Chapter

Refractive Lensectomy and Microinvasive Glaucoma Surgery (MIGS): An Initial Approach in Glaucoma Patients over 50 Years of Age

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Abstract

Glaucoma is a common cause of blindness worldwide, affecting patients at an average age of 57 years old. This is a disease of ocular anatomy commonly caused by a blockage of trabecular meshwork leading to an increase in intraocular pressure and glaucomatous optic neuropathy. The lens enlarges in width with age, often contributing to this, with obstruction of the angle due to pupillary block in angle-closure glaucoma. In open-angle glaucoma, there is often increased pigment liberation and obstruction of the trabecular meshwork due to increased iridolenticular and zonular contact. Recent studies looking at cataract extraction, refractive lensectomy, and the Hydrus stent have demonstrated adequate safety and efficacy for the treatment of glaucoma. We review the latest glaucoma treatment algorithm and results with early cataract surgery/refractive lensectomy and microinvasive glaucoma surgery to be considered as initial treatment for patients with glaucoma over 50 years of age.

Keywords: glaucoma, refractive lensectomy, microinvasive glaucoma surgery, MIGS

1. Introduction

Glaucoma is a progressive and chronic optic neuropathy characterized by degeneration of the inner layers of the retina, specifically the retinal ganglion cells [1, 2]. As these cells and their axons degenerate with increasing age, the risk of vision loss increases. As a leading cause of blindness worldwide, glaucoma cases are predicted to grow with the increasing aging population by more than double between 2010 and 2050 in the United States [3].

Glaucoma most commonly occurs in people over the age of 40 and rises in prevalence as people age. Natural aging leads to altered age-associated ocular tissue, such as the extracellular matrix. In glaucoma, extensive extracellular matrix remodeling takes place in the trabecular meshwork and the optic nerve leading to tissue stiffening and fibrosis that can cause an increase in intraocular pressure [2, 4]. Additionally, with age, the lens enlarges in width and volume causing greater iridolenticular and iridozonular contact during accommodation [5, 6]. This increased contact leads to pigment liberation that can obstruct the trabecular meshwork and lead to the narrowing of anterior angle structures [5]. Although the outcomes of this ocular pathology can be severe, population-level surveys have demonstrated that many people with glaucoma are unaware that they have it due to its asymptomatic progressive manner [7, 8]. In addition to age, the prevalence of glaucoma cases is higher in Black Americans and individuals of African descent are at higher risk than other races for developing primary open-angle glaucoma [3, 9].

While early treatment of glaucoma has shown to be efficacious, no treatment yet exists for restoring loss of vision of glaucomatous optic neuropathy, therefore emphasizing the importance of early intervention and prevention of vision loss. The standard treatment for glaucoma is trabeculectomy, which is an ocular surgical technique performed to create a new pathway for fluid within the eye to be drained subconjunctivally with associated risks and complications [10]. Recent studies looking at cataract extraction/refractive lensectomy and the Hydrus stent have demonstrated strong safety and efficacy as a novel earlier treatment of glaucoma [11, 12]. This chapter will explore the current literature to report the use of refractive lensectomy in combination with microinvasive glaucoma surgery (MIGS) as an earlier and initial treatment for glaucoma thereby reducing the need for trabeculectomy.

2. Current treatment options for glaucoma

The two most common types of age-related primary glaucomas include open-angle glaucoma and angle-closure glaucoma. Primary open-angle glaucoma (POAG) is the most common type in the United States, affecting nine out of 10 people with glaucoma [13]. The mean normal intraocular pressure (IOP) is 15 mmHg and individuals with untreated glaucoma present with a mean normal IOP of 18 mmHg [14]. Both of these groups of patients often have age-related enlarged lenses contributing to the obstruction of the trabecular meshwork mechanically or with increased particulate trabecular meshwork pigment. According to the American Academy of Ophthalmology, the standard goal to treat POAG is to lower IOP by 25% [15, 16]. We revisit this in this chapter.

2.1 Topical glaucoma medications

While increasing evidence supports the use of Selective Laser Therapy (SLT) as the initial treatment for POAG, topical medications are of the most utilized treatments for glaucoma [17]. Topical eye drops within the drug classes of beta-blockers, diuretics, cholinergic agonists, alpha agonists, rho-kinase inhibitors, and prostaglandin analogs have been used to lower IOP [18]. Of these, prostaglandin analogs have shown greater efficacy than beta-blockers in reducing IOP with fewer systemic side effects [19, 20]. If monotherapy is not effective, additional topical drugs have been added in conjunction to reduce IOP. Although these pharmacologic agents have demonstrated success in reducing the rate of visual field loss, studies examining the results from the Early Manifest Glaucoma trial have shown disease progression despite reduced IOP [21]. Additionally, topical medications for glaucoma require reliable patient adherence to reap the benefits [22]. Previous studies have recognized decreased patient adherence with an increasing number of prescribed topicals to treat glaucoma [23]. Other studies have shown that medication adherence in glaucoma patients is affected by disease severity, demonstrating that those with the most severe disease had higher levels of adherence [22]. These findings challenge the vast benefits of treating glaucoma early with topical medications. If patients with mild glaucoma are less likely to adhere to topical medication treatment, the susceptibility to disease progression increases. Topical medications have also been shown to increase the risk of cataract formation [24]. Despite the initial lowering of intraocular pressure, patients with this side effect can have worsening enlargement of the lens with increased pigment liberation from iridolenticular rubbing or narrowing of the angle, potentially worsening trabecular meshwork outflow.

A long-term history of topical glaucoma medication use and high preoperative glaucoma drug scores have been recognized as a risk factors for surgical failure of trabeculotomy [25–28]. In a recent study conducted by Okuda et al., researchers examined the perioperative factors that affected the surgical success of ab-interno microhook trabeculotomy. The findings revealed that patients taking anti-glaucoma eye drop medications for more than 4.5 years had a lower success rate of cataract surgery and microinvasive trabeculectomy [25]. These findings may be attributed to the substances found within glaucoma eye drops, such as benzalkonium chloride (BAK), that can cause prolonged inflammation and damage to the drainage of the aqueous humor through Schlemm's canal. Preceding studies have suggested that the mechanism by which BAK prolongs inflammation is through an increase in the number of tissue regulators, such as conjunctival macrophages, fibroblasts, and lymphocytes, and a decrease in the number of conjunctival goblet cells that lubricate the ocular surface [26–29]. Other studies have found that BAK may affect aqueous outflow by increasing oxidative stress in the cells of the trabecular meshwork and endothelium, leading to apoptosis and an eventual increase in IOP [30, 31]. Therefore, the effects of chronic inflammation caused by prolonged glaucoma medication use can lead to remodeling of the aqueous humor outflow pathway, and eventually antagonize the opening of the trabecular meshwork during a trabeculectomy or distal outflow after a Schlemm's canal procedure [25].

Additional reports have suggested that the outflow pathway may undergo disuse atrophy with extended glaucoma medication use. The most commonly used topical eye drops for glaucoma, with the exception of rho-kinase inhibitors, relieve ocular pressure by reducing the production of aqueous humor and promoting its drainage through the uveoscleral pathway [32]. Consequently, prolonged use of these medications may lead to disuse atrophy of the pathway of Schlemm's canal, which should typically function to collect the aqueous humor from the anterior chamber of the eye. As such, this can lead to complications with filtration surgery, as demonstrated by Johnson and Matsumoto [33], who recognized a decrease in the size of Schlemm's canal following filtration surgery. Their findings demonstrated that following successful surgery, the aqueous outflow enters the filtration bleb and bypasses the trabecular meshwork and canal resulting in under perfusion and eventual atrophy of these structures [33]. The prolonged use of topical glaucoma medications decreases the success rate of filtration surgeries due to the remodeling, inflammation, and eventual dysfunction of these pathways. It is, therefore, imperative that glaucoma medications be prescribed responsibly, particularly with long-term use, and other treatment options are considered to avoid potential issues with poor adherence or overuse.

2.2 Laser therapies

Laser therapies are used to treat glaucoma by targeting thermal energy toward the trabecular meshwork to open the space in adjacent structures and improve outflow [34]. This therapy was first used in response to high IOPs that were not reduced in response to medical management. Today, laser therapies are used earlier in disease progression without waiting for maximal medical management [35]. The most common form of laser surgery used is Selective Laser trabeculoplasty (SLT), which is used as both a primary and adjunct therapy [36]. This treatment option has been shown to be cost-effective in comparison to medical therapy [37, 38] and shows similar outcomes in reducing IOP [39]. However, SLT has been shown to have a low success rate in treating advanced glaucoma, in particular, following the use of multiple glaucoma medications. Furthermore, the reported predictors of success in SLT treatment have shown conflicting findings [40, 41].

There are several possible reasons for conflicting results with SLT treatment. First, higher success rates using SLT have been demonstrated in patients with the earlier disease and higher baseline IOP (above 22 mmHg) [36, 42, 43]. Furthermore, SLT therapy may have higher rates of failure when treating patients with lower baseline IOPs and more advanced disease [40], therefore, inferring that this therapeutic option may be less efficacious in some patients. Additionally, many confounding variables may affect the success rate of laser therapy today that were not present many years ago. As noted by Song et al., many individuals undergoing glaucoma treatment may be taking a newer class of drugs, such as prostaglandin agonists, α-2 adrenergic agonists, or topical carbonic anhydrase inhibitors, that may contribute to the higher failure rate of SLT therapy today in comparison to 20–30 years ago [40, 44–46]. In addition, findings from the Laser in Glaucoma and Ocular Hypertension (LiGHT) trial have revealed that despite successful SLT at 6 years, 19.7% of patients still progressed with their glaucoma compared to 26.8% with eyedrop therapy (SLT LiGHT trial 6-year data presented at American Glaucoma Society March 2021, Nashville, Tennessee).

Other laser therapies that are currently being studied include titanium-sapphire laser trabeculoplasty, pattern scanning trabeculoplasty, and cyclophotocoagulation [35]. Of these, cyclophotocoagulation is increasingly being used by glaucoma surgeons in combination with other therapies [47, 48]. Although micropulse transscleral cyclophotocoagulation (MPTCP) has been used to reduce IOP [49, 50], studies have shown low success rates with repeated treatments [50–52]. A retrospective case series conducted at the National University of Singapore found low rates of success in lowering IOP despite multiple attempts at MPTCP [52]. Additionally, the IOP-lowering effects of repeated MPTCP were short-lasting with a median time of 4.6 months [52]. The safety and efficacy of this treatment are dependent on the duration and power settings of the laser, which has differed between studies [51, 52]. In comparison to continuous-wave transscleral cyclophotocoagulation and endocyclophotocoagulation, MPTCP has been shown to have a better safety profile [53, 54]. Complications associated with MPTCP may be due to repeated treatments of energy on the targeted pigmented tissues, particularly if the duration between consecutive treatments is short [52, 53, 55]. While the MPTCP is an overall safe option with only mild risks of ocular complications, the short longevity span of reduced IOP suggests other treatment options can have better long-term efficacy for glaucoma patients.

2.3 Trabeculectomy

The gold standard for treating glaucoma has traditionally been trabeculectomy for filtration surgery. While topical eyedrop and or SLT can slow progression, surgery may be required for cases that do not respond to these treatments or are more severe.

The findings in the Collaborative Initial Glaucoma Treatment study [56] and the Advanced Glaucoma Intervention Study [57] concluded that glaucomatous visual field deterioration could be reduced with trabeculectomy. Despite its popularity, many risk factors including higher preoperative IOP, postoperative inflammation, younger age, and diabetes were associated with a higher rate of trabeculectomy failure [57]. The risk of requiring cataract surgery following trabeculectomy surgery is reported between 20% and 52% postoperatively. Furthermore, the Collaborative Normal-Tension Glaucoma Study [58] and the Collaborative Initial Glaucoma Treatment Study [59] have demonstrated an increased incidence of cataracts in individuals who had undergone filtration surgery. Other side effects of trabeculectomy, as summarized by Chou et al., include blebitis, blebitis-associated endophthalmitis, diplopia, tube erosions, damage to the corneal endothelium, and hypotony [60]. Although trabeculectomy is effective in reducing IOP in patients with open-angle glaucoma, the higher incidence of short- and long-term complications offer the possibility of exploring further treatments for glaucoma. Due to its efficacy in treating normal-tension glaucoma (NTG) and achieving low intraocular pressure in patients with advanced glaucoma, the use of trabeculectomy is important and will likely persist. Trabeculectomy also offers better IOP lowering compared to the Xen 45 Gel stent [61].

2.4 Drainage implants for glaucoma

Glaucoma drainage implants (GDI) were once more commonly used to treat refractory glaucoma. These work by using a tube to divert the aqueous humor from the anterior chamber of the eye. The Tube versus Trabeculectomy (TVT) Study [62] demonstrated the shift in practice patterns to the use of GDI. The study found that patients who had a previous trabeculectomy and/or cataract extraction with uncontrolled glaucoma (>18 mmHg) had better success with tube shunt surgery in a 5-year follow-up than those who underwent trabeculectomy. The findings revealed a 29.8% probability of failure in the group receiving the tube shunt, compared to the 46.9% probability of failure in the group with trabeculectomy [62]. The failure rate for trabeculectomy resembled those shown in previous studies [63–65], while the failure rate of the tube shunt was lower than previously reported [66, 67]. While most GDIs have a similar design, the most commonly used are the Ahmed valve (New World Medical, Inc., Rancho Cucamonga, CA) and the Baerveldt implant (Abbott Medical Optics, Inc., Santa Ana, CA) and have not shown differences in superiority [68]. Drainage tube implants continue to be a very important treatment for glaucoma patients. Since these devices are large and use a substantial amount of conjunctival space, they can cause cataract formation and corneal decompensation. Glaucoma tube shunts are usually performed in conjunction with or preferably after cataract surgery has been performed. In this procedure, placing the tube in the ciliary sulcus, reduces the risk of corneal decompensation [69]. Glaucoma tube shunt surgery has also been reported combined with goniotomy and retrobulbar tube placement [70].

3. Refractive lensectomy and intraocular lens placement

Refractive lensectomy, also referred to as refractive lens exchange or clear lens extraction, is similar to cataract surgery as both procedures involve the removal of the natural lens of the eye and replacing it with a synthetic lens. Individuals with primary angle-closure diseases have a shallow anterior chamber due to a thicker lens in the anterior position [71]. Refractive lensectomy is a surgical procedure that can remove the lens to relieve crowding of the angle and deepen the anterior chamber, as shown in the literature [72, 73]. The EAGLE Study was a prospective multicenter clinical study that found that in patients with angle-closure glaucoma, those who underwent a refractive lensectomy (clear lens extraction with intraocular lens) presented with a lower IOP and less medication than patients in the iridotomy group [74]. This surgical procedure also plays a role as a solution to a refractive error in hyperopia, particularly in patients with narrow angles. Glaucoma patients with high degrees of myopia and hyperopia can also benefit from an improved vision from refractive lensectomy and associated intraocular pressure lowering. We further review the use of refractive surgery in patients with myopia and hyperopia.

3.1 Refractive lensectomy in myopia

Myopia, commonly referred to as nearsightedness, is a refractive error that occurs when the eye does not focus light properly on the retina. When mild, this is referred to as mild myopia and when severe, this is referred to as high myopia, which typically stabilizes between the ages of 20–30 years old [75]. Refractive lensectomy has been used to correct high myopia, particularly among those who are approaching or currently have presbyopia [76]. The procedure is performed by skilled experienced surgeons using modern phacoemulsification techniques and causes less disturbances to the homeostasis of the eye by using small incision sizes, improved stability in the anterior chamber, and foldable intraocular lenses [76, 77].

Many studies and reviews have assessed the results and risks of lens refractive procedures, as summarized by Alio et al. [76]. Jean Arne compared phakic intraocular lens (IOL) implantation with clear lens extraction (CLE) in 39 patients aged 30–50 years old and found a lower risk for loss of best correct visual acuity (BCVA) in the phakic IOL group at the one-year follow up [78]. In another study comparing refractive lens exchange (RLE) and Collamer lens (Visian) implantation in patients with myopia younger than 45 years old, the results revealed better outcomes in patients who underwent RLE [79]. In this study, patients in the RLE group experienced no serious complications, while those with the Visian implantation demonstrated pigment dispersion, lens opacity, macular hemorrhage, or pupillary block glaucoma [79]. Additional studies examining the efficacy of RLE have demonstrated encouraging results and revealed a rapid and predictable improvement in vision in patients with high myopia as demonstrated by improved corrected distance visual acuity [77, 80–82].

Although the complications associated with this surgery have a low incidence [83], the visual consequences, lest they occur, may present with real sight-threatening risks including endophthalmitis, intraoperative suprachoroidal hemorrhage, and retinal detachment (RD) [77]. RD is a most common vision-threatening complication of RLE and can occur more commonly in eyes with myopia greater than −10.0 D in unoperated eyes and in eyes following cataract extraction with IOL implantation [76, 84]. The hypothesized reasons behind the increased risk for RD include the increased risk for myopic eyes for predisposed retinal lesions, as well as the induction of iatrogenic factors following refractive surgery [84]. To avoid these complications, the state of the vitreous body should be assessed through preoperative funduscopic examination. The following guidelines were provided by Alios et al. [76] for when to avoid RLE in myopic eyes:

- Eyes with advanced peripheral lattice degenerations
- Young eyes with no posterior vitreous detachment
- Lacquer cracks in high myopia or myopic CNV in the fellow eye
- Presbyopia eyes with macular degeneration beginning in the following eye.

Pre- and postoperative consultation with a retinal specialist can be performed to rule out retinal tears or breaks and prophylactically treat any suspicious retinal degeneration. This has also reduced the risk of retinal detachment [85].

3.1.1 Calculating intraocular lens power

Refractive lens exchange (RLE) requires safety, consistency, and effectiveness during surgery and in the postoperative period for a successful refractive outcome. Accordingly, the accuracy of preoperative procedures for intraocular lens (IOL) power calculations is imperative along with the proper choice of surgical procedure. Kaweri et al. [86] noted that individuals undergoing RLE are comparatively younger and should be advised on the potential loss of accommodation if the monofocal lens is implanted and the photic phenomenon if the multifocal lens is implanted. The surgical technique in RLE is similar to that of cataract surgery and has ideal technical elements that may ensure a successful outcome, as concisely detailed below by Alio et al. [76]

1. Ocular tissues including the corneal endothelium and iris should undergo minimal trauma.
2. Surgically induced or preexisting astigmatisms may be avoided by the surgeon by securing a watertight micro-incision (2.2 mm or less) in a clear cornea about 1.0 mm from the limbus.
3. The posterior chamber IOL should be fixated in the capsular bag, aiming for little to no induction of posterior capsular opacification.

Considerations should be made by the surgeon to address the specific ocular anatomy of the eye, such as those with myopia, extended axial lengths, or hyperopia [76].

3.1.2 Surgical recommendations in high myopia

Eyes with high axial myopia may present with an abnormal depth and stability, requiring the use of a heavy viscoelastic material by surgeons [76]. Many eyes with high myopia have significant astigmatism and may benefit from a temporal approach [86]. Recent advances in clear lens extraction surgery have led to novel approaches in bimanual micro-incisional phacoemulsification. Fine et al. [87] detailed an alternative surgical approach to the traditional coaxial phacoemulsification that involved the removal of the crystalline lens through two 1.2 mm incisions. Using bimanual microincision phacoemulsification, a separate irrigating handpiece can be used for infusion and a sleeveless phacoemulsification needle is used for aspiration and phacoemulsification [87]. This method is conducive to the emulsification and fragmentation of lens material without the generation of significant thermal energy. Additionally, this surgical technique is especially important for patients with a significant risk for retinal detachment following lens extraction, such as those with high myopia [88]. This surgical technique can improve the stability of the chamber, decrease the risk of endophthalmitis, and most importantly reduce the risk of astigmatism induced by surgery [87].

Lens-iris diaphragm retropulsion syndrome may occur during phacoemulsification in highly myopic eyes when the anterior chamber of the eye is deepened, the iris becomes concave, the lens-iris diaphragm is posteriorly displaced, and the pupil dilates in response to the weight of the water column [89]. To avoid this during surgery, the bottle height should be kept low to reduce the infusion limit [89]. Furthermore, an additional instrument may be used to carry out upward tenting of the iris so that the integrity of the ocular structures may be maintained [86]. Capsulorrhexis is used to remove the capsule of the lens of the eye during cataract surgery and should have a 360-degree overlap over the optic in these patients to prevent posterior capsule opacification [90].

The suprascapular approach of phacoemulsification is the preferred, safer method. In this method, the nucleus is prolapsed and emulsified within the anterior chamber [91]. It is recommended that endothelium is coated with viscoelastic prior to phacoemulsification to avoid sudden decompression of the chamber [91]. When compared to the endocapsular technique, the suprascapular approach had an insignificant difference in cell loss, but was more advantageous in cases with zonular weakness and posterior capsular rupture [79]. Accordingly, a successful refractive lens exchange therapy can be achieved with a correctly positioned capsulorrhexis and minimal fluctuations in the anterior chamber [86]. These methods can help maintain the integrity of the ocular structure while minimizing the expenditure of phaco energy.

3.1.3 Selecting the intraocular lens in patients with myopia

In recent years, the growing interest in microincision cataract surgery has led to the increased availability of more flexible IOL. Following refractive lensectomy, a foldable low power lens may be inserted to prevent the development of posterior capsular opacification and the frontward movement of the vitreous [92]. Upon evaluation of the benefits and risk of phacoemulsification to correct high myopia, Fritch found that implantation of an IOL reduced the risk the retinal detachment [93]. The National Outcomes of Cataract Extraction conducted a study that further confirmed these findings and suggested that the probability of retinal detachment following phacoemulsification was less than 1% [94].

Monofocal, toric, and multifocal lenses are used in cataract surgery to replace the natural lens. In refractive lensectomy, a multifocal IOL may be used to achieve contact lens/spectacle independence following surgery and function by distributing light energy into different foci at the expense of contrast sensitivity. When implanting an IOL, it is important to consider the modular transfer function. Trifocal lenses are a subclass of multifocal lenses that have demonstrated excellent near, intermediate, and distant vision but have an inadequate modular transfer in comparison to bifocals [86]. Although in a retrospective study of 787 eyes conducted by Yoon et al. [95], the researchers found that the trifocal diffractive lens demonstrated better intermediate vision than the bifocal diffractive IOL without compromising vision quality.

3.2 Refractive lensectomy in hyperopia

Hyperopia (farsightedness) is a refractive error associated with shallow anterior chambers that are more susceptible to closed-angle glaucoma. Refractive lens surgery corrects high levels of hyperopia through the replacement of the natural lens with an IOL. Hyperopic eyes may benefit from refractive lensectomy due to the increased risk of developing angle-closure glaucoma caused by the small size of the eye and shallow anterior chamber. Several studies have shown satisfactory results in treating hyperopia with refractive lensectomy. Ge et al. compared pseudophakic IOL implant and RLE in the treatment of hyperopia and found that the uncorrected visual acuity was slightly better in the group that underwent RLE and no retinal detachment presented in either group [96]. Fink et al. evaluated refractive lensectomy as a surgical treatment for hyperopia and found refractive lensectomy to be a good alternative to photorefractive keratectomy or laser *in situ* keratomileusis (LASIK) [97]. To follow, Alfonso et al. conducted a prospective study evaluating 41 eyes that underwent RLE following hyperopic LASIK and found that refractive lensectomy following LASIK was safe, effective, and predictable [98]. The safety and efficacy of refractive lensectomy were further confirmed by Preetha et al. [99] and Hoffman et al. [100] through their successful reports of clear lens extraction and bilateral RLE, respectively, in hyperopic eyes.

Similarly, to myopia, ocular pathologies that lead to an increased risk factor for retinal detachment, such as lacquer cracks or lattice degenerations, may be considered contraindications for refractive lensectomy. Additionally, ocular pathologies, such as corneal, diabetic retinopathy, and age-related macular degeneration, can result in poor vision postoperatively, although the risk of postoperative complications in refractive lensectomy is lower than RLE in the treatment of myopia [76, 86, 101].

3.2.1 Surgical recommendations in high hyperopia

Eyes with hyperopia are shorter (axial length < 21 mm) and have an increased risk of macular edema and choroidal effusion during refractive lens exchange [76]. Due to the increased predisposition to closed-angle glaucoma in hyperopic eyes, these individuals are good candidates for RLE, although the complication rate is higher, as demonstrated by Yosar et al. [102]. Hyperopic eyes have an increased risk of developing uveal effusion, iris prolapse, corneal endothelial trauma, cystoid macular edema, and choroidal hemorrhage, making this procedure especially challenging for surgeons [86, 102, 103]. Choroidal hemorrhages may be averted by minimizing fluctuations in the chamber. As with myopia, hyperopic eyes can benefit during surgery from the use of dispersive viscoelastic to the endothelium to prevent damage [86]. Contrastingly, during surgery, a higher bottle height can be used during phacoemulsification to forestall the positive vitreous pressure [86]. A pars plana vitreous tap with an MVR blade and vitrector can deepen the anterior chamber prior to phacoemulsification [104]. Sclerotomy windows can be dissected to reduce the risk of choroidal effusions [105].

More recent reports, including that conducted by Yosar et al., found that cataract surgery in the hyperopic eye was associated with good visual outcomes with a corrected distance visual acuity in 74.6% of study patients, but the complication rate remained higher than that of routine cataract surgery at 25.4% [102]. These findings were further supported by Zhang et al. [106] who found that in patients with malignant glaucoma, using a 23-gauge transconjunctival pars plana vitrectomy combined with lensectomy was a relatively safer manipulation. In comparison to stand-alone lens extraction, the combined surgery was effective by significantly deepening the anterior chamber of the eye (0.507 ± 0.212 mm to 3.080 ± 0.313 mm) and eliminating the blockade of the aqueous in all eyes [106]. Although there was no significant improvement in best-corrected visual acuity at the 21.2 months follow up, the findings also revealed that none of the patients experienced a recurrence of aqueous misdirection, the mean IOP decreased significantly from 43.14 ± 6.53 mmHg to 17.29 ± 1.80 mmHg and the number of postoperative anti-glaucoma medications decreased [106].

Recent studies have contributed to the increasing evidence that lens extraction, in comparison to laser peripheral iridotomy (LPI), may have an advantage. In a retrospective study looking at data from 914 eyes, Ong et al. [107] determined that over 3 years of follow-up, individuals who underwent lens extraction were less likely to experience progression of visual field loss (odds ratio 0.35, 95% confidence interval 0.13–0.91). These patients who received phacoemulsification also required fewer postoperative medications to lower intraocular pressure compared to those with standard care at 12-months. The results of this study also found no additional benefit in combining phacoemulsification with viscogonioplasty, trabeculectomy, or goniosynechialysis in the short- to medium-term outcomes. Additional studies are needed to examine longer periods of follow-up [107]. In selecting IOL power in high hyperopia, studies have compared different formulae to determine the accuracy of formulae predictions. Bai et al. [108] compared the accuracy of Haigis, Hoffer Q, SRKII, Holladay, and SRK/T formulae in 31 eyes and found that the Haigis was the most accurate in IOL in patients with high hyperopia and showed the smallest mean prediction errors (0.37 ± 0.14). The study also found that Hoffer Q was most accurate when measuring axial lengths using A-scan [108]. Comparatively, Kane and Melles [109] conducted a multicenter retrospective case series comparing IOL formulae in 182 eyes using a high power IOL of 30 or more diopters. The formulae compared in this study included Haigis, Hoffer Q, and SRKT, as examined in the previous study, but also included Barrett Universal II, Emmetropia Verifying Optical 2.0, Hill-RBF 2.0, Holladay 1, Holladay 2, Kane, and Olsen. The researchers concluded that the Kane formula had the lowest prediction error within ±0.50 D at 58.8% [109]. Kane and Melles found that the Haigis formulae had a slightly lower prediction error within ±0.50 D at 55.5% [109].

4. Microinvasive glaucoma surgery

The last decade has brought about many new innovations in surgical treatment options and devices for glaucoma. Microinvasive glaucoma surgery (MIGS) is a term used to summarize the surgical interventions that safely and effectively reduce IOP by causing minimal disruption to the normal ocular anatomy, typically through an ab interno approach [110]. The intention of most MIGS procedures is to achieve a lower IOP in glaucoma patients in a shortened surgical time with less postoperative medications needed [110].

The HORIZON study is the largest, prospective, randomized, controlled MIGS pivotal trial that includes data from 556 patients at 38 centers in nine countries [111]. Current data report the 5-year results of this trial with 80% patient follow up comparing cataract surgery alone with combined cataract surgery and intracanalicular stent. The data revealed that after 5 years, cataract surgery in combination with the implantation of the Hydrus microstent was safe, resulting in a sustained lowering of

IOP and reduction in medication use, and reducing the need for additional postoperative glaucoma filtration surgery compared to cataract surgery alone [111]. Cataract patients taking one drop at the time of cataract surgery demonstrated a medication-free rate of 73% following treatment. Of the entire patient cohort, 66% of the patients remained medication-free at the 5-year mark. These findings are pertinent as the data suggest that a reduction in patient adherence to multiple medication regimens can lead to adverse effects [112]. As shown in this trial, MIGS reduces the need for medication and, therefore, lessens the burden of potential adverse effects due to poor patient adherence and can improve patient quality of life. Another key finding of the HORIZON Study is the reduced need for additional surgery. While most patients enrolled in the study had mild glaucoma, the 5-year results showed that those who underwent cataract surgery with the Hydrus microstent were less likely to require invasive incisional glaucoma surgery by more than 2:1 [111]. Visual field analysis showed that patients who underwent cataract surgery and Hydrus had a 47% rate of decreased visual field progression from −0.49 db/year in the cataract surgery alone group to −0.26 db/year in the Hydrus microstent group ($P_d = 0.0138$) [113]. It is important to note that the patients in this study were limited to POAG eye with age-related cataracts as the only comorbidity. Patients with secondary open-angle glaucoma were not included.

Additional studies have been conducted to determine the efficacy of stents in MIGS procedures. In the 7-year outcomes of the Manchester iStent study, the findings also demonstrated safe outcomes with a maintained reduction in IOP and a decrease in the number of glaucoma medications [114]. The most common complications postoperatively occurred in 3–4% of patients in which the iStent was malpositioned and there was obstruction by blood or iris [114]. Gilmann et al. [115] used in vivo optical coherence tomography to analyze the anatomical and physiological effects of the iStent. The findings suggested that a large portion (45.7%) of iStent inject microstents may be burrowed with the trabeculum and may be related to the increase in device protrusion in the anterior chamber of the eye [115]. Similar results have also been demonstrated with the Kahook dual blade (New World Medical, Rancho Cucamonga, CA). Using the Kahook dual blade (KDB), removal of the trabecular meshwork may be obtained through a minimally invasive approach. This device has demonstrated a clinically significant reduction in IOP as a stand-alone procedure and in combination with cataract surgery [116]. Arnljots and Economou [116] found KDB to offer advantageous reductions in IOP in comparison to the iStent inject and the 1-year results from a prospective study by Elhilali et al. showed KDB to be at least as effective as goniotomy [117]. Additional studies have demonstrated an affordable MIGS option that can be performed with Sinskey hook goniotomy and a 23-, 25-, or 27-gauge straight cystotome [47]. This method is especially useful in resource-poor areas and may be performed at the time of cataract surgery to reduce IOP and restore aqueous outflow to the collector channels [47, 118]. The advantages of this surgery as demonstrated by Tanito include a simple surgical technique, decreased surgery time, less invasiveness to the ocular surface, and no requirement for expensive devices [118].

The complications prominent in trabeculectomy procedures, such as endophthalmitis, bleb, and revisions of bleb, may be avoided in MIGS procedures. The complications associated with MIGS include mispositioning and acutely elevated IOP, which typically occurs in the first month postoperatively and resolves with conservative treatment without the need for further surgery [119]. These complications are infrequent and often transient. As interest in MIGS continues to grow, surgeons continue to utilize this method for effective early intervention in the treatment of glaucoma.

In a recent Iris registry report on MIGS, patients receiving MIGS with and without phacoemulsification showed substantial IOP reduction postoperatively with low complication rates [120]. Overall, MIGS were more likely to fail and require reoperation when performed standalone with nearly a quarter of eyes requiring additional intervention by 2 years [120]. Black patients, eyes with moderate to severe glaucoma, and eyes with higher baseline IOP were more likely to undergo reoperations after MIGS [121].

5. Combined refractive Lensectomy and microinvasive glaucoma surgery

In a study presented at the American Society of Cataract and Refractive Surgery Meeting 2021, Laroche et al. [11] reported the results of clear lensectomy and Hydrus microstent in 134 Black and Afro-Latino patients with glaucoma. The findings revealed that 82.8% of patients were medication free at 1 year. Using the Hodapp-Parrish-Anderson criteria, patients in this study were subdivided into mild, moderate, or advanced glaucoma and presented at an average age of 67.9 years (younger than the typical age for cataract surgery at 73 years). While all patients in this study had a reduction in IOP (mean IOP at 1 year = 13.8 ± 3.1, p = 0.16), the greatest effect in IOP reduction at 1-year follow-up was in patients with mild glaucoma [11]. The greatest reduction in a number of medications was seen in patients with moderate glaucoma, with 92.3% of patients in this group with reduced medication use at 1 year [11]. These findings further emphasized the successful outcomes of early cataract surgery/clear lensectomy combined with MIGS in patients with glaucoma over 50 years of age. Although spikes in IOP (defined as an IOP of >30 mmHg or an increase in IOP >10 mmHg), corneal edema, and hyphema were noted postoperatively, these adverse events were non-vision threatening, self-limiting, and required no further intervention [11].

In a study presented at the World Glaucoma Association 2021 on clear lensectomy and Sinskey hook goniotomy, Laroche et al. [122] detailed the findings collected from 38 eyes with moderately advanced glaucoma measured according to the Humphrey visual field exam. The results of this study demonstrated the effectiveness of combined clear lensectomy and Sinskey hook goniotomy in reducing intraocular pressure and postoperative medication use at 6-months [122]. The baseline medically treated IOP of study participants decreased from 16.45 ± 4.8 mmHg to 13.24 ± 3.0 mmHg over the 6-months and remained at statistically significantly reduced levels [122]. Of the patients treated, 30/38 (78%) no longer used medication at 6 months [122]. High-risk sociodemographic groups, such as Blacks and Afro-Latinos, may face financial burdens that impact medication adherence [123], and therefore can benefit from early combined surgery that reduces the need for further medication use. In the study, transient hyphema occurred in two subjects, which commonly occurs 1 week following goniotomy, and posed no threat to the patients' vision [122]. The Sinskey hook used in this study is also of interest due to its affordable price. The Kahook Dual Blade has been reported by Chen et al. [124] to be the most cost-effective device in terms of cost per reduction of mmHg in intraocular pressure, in comparison to the iStent inject, Trabectome, and Hydrus microstent. The Sinskey hook is readily available as it is a part of most standard cataract sets, making goniotomy more accessible for resource-poor areas and is less costly than the Kahook Dual Blade. This combined therapy can be considered as a safe, first-line treatment for patients with mild to moderate glaucoma by reducing IOP and reducing the need for medication. The use of a Sinskey hook as a more affordable makes this surgery more accessible and affordable in places, such as sub-Saharan Africa, where glaucoma is very prevalent, but resources are limited [125].

Most MIGS procedures do not require an incision to the sclera and are frequently used in combination with phacoemulsification and intraocular lens implantation [110]. The combination of refractive lensectomy and microinvasive glaucoma surgery serves two pivotal purposes in the treatment of POAG—(1) the aging enlarged lens may be removed as the primary contributing cause of glaucoma and (2) physiologic outflow may be restored via collector channels, Schlemm's canal, and the aqueous veins by way of the microinvasive trabecular bypass [5, 113]. This procedure is both efficacious and safe due to the strong outcomes and minimal adverse effects, as previously mentioned above. Therefore, patients over the age of 50 with glaucoma should be considered for the combined treatments of refractive lensectomy and microinvasive trabecular bypass as the first line of treatment, prior to severe disease progression.

Prolonged preoperative glaucoma medication use has been identified as a potential risk factor for the surgical failure of trabeculectomy for reasons that are hypothesized to be related to prolonged inflammation or potential atrophy of the outflow pathway [25]. This outcome further emphasizes the need for early surgery in patients with glaucoma. Additionally, the significant concerns associated with poor medication adherence in long-term glaucoma medical management are addressed in this combined therapy. The need for continuous glaucoma medication is reduced with early intervention with earl cataract surgery/refractive lensectomy with MIGS through the reduction of IOP. Additional long-term studies are needed to determine the extent of the reduction in medication need and burden on patients.

While medical therapy continues to be the first line of treatment for glaucoma, these therapies are now being challenged as the safety, efficacy, advancements, and long-term outcomes of surgical treatments continue to advance. Studies examining the results of combination cataract extraction/refractive lensectomy and MIGS using a microstent have demonstrated a decrease in medication burden and reduction in IOP [125]. As previously mentioned, an additional benefit to these procedures is the affordable price of using tools, such as the Sinskey hook or 23-gauge cystotome, particularly useful in resource-poor areas [126].

6. Conclusion

Glaucoma can lead to irreversible blindness and its severity can affect individuals based on the cost of treatment and impact on quality of life [127]. Although the current first-line treatment options for glaucoma begin with medical management, novel surgical techniques have shown to be effective with long-term efficacy and minimal adverse effects. Additionally, long-term medical management poses the risk of poor patient adherence and may not be sustainable for all individuals. Patients can benefit from early surgical intervention and a reduction in postoperative medication, particularly those in communities at the highest risk for glaucoma and those who have a greater disease burden. Black, Hispanic, and elderly populations are at a disproportionately higher risk of glaucoma [128, 129]. Early treatment interventions and accessible care are imperative to stop glaucoma progression before its severity becomes irreversible [130].

In conclusion, the current standards for the treatment of glaucoma should continue to evolve as innovative and effective surgical techniques are increasing in use in practice. The combined refractive lensectomy and MIGS procedure is a safe and effective early intervention with long-term outcomes that should continue to be further studied. This medical intervention can achieve a decreased IOP in the patient, as well as a reduced medication burden while preserving the visual field. Surgeons should be highly skilled and experienced with very low complication rates.

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