon Laboratories Inc., Fort Worth, TX)
It is a small, stainless steel implant less than 3 mm in size which diverts aqueous from the anterior chamber into the subconjunctival space similar to a conventional trabeculectomy (Figure 5). It has an inner diameter of 50 μm for providing non-valved restricted aqueous outflow. It is inserted under a partial thickness scleral flap using its device inserter, after making an opening into the anterior chamber under the scleral flap with a 25-27 gauge needle (400 microns outer diameter). There is less bleeding as no iridectomy is required. This device is available in various models (R-50, P-50, P-200). The flange end is placed underneath the flap while the spur-like projection near its inner end prevents extrusion of the device.

Studies have found similar IOP-lowering efficacy of Ex-PRESS shunt as compared to conventional trabeculectomy. This implant is indicated for patients who are poor candidates for iridotomy due to risk of bleeding or inflammation. Those patients who have very narrow angles, neovascular glaucoma, uveitis or severe dry eye are not good candidates for this implant. The higher cost of this implant is a matter of consideration when deciding for primary Ex-PRESS implant insertion.

AqueSys XEN implant
This implant consists of a soft flexible hydrophilic gelatin tube with an inner diameter of 65 microns. It is placed via ab interno into the subconjunctival space, where it hydrates and swells in place, thus preventing migration. The idea is to create a subconjunctival filtration bleb without opening the conjunctiva. There is no published data yet about the device.

InnFocus Microshunt (InnFocus, Inc., Miami, FL, USA)
This implant consists of a flexible needle like tube made of a highly biocompatible material SIBS, with fins halfway across its length to act as stopper to minimize aqueous leakage and to prevent internal migration of the tube. The internal diameter of this tube is 70 μm. It is inserted using the ab-externo approach through a small scleral pocket into the anterior chamber, making a thin needle tract.

C. Suprachoroidal Shunts
Suprachoroidal shunts are based on the principle that there is a pressure gradient of 1-5 mmHg between the anterior chamber and the suprachoroidal space, the pressure in suprachoroidal space being lower. This creates a unidirectional flow towards the suprachoroidal space. Various suprachoroidal shunts have been developed and are undergoing trial for efficacy for favourable results.

CyPass micro-shunt (Transcend Medical, Inc., Menlo Park, CA)
It is a 6.35 mm fenestrated tubular shunt with an external diameter of 510 microns, made of polyimide, designed for use with cataract surgery. It is inserted into the suprachoroidal space and promotes aqueous outflow from anterior chamber to the suprachoroidal space across the uveoscleral pathway. It is inserted via transcameral over a guidewire with a special tip that disinserts the ciliary body from the scleral spur to create a controlled cyclodialysis, and the device is then inserted in the cleft created. Results of this novel device in open angle glaucoma (OAG) patients in combination with cataract surgery have been favourable, reporting upto 30-35% IOP reduction. Transient hyphema, hypotony and postoperative inflammation have been seen with its use in few cases. The first large scale study to evaluate its efficacy in OAG with or without cataract surgery was CyCLE (CyPass Clinical Experience) Study, which reported 26-37% IOP reduction. Clinical studies by Garcia-Feijoo et al have found a 35% IOP reduction in medically uncontrolled open angle glaucoma precluding need for invasive glaucoma surgery in >80% patients. Hoeh et al have also found encouraging results of CyPass micro-shunt combined with phacoemulsification. It is being actively assessed in the US based COMPASS trial.

![Figure 5: Ex-PRESS glaucoma microshunt](image-url)
SOLX Gold Microshunt (GMS, SOLX, Boston, Massachusetts, USA)
This device is based on the observation that gold has excellent biocompatibility and inertness in the human eye. It is a nonvalved flat plate drainage device, made of 24-karat medical-grade gold measuring 3.2 mm X 5.2 mm X 44 µm thick, weighing 6.2 mg, composed of two leaflets joined together vertically (Figure 6a). This is inserted into the suprachoroidal space to shunt aqueous from the anterior chamber (Figure 6b). It includes 19 microchannels (10 closed, 9 open) for aqueous to percolate which can be opened more with laser energy after surgery, if a further IOP decrease is desired. The device is positioned through a fornix-based conjunctival flap and under a 4 mm full-thickness scleral dissection into the created suprachoroidal space by ab-externo route.

Recent studies have found good IOP lowering efficacy with Gold microshunt in refractory glaucoma but with adjunctive anti-glaucoma medications. Reports have suggested formation of a thin inflammatory membrane obstructing the anterior holes of the device as a possible cause of failure.

iStent Supra: (Glaukos Corporation, Laguna Hills, CA, USA) is the third generation Glaukos device for ab-interno implantation into the suprachoroidal space in both phakic and pseudophakic eyes. It has a lumen of 0.16-0.17 microns, made of heparin-coated polyethersulfone and a titanium sleeve.

Aquashunt: (OPKO Health Inc., Miami, FL, USA) is a polypropylene curved device with a tapering edge, implanted ab-externally that has a single large lumen as compared to multiple small channels in SOLX Gold microshunt.

STARflo: (iSTAR medical, Isnes, Belgium) is made of a sheet of porous silicon material (STAR) with an anvil-like head to prevent its extrusion, placed in suprachoroidal space via ab-externo approach.

Fugo Blade in Glaucoma
Fugo blade (Medisurg Ltd., Norristown, PA) is an electrosurgical device being used lately in paediatric eye surgery and cataract surgery. It cuts tissue with a high degree of precision by producing a microscopic plasma cloud surrounding its filament and causing non-cauterising haemostasis.

Fugo Blade Transciliary Filtration- in this ab-externo application of Fugo blade, a full thickness scleral window is created overlying the pars plicata and an opening is created through the pars plicata into the posterior chamber, thus creating an external drainage channel from the posterior chamber directly.

Fugo Blade Goniotomy- Multiple ab-interno goniotomies are made using Fugo blade to create a direct communication between the anterior chamber and SC by removal of a segment of the TM.

Current operative techniques for ab-interno MIGS require direct gonioscopy, intraoperative manipulation of microscope and patient head tilting. Better intraoperative surgical techniques may reduce the existing complications with these newer procedures. Most of the existing studies have used these devices in conjunction with cataract surgery. The efficacy of most microinvasive devices is modest in comparison to trabeculectomy or glaucoma drainage devices, but their advantage over these invasive surgeries lie in their better safety profiles. Hence they are best suited for early to moderate, uncomplicated glaucoma cases, and not for advanced glaucomatous damage where IOP requirement is in low teens.

Cite This Article as: Garg A, Jain R, Yadava U. Advances in Glaucoma Surgery. Delhi J Ophthalmol 2016;27;44-9.

Acknowledgements: None

Date of Submission: 11/02/2016       Date of Acceptance: 08/05/2016
Conflict of interest: None declared
Source of Funding: Nil
References

1. Sihota R, Gupta V, Agarwal HC. Long-term evaluation of trabeculectomy in primary open angle glaucoma and chronic primary angle closure glaucoma in an Asian population. *Clin Exp Ophthalmol* 2004; 32:23-8.

2. Landers J, Martin K, Sarkies N, Bourne R, Watson P. A twenty-year follow-up study of trabeculectomy: risk factors and outcomes. *Ophthalmology* 2012; 119:694-702.

3. Gedde SJ, Schifffman JC, Feuer WJ, et al. Three-year follow-up of the tube versus trabeculectomy study. *Am J Ophthalmol* 2019; 180:670-84.

4. Saheb H, Ahmed IIK. Micro-invasive glaucoma surgery: current perspectives and future directions. *Carr Opin Ophthalmol* 2012; 23:96-104.

5. Samuelson TW, Katz LJ, Wells JM, Duh Y-J, Giamporcaro JE, for the US iStent Study Group. Randomized evaluation of the trabecular microbypass stent with phacoemulsification in patients with glaucoma and cataract. *Ophthalmology* 2011; 118:459-67.

6. Voskanyan L, García-Feijoó J, Belda JI, Fea A, Jünemann A, Shaarawy T, et al. Histological findings of failed gold micro shunt implantation to the supraciliary space in patients with glaucoma: A pilot study. *Arch Ophthalmol* 2009; 127:264-9.

7. Francis BA, Minckler D, Baerveldt G, Ramirez MA, Mosaed S, Wilson R, Cristoforo B, et al. Initial Clinical Experience With the CyPass Micro-stent: Safety and Surgical Outcomes of a Novel Supraciliary Microstent. *J Glaucoma* 2016; 25:106-12.

8. Melamed S, Ben Simon GJ, Goldenfeld M, Simon G. Efficacy and safety of gold micro shunt implantation to the supraciliary space in patients with glaucoma: A pilot study. *Arch Ophthalmol* 2009; 127:264-9.

9. Lewis RA, von Wolff K, Tetz M, Kearney JR, Smith SD. Novel Glaucoma Procedures- A Report by the American Academy of Ophthalmology. *Ophthalmol* 2011; 118:1466-80.