Lasers have been used in ophthalmology since within a decade of its invention in 1960. The argon laser was found to be most suitable for the eye as the blue-green wavelengths were better absorbed by hemoglobin and melanin in ocular tissue. The first reported use of lasers for glaucoma was in the 1970s, initially for iridotomy and trabeculoplasty. The physician now has a range of lasers to use for the prevention, modulation, and treatment of glaucoma and to augment surgical procedures. This article reviews the types of lasers used in open angle glaucoma, their efficacy, and side effects.

Laser to the Trabecular Meshwork
Laser Trabeculoplasty (Argon Laser Trabeculoplasty and Selective Laser Trabeculoplasty) Indications
Open angle glaucoma as primary treatment or as an adjunct to medical therapy.

Efficacy
The glaucoma laser trial showed that argon laser trabeculoplasty (ALT) was at least as effective as initial treatment with timolol maleate 0.5% and the procedure gained popularity in the 1990s. However, the visible thermal damage, limited repeatability, late pressure rise, and treatment failure along with the technical skill required to correctly identify angle structures likely reduced its popularity among comprehensive ophthalmologists. A laser that delivers over 100 times less energy than ALT while providing a similar intraocular pressure (IOP)-lowering effect was developed by Latina in 1995. It is a frequency-doubled, Q-switched, neodymium: yttrium aluminium garnet (Nd:YAG) laser and delivers a 400 µm diameter treatment spot in 3 nanoseconds. In addition, the large spot size facilitating less-precise identification of angle structures during laser application led to increased interest in this modality.

Two independent meta-analyses in 2013 reported on six randomized controlled trials (although not the same six) comparing SLT with ALT. Wang and He reported no significant difference in IOP lowering at all-time points up to 5 years in patients who were naïve to laser, and no statistical difference in IOP lowering at 6 months for those who had previous laser treatments. By contrast, Wang and Cheng reported an overall weighted mean difference of 0.6 although they did not stratify the time to follow up. For repeated treatments, Wang and Cheng reported SLT to be more effective than ALT with a weighted mean difference of 1.48.

Technique
Pretreatment with topical anesthetic and prophylactic hypotensive agent such as apraclonidine or brimonidine.

Various lenses may be used for ALT including the Goldmann three mirror lens, the Ritch trabeculoplasty lens, and the LASAG contact glass anterior (CGA) lens. The Latina lens was designed specifically for the SLT and has no spot size magnification.

The laser settings are shown in Table 1. The ALT aiming beam is focused on the junction of the anterior non-pigmented and posterior pigmented trabecular meshwork with the power titrated to achieve slight blanching. For SLT, the spot size is fixed at 400 µm and power is titrated to achieve...
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small champagne bubbles. The power setting is usually inversely related to the amount of pigmentation seen.

Postlaser topical anti-inflammatory medication is typically prescribed for a few days. Pre-laser hypotensive agents are typically continued and IOP assessment is recommended 1–4 hours after the laser and again a few weeks later to assess the response.

Complications

Complications following ALT and SLT are similar in frequency and severity. Early postoperative elevation of IOP of more than 5 mmHg can occur in up to 34 % of patients in ALT1 and SLT.2 This reduces significantly to <10 % with the use of alpha-2 adrenergic drops immediately pre- or postlaser.3

Anterior uveitis occurs up to 83 % of the time but tends to settle without topical medication.4 Peripheral anterior synaechiae (PAS) although more common with ALT, can occur with SLT and have been reported in around 1 % of cases.1 Other rare complications include hyphema,5 choroidal effusion,6 and cystoid macular edema.7 More recently, there have been reports of corneal stromal hazy requiring intensive topical steroids following SLT. The etiology of this remains unclear.8,9 Higher energy levels, more segments treated,10 posterior placement of laser, and heavy angle pigmentation have been associated with postprocedure IOP spikes, PAS,11 and anterior uveitis.

Newer Lasers for Trabeculoplasty

Newer lasers for trabeculoplasty include micropulse diode laser trabeculoplasty (MLT), titanium sapphire laser trabeculoplasty (TSLT), and excimer laser trabeculotomy (ELT).

MLT uses a 532/810 nm diode laser. It has a long interval between the pulses of thermal energy giving sufficient cooling time to avoid injury to the pigmented trabecular meshwork and its surrounding tissues. In theory, MLT is less traumatic than ALT and SLT which potentially may translate to a better safety profile and repeatability. In a phase II clinical study, 25 % failed and the remaining 75 % (15 eyes) had a mean reduction of 22 % at 12 months.11 A retrospective study on MLT showed only three eyes (7.5 %) had an IOP reduction of more than or equal to 3 mmHg. However, this was a mixed group of primary and secondary open angle glaucoma, with 36 % already on three or more glaucoma medications.12 A short-term prospecative randomized trial of MLT versus ALT showed MLT to be less efficacious than ALT. MLT had a mean IOP decrease of 2.5 mmHg (12 %) compared with ALT, which had a mean IOP decrease of 4.9 mmHg (22 %) at 3 months.13 There are currently two registered trials that are in the recruitment stage comparing MLT to SLT that may help our understanding of its efficacy.

TSLT uses a 790 nm laser with a 7 msec exposure time and a spot size of 200 μm. The near-infrared wavelengths are thought to penetrate deeper into the pigmented trabecular meshwork and also have an effect on the juxta-canular region and inner wall of Schlemm’s canal. In a study comparing TSLT to ALT, both lasers had a similar efficacy (8.3 mmHg versus 6.5 mmHg IOP reduction, respectively [p=0.05]).14 There are several ongoing trials evaluating the efficacy of this technology.

Table 1: Selective Laser Trabeculoplasty versus Argon Laser Trabeculoplasty Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Selective Laser Trabeculoplasty</th>
<th>Argon Laser Trabeculoplasty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot size</td>
<td>400 μm</td>
<td>50 μm</td>
</tr>
<tr>
<td>Energy output</td>
<td>0.3–1.5 mJ</td>
<td>500–1,000 mW</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>3 ns</td>
<td>0.1 s</td>
</tr>
<tr>
<td>Power</td>
<td>600–1,200 mW</td>
<td>0.5–0.8 mJ</td>
</tr>
<tr>
<td>Fluence</td>
<td>600 mJ/cm²</td>
<td>60,000 mJ/cm²</td>
</tr>
<tr>
<td>Number of burns</td>
<td>45–55 over 180°</td>
<td>45–55 over 180°</td>
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</tbody>
</table>

ELT is a 308 nm xenon chloride laser with a pulsed delivery of 1.2 mJ over 80 nm duration. It is designed to enhance aqueous outflow by creating microperforations in the trabecular meshwork and inner wall of Schlemm’s canal. A recent study looking at phacoemulsification combined with ELT showed an overall reduction of 4.5 mmHg (23 %) at 12 months. Those with a higher preoperative IOP (>21 mmHg) had a better IOP response (9.5 mmHg, 37 %).21 Babighian et al. performed a randomized controlled trial comparing ELT with SLT. Eight spots were equally distributed at a distance of 500 μm from one another over the anterior trabeculum in the ELT group. At 24 months, 53 % of the ELT group and 40 % of the SLT group had a IOP reduction of 20 % or more.22 Complications included anterior chamber bleeding (80 %) and transient pressure spikes (20 %).

Laser to the Ciliary Body

Transscleral Cyclodiode

Transscleral cyclophotocoagulation has traditionally been reserved for end-stage glaucoma with little or no visual potential, where all other treatment options have been tried and failed.

The American Academy of Ophthalmology (AAO) Ophthalmic Technology Assessment Committee stated that “Cyclophotocoagulation is indicated for patients with refractory glaucoma who have failed trabeculectomy or tube shunt procedures, patients with minimal useful vision and elevated IOP, patients who have no visual potential and need pain relief, and patients with complicated glaucoma and conjunctival scarring from previous surgery.”23 This general apprehension stems from the perceived high-risk complications of phthisis, sympathetic ophthalmia, and vision loss largely from the historical use of cryotherapy. Newer treatment protocols with lower energy levels and longer duration have made transscleral cycloidiode (TSD) safer and more accepted. In recent years, there has been a shift in the timing at which this treatment is considered in the glaucoma management paradigm. In a UK survey, 60 % of 180 responders would perform TSD at any visual acuity24 and there have been reports of good success in using TSD as a primary treatment in developing countries where access and compliance is poor.25 TSD has also been advocated as a safe alternative in acute angle closure that is nonresponsive to conventional treatment.26

Efficacy

There is a correlation between energy used and treatment success. Many studies report good IOP reduction with TSD with 54 to 93 % achieving an IOP of under 21 mmHg.25

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Technique
The G-Probe is designed to direct energy to the ciliary body, some surgeons prefer to transilluminate through the pupil to identify the location of the ciliary body as a dark band posterior to the limbus.

The procedure should be performed under retrobulbar anesthesia. The author recommends the following starting settings: 1,500 mW, 2,000 mS x 20 shots.

Complications
There is a correlation between energy used and complications. In treatment protocols that use less than 80 J per session, they report no hypotony or phthisis. Vision loss is also similar to other surgical procedures. In a summary of 19 studies, many with end-stage secondary glaucoma, 23 % lost two or more lines (range 0–55 %). However, when TSD is performed on eyes with at least 20/60 vision, 68 % retained 20/60 at 5 years and 31 % lost more than two lines of vision. This is comparable to the Tube vs Trabeculectomy study at 5 years, which reported an overall 44 % loss of 2 or more Snellen lines.

Endoscopic Cyclophotocoagulation
Endoscopic photoablation was first described by Shields in 1986. As the diode laser energy is applied under direct visualization of the ciliary processes, there is less damage to the surrounding tissue compared with the TSD. It is reported that only 35 % of TSD energy reaches its intended target with the remaining causing unwanted trauma.

Indications
As it is an intraocular procedure, it is often combined with phacoemulsification in patients with good visual prognosis as well as being used independently for end-stage refractory glaucoma.

Efficacy
The combined phaco-endoscopic cyclophotocoagulation (ECP) has a reported mean IOP reduction of 7 mmHg at 2 years, with no change in topical medication use or vision loss. However, there are no randomized controlled trials comparing photoablation alone to combined phaco-ECP. ECP performs well in refractory glaucoma, with studies reporting a success rate (<21 mmHg) of around 80 % at 2 years. ECP also compares favorably with the Ahmed glaucoma drainage device in refractory glaucoma.

Technique
The ECP laser probe contains a light source, a camera, and helium-neon aiming beam. The endoscopic view is displayed on a monitor to allow direct visualization of the ciliary process. Between 180–360° of ciliary process is treated. Lindfield et al. recommends 250 mW for 3.5 seconds to be applied to each ciliary process. Intracameral dexamethasone 0.8mg/0.2 ml is also recommended.

Complications
The ECP Collaborative Study Group reported the following complications in 5,824 eyes: IOP spike (15 %), hemorrhage (4 %), choroidal effusion (0.4 %), retinal detachment (0.3 %), vision loss of more than two lines (1 %), and hypotony or phthisis (0.1 %). The incidence of serious complications was low and occurred in neovascular glaucoma and refractory glaucoma groups.

Lasers to Augment Glaucoma Surgery

Laser Suture Lysis
Trabeculectomy is the most commonly performed surgery for glaucoma. The trabeculectomy scleral flap covers the sclerostomy and is held down by sutures to reduce postoperative hypotony. These sutures can be later cut with an argon laser to titrate the postoperative aqueous flow and IOP.

The procedure was originally described by Lieberman and Hoskins and Migliazzo. Suture lysis lens (Hoskins or Blumenthal) has a clear pointed tip that when placed over the scleral suture, blanches the conjunctival vessels, magnifies the suture, and focuses the laser beam. A review of 200 consecutive trabeculectomies reported around 50 % required suture lysis.

Technique
Recommended argon laser settings are 50 µm spot size, 0.1 seconds duration, and power of 400 mW. The beam is focused on the suture. Placing longer scleral flap sutures and removing thick tenons during surgery facilitates identifying the flap sutures for postoperative suture lysis.

Complications
This procedure is not without risk. Complications mainly occur due to a sudden decompression of the eye and include: flat anterior chamber (13 %), malignant glaucoma (2 %), iridocorneal effusion (2 %), corneal dellen (1 %), hypotony (3 %), hypotony maculopathy (2 %), conjunctival burns (<1 %), and wound leaks (<1 %).

Laser Goniopuncture
Deep sclerectomy (DS) is a nonpenetrating filtration procedure that depends on aqueous flow through the trabeculo-Descemet’s membrane (TDM) into Schlemm’s canal and the subconjunctival space. Laser goniopuncture (LGP) can be performed in eyes with unsatisfactory IOP post-DS to puncture the TDM and convert the procedure to a trabeculectomy to further lower the IOP. LGP is considered a minor follow-up procedure to DS in the same way laser-suture lysis is to trabeculectomy.

Technique
A glass CGAL gonioscope contact lens (Haag-Streit AG, Koeniz, Switzerland) is used to visualize the semi-translucent TDM. Around one to 20 shots at energy levels of 2–6 mJ are directed to the anterior edge of the TDM using the N2:YAG laser.

Efficacy
Reported LGP rates range from 4.7 % to 63 %. A critical evaluation of nonpenetrating surgery by Sarodia et al. suggest a great importance of LGP in DS, with lower success rates of DS when LGP rates are low. There has been a steady increase in LGP rates being reported. LGP has good efficacy in reducing IOP after DS. Mermod reports an 83 % immediate reduction of IOP and Detry-Morel reported mean IOP of 15 mmHg post-LGP.

Complications
Iris incarceration can occur postlaser and prophylactic argon laser iridoplasty, a smaller size puncture, and targeting a more anterior puncture site can help prevent this. The incarcerated laser can be released using argon or N2:YAG laser. There is also a risk for hypotony and its associated complications after this procedure.
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Conclusion
The management trends of primary open angle glaucoma (POAG) are constantly evolving. Much recent research has focused on minimizing the risks for and adverse reactions to current therapy. In glaucoma medications we have seen the increase number of preservative-free medications to reduce ocular surface pathology. In surgery, we have the introduction of minimally invasive glaucoma procedures (MIGS), which include ECP and ELT. These procedures are often combined with phacoemulsification and are targeted at ocular hypertensive patients or early POAG on a low number of medications. They compensate for a lower efficacy compared with filtration surgery with an improved safety profile. All these procedures have shown promise in the short term but will have to prove long-term efficacy in order to replace the current conventional therapy.