Clinical Ophthalmology

Dovepress
Taylor & Francis Group

Open Access Full Text Article

EXPERT OPINION

Update on Surgical Techniques Best Practices to Optimize Outcomes Following Gel Stent Implantation

Vanessa Vera[1], Arsham Sheybani[2], Joseph F Panarelli[3], Davinder S Grover[4], James Lee[5], Earl Randy Craven[2], Thomas W Samuelson[6], Iqbal Ike K Ahmed[7]

[1]Allergan, an AbbVie company, Irvine, CA, USA; [2]Washington University School of Medicine, St Louis, MO, USA; [3]Department of Ophthalmology, New York University Langone Health, New York, NY, USA; [4]Glaucoma Associates of Texas, Dallas, TX, USA; [5]Colorado Eye Institute, Colorado Springs, CO, USA; [6]Minnesota Eye Consultants, University of Minnesota, Minneapolis, MN, USA; [7]John Moran Eye Center, University of Utah, Salt Lake City, UT, USA

Correspondence: James Lee, Colorado Eye Institute, Colorado Springs, CO, 80924, USA, Email jlee@eyescolorado.com

Abstract: The XEN®45 Glaucoma Treatment System (gel stent; Allergan, an AbbVie company, Irvine, CA, USA) is a minimally invasive bleb-forming surgical device that was originally approved to lower intraocular pressure by diverting the aqueous humor from the anterior chamber to the subconjunctival space (like trabeculectomy) following ab-interno placement. Since approval of the gel stent in multiple countries, the implantation technique has evolved considerably, being performed ab interno or ab externo with open or closed conjunctiva, based on patients' needs and/or surgeons' preferences. Additional technical variations that can facilitate gel stent placement and/or improve outcomes have also emerged. This article aims to increase awareness of these developments to facilitate informed decision-making and improve surgical success and outcomes for patients.

Keywords: ab interno, ab externo, glaucoma, intraocular pressure, surgical outcomes, XEN

Introduction

For patients with glaucoma in whom surgery is indicated[1] to lower intraocular pressure (IOP) to their target value and minimize damage to the optic nerve, trabeculectomy has long been the gold standard procedure. Trabeculectomy is effective at lowering IOP because it diverts the aqueous humor directly from the anterior chamber to the subconjunctival space, bypassing the primary site of resistance to outflow, ie, the trabecular meshwork.[2,3]

The first published description of trabeculectomy in 1968[4] involved a full-thickness sclerectomy and surgical removal of a small section of Schlemm's canal and adjacent trabecular meshwork. This was intended to eliminate the resistance barrier over a short distance and restore aqueous outflow, but was found to produce a filtering bleb as well in many patients. Unfortunately, the procedure was associated with serious complications of postoperative hypotony (for example) and a high failure rate. Since then, trabeculectomy has greatly evolved. The full-thickness sclerectomy has been replaced with the creation of a half-thickness scleral flap, and both Schlemm's canal and the trabecular meshwork remain undissected.[5,6] In addition, the original limbus-based conjunctival flap has been replaced with a fornix-based conjunctival flap, which is technically easier to perform, has a lower incidence of buttonholing as an adverse event, and may shorten the surgery time.[5–7] Intraoperative use of antimetabolites/antifibrotics (eg, mitomycin C [MMC]) has also become widely accepted as it markedly increases the success rate, despite a known risk of complications.[8,9] Nonetheless, to date, trabeculectomy remains associated with significant postoperative complications,[10–22] which led to the development of alternative procedures, including minimally invasive glaucoma surgery[23,24] with devices such as iStent Inject (Glaukos Corp, San Clemente, CA, USA) and the Hydrus Microstent (Alcon, Geneva, Switzerland), as well as minimally invasive

Received: 19 July 2024
Accepted: 2 December 2024
Published: 31 January 2025

bleb-forming surgery[23,24] (MIBS) with devices such as the PreserFlo Microshunt (Santen Pharmaceutical, Osaka, Japan) and XEN®45 Glaucoma Treatment System (gel stent; Allergan, an AbbVie company, Irvine, CA, USA).

The gel stent was designed to bypass ocular structures of high resistance (trabecular meshwork and Schlemm's canal) and allow drainage of aqueous humor directly from the anterior chamber to the subconjunctival space (area of lower resistance),[25] similar to trabeculectomy. However, the gel stent's length and inner diameter were determined based on the Hagen-Poiseuille equation for laminar flow, to reduce the risk of hypotony following gel stent implantation, compared with trabeculectomy.[26,27]

Implantation of the gel stent has also evolved since publication of the pivotal study in 2017.[28] Originally approved for placement using an ab-interno approach,[29,30] surgeons have adapted the surgical procedure for use in real-world settings to allow both ab-interno and ab-externo implantation with closed or open conjunctiva.[25,31] In the pivotal study, subconjunctival pretreatment of the target area with an MMC-soaked sponge was required by the United States (US) Food and Drug Administration,[28] whereas most recent studies use a subconjunctival injection of MMC solution instead (allowing for a more accurate application/dosing of MMC[32] while sparing the conjunctiva from dissection). Instead of advising that the implanted gel stent be "visually free and mobile", we now recommend that the implanted gel stent be physically free from Tenon's tissue by creating and maintaining a plane/space/pocket in which the implant is placed to reduce the risk of stent obstruction and subsequent fibrosis, and to facilitate aqueous humor outflow. Even the target population for gel stent placement has evolved, having advanced glaucomatous damage[24] with a baseline average visual field mean deviation of −15.0 dB in the pivotal study[28] versus moderate glaucomatous damage[24] with a baseline average visual field mean deviation of −8.0 dB in the APEX study[33] and −7.4 dB in the Gold-Standard Pathway Study.[34]

This article aims to describe and summarize (Table 1) the latest developments and surgical pearls regarding gel stent implantation and how to ensure that the implant is free of Tenon's tissue, whether a closed or open conjunctiva via ab-interno versus ab-externo approach is used, in hope of facilitating informed decision-making and improving surgical success and outcomes for patients with open-angle glaucoma (OAG).

Table 1 Key Steps to Increasing Surgical Success of the Gel Stent Implantation, Regardless of the Approach Used[a]

Preoperatively
Reduce ocular surface inflammation by managing ocular surface disease and starting corticosteroids a few weeks before surgery
When possible, reduce the number of IOP-lowering medications
Intraoperatively
Before the stent is deployed, any torsion/counterforce (including the traction suture) should be released to allow the eye to return to its natural position
Ensure that the gel stent is free from Tenon's tissue by adopting a surgical technique that creates a space/pocket whether you perform the primary needling, PoST, or small incision, open the conjunctiva or not, or use an ab-interno or ab-externo approach
Leave OVD in the subconjunctival space; keeping the created space/pocket open can potentially reduce the risk of bleb failure by maintaining the tissues separated
MMC is key to the implantation's success as it minimizes bleb fibrosis; the right dose (typically 40–60 ug) and technique should be determined based on the patient's characteristics
The final goal of the surgery is to connect the anterior chamber to the subconjunctival space: a 1, 2, 3[b] positioning is ideal for posterior bleb formation
Stay away from the iris and cornea during implantation
Try to prevent bleeding by planning the surgery and needle exit point to avoid scleral vessels as much as possible; immediately control bleeding with pressure or cautery

(*Continued*)

Table 1 (Continued).

To reduce the risk of nasal blebs and erosion, the final implant position should be as close as possible to 12 o'clock
Confirm intraluminal outflow when possible, either directly by visualization of a slow beading at the distal end of the implant, or indirectly from a bleb forming posteriorly following priming of the implant (instead of an anterior bleb raising at the implant scleral exit)
Postoperatively
To set the bleb for success, an appropriate regimen of corticosteroids should be prescribed in the early postoperative phase
In patients where occlusion of the implant is suspected (ie, with a sudden IOP increase), consider using Nd:YAG laser instead of needling
Postoperative needling should be attempted when bleb fibrosis is suspected[35]
When the first implantation is considered suboptimal (eg, learning curve, nonoptimized surgical technique, or unknown history of prior surgery), consider implanting another gel stent in a different location, using your most successful technique/approach

Note: [a] Although the authors do not necessarily follow all of the steps described in this table (please see the sections on Preparing for implantation; XEN45 implantation with closed conjunctiva or a small suture-free incision; XEN45 implantation with open conjunctiva; Current experience with XEN63; Postoperative care; Minimizing postoperative fibrosis; Long-term gel stent outcomes and obstruction; and When to perform a second gel stent implantation for details), there is general agreement that these are important considerations. [b] ~1 mm in the anterior chamber, ~2 mm as scleral tunnel, and ~3 mm in the subconjunctival space.
Abbreviations: IOP, intraocular pressure; MMC, mitomycin C; Nd:YAG, neodymium-doped yttrium aluminum garnet; PoST, posterior sweep of Tenon's capsule; OVD, ocular viscoelastic device.

Preparing for Implantation

In the early 1990s, long-term use of topical IOP-lowering combination therapy was identified as a significant risk factor for failure of a glaucoma filtering procedure.[36,37] Therefore, some of the authors recommend starting a preoperative medication regimen with topical/ophthalmic corticosteroids to prepare the ocular surface for surgery and help curb the ocular inflammatory response from the surgery or any preexisting inflammation (eg, ocular surface disease, chronic use of glaucoma medications, etc).

Some of the authors also recommend, when possible, reducing the number of topical IOP-lowering medications (especially agents causing hyperemia) before surgery and, if needed, replacing them with preservative-free alternatives or oral carbonic anhydrase inhibitors (Figure 1). It is worth noting, however, that some authors often skip those steps to avoid delaying the surgery.

The surgical procedure starts with a standard preparation and draping of the surgical field, followed by placement of a corneal traction suture (if preferred as a method for traction) in the target quadrant, ensuring that the traction suture does not obstruct view of the implantation. To do so, JP typically places a 6.0 Vicryl suture slightly nasally or temporally to avoid interference with visualization of the implant in the anterior chamber (Figure 2).

Scleral vessels should then be identified, and the surgical plan should involve avoiding placement of the implant through those vessels to prevent subconjunctival hemorrhage.

It is also important to position the implant in the angle so as to keep it away from the iris (which can otherwise block and obstruct the implant, especially in the presence of a low IOP in the early postoperative period) and the cornea (to reduce the risk of endothelial cell loss); one should aim to enter the anterior chamber above the trabecular meshwork.

These steps apply to all gel stent implantation approaches, whether performed via an ab-interno or ab-externo approach with closed or open conjunctiva.

XEN45 Implantation with Closed Conjunctiva or a Small Suture-Free Incision

Rationale

Implantation of the gel stent with closed conjunctiva (or suture-free incision) has minimal impact on the conjunctival tissue, allowing for a quick postoperative recovery and sparing the tissues for future surgical procedures.

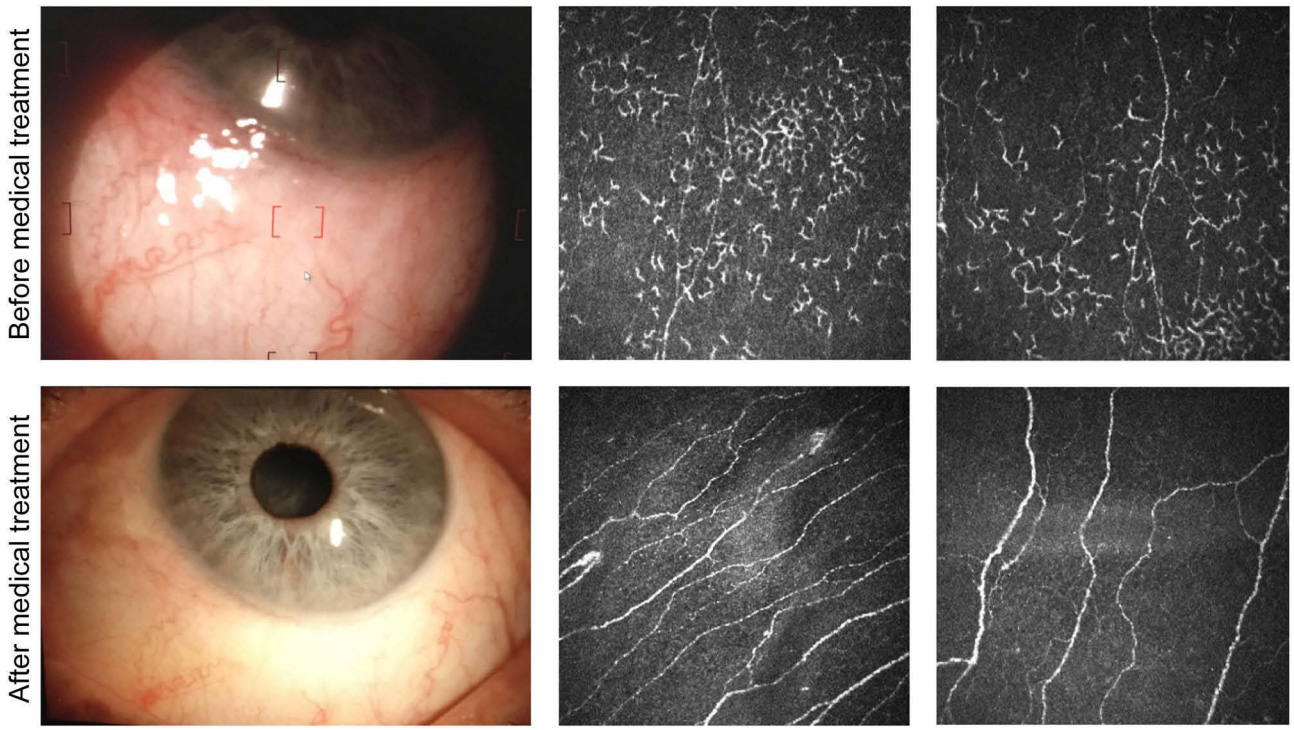

Figure 1 Case of a patient with baseline intraocular pressure (IOP) of 30 mmHg on 4 glaucoma medications who was referred for surgery. Preoperatively, the patient was treated with topical corticosteroids (benzalkonium chloride-free) three times a day (TID), and IOP-lowering medications were replaced with a preservative-free prostaglandin (once daily) and oral acetazolamide (250 mg TID) to reduce inflammation and prepare the ocular surface for gel stent implantation. Slit lamp (ocular surface) and confocal microscopy (corneal sub-basal nerve plexus layer) images were taken before medical treatment and 3 weeks after medical treatment. Top row: Ocular surface inflammation and high dendritic cell density at baseline. Bottom row: Quiet eye with a lower dendritic cell density at 3 weeks post-medical treatment. Images courtesy of Matteo Sacchi.

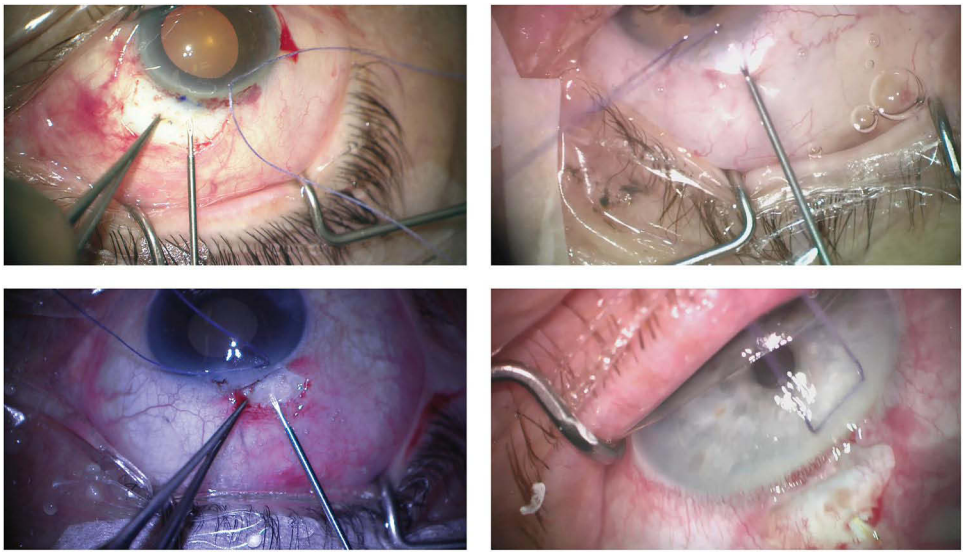

Figure 2 Images showing off-center placement of corneal traction sutures to avoid obstructing visualization of the gel stent during implantation. Images courtesy of Joseph Panarelli and Thomas Samuelson.

Ab-Interno Approach

Ab-interno implantation of the gel stent with closed conjunctiva is based on the technique previously described by Sheybani et al,[34] and follows the usual steps: paracentesis, use of an ophthalmic viscoelastic device (OVD), creation of a main corneal incision, engaging the angle (with the needle of the injector), exiting in the subconjunctival space (after

any torsion/counterforce from the traction suture or other source has been released to allow the eye to return to its natural position), and deploying the implant to leave ~1 mm in the anterior chamber, ~2 mm as scleral tunnel, and ~3 mm in the subconjunctival space.

After or before deployment, additional maneuvers are needed to ensure that the implant is not caught or embedded in Tenon's tissue, which in turn ensures outflow and increases the probability of surgical success (Figure 3; Video #1). These latest improvements are presented below.

Surgical Pearl from Arsham Sheybani: Primary Needling

- I consistently perform a primary needling after implantation. The rationale is that the subconjunctival space is a virtual space (ie, we create it or dissect the tissues, but it is not a true potential space or pre-existing cavity) and the distal end of the gel stent often gets caught in Tenon's layer. This can cause additive resistance to the aqueous humor outflow at a minimum, or it can cause the implant to point upward toward the conjunctiva (Figure 4; Video #2), a risk factor for conjunctival erosion. In my experience with intraoperative optical coherence tomography (OCT), Tenon's layer can indeed be seen around almost all devices, despite attempts for superficial placement of the gel stent (Figures 5 and 6; Video #3).
- It is also well known that early postoperative needling is commonly needed to increase surgical success of the gel stent; it thus seems logical to adopt primary needling as part of the standard implantation procedure instead of the postoperative care.
- Performed as shown in Video #3, after priming or forming a bleb (recommended to reduce the risk of conjunctival perforation), a primary needling with a 27G hypodermic needle ensures that the Tenon-related resistance is obviated (underneath and above the implant) and the distal end of the gel stent is free and lying flat. However, caution is necessary to avoid sweeping too aggressively/rapidly and causing a loss of view due to subconjunctival hemorrhage. Some surgeons use a 27G needle to make a small puncture hole through which a cyclodialysis spatula is inserted and used to do a broad sweeping (preferably in a relatively dry area to ensure good visualization of Tenon's

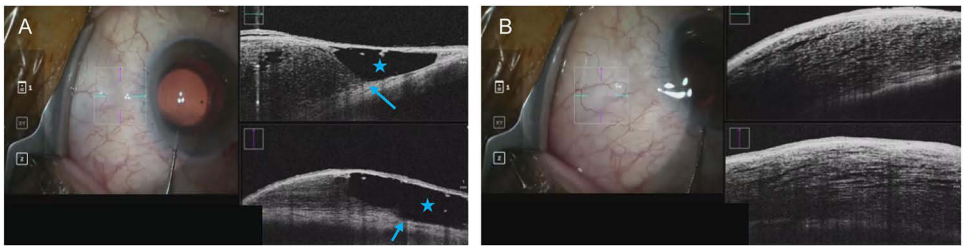

Figure 3 Intraoperative live optical coherence tomography images showing (**A**) insertion/beginning of Tenon's capsule (blue arrow), as well as a hyporeflective space indicative of a lack of Tenon closer to the limbus (blue star), and (**B**) hydrated, expanded Tenon tissue 3 to 10 mm posterior to the limbus. Images courtesy of Herbert Reitsamer.

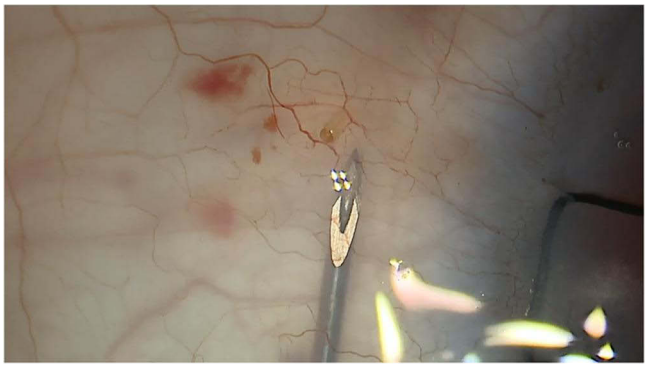

Figure 4 Image showing a gel stent pointing up, prior to the primary needling. Image courtesy of Arsham Sheybani.

https://doi.org/10.2147/OPTH.S487718

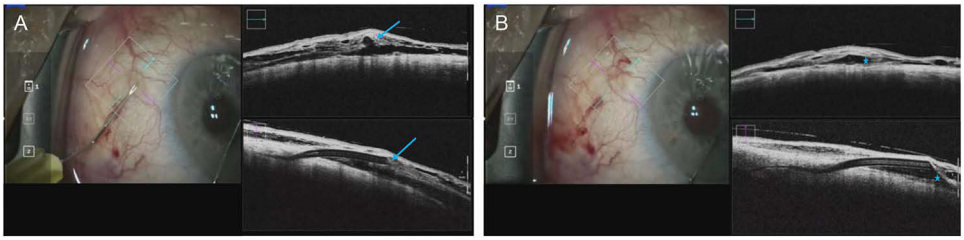

Figure 5 Intraoperative live optical coherence tomography images showing (**A**) intraTenon placement of the gel stent and interstitial tissue surrounding the distal tip of the implant (blue arrows) before primary needling, and (**B**) subTenon placement of the gel stent and hyporeflective space (stars) after primary needling. Images courtesy of Herbert Reitsamer.

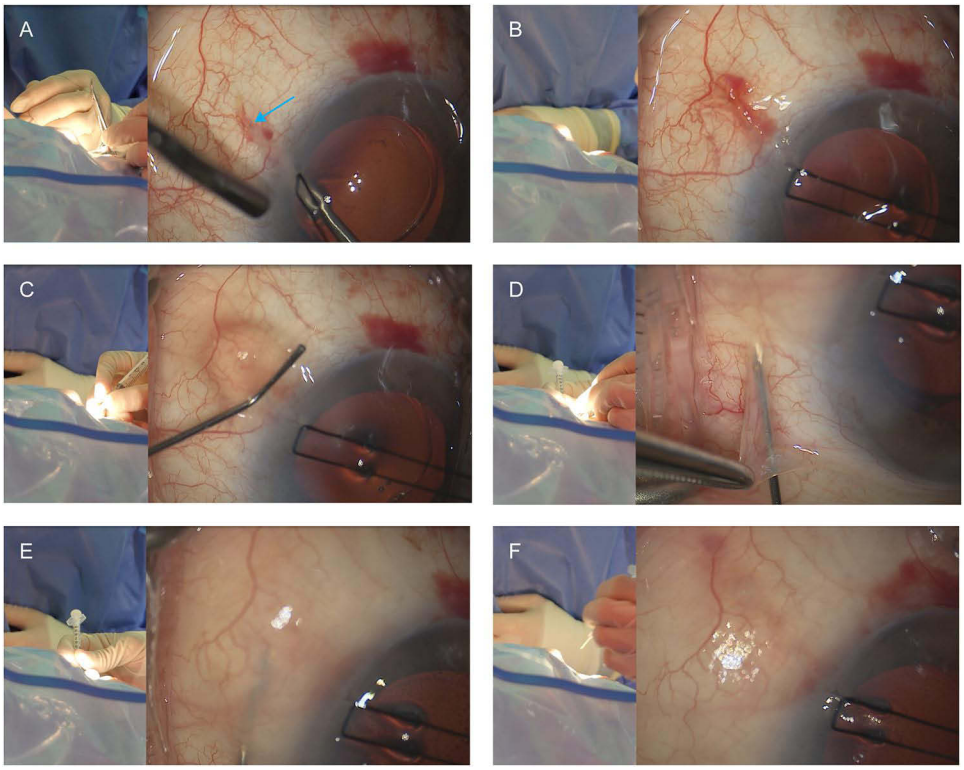

Figure 6 Images showing key steps of the primary needling. (**A**) Gel stent slightly curled (blue arrow) right after implantation. (**B**) Curled gel stent despite external manipulation. (**C**) Bleb formation showing a focal, tense bleb before the primary needling and suggesting interstitial placement (outflow resistance). (**D**) Elevation of the conjunctiva with forceps to keep the needle off the scleral bed/vessels. (**E**) Primary needling. (**F**) Diffuse bleb appearance after primary needling. Images courtesy of Arsham Sheybani.

tissue), with good reproducibility and a lower risk of conjunctival/scleral trauma, compared with using a needle (oral communication from Dr. Manjool Shah, November 2023).

- Injecting an OVD after the primary needling (Figure 7) provides better tissue separation, prevents contact, and thus reduces the risk of fibrosis. Some surgeons use OcuCoat (Bausch + Lomb, Laval, Quebec, Canada), which has a good viscosity/stiffness balance, compared with ProVisc (Alcon) and Healon (Johnson & Johnson Vision, Jacksonville, FL, USA).
- Inserting the needle as far away from the gel stent as possible and keeping it off the scleral bed/vessels reduces the risk of bleb leak (which can lead to bleb failure) and minimizes subconjunctival hemorrhage, respectively.
- One should also ensure to fulcrum the needle at the site of insertion (instead of pulling upward) to avoid tearing the conjunctiva. Should the latter occur, however, I (AS) recommend suturing it.

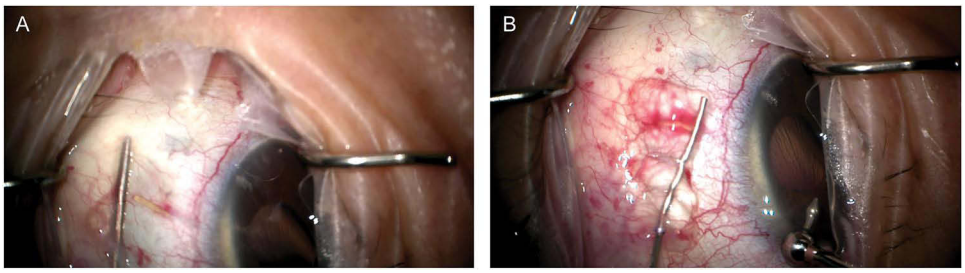

Figure 7 Images showing (**A**) a primary needling with cyclodialysis spatula and (**B**) injection of an ocular viscoelastic device after the primary needling. Images courtesy of Manjool Shah.

- To avoid pulling/moving/displacing the implant, it is best to start sweeping the needle far from the distal end of the gel stent (and underneath it) before going closer to its base (where it exits in the sclera); sweeping can then proceed from the base of the implant toward the cul-de-sac until Tenon's resistance is no longer felt. If the implant is curled, sweep gingerly to gently release it from Tenon's tissue; if the implant is straight and appears mostly free, the sweeping can be a bit more aggressive.
- Proper visualization throughout the process is key. The goal is to separate the tissue planes so the needle moves freely and easily within the created space; if the primary needling is successful, one should not see the gel stent move with Tenon's layer.
- In cases in which the view of the implant is lost due to hemorrhage, primary needling should be paused; the hemorrhage should first be stopped and then displaced superiorly (or away from the implant) by sweeping the blood with a blunt cannula against the conjunctiva. If the hemorrhage is significant, a peritomy and/or cautery may be necessary to clear the blood.
- In my experience, ab-interno implantation with closed conjunctiva and primary needling reduces the postoperative needling rate from ≥30% to <10%, compared with the same implantation technique without primary needling, and results in more favorable surgical success. The key is to raise the bleb to create space to work and sweep/needle as far away from the entry site as possible, starting at the distal end of the implant. Leaving OVD in the space keeps it open and avoids compression of the bleb (which eventually causes the tissues to stick together). Interestingly, Franco et al presented[38] a technique (Air and Visco) in which an OVD is injected in the subconjunctival space after pneumo-dissection of Tenons' tissue and before ab-interno implantation of the gel stent. The needling rate was 20%,[38] perhaps suggesting that pneumo-dissection is not as effective as a primary needling in creating a Tenon-free window. It is also worth noting two retrospective studies that compared outcomes in patients who underwent ab-interno implantation of the gel stent with or without a primary needling (and without subconjunctival OVD).[39,40] At 12 months, both showed no statistically significant differences between groups in terms of IOP and medication number reductions from baseline, but fewer postoperative interventions,[39] needling,[40] and clinic visits[40] were required when the primary needling was performed.
- One potential disadvantage of this procedure, compared with the open-conjunctiva approach, is that one cannot really verify that outflow occurs through the implant (intraluminal flow), as opposed to peritubular flow. Also, subconjunctival hemorrhage can sometimes force the surgeon to open the conjunctiva. Raising the bleb by priming the implant and removing the OVD before needling can provide the space needed to avoid hitting a scleral vessel or puncturing the conjunctiva. Nonetheless, I still recommend being familiar with alternative implantation techniques in case Tenon's tissue is thicker than estimated or subconjunctival hemorrhage obstructing the view does occur.

The data and my (AS) experience point convincingly to the importance of primary needling following gel stent implantation. If primary needling is not performed systematically, proper placement of the gel stent (subTenon or anterior to Tenon's capsule) and use of a higher dose of MMC (see "Minimizing postoperative fibrosis" below) injected in the subconjunctival/subTenon space are –in our (AS, DG) opinion– critical to minimize fibrosis/scarring. However, I (AS) prefer to avoid high MMC doses when possible.

https://doi.org/10.2147/OPTH.S487718

Surgical Pearls from Davinder Grover: Pull Test and Posterior Sweep of Tenon's Capsule (PoST)

- Following placement of the gel stent with closed conjunctiva, one should gently mobilize adjacent conjunctiva and perform a pull test (Video #4); one may not realize how often the implant gets caught (curled or not) in Tenon's tissue unless a routine check-up is implemented.
- If the gel stent moves with the conjunctiva, it is very likely embedded within Tenon's capsule (movement on the "pull test"). At this point, a PoST technique should be performed (Video #4) to create a Tenon-free window.[41]
- Initially designed for needling of the implant at the slit lamp, the Grover Fellman (GF) Spatula[42] (Epsilon USA, Chino, CA, USA) is now used to perform the PoST technique immediately following gel stent implantation. This spatula provides a stiffer tool with a blunted, tapered tip (compared with a 30G needle) to allow atraumatic sweeping of Tenon's tissue far into the fornix (10–12 mm) and away from the gel stent, while minimizing the risk of conjunctival perforation and cutting blood vessels (which can happen with a sharper instrument).
- Once the gel stent is implanted, I (DG) rotate the globe inferiorly with the traction suture and, with a bent, marked 30G needle, create a small entry site into the superior temporal conjunctiva (as far posteriorly as possible in the superior temporal area to prevent the entry wound from leaking). The GF spatula is inserted through this site, which is easily identified by the marked entry point, and the tapered tip of the instrument allows to tunnel through Tenon's tissue more easily and in a controlled fashion.
- When performing the PoST technique, it is important to 1) have good scleral support (ie, 2.0–2.5 mm of scleral tunnel to prevent implant displacement and peritubular flow), 2) sweep very slowly/gently (while keeping your eyes on the implant to avoid dragging it), 3) start sweeping on the scleral side of the implant before delicately proceeding to the conjunctival side, 4) stop sweeping if the implant starts moving (getting pulled out of the eye) and gently push the implant back into the anterior chamber before resuming sweeping, 5) avoid sweeping too far nasally (to avoid formation of a nasal bleb), and 6) inject MMC at the end of the surgery, as far posteriorly as possible into the area where Tenon's tissue was swept.
- The goal is to ensure that Tenon's tissue is disinserted in an area surrounding the gel stent, as small, localized disinsertions will otherwise tend to create walled-off blebs or Tenon's cysts.
- Tenon's tissue is rather thick, and one can usually see the disinserted tissue bunch up posteriorly to the Tenon-free window. Injecting MMC into this Tenon's tissue allows delivery of MMC directly posterior to where the aqueous humor is being shunted, minimizes the risk of anterior migration of MMC (which could lead to an anterior ischemic bleb), and favors a better bleb morphology. Before I started performing the PoST technique, I typically injected 60–80 µg of MMC (0.15–0.2 mL of a 0.4 mg/mL solution). However, since implementing the PoST technique, I have reduced my dose of MMC to ~40–60 µg (0.1–0.15 mL of a 0.4 mg/mL solution).
- The pull test and PoST technique should be repeated until the implant no longer moves with the conjunctiva.
- Intracameral dexamethasone is then given at the conclusion of the case. If the eye has previously undergone angle surgery, there is sometimes an increased risk of reflux bleeding and hyphema, in which case I typically give dexamethasone as a subconjunctival injection instead.
- If the entry wound leaks or there is a buttonhole, I use a single interrupted (or mattress) nylon suture to close the conjunctiva. Usually, Tenon's tissue is thicker in the superior temporal quadrant, so be sure to incorporate Tenon's tissue when placing a suture through the small conjunctival opening.
- In my experience, the PoST technique can provide an ideal (diffuse[25]) bleb morphology, predictably result in low-teen IOP with ≤1 medication at 12 months, and lower the postoperative needling rate to <10%. Additionally, visibility of the gel stent in the subconjunctival space is usually improved and I can regularly appreciate microcysts within the bleb, which was not always the case before implementation of the PoST technique.
- If a perforation occurs while sweeping to disinsert Tenon's tissue, I recommend removing the implant and reinjecting the implant in another area as sutures will often times not remedy the situation. This is also why I perform the PoST technique with the GF spatula instead of a needle.
- Since 2023, I also routinely leave a small OVD "crown" around the subconjunctival tip of the gel stent. Specifically, once the PoST technique is complete, I tunnel to the subconjunctival space around the distal tip of the implant and

inject a small amount of Healon GV (Johnson & Johnson Vision) to create/maintain a small space that may inhibit fibroblast proliferation and consequent scar tissue formation around the subconjunctival tip of the implant in the immediate postoperative period (Figure 8).

- With this PoST technique, I see preimplantation IOPs in the mid-20s (mmHg) on several IOP-lowering medications decrease to the low-teens (mmHg) on ~1.0 IOP-lowering medication postimplantation, without major differences between the implant alone and phacoemulsification plus implant. That being said, in some analyses, eyes that received the gel stent as a standalone procedure tended to have a slightly lower IOP than those that underwent a combined phacoemulsification/gel stent procedure.

Data

In a retrospective study of 87 eyes (70 patients) with OAG refractory to prior surgical procedure and/or medications, ab-interno placement of the gel stent with closed conjunctiva (with or without phacoemulsification) followed by the PoST technique reduced the mean IOP from 18.7 mmHg (medicated baseline) to 13.1 mmHg (month 12), and the mean medication count from 3.4 (baseline) to 1.4 (month 12), representing reductions of 5.5 mmHg and 2.1 medications (P<0.005 for both).[41] Notably, these findings are consistent with previously published studies in which reductions of 6.1–8.4 mmHg and 1.4–2.1 medications were reported.[33,34,43,44] However, our postoperative needling rate was considerably lower (9.2%; n=8/87)[36] than that previously published (23%–45%),[33,34,43–46] suggesting that the PoST technique can reduce the rate of postoperative needling.

Surgical Pearl from James Lee: Small-Incision Implantation

An alternative method to performing a primary needling or the PoST technique systematically, is the minimally invasive, small-incision, suture-free technique that allows subTenon placement of the gel stent and provides a large area of low resistance in the subTenon space, while requiring minimal manipulation of the conjunctiva (Video #5). Exposure to

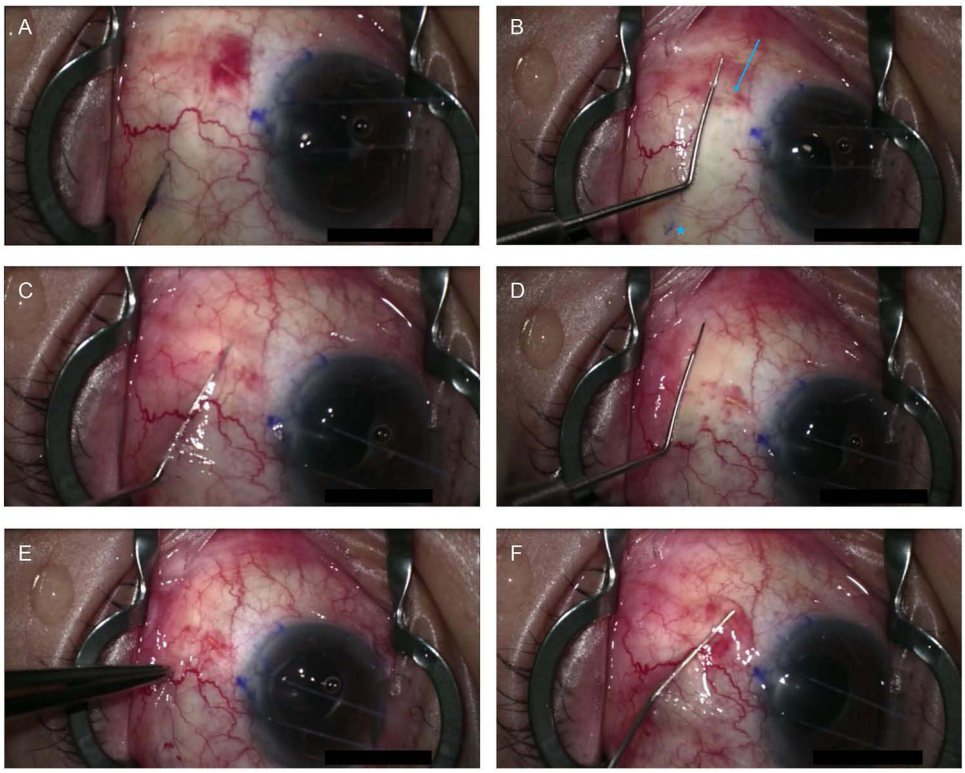

Figure 8 Images showing key steps of the PoST technique. (**A**) Entry site of the marked 30G needle. (**B**) Identification of the gel stent (blue arrow) and conjunctival entry point (blue star) using the Grover Fellman spatula. (**C**) Sweeping of Tenon's tissue surrounding the gel stent. (**D**) Tenon-free window. (**E**) Pull test demonstrating that the gel stent is not moving with the conjunctiva or embedded in Tenon's tissue. (**F**) Subconjunctival injection of a small amount of ocular viscoelastic device to create a "crown" around the distal tip of the implant. Images courtesy of Davinder Grover.

https://doi.org/10.2147/OPTH.S487718

MMC is also minimal (area-wise), which is important as MMC can lead to corneal and conjunctival toxicity, produce avascular blebs, inhibit lymphangiogenesis,[8,32,47] and thus prevent use of other incisional procedures in the future.

The objective is to create a large, easily sealable, and well-defined subTenon space before implantation of the gel stent, with minimal damage to the overlying conjunctiva, so the area can be utilized for future surgeries if required. In my (JL) opinion, it is easier and more reproducible to create the subTenon space first and target it for implantation than to implant the gel stent and then perform a primary needling or the PoST technique. This approach also allows to apply a very low dose of MMC to a very specific area and thus minimize toxicity.

- A small (4-mm) conjunctival incision is made in the superotemporal conjunctiva. This allows easier disinsertion of Tenon's tissue from the sclera.
- Instead of needling, blunt-tipped dissecting scissors are then used to create (by repeatedly opening and closing the scissors without actual cutting) a large subTenon space extending from the superotemporal incision site to within 1.5 mm of the limbus in the target zone, and posteriorly to at least 15 mm (Video #5).
- After irrigation of the subTenon space with lidocaine and epinephrine (for anesthesia and hemostasis), MMC is applied using a presoaked sponge inside a 3D-printed cartridge, starting at 1.5 mm from the limbus and moving sequentially to 8 mm posteriorly. This allows direct surface contact with Tenon's tissue and the sclera while preventing excess MMC from damaging the surrounding tissues. The MMC exposure time and concentration are controlled based on a patient's risk profile for excessive subTenon space scarring. For example, I (JL) generally use 0.1 mL of a 0.4 mg/mL solution for 30 sec in patients at low risk of fibrosis, and increase exposure time to 45 sec in patients at high risk of fibrosis, and no MMC-related complications have occurred so far in my practice.
- The subTenon space is then expanded with ProVisc (Alcon) to ease implantation in the preferred/targeted site.
- At this point, the gel stent can be delivered either ab interno or ab externo, depending on the patient's anatomy. Placement is confirmed, and adjustments to the implant positioning are performed if needed.
- Once the excess of ProVisc is swept out of the subTenon space, making sure to leave enough behind to separate the overlying conjunctiva/Tenon's layer from the sclera and minimize tissue contact, the incision is closed with tissue/fibrin glue (Figure 9).
- If the patient's IOP reaches 10 mmHg in the early postoperative period (usually within 1–2 weeks), digital massage of the eye is advised twice a day for 2–3 months.

A similar ("semi-open") procedure was described by Kong et al[48] and although the rate of qualified success (IOP 6–21 mmHg or IOP reduction from baseline >20% with or without medications) at 12 months was high (97%), the rate of complete success (without medications) appeared low (32%). Whether this could be due to technical differences between approaches (eg, target quadrant) is unclear. Whether a primary needling, the PoST technique, or the suture-free implantation approach is used, the goal is to place the implant below Tenon's layer and eliminate Tenon's resistance by creating a space, and to leave OVD in the created space to keep it open (ie, maintain the tissues separated), which was shown (in the authors' experience) to reduce the need for postoperative needling, as well as the risk of bleb failure. If postoperative needling is needed, having disinserted/swept Tenon's tissue away during implantation will facilitate visualization of the implant and thus the needling itself. This does not mean, however, that the gel stent cannot be successfully implanted without dissection of Tenon's tissue. For example, a case of gel stent implantation with OVD and without mechanical dissection of Tenon's tissue was reported in an eye with advanced pseudoexfoliation glaucoma that had previously undergone several glaucoma surgeries/procedures.[49] Specifically, Healaflow (Anteis S.A., Geneva, Switzerland) was used to create a subconjunctival "bubble" within which the subconjunctival end of the gel stent was positioned. Six months after implantation, IOP remained stable and at target (14 mmHg), without any medication.[49]

Most studies of the gel stent published to date are based on the ab-interno implantation with closed conjunctiva. In our opinion, advantages of this approach and related technical pearls (described above) include sparing the conjunctival tissue and the fact that surgical sutures are typically not needed. Disadvantages include the fact that the procedure does not allow to confirm redirection of aqueous outflow through the implant (versus peritubular flow). It is also noteworthy

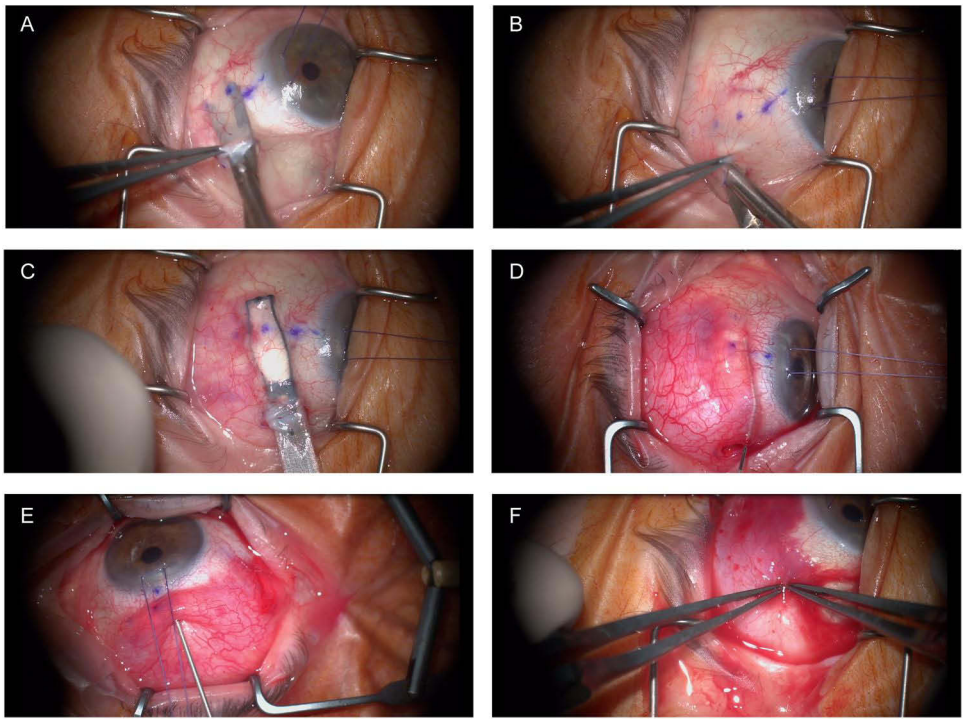

Figure 9 Images showing key steps of the small-incision implantation technique. (**A**) Small (4-mm) conjunctival incision and dissection of a large subTenon space. (**B**) Posterior dissection of the subTenon space. (**C**) Controlled application of mitomycin C. (**D**) Expansion of subTenon's space with an ocular viscoelastic device. (**E**) Gel Stent implantation. (**F**) Closure of the conjunctival incision with tissue/fibrin glue. Images courtesy of James Lee.

that this procedure requires healthy, mobile conjunctiva in the target implantation area and is thus usually not indicated for patients who (for example) have conjunctival scarring due to a prior incisional glaucoma surgery in the target area.[31]

Ab-Externo Approach

Compared with ab-interno closed-conjunctiva implantation, the ab-externo closed-conjunctiva implantation tends to be an even less invasive procedure as it does not require corneal incisions, use of an OVD, or maneuver in the anterior chamber (ie, irrigation). It also expands the treatment area to the superotemporal quadrant and does not require crossing over the lens, making it potentially safer.[50]

The procedure, also known as transconjunctival implantation, is performed similarly as previously described by Vera et al.[25] Any of the aforementioned techniques describing how to ensure that the implant is free of Tenon's tissue and the implantation space/pocket remains open can be used in conjunction with this implantation approach to minimize fibrosis and increase the probability of surgical success. Some surgeons also stain the implant (with a purple marker or Trypan blue) to facilitate visualization of the implantation progress, or in cases with a particularly thick conjunctiva (oral communication from Dr. Robert J. Noecker, November 2023).

XEN45 Implantation with Open Conjunctiva

Rationale

Implantation of the gel stent with open conjunctiva has the advantage of allowing placement beneath Tenon's layer (which lowers the risk of conjunctival erosion, gel stent extrusion, and late infection), better control of the gel stent positioning, and implantation in patients with some conjunctival scarring.[31] The surgeon can indeed move or dissect Tenon's capsule, choose the exact placement location, visually confirm intraluminal flow, and make small adjustments more easily with the open-conjunctiva approach than the closed-conjunctiva approach.[31] It also allows the use of higher concentrations of MMC (see "Minimizing postoperative fibrosis" below), as two tissue layers cover the implant, and could be an alternative surgery after implantation with closed conjunctiva fails.

https://doi.org/10.2147/OPTH.S487718

Ab-Interno Approach by Joseph Panarelli

The basic procedure is as previously described,[31] with additional details, adjustments, and guidance (Video #6).

- On surgery day, I like to start with a retrobulbar block so the patient remains still and comfortable throughout the procedure, but local anesthesia with a subconjunctival or subTenon injection of lidocaine 2%/epinephrine can be used instead.
- Regarding MMC, my preference is to do a subTenon injection of 60 ug as the implant will be placed under Tenon's and conjunctival tissues.
- A fornix-based conjunctival flap is created (3–4 mm long) at the 11 or 1 o'clock position.
- Vannas scissors are used to make a small opening in the conjunctiva; dissection then proceeds posteriorly until incision of Tenon's capsule at the desired insertion point.
- A superonasal or superotemporal pocket is dissected with blunt Westcott scissors, and cautery is used as needed to control bleeding. As mentioned above, staining the implant (with a purple marker or Trypan blue) will facilitate assessment of progress and positioning.
- Once the pocket is created and paracentesis is completed, a 2-mm clear corneal incision is made, and the anterior chamber is filled with a cohesive OVD.
- The injector needle is then inserted through the corneal incision and advanced across the anterior chamber toward the target quadrant and into the angle.
- The needle tip (bevel facing up) enters the trabecular meshwork and is pushed through the sclera so as to exit 2 mm posteriorly to the limbus. To help stabilize the eye, provide good countertraction, and avoid a flick during this step, Colibri forceps (0.12 mm), the Vera hook, or other instrument can be inserted into the paracentesis.
- Once the needle exits the sclera, any torsion/counterforce (including the traction suture) is released to allow the eye to return to its natural position before the stent is deployed. I (JP) actually like delivering the implant with the two-hand technique to avoid flicking (one hand on the injector and second hand to move the slider).
- Ideal positioning in the eye leaves ~1 mm in the anterior chamber, ~2 mm as scleral tunnel, and ~3 mm in the subconjunctival space. Gonioscopy should be performed to confirm angle placement.
- The open conjunctiva and direct visualization of the gel stent's external end allow micro-adjustments to be made easily, ie, pull the implant out or push it into the anterior chamber (using tying forceps) as needed to ensure proper positioning, and observation of peritubular flow (if present).
- After removal of the OVD from the anterior chamber, a Weck-Cel (BVI Medical, Waltham, MA, USA) is used to touch the distal end of the gel stent and confirm that the aqueous humor flows through; if not, the gel stent should be primed by back-flushing it (from outside the eye) with sterile balanced salt solution (BSS) in a 25G or 27G cannula.
- Tenon's layer and the conjunctiva are then carefully pulled up (to avoid dragging the implant into the anterior chamber) and forward, laid over the gel stent, and closed in a watertight fashion with either two winged sutures or two horizontal mattress stitches on the limbal side plus a short running closure on the other side. I (JP) do not necessarily do a two-layer closure but will sequentially pass through Tenon's tissue and the conjunctiva to suture them down.
- Before the peritomy is fully closed, I (JP) inject Healon GV or even Healon5 (Johnson & Johnson Vision) to keep the space open and maintain the tissues separated (where the bleb will form).
- The corneal incisions should be hydrated with BSS, and a bleb should form. A Seidel test should also be performed to ensure that there is no conjunctival or corneal incision leak.

Ab-Externo Approach by Joseph Panarelli and Thomas Samuelson

In addition to the aforementioned advantages associated with implantation of the gel stent with an open conjunctiva, ab-externo implantation can be beneficial not only for the reasons mentioned above but also because 1) it allows treatment of patients that may otherwise not be eligible for ab-interno implantation (eg, due to prior trabeculectomy in the superior or superonasal area and/or certain facial features); 2) it reduces the likelihood of the gel stent's distal end becoming

embedded in Tenon's tissue due to fibrosis;[25,31] and 3) it is –in my (JP) opinion– less prone to early failure. Consistent with points #2 and #3, Han et al[51] reported blebs with greater horizontal extent at 2 weeks and 1 month following ab-externo implantation with open conjunctiva, which was associated with a lower surgical failure rate and higher success rate (ie, IOP ≤18 mmHg and either IOP reduction ≥30% or medication reduction ≥2 with final IOP inferior to baseline if baseline IOP was ≤18 mmHg) early on and at 12 months (74% versus published values for the standard ab-interno approach).

Some surgeons may also be more at ease with the ab-externo approach with open conjunctiva as it is technically closer to the approach used with glaucoma drainage device implantation,[25,31] making the learning curve shorter and troubleshooting easier.

From a practical viewpoint, this procedure is based on that previously described by Panarelli et al,[31] with a few modifications, additional details, and recommendations (Video #7 and Video #8).

- A 2–3 clock-hour limbal peritomy is made in the superonasal or superotemporal quadrant, followed by blunt dissection with Westcott scissors to separate the conjunctiva-Tenon's adhesions and access the subTenon space (Video #8).
- It is best to cauterize the blood vessels at this point as this allows better visualization and reduces the risk of blood later occluding the distal end of the gel stent. However, cautery should not be overused as scleral elasticity helps maintain the implant in place and avoid migration postoperatively. Excessive cautery on the scleral tissue will reduce scleral elasticity and thus implant stability over time.
- In cases of significant or thick Tenon's tissue (due to age, inflammation, scarring, or other risk factors), a limited tenonectomy can be performed. This can potentially decrease the risk of stent obstruction and early failure, but it can also increase the risk of a "thin bleb" forming with potential for conjunctival erosion.
- Once the gel stent injector is situated in the sclera (avoiding the 12 o'clock position), with the needle bevel up, a 2.0-mm scleral tunnel is created from the limbus (a longer tunnel tends to lead to a more anterior positioning of the implant while a shorter tunnel increases the chances of peritubular flow). The needle is then advanced through the sclera until the tip reaches the surgical limbus (Video #7).
- At this point, the needle is tilted downward (~30°) and advanced until it enters the anterior chamber.
- To avoid fragmenting the gel stent or under-/over-deployment, I (JP) recommend the following precautions: 1) check that there is no side or upward pressure on the injector and 2) pull the injector slightly back so that its sleeve is ~1 mm from the scleral entry point (Video #8). In my (TS) opinion, absolute control of the eye position is required during implantation. That is, the injector trocar must not influence the eye position. If it does, the eye will rotate as soon as the needle exits the sclera. Because the gel stent is still partially within the injector at this point, any rotation of the globe risks the so-called "flick" amputation of the stent. The eye position must thus be entirely controlled with either the traction suture or with a toothed forceps to eliminate any rotation as the needle exits the eye and the deployment is completed (Video #7).
- Alternatively, I (JP) use a 27G bent needle (as is done for tubes) and make a 2-mm tunnel. In my experience, this results in less peritubular flow while allowing better control. The technique is more ergonomic, easier to use in patients with deep-set eyes or prominent brows, and one does not have to worry about flicks.
- Once the gel stent is implanted, aqueous humor outflow through the gel stent should be visible and confirmed; if peritubular flow is present, I (JP) recommend drying the area with a Weck-Cel and confirming flow from the distal end of the stent. A 10.0 nylon encircling suture can be placed ~1 mm posteriorly to the limbus to reduce flow and minimize the risk of early hypotony, although I do not routinely do this. If flow is not seen after implantation, the chamber can be pressurized to prime the implant. If there is still no flow, the gel stent could be primed by back-flushing it (from outside the eye) with sterile BSS in a 25G or 27G cannula.
- Once flow through the gel stent is confirmed, its position can be adjusted with tying forceps so that ~1 mm extends in the anterior chamber (as described above).
- To reduce the risk of the stent becoming entangled within Tenon's tissue, I (TS) make sure that the gel stent lays flat and then insert a sheet's glide under Tenon's layer but over the stent to protect its position. A perfectly placed

implant can potentially be bent sideways or dragged forward by Tenon's tissue as the conjunctival flap is pulled forward to the limbus during placement of the initial sutures (peritomy closure). I (TS) also inject dexamethasone and an OVD (Amvisc Plus, Bausch + Lomb) within the created pocket to reduce inflammation and further elevate Tenon's tissue (ie, create a domed canopy to keep the pocket open and the tissues separated), which in turn will help maintain the stent position, prevent its entanglement within Tenon's tissue, and minimize the risk of bleb failure. Once the initial sutures are placed and the conjunctiva has been advanced to the limbus, the sheet's glide is removed, and the peritomy closure is completed (Video #7).

- In my (TS) opinion, it is essential to inspect the stent position repeatedly to ensure that closure of the peritomy does not influence positioning.
- The Tenon and conjunctival tissues may be sutured together or in layers with polyglactin or nylon sutures (Video #8). My (JP) preference is to use horizontal mattress sutures at the limbus and a running wing suture at the one end (Figure 10).
- In patients at high risk for hypotony (eg, post-vitrectomy or with high myopia), an OVD agent (Amvisc Plus) is added at the end of the case and left in the anterior chamber. The amount used should be sufficient to maintain the anterior chamber while minimizing the risk of interfering with outflow through the gel stent (especially during the first 2–3 postoperative days) and consequent IOP spikes. The aqueous humor should eventually dilute the OVD, obviating the potential barrier to outflow.

In our (JP, TS) opinion, this approach is more flexible and forgiving than implantation with a closed conjunctiva approach, and the surgical time is essentially the same and predictable day after day. This is my (TS) fourth and favorite iteration of the gel stent surgical procedure, having transitioned from ab-interno implantation with closed conjunctiva to ab-externo/transconjunctival implantation with closed conjunctiva, then ab-externo implantation with open conjunctiva, and finally ab-externo implantation with open conjunctiva and an enhanced pocket (as described above).

Current Experience with XEN63

Rationale

Having a larger lumen, the 63-µm gel stent has the potential to produce greater reductions in IOP and IOP-lowering medications than the 45-µm version, due to lower resistance to outflow, albeit with a greater risk of hypotony. The inner diameter of the 63-µm gel stent (also 6-mm long) is nearly 40% larger than that of the 45-µm gel stent, increasing the lumen area by ~96%, while its outer diameter is only 12% greater (ie, 250 versus 220 µm, respectively), allowing use in the same injector and 27G needle. It is also worth noting that the outflow capacity of the 63-µm gel stent is ~1.24 µL/min/mmHg, compared with ~0.33 µL/min/mmHg for the 45-µm gel stent and ~1.30 µL/min/mmHg for the PreserFlo Microshunt[52] (Santen Pharmaceutical), another MIBS device approved for treatment of primary OAG.[53] Moreover, the IOP drop within the 63-µm gel stent has been estimated at ~1.6 mmHg, compared with ~6 mmHg for the 45-µm gel stent and ~1.5 mmHg for the PreserFlo Microshunt (assuming an outflow of 2 µL/min for all). This represents a considerable difference in pressure drop between the two gel stents in steady-state conditions of bleb resistance, and suggests that IOP lowering with the 63-µm gel stent should –theoretically– be 4.0 to 4.5 mmHg greater than with the 45-µm gel stent.

Ab-Interno Approach with Closed Conjunctiva by Ike Ahmed

The 63-µm (inner diameter) gel stent has received CE Mark in 2011 and is indicated (in Europe and Canada) for the treatment of patients with primary OAG in whom previous medical treatments have failed.[29] The surgical steps are similar to those used with the 45-µm version, including the need to release any torsion/counterforce from the traction suture and allow the eye to return to its natural position before the stent is deployed, and have been previously described by Vera et al.[25]

- Primary needling with a 30G needle is recommended to ensure that the implant is free of Tenon's tissue, after which MMC (0.1 mL of a 0.4 mg/mL solution – see "Minimizing postoperative fibrosis" below) is injected intra-Tenon and massaged over the area (Video #9).

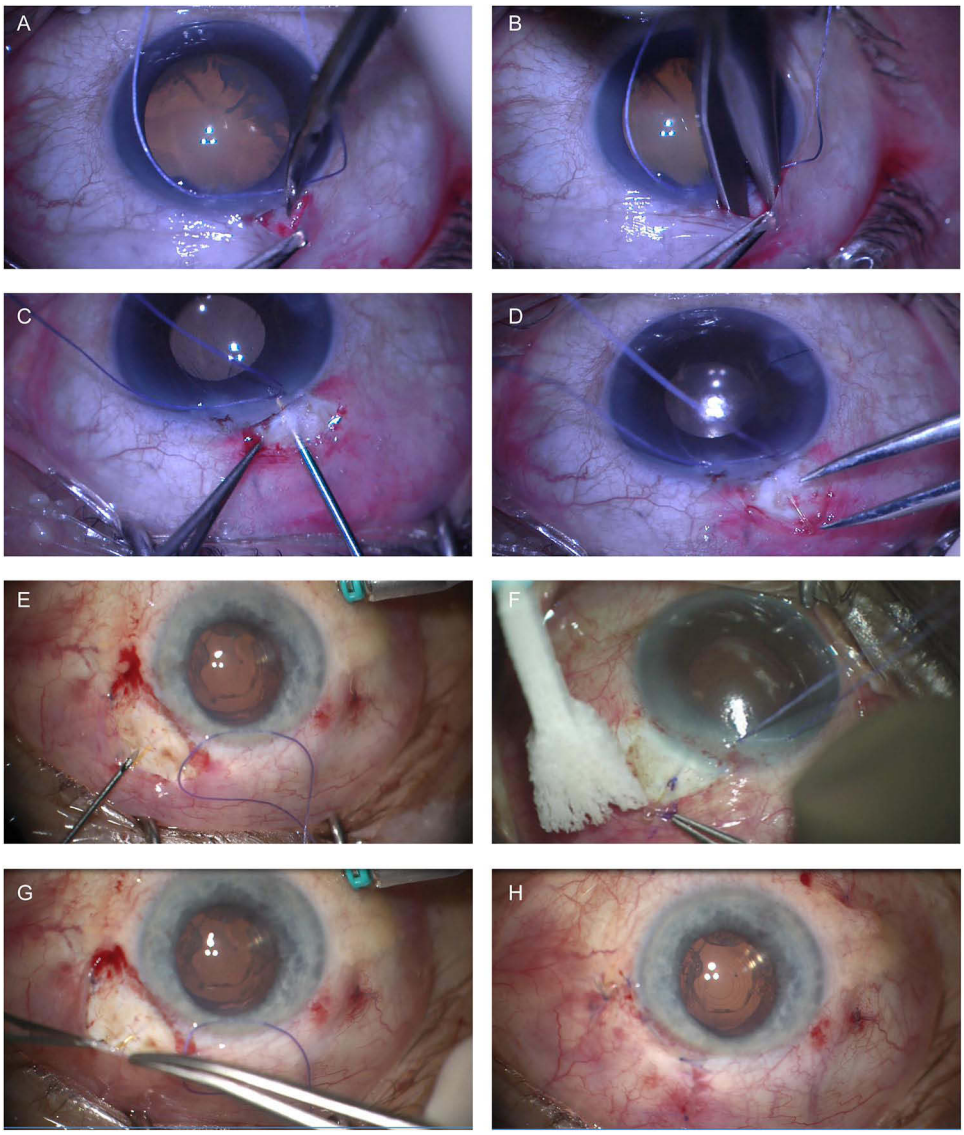

Figure 10 Images showing key steps of gel stent implantation with open conjunctiva. (**A**) A small peritomy is made. (**B**) Posterior dissection of Tenon's capsule. (**C**) Gel stent implantation. (**D**) Gel stent measurement and adjustment. (**E**) Gel stent priming with a 27G needle or cannula. (**F**) Direct visualization of outflow through the gel stent. (**G**) Careful closure of the Tenon and conjunctiva over the gel stent. (**H**) Watertight closure of the incision. Images courtesy of Joseph Panarelli.

- Technically speaking, needling is performed exactly the same way whether the 45-µm or 63-µm gel stent is used with or without phacoemulsification.
- When performing implantation with closed conjunctiva, it may be beneficial to prime the implant before implantation (Figure 11).

Ab-Externo Approach with Open Conjunctiva by Ike Ahmed

- After placing a corneal traction suture, a limbal peritomy (2–4 clock hours) in one of the superior quadrants is performed as close to the 12 o'clock position as possible, followed by release of Tenon's capsule from its insertion 1.5 mm from the limbus. This will result in Tenon's tissue retracting posteriorly. To avoid damaging Tenon's tissue, it is important to identify the anterior capsule under the conjunctiva, grasp it and elevate it off the sclera, and release further adhesions. One should only bluntly dissect with Wescott scissors once it is clear that the subTenon space can be visualized under Tenon's flap. I (IA) recommend doing a deep posterior dissection.

https://doi.org/10.2147/OPTH.S487718

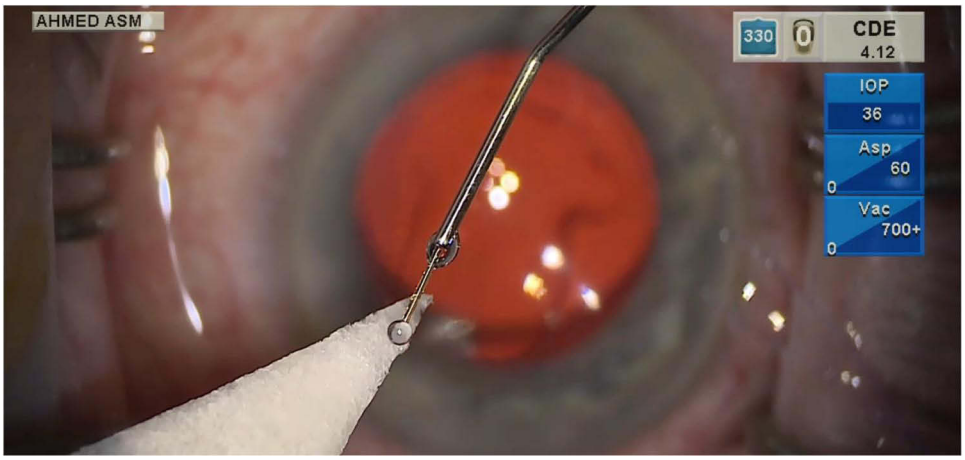

Figure 11 Priming of the 63-μm gel stent with a 27G cannula before implantation. Outflow can be visualized as small beading at the end of the implant. After flow through the lumen is confirmed, the implant is carefully reloaded back into the injector needle for implantation. Images courtesy of Iqbal Ike K Ahmed.

- A superior pocket is then created, and bleeding vessels are gently cauterized as needed with a 23G endodiathermy. Excessive cautery on the scleral tissue should be avoided as it will reduce scleral elasticity and implant stability over time (the implant's position depending on the scleral tunnel and tissue elasticity).
- MMC (0.4 mg/mL) is administered subTenon, either by injection (0.1 mL) or with sponges, being careful not to let MMC settle at the limbus. If injecting, one should not inject into Tenon's tissue as this will hydroexpand it and increase the risk of entrapment of the implant when closing. It is best to create a pool of MMC under Tenon's tissue and allow absorption in the tissue.
- Placing the gel stent injector ~2.0 mm from the limbus, bevel up on the sclera, the scleral tunnel is created (a shorter tunnel will increase the chances of peritubular flow and hypotony).
- The traction suture is used for countertraction as the needle is advanced through the sclera until the needle tip reaches the blue line.
- The needle is then tilted downward 30 degrees and advanced until it enters the anterior chamber. Specifically, I (IA) recommend advancing the slider halfway down and stopping. At this point, the entire injector/needle is slowly withdrawn from the scleral tract, allowing the implant to be laid in position. Any side or upward pressure on the injector (eg, from the traction suture) should be released to avoid breaking the implant. Turning the needle so the bevel faces down when withdrawing the needle can prevent flicking of the implant, which can otherwise occur with an upward bevel.
- For ab-interno implantation, the approach has been previously described by Vera et al[25] (Video #10).
- The implant position can then be adjusted as needed with a pair of non-toothed forceps, ensuring that ~1 mm is visible in the anterior chamber (which can be confirmed with gonioscopy) and ~3 mm lies in the subTenon space.
- At this point, aqueous humor outflow through the stent should be visible by injecting BSS through a side port (no OVD is used in the anterior chamber with this approach). Alternatively, a 26G needle can be used to backflush the implant to initiate flow. In high-risk cases, a 9.0 or 10.0 nylon ripcord can be placed in the internal lumen of the implant to reduce outflow and minimize the risk of early hypotony.
- If peritubular flow is present, it is typically a transient phenomenon measured in hours and days, not weeks.
- Tenon's tissue and the conjunctiva are then cautiously repositioned (to avoid dragging the gel stent into the anterior chamber) and sutured using a two-step approach: two wing sutures with 10–0 Vicryl are used to reposition Tenon's layer 1–2 mm from the limbus (making sure it is closed tautly), followed by closure of the conjunctiva at the limbus.
- A bleb should form.
- In having performed similar numbers of implantations with closed and open conjunctiva, I (IA) have observed that the bleb morphology differs between these approaches and appears to favor the open conjunctiva approach, likely because Tenon's tissue remains more uniform (due to dissection) and blebs tend to be more posterior and diffuse, similar to trabeculectomy.

Data

Placed ab-interno with closed or open conjunctiva, the 63-µm gel stent was shown to produce greater reductions in IOP (by ~4.8 mmHg; *P*=0.02) and medications (by ~1.5; *P*=0.0001) than the 45-µm gel stent.[54] These findings are clinically relevant and important as the Hagen-Poiseuille equation, outflow capacity, and within-implant pressure drop predicted an additional IOP reduction of ~4.0–4.5 mmHg with the 63-µm gel stent. Moreover, the reduction in medication count was not only statistically significant but considerable as well.

Compared with the 45-µm gel stent, the 63-µm gel stent was also shown to statistically significantly improve the rate of complete success (defined as IOP of 6–17 mmHg and ≥20% IOP reduction from baseline without IOP-lowering medications) by ~2.3 times (95% CI, 1.2, 4.3) at 12 months postimplantation.[54] Mean IOP at 1 year was 12.7 mmHg on 0.6 medications with the 63-µm gel stent (n=41/42) versus 15.5 mmHg on 1.7 medications with the 45-µm gel stent (n=37/42), and the proportion of medication-free patients at 1 year was statistically greater with the 63-µm gel stent (75%) than the 45-µm gel stent (40%; *P*=0.0013).[54] The rate of qualified success (defined as IOP of 6–17 mmHg and ≥20% IOP reduction from baseline with IOP-lowering medications or laser trabeculoplasty) was also improved with 63-µm gel stent, but the difference did not reach statistical significance.[54]

As might be expected, our study revealed more adverse events with the 63-µm gel stent than the 45-µm gel stent, and the rate of early hypotony-related complications such as choroidals/choroidal folds and shallow anterior chamber was ~5 times greater with the 63-µm gel stent than the 45-µm gel stent.[54] Although most adverse events and early complications were transient, caution is advised in patients at higher risk for such events, including older patients and those with myopia. In our experience,[54] IOPs in the single digits last approximately 1 week (when observed) and most eyes exhibiting early hypotony in the presence of a deep anterior chamber and choroidals were stable, only requiring atropine (as cycloplegic) and observation. Nonetheless, I (IA) recommend a conservative approach and anterior chamber reformation with an OVD, especially in cases of shallow anterior chamber with big choroidals.

Although the outer diameter of the 63-µm gel stent is modestly greater than that of the 45-µm gel stent and should thus fit a little more tightly, there is still a risk of peritubular flow. Notably, however, serious adverse events were rare overall, and the rate of postoperative interventions (including needling and secondary surgeries) observed with the 63-µm gel stent was similar to that of the 45-µm gel stent.[54]

Potential limitations of our study[54] included the small sample size (N=42 for each gel stent) and the fact that only ab-interno implantation was performed. Also, subgroup analyses based on the conjunctiva (open versus closed) were not conducted. As findings from large, prospective, multicenter studies of the 63-µm gel stent with long-term surveillance are published to expand the literature on this implant, it is hoped that the 63-µm gel stent will provide an additional option/tool for ophthalmologists worldwide to help improve patient outcomes.

Postoperative Care

Postoperative care typically involves a topical/ophthalmic antibiotic to be used at home four times a day for 1 week. Regarding the use of topical/ophthalmic corticosteroids, there is no consensus, and different management options are used by the authors based on their clinical experiences, such as:

- ≥4 times a day for the first 2–4 weeks, with tapering afterwards. Additionally, nonsteroidal anti-inflammatory drugs can be used for 4 weeks.
- Every 2 hours for the first week and then tapered over 8–10 weeks.
- Following a standard/uncomplicated implantation with a clear anterior chamber at postoperative week 1, start tapering the corticosteroids (ie, three times a day during week 2, twice daily during week 3, and once daily for 1 or 2 additional weeks).

Minimizing Postoperative Fibrosis

Overall, different approaches to injecting MMC have been widely adopted. For example, a subconjunctival injection of 40 µg of MMC (0.1 mL of a 0.4 mg/mL solution) before the implant is placed is often used, preferably in the superior

quadrant. Nonetheless, total MMC doses commonly range from 20 µg (0.1 mL of a 0.2 mg/mL solution) in patients at very low risk of scarring to 60 µg (0.2 mL of a 0.3 mg/mL solution or 0.15 mL of a 0.4 mg/mL solution) in patients at high risk of scarring. In the past, doses higher than 60 µg (eg, 0.2 mL of a 0.4 mg/mL solution) have been used by the authors in patients at very high risk of scarring. However, unfavorable bleb characteristics (eg, avascular, limbal, or with thin conjunctiva) were more likely to occur,[9] and such doses are no longer advised (or should be used with extreme caution). Some surgeons also believe that the total volume of MMC solution should not exceed 0.15 mL (to avoid raising IOP). Dr. Grover, for example, typically uses 0.10–0.15 mL of a 0.4 mg/mL solution (40–60 µg, respectively), while Dr. Panarelli uses 0.15 mL of a 0.4 mg/mL solution.

If a primary needling is performed and the MMC injection truly targets the subconjunctival space, there is probably no need to exceed 40 µg of MMC and the recommended volume. It is worth mentioning, however, that some surgeons prefer to inject MMC into Tenon's tissue (distally from the implant tip) and then massage it forward with a cannula; Tenon's tissue almost becomes friable and easier to pull away (oral communication from Dr. Lauren S Blieden, November 2023).

Subconjunctival injection of MMC after the implant has been placed has also been recommended by other authors, as it provides the additional benefit of applying the MMC exactly where the implant outflow occurs while avoiding the risk of blood obscuring view of the implantation site. If an OVD such as OcuCoat was used to raise the bleb prior to needling, its presence will also facilitate the MMC injection into the Tenon's stump and reduce MMC migration toward the limbus, thus lowering the risk of limbal toxicity. It may thus be worth implementing this step as part of the standard implantation procedure.

Whether used pre- or postoperatively during implantation with a closed conjunctiva approach, it is important to remember that one should aim to apply the MMC at least 10 mm posterior to the limbus and try to create a barrier at the limbus (with a cotton ball, Weck-Cel, or OVD). Because of the natural posterior-to-anterior "migration" (due to the forces of the lid and fornix), the MMC will be pushed forward, and the effective final MMC location should be ~5 mm from the limbus. Any MMC applied closer to the limbus will not have much antifibrotic effect on the distal end of the implant and could create perilimbal ischemia or focal limbal stem cell deficiency with keratopathies developing in that area.

It is also worth noting that when implantation with open conjunctiva is performed, one should be careful to avoid MMC settling or contacting the conjunctival edges of the peritomy whether used pre- or postoperatively.

Long-Term Gel Stent Outcomes and Obstruction

In some patients, a sudden increase in IOP can be seen months or years after successful surgery and apparent control of the patient's IOP. In our (DG, AS) opinion and experience, bleb failure due to fibrosis tends to occur gradually, so these abrupt IOP elevations are most likely caused by some debris occluding the internal lumen of the stent and restricting flow, which I (AS) have been able to document in some cases, using OCT. Left unattended, flow restriction can in turn allow the surrounding tissue to compress the bleb and promote fibrosis. When a patient presents with such sudden IOP elevation, a neodymium-doped yttrium aluminum garnet (Nd:YAG) laser rescue should thus be the first intervention attempted (not needling[35]).

The use of Nd:YAG laser has been previously shown to reestablish outflow by Fellman et al.[55] In our (AS, DG) experience, this rescue treatment, together with the creation of an implantation pocket without Tenon's resistance, has contributed to reducing the postoperative needling rate to ≤10% following gel stent implantation. Our (AS, DG) preferred approach for patients with sudden IOP elevations is as follows:

- Check the lumen of the gel stent end located in the anterior chamber and do not perform needling as first rescue treatment step if that lumen is occluded. Even if you are unable to see debris or an occlusion, do not assume that fibrosis is the primary cause of failure.
- Apply five to eight shots/pulses of Nd:YAG laser through a gonioscopy mirror that same day, using 0.3 to 1 millijoules as settings and starting away from the gel stent in the anterior chamber (one will sometimes see the shockwave disrupt the occlusion) before aiming at the internal lumen of the implant.

- If the Nd:YAG rescue treatment works, you will see an elevation of the bleb, along with a considerable reduction in IOP without hypotony (eg, from 35 to 25 mmHg in ~5 minutes), and the patient has a 50% chance of not requiring a needling later. As the occluding materials is broken down and dislodged, you may even see air bubbles and/or debris pass through the implant.
- One should not expect the IOP to decrease as quickly as post-needling of a bleb, so I (DG) recommend measuring the IOP ~20 minutes after the laser rescue treatment, and then again 1 week later (if possible).
- In our opinion, it is best to avoid needling patients in whom the bleb rises immediately after the laser rescue treatment.

When to Perform a Second Gel Stent Implantation

If the first gel stent surgery fails for an identifiable technical reason (eg, during the early learning curve, if phacoemulsification performed immediately before implantation of the gel stent causes inflammation that interferes with outflow through the implant, or the chance of surgical failure due to ocular surface disease or inflammation is high), it may be possible to perform a second implantation in another area, using a different technique. However, if subconjunctival filtration appears suboptimal despite flawless implantation of the gel stent, then it may be preferable to consider an alternate glaucoma filtration surgery.

Discussion

This technique-based article indicates that, regardless of the implantation approach, curbing ocular surface inflammation preoperatively (by managing ocular surface disease and/or starting a corticosteroid regimen) will help increase the odds of surgical success. Based on published studies of trabeculectomy,[36,37] also a bleb-forming procedure, reducing the number of IOP-lowering medications before the surgery should increase the odds of surgical success as well.

Intraoperatively, ensuring that the gel stent is free from Tenon's tissue by creating an implantation space/pocket and keeping this implantation space/pocket open with an OVD is critical to minimize the risk of bleb failure, regardless of the preferred surgical (ab-interno versus ab-externo with open or closed conjunctiva) and space-creating (eg, primary needling, PoST, opening/dissecting the conjunctiva, or small incision) techniques. Use of MMC (typically 40–60 µg) is also strongly advised to help minimize bleb fibrosis and failure. In terms of implant positioning, we aim to put the implant as close as possible to 12 o'clock and away from the iris and cornea, with 1 mm in the anterior chamber, 2 mm as scleral tunnel, and 3 mm in the subconjunctival space. One should then seek to confirm intraluminal flow (when possible) and also be prepared to control bleeding with pressure or cautery if it occurs.

If one is caring for patients that have a greater need for IOP lowering (eg, with more advanced disease or a higher risk of progression), the 63-µm gel stent may be beneficial and is worth considering.

Postoperatively, an early regimen of corticosteroids should be prescribed, needling should be reserved for cases of suspected bleb fibrosis, sudden IOP increases should be addressed with Nd:YAG, and a replacement implant targeting a different area may be considered if the initial implantation is deemed suboptimal for identifiable reasons. This information is summarized in Table 1.

Optimizing surgical techniques over time and sharing best practices with colleagues has been key to offering the best possible outcomes for our patients. As studies of the gel stent conducted worldwide continue to be published,[38,49,56–82] additional surgical pearls and tips will undoubtedly emerge and lead to further refinement of the implantation technique. This article describes the key learnings and changes in the surgical techniques that are currently being used to implant the gel stent. It is based on the authors' extensive experience, which has led them to achieve better outcomes and surgical success. We are hopeful that the article will increase awareness about these surgical options and pearls, and –ultimately– enable informed decision-making to improve outcomes in real-world/typical clinical settings.

Conclusions

The various techniques described herein should allow glaucoma surgeons to accommodate their patients' needs, as well as their own preferences, when considering the gel stent as bleb-forming surgery to lower a patient's IOP and medication burden. Whether placement of the 45-µm or 63-µm gel stent is performed with a closed or open conjunctiva, via an ab-

interno or ab-externo approach, the developments/steps detailed above and summarized in Table 1 are key to reduce the risk of surgical/bleb failure. As surgeons implement and become proficient with those developments/steps, gel stent implantation should become more predictable and patient outcomes should improve.

Data Sharing Statement

Data sharing is not applicable to this article as no datasets were generated or analyzed by AbbVie during the current study.

Ethics Approval and Informed Consent

All data and videos presented in this manuscript have been acquired under Institutional Review Board or Ethics Committee approved protocols and in accordance with the Health Insurance Portability and Accountability Act. All patients provided written informed consent before undergoing treatment.

Notes on Contributors

All authors have been using the gel stent since it was cleared by the US Food and Drug Administration in 2016, and most of them already had experience with it by the time of approval in the US. The authors have taught and/or performed thousands of implantations and have tried multiple techniques or surgical approaches, moving forward with the learnings of the past 10 years.

Acknowledgments

Medical writing support was provided by Michele Jacob, PhD, of Evidence Scientific Solutions (Philadelphia, PA), and funded by AbbVie.

Funding

AbbVie funded this publication and participated in its development, review, and approval. All authors participated in the drafting, review, and approval of this publication.

Disclosure

Vanessa Vera and Earl Randy Craven are employees of Allergan (an AbbVie company) and may hold AbbVie stock. Arsham Sheybani has received consulting honoraria from Allergan (an AbbVie company), Alcon, Nova Eye, and Glaukos. Joseph F Panarelli has received consulting honoraria from Aerie Pharmaceuticals, Allergan (an AbbVie company), AOI Ophthalmics, Avisi, CorneaGen, Ellios, Glaukos Corp, New World Medical, Nova Eye, Ocular Therapeutics, Santen Pharmaceutical, and Zeiss; research support from Allergan (an AbbVie company); non-financial support from Research to Prevent Blindness, outside the submitted work. Davinder S Grover has received consulting honoraria from Allergan (an AbbVie company), New World Medical, Nova Eye Medical, Olleyes, Reichert, and Sanoculis; speaker honoraria from Allergan (an AbbVie company), Nova Eye Medical, and Reichert; research funds from Allergan (an AbbVie company) and New World Medical; equity from Nova Eye Medical and Olleyes; personal fees from Belkin Vision, Elios, Olleyes, and Regeneron; and is a Medical Advisory Board member of CATS Tonometer, iSTAR Medical, Nova Eye Medical, Sanoculis, and Versant Health. James Lee has received consulting honoraria from Allergan, an AbbVie company. Thomas W Samuelson has received consulting honoraria from Equinox and is an advisory board member of Equinox. Iqbal Ike K Ahmed has received consulting honoraria from Ace Vision Group, Aequus Pharmaceuticals, Aerie Pharmaceuticals, Akorn, Alcon, Aliph Medical, Allergan (an AbbVie company), Aqua Health, ArcScan, Avellino Lab USA, Avisi, Bausch Health, Beaver Visitec, Belkin Vision, Beyeonics, Bionode, Carl Zeiss Meditec, Centricity Vision, CorNeat Vision, Custom Surgical, Elios Vision, ElutiMed, Equinox, Exhaura Limited, eyeFlow, EyedMed, EyeD Pharma, Eye to Eye TeleHealth, EyeQ Technologies, Genentech, Glaukos Corp, Gore, Heine, Heru, Hexiris Pharma, Iantrek, InjectSense, Iridex, iCare, iSTAR Medical, Ivantis, Johnson & Johnson Vision, Labtician Thea, LayerBio, Leica Microsystems, Life Long Vision, Liqid Medical, Long Bridge Medical, Medicontur, MicroOptx, MST Surgical, Myra Vision/Shifamed LLC, New World Medical, NovaEye, Ocular

Instruments, Ocular Therapeutix, Oculo, Oculus Surgical, OcuSciences, Omega Ophthalmics, Peripherex, PolyActiva, PulseMedica, Radiance Therapeutics, Radius XR, Rheon Medical SA, Ripple Therapeutics, Samsara Vision, Sanoculis, Santen Pharmaceutical, Sight Sciences, Singapore Biodesign Programme Office, Smartlens, Stroma, Thea Pharma, TFS Health Science, ViaLase, Visci Ltd, Visus Therapeutics, Vizzario, VSY Biotechnology, and Zilia; speaker honoraria from Alcon, Allergan (an AbbVie company), Carl Zeiss Meditec, Heine, Johnson & Johnson Vision, and MST Surgical; and research support from Aerie Pharmaceuticals, Alcon, Allergan (an AbbVie company), Bionode, Glaukos Corp, iCare, Ivantis, Johnson & Johnson Vision, New World Medical, and Santen Pharmaceutical.

References

1. Radcliffe NM, Shah M, Samuelson TW. Challenging the "topical medications-first" approach to glaucoma: a treatment paradigm in evolution. *Ophthalmol Ther*. 2023;12(6):2823–2839. doi:10.1007/s40123-023-00831-9
2. Qin M, Yu-Wai-Man C. Glaucoma: novel antifibrotic therapeutics for the trabecular meshwork. *Eur J Pharmacol*. 2023;954:175882. doi:10.1016/j.ejphar.2023.175882
3. Fan X, Bilir EK, Kingston OA, et al. Replacement of the trabecular meshwork cells - A way ahead in IOP control? *Biomolecules*. 2021;11(9):1371. doi:10.3390/biom11091371
4. Cairns JE. Trabeculectomy. Preliminary report of a new method. *Am J Ophthalmol*. 1968;66(4):673–679. doi:10.1016/0002-9394(68)91288-9
5. Rao A, Cruz RD. Trabeculectomy: does it have a future? *Cureus*. 2022;14(8):e27834. doi:10.7759/cureus.27834
6. Razeghinejad MR, Fudemberg SJ, Spaeth GL. The changing conceptual basis of trabeculectomy: a review of past and current surgical techniques. *Surv Ophthalmol*. 2012;57(1):1–25. doi:10.1016/j.survophthal.2011.07.005
7. Koike KJ, Chang PT. Trabeculectomy: a brief history and review of current trends. *Int Ophthalmol Clin*. 2018;58(3):117–133. doi:10.1097/IIO.0000000000000231
8. Grover DS, Kornmann HL, Fellman RL. Historical considerations and innovations in the perioperative use of mitomycin C for glaucoma filtration surgery and bleb revisions. *J Glaucoma*. 2020;29(3):226–235. doi:10.1097/IJG.0000000000001438
9. Bell K, de Padua Soares Bezerra B, Mofokeng M, et al. Learning from the past: mitomycin C use in trabeculectomy and its application in bleb-forming minimally invasive glaucoma surgery. *Surv Ophthalmol*. 2021;66(1):109–123. doi:10.1016/j.survophthal.2020.05.005
10. Marcos Parra MT, Salinas López JA, López Grau NS, Ceausescu AM, Pérez Santonja JJ. XEN implant device versus trabeculectomy, either alone or in combination with phacoemulsification, in open-angle glaucoma patients. *Graefes Arch Clin Exp Ophthalmol*. 2019;257(8):1741–1750. doi:10.1007/s00417-019-04341-y
11. Liu H, Zhang H, Li Y, Yu H. Safety and efficacy of canaloplasty versus trabeculectomy in treatment of glaucoma. *Oncotarget*. 2017;8(27):44811–44818. doi:10.18632/oncotarget.14757
12. Wang W, Zhang X. Meta-analysis of randomized controlled trials comparing EX-PRESS implantation with trabeculectomy for open-angle glaucoma. *PLoS One*. 2014;9(6):e100578. doi:10.1371/journal.pone.0100578
13. Chen G, Li W, Jiang F, Mao S, Tong Y. Ex-PRESS implantation versus trabeculectomy in open-angle glaucoma: a meta-analysis of randomized controlled clinical trials. *PLoS One*. 2014;9(1):e86045. doi:10.1371/journal.pone.0086045
14. Gedde SJ, Singh K, Schiffman JC, Feuer WJ, the Tube Versus Trabeculectomy Study Group. The Tube Versus Trabeculectomy Study: interpretation of results and application to clinical practice. *Curr Opin Ophthalmol*. 2012;23(2):118–126. doi:10.1097/ICU.0b013e32834ff2d1
15. Gedde SJ, Herndon LW, Brandt JD, et al. Postoperative complications in the Tube Versus Trabeculectomy (TVT) Study during five years of follow-up. *Am J Ophthalmol*. 2012;153(5):804–814.e801. doi:10.1016/j.ajo.2011.10.024
16. Gedde SJ, Heuer DK, Parrish RK, 2nd, the Tube Versus Trabeculectomy Study Group. Review of results from the Tube Versus Trabeculectomy Study. *Curr Opin Ophthalmol*. 2010;21(2):123–128. doi:10.1097/ICU.0b013e3283360b68
17. Chai C, Loon SC. Meta-analysis of viscocanalostomy versus trabeculectomy in uncontrolled glaucoma. *J Glaucoma*. 2010;19(8):519–527. doi:10.1097/IJG.0b013e3181ca7694
18. Gedde SJ, Schiffman JC, Feuer WJ, et al. Three-year follow-up of the Tube Versus Trabeculectomy Study. *Am J Ophthalmol*. 2009;148(5):670–684. doi:10.1016/j.ajo.2009.06.018
19. Gedde SJ, Schiffman JC, Feuer WJ, Herndon LW, Brandt JD, Budenz DL. Treatment outcomes in the Tube Versus Trabeculectomy Study after one year of follow-up. *Am J Ophthalmol*. 2007;143(1):9–22. doi:10.1016/j.ajo.2006.07.020
20. Yalvac IS, Sahin M, Eksioglu U, Midillioglu IK, Aslan BS, Duman S. Primary viscocanalostomy versus trabeculectomy for primary open-angle glaucoma: three-year prospective randomized clinical trial. *J Cataract Refract Surg*. 2004;30(10):2050–2057. doi:10.1016/j.jcrs.2004.02.073
21. Kobayashi H, Kobayashi K, Okinami S. A comparison of the intraocular pressure-lowering effect and safety of viscocanalostomy and trabeculectomy with mitomycin C in bilateral open-angle glaucoma. *Graefes Arch Clin Exp Ophthalmol*. 2003;241(5):359–366. doi:10.1007/s00417-003-0652-6
22. Carassa RG, Bettin P, Fiori M, Brancato R. Viscocanalostomy versus trabeculectomy in white adults affected by open-angle glaucoma: a 2-year randomized, controlled trial. *Ophthalmology*. 2003;110(5):882–887. doi:10.1016/S0161-6420(03)00081-2
23. Qidwai U, Jones L, Ratnarajan G. A comparison of iStent combined with phacoemulsification and endocyclophotocoagulation (ICE2) with the PreserFlo MicroShunt and XEN-45 implants. *Ther Adv Ophthalmol*. 2022;14:25158414221125697. doi:10.1177/25158414221125697
24. European Glaucoma Society Terminology and Guidelines for Glaucoma, 5th Edition. *Br J Ophthalmol*. 2021;105(Suppl 1):1–169. doi:10.1136/bjophthalmol-2021-egsguidelines
25. Vera V, Gagne S, Myers JS, Ahmed IIK. Surgical approaches for implanting Xen gel stent without conjunctival dissection. *Clin Ophthalmol*. 2020;14:2361–2371. doi:10.2147/OPTH.S265695
26. Lewis RA. Ab interno approach to the subconjunctival space using a collagen glaucoma stent. *J Cataract Refract Surg*. 2014;40(8):1301–1306. doi:10.1016/j.jcrs.2014.01.032
27. Sheybani A, Reitsamer H, Ahmed II. Fluid Dynamics of a Novel Micro-Fistula Implant for the Surgical Treatment of Glaucoma. *Invest Ophthalmol Vis Sci*. 2015;56(8):4789–4795. doi:10.1167/iovs.15-16625

28. Grover DS, Flynn WJ, Bashford KP, et al. Performance and safety of a new ab interno gelatin stent in refractory glaucoma at 12 months. *Am J Ophthalmol*. 2017;183:25–36. doi:10.1016/j.ajo.2017.07.023
29. Allergan (an AbbVie company). Directions for use for the XEN•63 Glaucoma Treatment System. Available from: https://www.abbvie.ca/content/dam/abbvie-dotcom/ca/en/documents/products/XEN%C2%AE_63_Directions_for_Use.pdf. Accessed December 23, 2024
30. AqueSys Inc. Directions for use for the XEN•45 Glaucoma Treatment System. Available from: https://allergan-web-cdn-prod.azureedge.net/allergancanadaspecialty/allergancanadaspecialty/media/actavis-canada-specialty/en/products/pms/xen-45-dfu-english-3037-004-rev-A.pdf. Accessed December 23, 2024.
31. Panarelli JF, Yan DB, Francis B, Craven ER. XEN gel stent open conjunctiva technique: a practical approach paper. *Adv Ther*. 2020;37(5):2538–2549. doi:10.1007/s12325-020-01278-1
32. Fiscella R, Leiter CW, Massoomi F, Noecker R, Sheybani A. Adjunctive antifibrotic therapy with mitomycin C and 5-fluorouracil: a review of their use in glaucoma surgery and considerations around ophthalmic compounding. *Curr Trends Ophthalmol*. 2019;2(1):154–169.
33. Reitsamer H, Sng C, Vera V, Lenzhofer M, Barton K, Stalmans I. Two-year results of a multicenter study of the ab interno gelatin implant in medically uncontrolled primary open-angle glaucoma. *Graefes Arch Clin Exp Ophthalmol*. 2019;257(5):983–996. doi:10.1007/s00417-019-04251-z
34. Sheybani A, Vera V, Grover DS, et al. Gel stent versus trabeculectomy: the randomized, multicenter, Gold-Standard Pathway Study (GPS) of effectiveness and safety at 12 months. *Am J Ophthalmol*. 2023;252:306–325. doi:10.1016/j.ajo.2023.03.026
35. Vera V, Sheybani A, Lindfield D, Stalmans I, Ahmed IIK. Recommendations for the management of elevated intraocular pressure due to bleb fibrosis after XEN gel stent implantation. *Clin Ophthalmol*. 2019;13:685–694. doi:10.2147/OPTH.S195457
36. Lavin MJ, Wormald RP, Migdal CS, Hitchings RA. The influence of prior therapy on the success of trabeculectomy. *Arch Ophthalmol*. 1990;108(11):1543–1548. doi:10.1001/archopht.1990.01070130045027
37. Broadway DC, Grierson I, O'Brien C, Hitchings RA. Adverse effects of topical antiglaucoma medication. II. The outcome of filtration surgery. *Arch Ophthalmol*. 1994;112(11):1446–1454. doi:10.1001/archopht.1994.01090230060021
38. Franco F, Serino F, Giansanti F. "Air and Visco" technique: a promising innovation in the surgical implantation of the Xen gel stent device. *Vision*. 2023;7(4). doi:10.3390/vision7040071
39. Buenasmañanas-Maeso M, Perucho-Martínez S, Monja-Alarcón N, Toledano-Fernández N. Impact of primary needling on the XEN implant clinical outcomes: a real-life retrospective study. *Clin Ophthalmol*. 2022;16:935–946. doi:10.2147/OPTH.S357575
40. Kerr NM, Lim S, Simos M, Ward T. Primary needling of the ab interno gelatin microstent reduces postoperative needling and follow-up requirements. *Ophthalmol Glaucoma*. 2021;4(6):581–588. doi:10.1016/j.ogla.2021.02.004
41. Liu A, Dhar L, Hung S, Fellman R, Grover DS. Brief report on 12-month outcomes of the ab interno gel stent using the intraoperative PoST (Posterior Sweep of Tenons) technique. *Ophthalmol Glaucoma*. 2024;7(6):624–626. doi:10.1016/j.ogla.2024.06.002
42. Grover DS, Fellman RL. Outcomes for ab interno bleb revision with a novel translimbal sclerostomy spatula. *J Glaucoma*. 2017;26(7):633–637. doi:10.1097/IJG.0000000000000686
43. Mansouri K, Guidotti J, Rao HL, et al. Prospective evaluation of standalone XEN gel implant and combined phacoemulsification-XEN gel implant surgery: 1-year results. *J Glaucoma*. 2018;27(2):140–147. doi:10.1097/IJG.0000000000000858
44. Reitsamer H, Vera V, Ruben S, et al. Three-year effectiveness and safety of the XEN gel stent as a solo procedure or in combination with phacoemulsification in open-angle glaucoma: a multicentre study. *Acta Ophthalmol*. 2022;100(1):e233–e245. doi:10.1111/aos.14886
45. Mansouri K, Bravetti GE, Gillmann K, Rao HL, TW C, Mermoud A. Two-year outcomes of XEN gel stent surgery in patients with open-angle glaucoma. *Ophthalmol Glaucoma*. 2019;2(5):309–318. doi:10.1016/j.ogla.2019.03.011
46. Midha N, Rao HL, Mermoud A, Mansouri K. Identifying the predictors of needling after XEN gel implant. *Eye*. 2019;33(3):353–357. doi:10.1038/s41433-018-0206-0
47. Bouhenni RA, Al Jadaan I, Rassavong H, et al. Lymphatic and blood vessel density in human conjunctiva after glaucoma filtration surgery. *J Glaucoma*. 2016;25(1):e35–38. doi:10.1097/IJG.0000000000000199
48. Kong YXG, Chung IY, Ang GS. Outcomes of XEN45 gel stent using posterior small incision sub-tenon ab interno insertion (semi-open) technique. *Eye*. 2022;36(7):1456–1460. doi:10.1038/s41433-021-01635-6
49. Villarreal E, Berkowitz E, Tiosano B. XEN45 gel stent combined with Healaflow injectable viscoelastic implant. *Case Rep Ophthalmol Med*. 2023;2023:7096406. doi:10.1155/2023/7096406
50. Gagné S, Yuen D, Cohen S. Transconjunctival XEN45 implantation for glaucoma performed at the slit lamp: a pilot study. *J Glaucoma*. 2022;31(8):675–681. doi:10.1097/IJG.0000000000002070
51. Han K, Lee J, Moon S. One-year outcomes of ab externo XEN45 gel stent implantation with an open conjunctiva approach in patients with open-angle glaucoma. *Korean J Ophthalmol*. 2023;37(5):353–364. doi:10.3341/kjo.2023.0044
52. Ibarz Barberá M, Hernández-Verdejo JL, Bragard J, et al. Evaluation of the ultrastructural and in vitro flow properties of the PRESERFLO MicroShunt. *Transl Vis Sci Technol*. 2021;10(13):26. doi:10.1167/tvst.10.13.26
53. Glaukos Canada. PRESERFLO™ MicroShunt Surgical Reference Guide. Available from: https://cgs-scg.org/wp-content/uploads/2021/11/Preserflo-Surgical-Reference-Guide-PM-CA-0059-2.pdf. Accessed December 23, 2024.
54. Hussein IM, De Francesco T, Ahmed IIK. Intermediate outcomes of the novel 63-µm gelatin microstent versus the conventional 45-µm gelatin microstent. *Ophthalmol Glaucoma*. 2023;6(6):580–591. doi:10.1016/j.ogla.2023.05.001
55. Fellman RL, Grover DS, Smith OU, Kornmann HL. Rescue of failed XEN-45 gel implant by Nd:YAG shock wave to anterior chamber tip to dislodge hidden intraluminal occlusion. *J Glaucoma*. 2021;30(7):e338–e343. doi:10.1097/IJG.0000000000001847
56. Zhang B, Shen XL, Wang XP, Gong D, Guo JH, Wang JT. [Clinical effect of XEN gel stent implantation or combined with phacoemusification and intraocular lens implantation on glaucoma]. *Zhonghua Yan Ke Za Zhi*. 2024;60(9):746–756. doi:10.3760/cma.j.cn112142-20231223-00304
57. Tan JCK, Hashimoto Y, Gabrielle PH, et al. Outcomes and baseline predictors of failure in primary standalone Xen45 gel stent versus trabeculectomy for glaucoma. *Ophthalmol Glaucoma*. 2024;7(6):539–550. doi:10.1016/j.ogla.2024.07.002
58. Rauchegger T, Krause SM, Nowosielski Y, et al. Three-year clinical outcome of XEN45 gel stent implantation versus trabeculectomy in patients with open angle glaucoma. *Eye*. 2024;38(10):1908–1916. doi:10.1038/s41433-024-03042-z
59. Papazoglou A, Höhn R, Schawkat M, et al. Swiss multicenter ab interno XEN45 gel stent study: 2-year real-world data. *Ophthalmol Ther*. 2024;13(6):1513–1525. doi:10.1007/s40123-024-00917-y

60. Oddone F, Roberti G, Giammaria S, et al. Effectiveness and safety of XEN45 implant over 12 months of follow-up: data from the XEN-Glaucoma Treatment Registry. *Eye*. 2024;38(1):103–111. doi:10.1038/s41433-023-02642-5
61. Nobl M, Freissinger S, Rudolph K, et al. Long-term outcomes of PreserFlo MicroShunt versus XEN45 gel stent in open-angle glaucoma. *Klin Monbl Augenheilkd*. 2024;241(7):805–812. doi:10.1055/a-2152-8455
62. Neubauer J, Suesskind D, Gassel CJ, Nasyrov E, Voykov B. Histopathological findings of failed blebs after microinvasive bleb surgery with the XEN gel stent and Preserflo MicroShunt. *Graefes Arch Clin Exp Ophthalmol*. 2024;262(9):2977–2984. doi:10.1007/s00417-024-06479-w
63. Nasyrov E, Merle DA, Gassel CJ, Wenzel DA, Voykov B. Two-year results of XEN gel stent implantation for pseudoexfoliative glaucoma in phakic versus pseudophakic eyes. *J Clin Med*. 2024;13(14):4066. doi:10.3390/jcm13144066
64. Nasyrov E, Gassel CJ, Merle DA, Neubauer J, Voykov B. Long-term efficacy and safety of XEN-45 gel stent implantation in patients with normal-tension glaucoma. *BMC Ophthalmol*. 2024;24(1):264. doi:10.1186/s12886-024-03522-6
65. Marchese V, Randazzo V, Badalamenti R, Anastasi M. Reviving XEN63 gel stent patency in uveitic glaucoma: a novel approach using 10-0 nylon probe. *J Curr Glaucoma Pract*. 2024;18(2):74–78. doi:10.5005/jp-journals-10078-1445
66. Lüke JN, Dietlein TS, Widder RA, et al. Matched case-control comparison of surgical success after XEN45 gel stent and PRESERFLO MicroShunt implantation in a Caucasian population. *Clin Exp Ophthalmol*. 2024;52(7):732–739. doi:10.1111/ceo.14407
67. Lin HZ, Wang JH, Lee YC. Factors associated with the efficacy of XEN gel implant. *Ophthalmol Ther*. 2024;13(2):597–614. doi:10.1007/s40123-023-00876-w
68. Lenzhofer M, Hohensinn M, Steiner V, et al. Mid-term surgical success after transscleral ab interno glaucoma gel stent implantation. *Acta Ophthalmol*. 2024;102(6):e906–e914. doi:10.1111/aos.16668
69. Larrosa JM, Martínez-de-la-Casa JM, Giménez Gómez R, et al. XEN-45 in the management of early glaucoma surgery: a national Delphi consensus study. *Arch Soc Esp Oftalmol*. 2024;99(3):98–108. doi:10.1016/j.oftal.2023.10.016
70. Kiessling D, Rennings C, Hild M, et al. Combined versus standalone XEN45 gel stent implantation in either phakic or pseudophakic patients: a case-matched study. *Graefes Arch Clin Exp Ophthalmol*. 2024;262(4):1253–1262. doi:10.1007/s00417-023-06283-y
71. Grosso A, Ceruti P, Garlasco J, et al. Double implantation of Xen 45 gel stent in primary open-angle glaucoma: a pilot study. *Int Ophthalmol*. 2024;44(1):243. doi:10.1007/s10792-024-03153-2
72. Gassel CJ, Nasyrov E, Wenzel DA, Voykov B. XEN45 gel stent in the treatment of pigmentary glaucoma: a two-year follow-up. *Eur J Ophthalmol*. 2024;11206721241261093. doi:10.1177/11206721241261093
73. Gan L, Wang L, Chen J, Tang L. Complications of XEN gel stent implantation for the treatment of glaucoma: a systematic review. *Front Med*. 2024;11:1360051. doi:10.3389/fmed.2024.1360051
74. Evers C, Anton A, Böhringer D, et al. XEN(®)-45 implantation for refractory uveitic glaucoma. *Graefes Arch Clin Exp Ophthalmol*. 2024;262(3):937–948. doi:10.1007/s00417-023-06254-3
75. Elubous KA. Navigating hypotony challenges with XEN gel implantation. *Expert Rev Med Devices*. 2024;21(4):277–284. doi:10.1080/17434440.2024.2327529
76. Elbably A, Richardson-May J, Amerasinghe N, et al. Xen-DS: a novel technique of ab externo Xen implantation augmented with a modified deep sclerectomy for surgical treatment of glaucoma. *Eye*. 2024;38(14):2775–2780. doi:10.1038/s41433-024-03146-6
77. Chen YQ, Yao YH, Ye Q, Wang XH, Lin Y, Zhu YH. [Three-year results of XEN gel stent implantation in the treatment of glaucoma]. *Zhonghua Yan Ke Za Zhi*. 2024;60(10):845–851. doi:10.3760/cma.j.cn112142-20240513-00225
78. Boscia F, Ferreri P, Sisto D, et al. Xen gel stent implant for persistent glaucoma after silicone oil removal. *Eur J Ophthalmol*;2024. 11206721241272273. doi:10.1177/11206721241272273
79. Bastelica P, Amatu J-B, Buffault J, Majoulet A, Labbé A, Baudouin C. One year efficacy and safety of inferior implantation of Xen 45® gel stent in refractory glaucoma. *J Fr Ophtalmol*. 2024;47(8):104260. doi:10.1016/j.jfo.2024.104260
80. Arnould L, Balsat E, Hashimoto Y, et al. Two-year outcomes of Xen 45 gel stent implantation in patients with open-angle glaucoma: real-world data from the Fight Glaucoma Blindness registry. *Br J Ophthalmol*. 2024;108(12):1672–1678. doi:10.1136/bjo-2023-325077
81. Ansari E. Five-year outcomes of ab interno Xen 45 gel stent implantation. *Graefes Arch Clin Exp Ophthalmol*. 2024;262(4):1263–1269. doi:10.1007/s00417-023-06294-9
82. Theilig T, Papadimitriou M, Albaba G, Meller D, Hasan SM. Results of open bleb revision as management of primary bleb failure following XEN 45 gel stent and Preserflo™ Microshunt. *Graefes Arch Clin Exp Ophthalmol*. 2023;261(11):3249–3255. doi:10.1007/s00417-023-06152-8