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Current Surgical Strategies for Refractory Glaucoma: Contemporary Role of Ahmed Glaucoma Valve and Emerging Alternatives

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ABSTRACT

***Background*:** Refractory glaucoma represents one of the most challenging conditions in ophthalmology because of its progressive nature, resistance to conventional medical therapy, and high risk of irreversible visual loss. These glaucomas are frequently associated with severe ocular inflammation, neovascularization, conjunctival scarring, and previous failed filtration surgeries, all of which significantly reduce the success of traditional surgical approaches. Over recent decades, major advances in glaucoma surgery have led to the development of multiple surgical modalities aiming to achieve long-term intraocular pressure (IOP) control while minimizing complications. Among these modalities, glaucoma drainage devices—particularly the Ahmed glaucoma valve (AGV)—have become increasingly important in the management of refractory glaucoma because of their effectiveness in providing alternative aqueous outflow pathways and reducing postoperative hypotony through a pressure-sensitive valve mechanism.

Aim: This review aims to provide a comprehensive overview of current surgical strategies for refractory glaucoma with particular emphasis on the contemporary role of Ahmed glaucoma valve implantation and emerging alternative procedures. The review further evaluates the mechanisms, indications, surgical outcomes, advantages, limitations, and complications associated with various surgical modalities used in refractory glaucoma management.

Conventional trabeculectomy augmented with antimetabolites remains an important surgical option; however, its efficacy is often limited in refractory glaucoma because of excessive postoperative fibrosis and aggressive wound healing responses. Consequently, glaucoma drainage devices have become preferred surgical interventions in many complex cases. Ahmed glaucoma valve implantation has demonstrated favorable outcomes in neovascular, uveitic, pediatric, traumatic, post-vitrectomy, and post-keratoplasty glaucomas. Nevertheless, long-term surgical success may still be compromised by encapsulated bleb formation and hypertensive phase development. Emerging surgical alternatives including minimally invasive glaucoma surgery (MIGS), cyclodestructive procedures, micropulse transscleral cyclophotocoagulation, endoscopic cyclophotocoagulation, and high-intensity focused ultrasound have expanded the therapeutic spectrum for refractory glaucoma management. Recent advances in biomaterials, wound healing modulation, and imaging technologies have further improved surgical planning and postoperative assessment.

Conclusion: Current surgical management of refractory glaucoma has evolved substantially with the increasing use of glaucoma drainage devices and development of newer minimally invasive and cyclodestructive techniques. Ahmed glaucoma valve implantation continues to play a central role because of its versatility and effectiveness across various refractory glaucoma subtypes. However, no single surgical modality is universally ideal, and procedure selection should be individualized according to glaucoma etiology, ocular anatomy, visual potential, and previous surgical history. Continued advances in surgical technology, fibrosis modulation, and personalized treatment strategies are expected to further improve long-term outcomes in refractory glaucoma management.

Keywords: Surgical Strategies, Refractory Glaucoma, Ahmed Glaucoma Valve, Emerging Alternatives

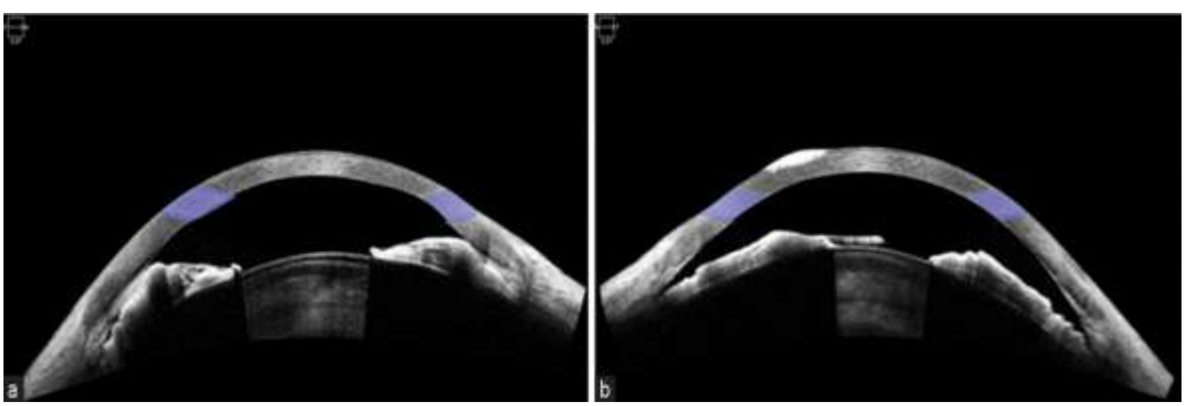
INTRODUCTION

Glaucoma remains one of the leading causes of irreversible blindness worldwide and is characterized by progressive optic neuropathy associated with degeneration of retinal ganglion cells, optic nerve head damage, and corresponding visual field loss. Elevated intraocular pressure (IOP) is considered the most important modifiable risk factor for disease progression, making effective pressure reduction the principal objective of glaucoma management. Although medical therapy and conventional filtration surgery successfully control IOP in many patients, a substantial subset continues to demonstrate progressive optic nerve damage despite maximal treatment. These cases are commonly categorized as refractory glaucoma and represent some of the most surgically challenging conditions encountered in ophthalmic practice. [1,2]

Refractory glaucoma encompasses a heterogeneous group of glaucomatous disorders characterized by uncontrolled IOP despite maximal tolerated medical therapy and/or previous failed glaucoma surgery. This category commonly includes neovascular glaucoma (NVG), uveitic glaucoma, traumatic glaucoma, aphakic and pseudophakic glaucoma, post-vitrectomy glaucoma, pediatric glaucomas, and glaucoma associated with corneal transplantation or severe ocular surface disease. Such eyes frequently exhibit extensive conjunctival scarring, chronic inflammation, altered anterior segment anatomy, and aggressive wound healing responses that significantly reduce the success of conventional filtration procedures. Consequently, management of refractory glaucoma often requires complex surgical strategies and individualized therapeutic planning. [3,4]

Trabeculectomy has historically been regarded as the gold standard surgical treatment for glaucoma because of its effectiveness in lowering IOP through creation of a subconjunctival filtration bleb. However, outcomes of trabeculectomy in refractory glaucoma are frequently compromised by excessive subconjunctival fibrosis and postoperative scarring. The use of antimetabolites such as mitomycin-C and 5-fluorouracil has improved filtration success by suppressing fibroblast proliferation and wound healing responses; nevertheless, these agents may also lead to serious complications including hypotony, bleb leakage, avascular blebs, infection, and endophthalmitis. Therefore, increasing attention has been directed toward alternative surgical modalities capable of achieving durable IOP reduction while minimizing postoperative complications. [5]

Over the past two decades, glaucoma drainage devices (GDDs) have become increasingly important in the management of refractory glaucoma. These devices provide an alternative pathway for aqueous humor drainage by diverting aqueous flow toward an episcleral plate where filtration occurs through a surrounding fibrous capsule. Among currently available GDDs, the Ahmed glaucoma valve (AGV) has emerged as one of the most widely utilized implants because of its pressure-sensitive valved mechanism, which reduces the risk of postoperative hypotony while maintaining effective aqueous drainage. Since its introduction, AGV implantation has demonstrated favorable outcomes across multiple refractory glaucoma subtypes and has become a cornerstone of modern glaucoma surgery. [6-8]



Figure(1): AS- OCT showing Right anterior synechia(a), left convex iris configuration(b) in patient with ICE syndrome [8]

Despite the increasing success of glaucoma drainage surgery, postoperative fibrosis and encapsulated bleb formation remain major causes of long-term surgical failure. The hypertensive phase following Ahmed valve implantation, characterized by transient postoperative elevation of IOP due to fibrovascular encapsulation around the plate, continues to represent a significant clinical challenge. Advances in wound healing modulation, anti-fibrotic therapy, and biomaterial engineering have therefore become essential components of contemporary glaucoma surgery research. [9]

In parallel with the evolution of glaucoma drainage devices, emerging surgical alternatives have expanded the therapeutic spectrum for refractory glaucoma management. Minimally invasive glaucoma surgery (MIGS) procedures, cyclodestructive techniques such as transscleral cyclophotocoagulation and micropulse cyclophotocoagulation, endoscopic cyclophotocoagulation, and high-intensity focused ultrasound have introduced less invasive approaches with varying mechanisms of IOP reduction. Although many of these procedures were initially developed for mild-to-moderate glaucoma, their role in selected refractory cases continues to evolve. [10,11]

The growing diversity of surgical options reflects the complexity and heterogeneity of refractory glaucoma itself. Selection of the most appropriate surgical intervention depends on multiple factors including glaucoma subtype, visual potential, ocular anatomy, conjunctival status, degree of inflammation, previous surgeries, and surgeon experience. Consequently, contemporary management increasingly emphasizes individualized treatment strategies tailored to each patient's specific clinical characteristics. [3,7]

The aim of this review is to provide a comprehensive overview of current surgical strategies for refractory glaucoma with particular emphasis on the contemporary role of Ahmed glaucoma valve implantation and emerging alternative procedures. The review further discusses the indications, mechanisms, outcomes, complications, and future perspectives of modern surgical approaches used in refractory glaucoma management.

Refractory Glaucoma: Definition, Classification, and Surgical Challenges

Refractory glaucoma refers to a group of glaucomatous disorders characterized by persistently elevated intraocular pressure (IOP) despite maximal tolerated medical therapy and/or previous unsuccessful glaucoma surgery. These glaucomas are typically associated with aggressive wound healing responses, chronic inflammation, altered aqueous outflow pathways, and severe conjunctival scarring, all of which substantially reduce the success of conventional filtration procedures. Because refractory glaucoma frequently progresses despite treatment, it represents a major cause of irreversible visual loss and often requires complex surgical intervention to preserve remaining vision. [12,13]

The term refractory glaucoma encompasses several secondary and complex glaucoma subtypes that demonstrate resistance to standard therapeutic approaches. Common forms include neovascular glaucoma (NVG), uveitic glaucoma, aphakic and pseudophakic glaucoma, traumatic glaucoma, glaucoma following vitreoretinal surgery, pediatric glaucoma, and glaucoma associated with penetrating keratoplasty or extensive ocular surface disease. Although these conditions differ in etiology, they share common pathophysiologic features including increased inflammation, fibrovascular proliferation, and excessive postoperative fibrosis that contribute to poor long-term surgical outcomes. [12,14]

Neovascular glaucoma is considered one of the most aggressive and visually devastating forms of refractory glaucoma. It develops secondary to retinal ischemia resulting from disorders such as proliferative diabetic retinopathy, central retinal vein occlusion, or ocular ischemic syndrome. Retinal hypoxia stimulates production of vascular endothelial growth factor (VEGF), leading to neovascularization of the iris and anterior chamber angle. These fragile fibrovascular membranes progressively contract, causing peripheral anterior synechiae and irreversible angle closure with severe elevation of IOP. Surgical management of NVG is particularly difficult because of active inflammation, intraoperative bleeding, and intense postoperative fibrosis. [15]

Uveitic glaucoma represents another important refractory subtype characterized by chronic intraocular inflammation and recurrent breakdown of the blood-aqueous barrier. Elevated IOP may result from inflammatory trabecular obstruction, corticosteroid response, synechial angle closure, or chronic structural damage to aqueous outflow pathways. Surgical intervention in uveitic glaucoma is challenging because persistent inflammation promotes subconjunctival scarring and filtration failure. Adequate perioperative inflammatory control is therefore essential to improve surgical success and reduce postoperative complications. [16]

Glaucoma following vitreoretinal surgery has also become increasingly prevalent because of the expanding use of pars plana vitrectomy and silicone oil tamponade in retinal disease management. Mechanisms of postoperative glaucoma include trabecular obstruction by silicone oil droplets, inflammation, synechial angle closure, and altered anterior segment anatomy. Previous vitreoretinal surgery frequently causes conjunctival scarring and anatomic distortion that complicate subsequent filtration surgery. In such cases, glaucoma drainage devices often provide more reliable long-term pressure control compared with conventional trabeculectomy. [17]

Pediatric refractory glaucoma constitutes a particularly complex surgical entity because of the unique biologic characteristics of childhood ocular tissues. Pediatric eyes exhibit vigorous wound healing responses with rapid fibroblast proliferation and aggressive subconjunctival scarring, leading to high rates of filtration failure. In addition, congenital ocular anomalies, poor examination cooperation, and lifelong risk of disease progression further complicate management. Long-term surgical success in pediatric glaucoma remains challenging despite advances in glaucoma drainage devices and antifibrotic strategies. [18]

One of the principal factors underlying surgical failure in refractory glaucoma is excessive postoperative fibrosis. Surgical trauma activates inflammatory cytokines, fibroblast migration, angiogenesis, and extracellular matrix remodeling, resulting in scar formation around filtration sites or drainage implants. Histopathologic studies have demonstrated that activated fibroblasts and myofibroblasts play central roles in collagen deposition and encapsulated bleb formation. The degree of fibrosis is influenced by multiple factors including patient age, glaucoma subtype, inflammation severity, previous surgeries, and conjunctival health. [5]

Trabeculectomy augmented with mitomycin-C or 5-fluorouracil has historically been utilized to suppress wound healing responses and improve filtration success. However, excessive inhibition of tissue repair may produce thin avascular blebs prone to leakage, hypotony, infection, and endophthalmitis. These limitations have contributed to the increasing preference for glaucoma drainage devices and alternative surgical strategies in refractory glaucoma management. Contemporary surgical approaches therefore aim not only to lower IOP effectively but also to achieve safer and more controlled modulation of postoperative wound healing. [5,7]

The complexity and heterogeneity of refractory glaucoma necessitate individualized treatment planning based on disease etiology, visual potential, ocular anatomy, conjunctival status, and previous surgical history. No single surgical modality is universally ideal for all refractory glaucomas, and successful management often requires integration of multiple therapeutic approaches. Continued advances in surgical technology, biomaterials, and biologic modulation of fibrosis are expected to further improve outcomes in these highly challenging cases. [4,7]

Mechanisms of Surgical Failure in Refractory Glaucoma

Surgical failure in refractory glaucoma is a multifactorial process primarily driven by excessive wound healing and postoperative fibrosis. Although modern glaucoma procedures aim to establish an alternative pathway for aqueous humor drainage, long-term surgical success ultimately depends on maintaining adequate filtration through subconjunctival tissues or drainage implant capsules. In refractory glaucomas, exaggerated inflammatory responses, fibroblast activation, angiogenesis, and extracellular matrix remodeling frequently compromise aqueous outflow and lead to progressive elevation of intraocular pressure (IOP). Understanding the biologic mechanisms underlying filtration failure is therefore essential for optimizing surgical outcomes and developing targeted antifibrotic strategies. [19,20]

The wound healing response after glaucoma surgery occurs through a sequence of overlapping inflammatory, proliferative, and remodeling phases. Surgical trauma initiates immediate release of inflammatory mediators including interleukins, transforming growth factor-beta (TGF-β), tumor necrosis factor-alpha, and vascular endothelial growth factor (VEGF). These cytokines recruit inflammatory cells, fibroblasts, and vascular endothelial cells to the surgical site. Although this response is necessary for tissue repair and wound closure, excessive activation results in aggressive subconjunctival fibrosis and failure of filtration pathways. [5,19]

Fibroblasts represent the principal effector cells responsible for postoperative scar formation. Following activation, fibroblasts migrate into subconjunctival tissues and differentiate into myofibroblasts capable of producing large quantities of collagen and extracellular matrix proteins. Myofibroblasts also possess contractile properties that contribute to tissue contraction and collapse of filtration spaces. Histopathologic studies of failed filtration blebs and encapsulated glaucoma drainage device capsules have demonstrated dense collagen deposition, fibroblast proliferation, and reduced interstitial permeability, all of which increase resistance to aqueous humor outflow. [5,21]

Angiogenesis plays an equally important role in postoperative fibrosis and surgical failure. VEGF is a central mediator in this process because it stimulates endothelial cell proliferation, vascular permeability, inflammatory cell migration, and fibroblast activation. Increased vascular permeability promotes leakage of plasma proteins and inflammatory mediators into healing tissues, further intensifying fibrovascular proliferation. Elevated VEGF expression has been strongly associated with aggressive subconjunctival scarring and encapsulated bleb formation after glaucoma surgery, particularly in neovascular glaucoma where ischemia-driven VEGF production is markedly increased. [14,22]

The hypertensive phase observed after Ahmed glaucoma valve implantation represents a characteristic example of postoperative fibrosis-mediated surgical failure. This phase typically occurs within the first few postoperative months after an initial period of satisfactory IOP reduction and is associated with fibrovascular encapsulation around the episcleral plate. Histologically, the filtering capsule during the hypertensive phase demonstrates dense collagen bundles, inflammatory cell infiltration, vascular proliferation, and activated fibroblasts. Increased capsular thickness and reduced permeability ultimately impair aqueous humor diffusion and compromise pressure control. [9,23]

Inflammation significantly amplifies the risk of surgical failure in refractory glaucoma. Eyes with chronic uveitis, neovascularization, previous ocular surgeries, or ocular surface disease exhibit enhanced inflammatory cytokine activity and accelerated wound healing responses. Repeated conjunctival manipulation and prior filtration procedures may also induce subconjunctival fibrosis before surgery even begins, thereby reducing the likelihood of successful filtration. In pediatric glaucoma, wound healing responses are particularly aggressive because of increased fibroblast activity and rapid tissue remodeling, contributing to high rates of filtration failure. [16,18]

Conventional antifibrotic agents such as mitomycin-C and 5-fluorouracil improve surgical outcomes by suppressing fibroblast proliferation and DNA synthesis. However, these agents act through nonspecific cytotoxic mechanisms that may impair physiologic tissue repair and result in thin avascular blebs, hypotony, bleb leakage, and late infection. Consequently, contemporary glaucoma surgery increasingly focuses on more selective and biologically targeted approaches capable of modulating wound healing while preserving tissue integrity. These include anti-VEGF therapy, biodegradable collagen matrices, sustained-release drug delivery systems, and tissue-engineered biomaterials. [5,24]

Failure mechanisms in glaucoma surgery therefore reflect a complex interaction between inflammation, angiogenesis, fibroblast activation, extracellular matrix remodeling, and individual patient factors. The multifactorial nature of postoperative fibrosis explains why no single antifibrotic strategy has proven universally effective in refractory glaucoma management. Ongoing research continues to explore targeted molecular therapies and biomaterial-based approaches aimed at improving long-term filtration function while minimizing complications associated with excessive wound inhibition. [19,24]

Diagnostic Evaluation of Refractory Glaucoma

Accurate diagnostic evaluation is essential in refractory glaucoma because successful surgical planning depends largely on identifying the underlying mechanism of intraocular pressure (IOP) elevation, degree of optic nerve damage, ocular anatomy, and associated comorbidities. Refractory glaucomas are highly heterogeneous disorders, and comprehensive preoperative assessment is necessary to determine the most appropriate surgical strategy, estimate visual prognosis, and minimize postoperative complications. Modern diagnostic modalities now allow detailed evaluation of anterior and posterior segment structures, aqueous outflow pathways, and optic nerve integrity, thereby improving individualized surgical decision-making. [25,26]

Comprehensive clinical examination remains the cornerstone of refractory glaucoma assessment. Measurement of IOP using Goldmann applanation tonometry is fundamental, although interpretation may be influenced by corneal abnormalities, edema, previous surgeries, or altered corneal biomechanics. Slit-lamp biomicroscopy provides important information regarding conjunctival scarring, bleb status, corneal clarity, anterior chamber inflammation, iris neovascularization, synechiae formation, and lens status. Careful evaluation of conjunctival mobility and integrity is particularly important when planning filtration surgery or glaucoma drainage device implantation because extensive subconjunctival fibrosis may significantly compromise surgical outcomes. [3,25]

Gonioscopy plays a critical role in determining the mechanism of glaucoma and guiding surgical management. Assessment of the anterior chamber angle allows differentiation between open-angle, angle-closure, synechial, and neovascular mechanisms. In neovascular glaucoma, gonioscopy may reveal fine neovascularization of the angle associated with fibrovascular membrane formation and progressive peripheral anterior synechiae. In uveitic glaucoma, inflammatory debris, peripheral anterior synechiae, or angle distortion may be identified. Gonioscopy is also essential for evaluating suitability for minimally invasive glaucoma surgery (MIGS), many of which require relatively preserved angle anatomy for effective implantation. [14,16]

Evaluation of the optic nerve head and retinal nerve fiber layer remains central to assessment of glaucoma severity and progression. Fundus examination may demonstrate characteristic glaucomatous changes including neuroretinal rim thinning, increased cup-to-disc ratio, optic disc hemorrhage, and retinal nerve fiber layer defects. Optical coherence tomography (OCT) has become an indispensable imaging modality for quantitative assessment of retinal nerve fiber layer thickness, ganglion cell complex integrity, and optic nerve head parameters. OCT allows objective structural monitoring of glaucoma progression and may assist in estimating visual prognosis before surgical intervention. [26]

Visual field testing provides functional assessment of glaucomatous damage and remains essential in determining disease severity and treatment goals. Standard automated perimetry is most commonly utilized to evaluate characteristic glaucomatous visual field defects and monitor progression over time. In advanced refractory glaucoma, however, visual field interpretation may become limited because of severe field constriction or poor patient reliability. Nevertheless, baseline functional assessment remains important when determining the urgency and aggressiveness of surgical management. [25]

Anterior segment imaging techniques have gained increasing importance in refractory glaucoma evaluation. Ultrasound biomicroscopy (UBM) provides high-resolution visualization of the anterior chamber angle, ciliary body, peripheral iris configuration, and tube position in eyes with glaucoma drainage devices. UBM is particularly valuable in eyes with opaque corneas or distorted anterior segment anatomy where gonioscopy may be limited. Anterior segment OCT also allows noncontact imaging of angle structures, filtering blebs, and drainage implant morphology, thereby assisting both preoperative planning and postoperative follow-up. [27,28]

Retinal evaluation is especially important in secondary glaucomas associated with posterior segment pathology. In neovascular glaucoma, fundus examination and fluorescein angiography may identify retinal ischemia secondary to proliferative diabetic retinopathy or retinal vein occlusion. Detection of ischemic retinal disease is essential because successful management often requires combined retinal and glaucoma treatment including panretinal photocoagulation and anti-vascular endothelial growth factor therapy. Similarly, previous vitreoretinal surgery, silicone oil tamponade, or retinal detachment repair may significantly influence surgical planning in post-vitrectomy glaucoma. [14,17]

Comprehensive diagnostic evaluation also includes assessment of systemic disease and patient-specific risk factors. Diabetes mellitus, autoimmune disorders, vascular disease, and previous ocular surgeries may significantly influence wound healing responses and surgical outcomes. In pediatric and congenital glaucomas, examination under anesthesia may be required to accurately evaluate corneal diameter, axial length, angle structures, and optic nerve status. Ultimately, detailed diagnostic assessment forms the basis for individualized surgical planning and selection of the most appropriate intervention for each refractory glaucoma subtype. [18,25]

The increasing sophistication of modern imaging technologies and diagnostic tools has substantially improved understanding of refractory glaucoma pathophysiology and surgical outcomes. Precise characterization of ocular anatomy, fibrosis risk, and disease severity allows more personalized treatment strategies and facilitates earlier identification of postoperative complications. As newer surgical techniques continue to evolve, advanced diagnostic evaluation will remain essential for optimizing long-term visual and pressure outcomes in refractory glaucoma management. [26-28]

Conventional Trabeculectomy and Its Limitations in Refractory Glaucoma

Trabeculectomy has long been regarded as the gold standard filtration surgery for glaucoma because of its ability to effectively lower intraocular pressure (IOP) through creation of a guarded fistula between the anterior chamber and subconjunctival space. The procedure facilitates drainage of aqueous humor into a subconjunctival bleb, thereby bypassing the trabecular meshwork and reducing aqueous outflow resistance. Since its introduction, trabeculectomy has achieved substantial long-term success in primary open-angle glaucoma and many secondary glaucomas. However, outcomes in refractory glaucoma are significantly less favorable because of aggressive postoperative fibrosis and altered ocular wound healing responses. [29,30]

The success of trabeculectomy depends largely on maintenance of a functional subconjunctival filtration bleb. Following surgery, controlled wound healing is required to preserve adequate aqueous outflow while preventing excessive leakage and hypotony. In refractory glaucoma, however, heightened inflammatory activity and fibroblast proliferation frequently result in rapid subconjunctival scar formation and bleb failure. Histopathologic studies have demonstrated that activated fibroblasts and myofibroblasts produce dense collagen deposition around the filtration site, progressively increasing resistance to aqueous drainage and leading to surgical failure. [20,21]

To improve surgical outcomes, antimetabolites such as mitomycin-C (MMC) and 5-fluorouracil (5-FU) became widely incorporated into trabeculectomy procedures. These agents inhibit fibroblast proliferation and DNA synthesis, thereby suppressing subconjunctival fibrosis and prolonging bleb survival. Mitomycin-C in particular significantly improved long-term success rates in high-risk glaucomas including neovascular, uveitic, aphakic, and previously operated eyes. Nevertheless, the use of antimetabolites is associated with important complications related to excessive wound inhibition and impaired tissue healing. [5,29]

One of the major limitations of trabeculectomy with antimetabolites is the development of thin avascular blebs that are structurally weak and prone to leakage. Chronic hypotony resulting from overfiltration may lead to hypotony maculopathy, choroidal detachment, shallow anterior chamber, and cataract progression. Furthermore, avascular blebs exhibit reduced resistance to microbial invasion and may predispose patients to blebitis and late-onset endophthalmitis, both of which are potentially vision-threatening complications. The risk of these complications is particularly elevated in younger patients and eyes requiring aggressive antimetabolite exposure because of severe fibrosis risk. [5,30]

Trabeculectomy outcomes are especially poor in eyes with severe conjunctival scarring or active inflammation. Previous ocular surgeries, chronic topical medication use, ocular trauma, vitreoretinal procedures, and inflammatory glaucomas may all induce subconjunctival fibrosis before surgery even begins. In neovascular glaucoma, extensive fibrovascular proliferation and elevated vascular endothelial growth factor (VEGF) expression further accelerate postoperative scarring and filtration failure. Similarly, pediatric eyes demonstrate vigorous wound healing responses with rapid fibroblast activation and aggressive bleb encapsulation, resulting in significantly reduced long-term trabeculectomy survival. [14,18]

Postoperative management after trabeculectomy also remains highly demanding. Frequent follow-up visits are often required for bleb manipulation, suture lysis, bleb needling, or additional antimetabolite injections to maintain filtration function. Despite meticulous postoperative care, long-term surgical success may gradually decline because of progressive subconjunctival remodeling and fibrosis. Consequently, many refractory glaucoma cases eventually require repeat surgery or conversion to glaucoma drainage device implantation. [29]

Because of these limitations, glaucoma drainage devices (GDDs) have increasingly become preferred surgical options in refractory glaucoma management. Unlike trabeculectomy, GDDs bypass scarred limbal tissues and direct aqueous humor toward a more posterior episcleral filtration area, where postoperative fibrosis may be comparatively less aggressive. Large clinical trials such as the Tube Versus Trabeculectomy (TVT) study demonstrated favorable long-term outcomes of tube shunt surgery in previously operated eyes and complex glaucomas, contributing to the expanding role of Ahmed glaucoma valve implantation and other drainage devices in modern glaucoma surgery. [8,31]

Although trabeculectomy remains an important surgical procedure in glaucoma management, its limitations in refractory glaucoma have stimulated the development of newer surgical approaches aimed at improving long-term safety and filtration durability. Advances in biomaterials, wound healing modulation, minimally invasive glaucoma surgery, and glaucoma drainage devices continue to reshape the surgical management of complex glaucoma cases. Nevertheless, careful patient selection and individualized surgical planning remain essential when considering trabeculectomy in eyes with refractory disease. [24,31]

Minimally Invasive Glaucoma Surgery in Refractory Glaucoma

Minimally invasive glaucoma surgery (MIGS) has emerged over the past decade as an important advancement in glaucoma management, aiming to reduce intraocular pressure (IOP) through less traumatic surgical approaches while minimizing complications associated with traditional filtration surgery. MIGS procedures are generally characterized by ab interno microincisional techniques, limited tissue disruption, rapid postoperative recovery, and favorable safety profiles. Although initially developed primarily for mild-to-moderate open-angle glaucoma, expanding surgical experience and technological advances have stimulated interest in their potential role within selected cases of refractory glaucoma. [32,33]

The fundamental principle of MIGS involves enhancement of aqueous humor outflow through physiologic or alternative drainage pathways with minimal conjunctival manipulation. Depending on the device and mechanism of action, MIGS procedures may target trabecular outflow pathways, the suprachoroidal space, or subconjunctival filtration. Compared with trabeculectomy and glaucoma drainage devices, MIGS generally produce more modest IOP reduction but demonstrate lower rates of severe postoperative complications such as hypotony, bleb leakage, and endophthalmitis. These characteristics have contributed to the increasing popularity of MIGS in glaucoma surgery. [32]

Trabecular bypass procedures are among the most widely utilized MIGS techniques. Devices such as the iStent and Hydrus microstent facilitate aqueous humor drainage through Schlemm's canal by bypassing the trabecular meshwork, which is considered the principal site of resistance in open-angle glaucoma. These procedures are commonly combined with cataract surgery and may effectively reduce medication burden in patients with mild-to-moderate disease. However, their efficacy in advanced refractory glaucoma remains limited because they rely on relatively preserved distal outflow pathways, which may already be compromised in secondary and complex glaucomas. [33,34]

Subconjunctival MIGS devices represent another important category with greater relevance to refractory glaucoma management. The XEN Gel Stent creates a controlled subconjunctival drainage pathway similar to trabeculectomy but through an ab interno minimally invasive approach. Because filtration occurs within the subconjunctival space, postoperative fibrosis remains an important determinant of long-term success. Studies evaluating the XEN implant in refractory glaucoma demonstrated favorable IOP reduction and reduced medication dependence; however, postoperative bleb needling and adjunctive antifibrotic therapy are frequently required to maintain filtration function. [10,35]

Despite the advantages of reduced tissue trauma and improved safety, several limitations restrict the widespread use of MIGS in severe refractory glaucoma. Most MIGS procedures achieve moderate rather than profound IOP reduction and may therefore be insufficient in eyes requiring very low target pressures because of advanced optic nerve damage. Additionally, eyes with neovascular glaucoma, extensive peripheral anterior synechiae, severe inflammation, angle closure, or prior conjunctival scarring may not be suitable candidates for many MIGS procedures. Consequently, glaucoma drainage devices and cyclodestructive procedures often remain more effective options in advanced refractory disease. [3,32]

Another important consideration is the limited long-term evidence regarding MIGS efficacy in refractory glaucoma. Most published studies primarily involve patients with mild-to-moderate primary open-angle glaucoma rather than complex secondary glaucomas. Furthermore, outcomes may vary significantly according to glaucoma subtype, ocular anatomy, and previous surgical history. Although some reports demonstrated encouraging results in selected refractory cases, the durability of pressure reduction achieved with MIGS remains uncertain in eyes with aggressive fibrosis and chronic inflammation. [33,35]

The role of MIGS in refractory glaucoma may nevertheless continue to expand as newer devices and surgical techniques are developed. Improvements in biomaterials, implant design, and wound healing modulation may enhance long-term filtration performance and broaden applicability to more complex glaucoma subtypes. Combination approaches integrating MIGS with cataract extraction, cyclodestructive procedures, or glaucoma drainage devices may also offer individualized solutions for selected patients. Additionally, the favorable safety profile of MIGS may be particularly advantageous in elderly patients or eyes with limited visual potential where minimizing surgical morbidity is essential. [24,32]

Although MIGS has transformed the surgical landscape of glaucoma management, its role in refractory glaucoma currently remains selective and complementary rather than replacing traditional filtration surgery or glaucoma drainage devices. Ahmed glaucoma valve implantation continues to provide more reliable long-term IOP reduction in advanced refractory disease because of its ability to bypass compromised physiologic outflow pathways and maintain filtration despite severe ocular pathology. Nevertheless, ongoing technological innovation and increasing surgical experience are likely to further define the future role of MIGS within the evolving spectrum of refractory glaucoma management. [7,33]

Cyclodestructive procedures represent an important surgical option in refractory glaucoma management, particularly in eyes with poor visual potential, severe ocular comorbidities, failed previous surgeries, or limited suitability for filtration procedures. Unlike trabeculectomy and glaucoma drainage devices, which primarily enhance aqueous humor outflow, cyclodestructive techniques lower intraocular pressure (IOP) through partial destruction of the ciliary body epithelium, thereby reducing aqueous humor production. Advances in laser technology and energy delivery systems have substantially improved the safety and predictability of these procedures, leading to their expanding role in contemporary glaucoma management. [36,37]

Traditional transscleral cyclophotocoagulation (TSCPC) utilizes diode laser energy applied through the sclera to ablate the ciliary processes. Laser-induced coagulative necrosis decreases aqueous secretion by destroying ciliary epithelium and reducing ciliary body perfusion. Historically, conventional TSCPC was reserved primarily for painful blind eyes or end-stage glaucoma because of concerns regarding severe inflammation, hypotony, phthisis bulbi, and unpredictable visual outcomes. Nevertheless, improvements in laser delivery techniques and energy titration have increased the use of cyclophotocoagulation in selected eyes with refractory glaucoma and useful residual vision. [36]

Micropulse transscleral cyclophotocoagulation (MP-TSCPC) represents a major advancement in cyclodestructive surgery. Unlike continuous-wave TSCPC, micropulse technology delivers laser energy in repetitive short pulses separated by cooling intervals, thereby minimizing collateral thermal damage to surrounding tissues. This selective energy modulation allows more controlled treatment of the ciliary body while reducing postoperative inflammation and hypotony risk. Clinical studies have demonstrated favorable IOP reduction with improved safety profiles compared with traditional cyclophotocoagulation, making MP-TSCPC increasingly attractive in refractory glaucoma management. [11,38]

One of the major advantages of MP-TSCPC is its applicability across a broad spectrum of glaucoma subtypes. Favorable outcomes have been reported in neovascular glaucoma, uveitic glaucoma, pediatric glaucoma, post-keratoplasty glaucoma, and eyes with previous failed filtration surgery. Because the procedure avoids conjunctival dissection and intraocular manipulation, it may be particularly valuable in eyes with severe conjunctival scarring or poor surgical candidacy. Additionally, repeat treatments may be performed if IOP reduction becomes insufficient over time, offering flexibility in long-term disease management. [38]

Endoscopic cyclophotocoagulation (ECP) provides another cyclodestructive approach with greater procedural precision. ECP utilizes an intraocular endoscope equipped with a laser probe, camera, and illumination system, allowing direct visualization and targeted photocoagulation of the ciliary processes. Compared with transscleral approaches, ECP permits selective treatment with reduced collateral tissue damage. The procedure is commonly combined with cataract surgery and may be useful in refractory glaucomas requiring moderate IOP reduction while preserving visual function. However, ECP requires intraocular access and specialized equipment, which may limit widespread availability. [39]

High-intensity focused ultrasound (HIFU) has also emerged as a novel cyclodestructive modality for refractory glaucoma. HIFU delivers focused ultrasonic energy to the ciliary body, inducing selective coagulation and reduction of aqueous humor production without direct tissue penetration. Preliminary studies demonstrated promising IOP reduction with relatively favorable safety profiles. The procedure may provide a nonincisional alternative for patients unsuitable for filtration surgery or glaucoma drainage device implantation. Nevertheless, long-term evidence regarding efficacy and durability remains limited. [40]

Despite their advantages, cyclodestructive procedures also possess important limitations. IOP reduction may be variable and less predictable compared with glaucoma drainage devices. Excessive ciliary body destruction may lead to hypotony, chronic inflammation, cystoid macular edema, or phthisis bulbi, particularly with aggressive treatment parameters. Additionally, because these procedures primarily reduce aqueous production rather than improve outflow, pressure reduction may be insufficient in some eyes with advanced disease requiring extremely low target IOPs. Careful patient selection and individualized energy titration therefore remain essential. [36,37]

The role of cyclodestructive procedures has evolved substantially from salvage therapy for blind painful eyes toward a broader application within contemporary refractory glaucoma management. Advances such as micropulse technology and endoscopic visualization have significantly improved safety and expanded indications to include eyes with useful visual potential. Nevertheless, glaucoma drainage devices—particularly Ahmed glaucoma valve implantation—continue to provide more consistent long-term IOP control in many advanced refractory glaucomas because they directly bypass compromised outflow pathways. Cyclodestructive procedures therefore serve primarily as complementary or alternative strategies within the increasingly diverse surgical armamentarium for refractory glaucoma. [7,38]

Glaucoma drainage devices (GDDs) have become a cornerstone in the surgical management of refractory glaucoma because they provide an alternative pathway for aqueous humor drainage independent of compromised trabecular or subconjunctival filtration pathways. Their use has expanded substantially over recent decades, particularly in eyes with previous failed filtration surgery, severe conjunctival scarring, neovascularization, chronic inflammation, or secondary glaucomas associated with poor trabeculectomy outcomes. Compared with conventional filtration surgery, GDDs often provide more predictable long-term intraocular pressure (IOP) control in complex glaucoma cases where aggressive postoperative fibrosis significantly limits surgical success. [41,42]

The fundamental principle of glaucoma drainage devices involves diversion of aqueous humor from the anterior chamber through a silicone tube connected to an episcleral plate positioned beneath the conjunctiva and Tenon's capsule. A fibrous capsule subsequently forms around the plate, and aqueous humor diffuses through this capsule into surrounding tissues and venous circulation. Long-term surgical success therefore depends largely on the permeability and thickness of the fibrous capsule surrounding the implant. Excessive encapsulation and fibrosis increase resistance to aqueous outflow and represent major causes of long-term failure. [7,20]

Figure(2) : MP3 probe in a case with refractory glaucoma [20]

Several glaucoma drainage devices have been developed, differing primarily in plate size, material composition, and presence or absence of flow-restricting mechanisms. The Molteno implant was one of the earliest widely utilized devices and consists of a non-valved plate system designed to facilitate posterior aqueous filtration. Larger plate surface areas generally provide greater long-term IOP reduction because of increased filtration area; however, non-valved implants are associated with increased risk of early postoperative hypotony due to unrestricted aqueous drainage immediately after surgery. [42]

The Baerveldt glaucoma implant is another commonly utilized non-valved device characterized by a large end-plate surface area that allows substantial long-term pressure reduction. To prevent excessive early filtration and hypotony, temporary tube ligation is typically required until a mature fibrous capsule develops around the plate. Clinical studies demonstrated excellent long-term IOP control with the Baerveldt implant, although complications such as hypotony, diplopia, corneal decompensation, and tube-related problems may occur. Comparisons between Ahmed and Baerveldt implants have shown that non-valved devices may achieve lower long-term IOPs, whereas valved devices often provide improved early postoperative safety. [43,44]

Among available GDDs, the Ahmed glaucoma valve (AGV) has become one of the most widely utilized implants in refractory glaucoma surgery. Unlike non-valved implants, the AGV contains a pressure-sensitive valve mechanism formed by thin silicone elastomer membranes that open when IOP exceeds approximately 8–12 mmHg. This valved design limits excessive early postoperative aqueous drainage and substantially reduces the risk of hypotony-related complications. Consequently, AGV implantation has become particularly attractive in eyes at high risk of postoperative hypotony or choroidal complications. [6,7]

Several AGV models have been developed, including silicone and polypropylene plate variants as well as pediatric-specific designs. The silicone FP7 model is currently preferred by many surgeons because of improved tissue biocompatibility and reduced inflammatory response compared with polypropylene models. Clinical studies have demonstrated significant postoperative IOP reduction and decreased medication dependence following AGV implantation across multiple refractory glaucoma subtypes including neovascular, uveitic, traumatic, pediatric, and post-vitrectomy glaucomas. [45]

Despite favorable outcomes, glaucoma drainage devices remain associated with several postoperative complications. Early complications include hypotony, shallow anterior chamber, choroidal detachment, hyphema, tube obstruction, and postoperative inflammation. Late complications may include encapsulated bleb formation, hypertensive phase development, tube erosion, corneal endothelial decompensation, diplopia, and implant exposure. The hypertensive phase following AGV implantation is particularly important because it reflects fibrovascular encapsulation around the plate and may compromise long-term filtration function. [7,23]

The Tube Versus Trabeculectomy (TVT) study significantly influenced contemporary glaucoma surgical practice by demonstrating favorable long-term outcomes of tube shunt surgery in previously operated eyes. The study reported lower failure rates and reduced incidence of persistent hypotony in tube surgery compared with trabeculectomy augmented with mitomycin-C. These findings contributed to the increasing preference for glaucoma drainage devices in complex glaucomas and reinforced the central role of AGV implantation within modern refractory glaucoma management. [31]

Advances in biomaterials, implant design, and adjunctive wound healing modulation continue to improve outcomes of glaucoma drainage surgery. Research into anti-fibrotic therapies, biodegradable scaffolds, and anti-vascular endothelial growth factor agents aims to reduce postoperative encapsulation and prolong filtration function. As surgical technology evolves, glaucoma drainage devices—particularly the Ahmed glaucoma valve—are expected to remain fundamental components of contemporary refractory glaucoma management because of their versatility, effectiveness, and applicability across a broad range of complex glaucoma subtypes. [24,41]

The Ahmed glaucoma valve (AGV) has become one of the most widely utilized glaucoma drainage devices in refractory glaucoma management because of its valved mechanism, favorable safety profile, and broad applicability across multiple complex glaucoma subtypes. Since its introduction by Mateen Ahmed in the early 1990s, AGV implantation has demonstrated effective intraocular pressure (IOP) reduction in eyes with previous failed filtration surgery, severe conjunctival scarring, neovascularization, chronic inflammation, and secondary glaucomas associated with poor outcomes after conventional trabeculectomy. Its pressure-sensitive valve system remains the principal feature distinguishing the AGV from non-valved glaucoma drainage devices. [46,47]

The Ahmed valve consists of a silicone drainage tube connected to a posterior episcleral plate containing thin elastomer membranes that function as a unidirectional valve mechanism. The valve opens when IOP exceeds approximately 8–12 mmHg, allowing controlled aqueous humor drainage toward the subconjunctival plate reservoir. This design reduces excessive early postoperative filtration and lowers the risk of hypotony-related complications such as shallow anterior chamber, choroidal detachment, and hypotony maculopathy. The silicone FP7 model is currently the most commonly used variant because of improved tissue biocompatibility and reduced inflammatory response compared with earlier polypropylene models. [45-47]

The standard surgical technique involves conjunctival peritomy and dissection of Tenon's capsule in the superotemporal quadrant, followed by fixation of the episcleral plate approximately 8–10 mm posterior to the limbus using nonabsorbable sutures. The valve is primed with balanced salt solution before implantation to confirm patency of the valve mechanism. A scleral tunnel or needle tract is then created for insertion of the drainage tube into the anterior chamber. The exposed tube is typically covered with a scleral, corneal, or pericardial patch graft to reduce the risk of tube erosion and conjunctival breakdown. Finally, conjunctival closure is performed carefully to ensure adequate implant coverage and minimize postoperative leakage. [7,48]

Alternative tube insertion sites may be selected depending on ocular anatomy and associated pathology. Pars plana tube placement is commonly utilized in vitrectomized eyes or eyes with compromised anterior chamber anatomy, whereas sulcus tube placement may reduce the risk of corneal endothelial damage in pseudophakic eyes. Accurate tube positioning is essential because malposition may result in tube obstruction, corneal decompensation, iris touch, or lens injury. Advances in surgical imaging and intraoperative visualization have further improved precision of tube placement and postoperative outcomes. [7]

Ahmed glaucoma valve implantation has demonstrated favorable surgical outcomes across multiple refractory glaucoma subtypes. Significant postoperative IOP reduction and decreased dependence on topical antiglaucoma medications have been consistently reported in neovascular glaucoma, uveitic glaucoma, traumatic glaucoma, post-vitrectomy glaucoma, aphakic glaucoma, and pediatric glaucoma. In neovascular glaucoma, AGV implantation is particularly valuable because it effectively bypasses angle closure caused by fibrovascular membranes while reducing the risk of severe postoperative hypotony. Combined use of anti-vascular endothelial growth factor therapy has further improved outcomes in these highly inflammatory eyes. [13,15]

Long-term success after AGV implantation is strongly influenced by postoperative wound healing and fibrosis around the episcleral plate. One of the most characteristic postoperative phenomena is the hypertensive phase, which generally occurs within the first few postoperative months after initial successful pressure reduction. This phase is associated with fibrovascular encapsulation around the implant plate, leading to increased outflow resistance and transient IOP elevation. Although the hypertensive phase may resolve spontaneously in some patients, persistent encapsulation is associated with reduced long-term surgical success and increased medication dependence. [9,23]

Several clinical trials have evaluated outcomes of AGV implantation compared with alternative surgical modalities. The Ahmed Versus Baerveldt (AVB) study demonstrated that both devices achieved substantial IOP reduction, although Baerveldt implants generally produced lower long-term IOPs at the cost of higher hypotony-related complications. In contrast, the valved design of the AGV provided improved early postoperative safety and reduced risk of severe hypotony. Similarly, the Tube Versus Trabeculectomy (TVT) study reinforced the expanding role of glaucoma drainage devices in complex glaucomas with previous failed surgeries. [31,44]

Despite its effectiveness, AGV implantation remains associated with several postoperative complications. Early complications include hyphema, hypotony, shallow anterior chamber, tube obstruction, and choroidal detachment. Late complications may include encapsulated bleb formation, tube exposure, corneal endothelial decompensation, diplopia, and implant failure secondary to fibrosis. Corneal endothelial loss represents an important long-term concern, particularly in eyes with anterior chamber tube positioning or preexisting corneal disease. Careful surgical technique, appropriate patient selection, and meticulous postoperative monitoring therefore remain essential to optimize long-term outcomes. [33,34]

The Ahmed glaucoma valve continues to occupy a central role in contemporary refractory glaucoma management because of its versatility, favorable safety profile, and applicability across a wide spectrum of complex glaucomas. Ongoing advances in biomaterials, tube design, anti-fibrotic therapy, and adjunctive wound healing modulation are expected to further improve long-term filtration function and reduce postoperative complications. As surgical technology continues to evolve, AGV implantation will likely remain one of the most important procedures in the management of advanced and refractory glaucoma. [24,47]

The versatility of the Ahmed glaucoma valve (AGV) has made it one of the most valuable surgical options across a broad spectrum of refractory glaucoma subtypes. Unlike conventional filtration surgery, which may fail rapidly because of aggressive subconjunctival fibrosis or severe ocular inflammation, AGV implantation bypasses compromised aqueous outflow pathways and provides relatively predictable intraocular pressure (IOP) reduction in complex eyes. Nevertheless, surgical outcomes vary according to glaucoma etiology, degree of inflammation, ocular anatomy, and previous surgical history. Understanding the unique characteristics of each refractory glaucoma subtype is therefore essential for optimizing patient selection and postoperative management. [49,50]

Neovascular glaucoma (NVG) represents one of the most common indications for AGV implantation. These eyes are characterized by severe retinal ischemia and elevated vascular endothelial growth factor (VEGF) levels, resulting in iris neovascularization, fibrovascular membrane formation, and progressive angle closure. Trabeculectomy outcomes in NVG are generally poor because of aggressive postoperative fibrosis and high risk of intraoperative bleeding. AGV implantation has demonstrated favorable outcomes in NVG because the valved mechanism reduces hypotony risk while bypassing synechially closed angles. Combined treatment with panretinal photocoagulation and anti-VEGF therapy has further improved surgical success by reducing active neovascularization and postoperative inflammation. Nevertheless, NVG continues to demonstrate relatively lower long-term success rates compared with other glaucoma subtypes because of persistent ischemia-driven fibrosis. [15,28]

Uveitic glaucoma presents another major indication for AGV implantation. Chronic intraocular inflammation, recurrent breakdown of the blood-aqueous barrier, and corticosteroid exposure contribute to elevated IOP and aggressive postoperative fibrosis in these eyes. Trabeculectomy in uveitic glaucoma is frequently complicated by bleb failure secondary to subconjunctival scarring and persistent inflammation. AGV implantation provides an alternative drainage pathway that may achieve more stable long-term pressure control. However, meticulous perioperative inflammatory suppression remains critical because uncontrolled inflammation significantly increases the risk of fibrosis, hypotony, and tube obstruction. Several studies demonstrated satisfactory long-term IOP reduction after AGV implantation in uveitic glaucoma when adequate inflammatory control is maintained. [16,38]

Glaucoma following vitreoretinal surgery has become increasingly prevalent because of the expanding use of pars plana vitrectomy and silicone oil tamponade in retinal disease management. Elevated IOP in these eyes may result from silicone oil migration, inflammatory trabecular dysfunction, synechial angle closure, or altered anterior segment anatomy. Previous vitreoretinal surgery frequently causes conjunctival scarring that limits the success of conventional filtration procedures. AGV implantation has shown favorable outcomes in post-vitrectomy glaucoma because it bypasses damaged outflow pathways and may be combined with pars plana tube insertion when anterior chamber anatomy is compromised. Nevertheless, surgical complexity may increase because of altered ocular anatomy and previous retinal interventions. [17]

Pediatric refractory glaucoma remains one of the most challenging glaucoma subtypes surgically because of aggressive wound healing responses and unique anatomic considerations. Children demonstrate rapid fibroblast proliferation and severe subconjunctival fibrosis, resulting in high failure rates after trabeculectomy. Ahmed glaucoma valve implantation has therefore become an increasingly preferred option in congenital and secondary childhood glaucomas. Pediatric-specific AGV models and adjunctive antifibrotic strategies have improved surgical outcomes; however, long-term success remains limited by encapsulation, tube migration, and ocular growth-related changes. Repeat surgeries are frequently required during long-term follow-up. [18,43]

Glaucoma after corneal transplantation or endothelial keratoplasty represents another important indication for AGV implantation. Elevated IOP may result from chronic corticosteroid therapy, angle distortion, peripheral anterior synechiae, or preexisting glaucoma. Surgical management is particularly complex because uncontrolled glaucoma threatens graft survival, whereas glaucoma surgery itself may accelerate endothelial cell loss and graft failure. Ahmed valve implantation provides effective pressure control in many post-keratoplasty eyes; however, careful tube positioning is essential to minimize corneal endothelial damage. Sulcus or pars plana tube placement may reduce direct endothelial trauma in selected cases. [42]

Traumatic glaucoma and aphakic glaucoma also frequently require glaucoma drainage device implantation because of extensive angle damage, conjunctival scarring, and altered anterior segment anatomy. Conventional filtration surgery in these eyes often demonstrates poor long-term success because of severe fibrosis and unpredictable wound healing responses. AGV implantation offers relatively stable pressure control while reducing the risk of postoperative hypotony in structurally compromised eyes.

However, traumatic eyes may exhibit increased risk of hyphema, inflammation, and tube obstruction secondary to peripheral anterior synechiae or vitreous prolapse. [3,47]

Although AGV implantation has demonstrated effectiveness across diverse refractory glaucoma subtypes, long-term surgical outcomes remain strongly influenced by the underlying disease process. Eyes with severe ischemia, chronic inflammation, or repeated previous surgeries generally exhibit more aggressive postoperative fibrosis and reduced filtration survival. Consequently, adjunctive therapies targeting wound healing modulation, anti-inflammatory control, and angiogenesis suppression continue to play an increasingly important role in optimizing outcomes after AGV implantation. Individualized surgical planning tailored to the specific glaucoma subtype therefore remains essential for maximizing long-term visual preservation and pressure control in refractory glaucoma management. [24,47]

Despite its effectiveness and favorable safety profile, Ahmed glaucoma valve (AGV) implantation remains associated with a variety of postoperative complications that may affect both short-term and long-term surgical outcomes. These complications may arise from surgical trauma, excessive aqueous drainage, implant-related mechanical factors, or postoperative fibrosis surrounding the episcleral plate. Although many complications are transient and manageable, others may significantly compromise visual function or lead to surgical failure. Careful patient selection, meticulous surgical technique, and close postoperative monitoring are therefore essential for optimizing outcomes after AGV implantation. [51,52]

Early postoperative complications commonly include hypotony, shallow anterior chamber, hyphema, choroidal detachment, tube obstruction, and excessive postoperative inflammation. Although the valved design of the AGV substantially reduces the incidence of severe hypotony compared with non-valved implants, transient hypotony may still occur because of overfiltration or peritubular leakage around the tube entry site. Shallow anterior chamber formation may subsequently lead to peripheral anterior synechiae, corneal endothelial touch, cataract progression, or malignant glaucoma in severe cases. Careful tube positioning and watertight scleral closure are therefore critical during surgery. [47,53]

Hyphema is particularly common in neovascular glaucoma because of fragile iris and angle neovascularization. Intraoperative or postoperative bleeding may obstruct the drainage tube, induce inflammation, and exacerbate fibrovascular proliferation around the implant plate. Persistent hyphema has been identified as an important risk factor for surgical failure because breakdown products and inflammatory mediators may accelerate subconjunctival fibrosis and encapsulated bleb formation. Preoperative anti-vascular endothelial growth factor therapy and adequate retinal ischemia management may reduce this complication in eyes with active neovascularization. [15,54]

One of the most important long-term complications of AGV implantation is the hypertensive phase, characterized by postoperative elevation of intraocular pressure (IOP) following an initial period of successful pressure reduction. This phenomenon is generally attributed to fibrovascular encapsulation around the episcleral plate, resulting in increased resistance to aqueous humor diffusion. Histopathologic studies demonstrated dense collagen deposition, fibroblast proliferation, and vascular congestion within encapsulated blebs. Persistent hypertensive phase may compromise long-term filtration function and increase dependence on topical antiglaucoma medications or additional surgical intervention. [9,23]

Tube-related complications represent another major concern following AGV implantation. Tube obstruction may occur secondary to fibrin, blood clots, vitreous incarceration, iris tissue, or inflammatory debris. Tube malposition can result in iris touch, corneal endothelial damage, or lens trauma. Progressive tube-cornea contact is particularly important because chronic endothelial cell loss may eventually lead to corneal decompensation and graft failure in eyes with previous keratoplasty. Sulcus or pars plana tube placement may reduce endothelial trauma in selected cases with compromised corneal status. [42,47]

Tube exposure and conjunctival erosion are among the most serious late complications because they significantly increase the risk of endophthalmitis. Mechanical friction between the tube and overlying conjunctiva, inadequate patch graft coverage, chronic inflammation, and ocular surface disease may contribute to conjunctival breakdown. Risk factors for tube exposure include pediatric age, multiple previous surgeries, inferior implant placement, and severe ocular surface pathology. Prompt surgical repair is generally required to prevent infectious complications and preserve implant function. [33]

Diplopia and motility disturbances may also occur after AGV implantation, particularly in eyes with large plate implants or extensive conjunctival fibrosis. Restrictive strabismus may result from scarring around extraocular muscles adjacent to the implant plate. Although many patients remain asymptomatic, significant motility limitation may occasionally require surgical revision or implant repositioning. Additionally, cosmetic conjunctival elevation and patient discomfort may occur because of the subconjunctival reservoir surrounding the plate. [34]

Long-term corneal endothelial decompensation represents an increasingly recognized complication of glaucoma drainage devices. Chronic mechanical tube-endothelium interaction, altered aqueous flow dynamics, and postoperative inflammation may contribute to progressive endothelial cell loss over time. This complication is particularly important in eyes with preexisting endothelial dysfunction, prior corneal transplantation, or shallow anterior chambers. Careful intraoperative tube positioning and ongoing endothelial monitoring are therefore essential during long-term follow-up. [42]

Although AGV implantation remains highly effective for refractory glaucoma management, postoperative complications continue to represent significant limitations to long-term surgical success. Advances in implant design, biomaterials, tube positioning techniques, and wound healing modulation may further reduce complication rates and improve implant longevity. Early recognition and appropriate management of postoperative complications remain critical for preserving visual function and maintaining long-term intraocular pressure control in patients undergoing Ahmed glaucoma valve surgery. [24,47]

The surgical management of refractory glaucoma continues to evolve rapidly with ongoing advances in biomaterials, minimally invasive techniques, imaging technologies, and molecular modulation of wound healing. Despite substantial improvements achieved with glaucoma drainage devices and modern cyclodestructive procedures, postoperative fibrosis and long-term surgical failure remain major challenges. Consequently, current research increasingly focuses on developing safer, more targeted, and individualized therapeutic strategies capable of achieving durable intraocular pressure (IOP) control while minimizing complications and preserving visual function. [55,56]

One of the most important future directions involves optimization of wound healing modulation following glaucoma surgery. Excessive subconjunctival fibrosis remains the principal cause of long-term filtration failure after trabeculectomy and glaucoma drainage device implantation. Traditional antimetabolites such as mitomycin-C effectively suppress fibroblast proliferation but are associated with significant tissue toxicity and complications. Therefore, newer biologic and biomaterial-based approaches—including biodegradable collagen matrices, sustained-release drug delivery systems, and anti-vascular endothelial growth factor (anti-VEGF) therapy—are being investigated to achieve more physiologic and selective control of postoperative fibrosis. [24,55]

Advances in biomaterial engineering have also contributed significantly to modern glaucoma surgery. Improved tube materials, biocompatible implant surfaces, and biodegradable scaffolds may reduce inflammation and fibrovascular encapsulation surrounding glaucoma drainage devices. Novel implant modifications aiming to improve aqueous flow dynamics and reduce capsular fibrosis continue to be explored. Future glaucoma drainage systems may incorporate drug-eluting surfaces capable of prolonged localized antifibrotic or anti-inflammatory therapy directly at the surgical site. Such innovations may improve long-term implant survival and reduce the need for postoperative interventions. [24,47]

Minimally invasive glaucoma surgery (MIGS) is expected to continue expanding within the spectrum of refractory glaucoma management. Although current MIGS procedures generally provide modest IOP reduction compared with traditional filtration surgery, improvements in implant design and surgical techniques may broaden their role in more advanced disease. Combination procedures integrating MIGS with cataract surgery, glaucoma drainage devices, or cyclodestructive approaches may provide individualized solutions for selected refractory cases. Additionally, future MIGS technologies may increasingly target alternative outflow pathways including the suprachoroidal and subconjunctival spaces. [32,33]

Cyclodestructive technologies are also undergoing substantial refinement. Micropulse transscleral cyclophotocoagulation (MP-TSCPC) has already demonstrated improved safety compared with traditional continuous-wave cyclophotocoagulation by minimizing collateral thermal damage. Future developments in laser delivery systems, ultrasound technology, and energy modulation may further improve precision and predictability of cyclodestructive procedures. High-intensity focused ultrasound and other nonincisional approaches may eventually provide safer alternatives for patients with severe ocular comorbidities or poor surgical candidacy. [38,40]

Advanced ocular imaging and artificial intelligence are expected to play increasingly important roles in glaucoma surgery planning and postoperative monitoring. High-resolution anterior segment optical coherence tomography and ultrasound biomicroscopy already permit detailed assessment of filtering blebs, drainage implant position, and subconjunctival fibrosis. Integration of imaging biomarkers with predictive artificial intelligence algorithms may allow earlier identification of patients at high risk of surgical failure and facilitate personalized postoperative management. Such technologies could potentially improve long-term filtration survival through earlier intervention before irreversible fibrosis develops. [27,28]

Personalized glaucoma surgery represents another emerging concept in refractory glaucoma management. Future treatment strategies may increasingly incorporate individualized assessment of inflammatory status, fibrosis risk, ocular anatomy, and genetic susceptibility to wound healing responses. Molecular profiling of cytokines and fibrosis-related biomarkers may eventually guide selection of specific antifibrotic therapies or implant types for individual patients. Personalized surgical planning may therefore optimize long-term outcomes while minimizing unnecessary surgical morbidity. [20,24]

Although Ahmed glaucoma valve implantation currently remains one of the most important surgical procedures for refractory glaucoma, no single modality is universally ideal for all patients. The future of refractory glaucoma surgery will likely involve integration of multiple complementary technologies including advanced glaucoma drainage devices, minimally invasive techniques, molecular wound healing modulation, targeted drug delivery systems, and precision imaging. Continued clinical research and long-term prospective studies remain essential to further improve visual preservation and quality of life in patients with refractory glaucoma. [47,55]

Conclusion

Refractory glaucoma remains one of the most challenging conditions in ophthalmic surgery because of its complex pathophysiology, aggressive wound healing responses, and high risk of irreversible visual loss. Contemporary surgical management has evolved substantially with the expanding role of glaucoma drainage devices, minimally invasive glaucoma surgery, and advanced cyclodestructive procedures. Among these modalities, the Ahmed glaucoma valve continues to play a central role because of its versatility, favorable safety profile, and effectiveness across multiple refractory glaucoma subtypes including neovascular, uveitic, pediatric, and post-vitrectomy glaucomas. Nevertheless, postoperative fibrosis, hypertensive phase development, and implant-related complications continue to limit long-term surgical success. Emerging advances in biomaterials, wound healing modulation, targeted molecular therapy, and personalized surgical planning are expected to further improve long-term outcomes and expand the therapeutic options available for refractory glaucoma management. Careful patient selection, individualized surgical strategies, and ongoing technological innovation remain essential for optimizing visual preservation and quality of life in these highly complex glaucoma cases.

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