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QLAUKOMA MÜALİCƏSİNDƏ DRENAJ CƏRRAHİYYƏSİNİN DÜNƏNİ, BU GÜNÜ VƏ SABAHI (ƏDƏBİYYAT İCMALI)

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XÜLASƏ

Hazırda qlaukoma geri dönməz korluq, əmək qabiliyyətinin itirilməsi və əlillik səbəbləri arasında lider mövqelərdən birini tutmağa davam edir və bununla da xüsusi sosial əhəmiyyət kəsb edir. Eyni zamanda, xəstələnmə hallarının artım tendensiyası qlobal xarakter daşıyır.

Medikamentoz terapiyasının bütün arsenalına və antiqlaukomatoz cərrahiyyə metodlarının təkmiləşdirilməsinə baxmayaraq, daha yüksək təhlükəsizlik profili və maksimal effektivliyi təmin edə bilən yeni texnologiyaların axtarışı, hazırlanması və tətbiqi oftalmocərrahlar arasında böyük maraq doğurmağa davam edir.

Biz 131 il dövr ərzində qlaukomanın müasir cərrahi müalicə metodları ilə bağlı mövcud elmi nəşrlərin təhlilini apardıq. Bu icmal kliniki praktikada qlaukoma zamanı geniş istifadə olunan drenaj cihazlarına həsr olunub. Xüsusilə, son onillikdə sürətlə inkişaf edən drenaj mikroinvaziv antiqlaukomatoz cərrahiyyə texnologiyasına, qlaukoma xəstəliyinin erkən və inkişaf etmiş mərhələlərində ənənəvi müalicəyə alternativ kimi xüsusi diqqət yetirilir. Məqalədə drenajların tətbiqinin tarixi, onların təsnifatı, modellərin xüsusiyyətləri və implantasiya üsulları araşdırılır.

Drenaj cihazlarından istifadə olunan cərrahi metodlarla bağlı müxtəlif aspektlərin öyrənilməsinə dair təqdim olunan klinik tədqiqat nəticələri bu metodların müasir qlaukoma müalicəsi konsepsiyalarına uyğunluğunu aydın şəkildə nümayiş etdirməklə yanaşı, onların tətbiq sahəsinin genişləndirilməsinin məqsədəuyğunluğunu göstərir. Cərrahi travmanı minimuma endirmək və davamlı hipotenziya effekti əldə etmək məqsədilə daha qabaqcıl, patogenez baxımından əsaslandırılmış texnologiyaların axtarışının zəruriliyi heç bir şübhə doğurmur. Bununla belə, əminliklə demək olar ki, artıq bu gün drenaj cərrahiyyəsi müasir qlaukoma müalicə alqoritmində layiqli yer tutur.

Açar sözlər: *qlaukoma, qlaukoma drenaj cihazları, "Baerveldt" implant, "Ahmed valve", "Molteno" implant, "PAUL" implant*

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DRAINAGE SURGERY IN GLAUCOMA TREATMENT: PAST, PRESENT AND FUTURE (LITERATURE REVIEW)

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SUMMARY

Currently, glaucoma continues to occupy one of the leading places among the causes of irreversible blindness, loss of ability to work and disability, thereby acquiring special social significance. At the same time, the trend of increasing incidence is global.

Despite the entire arsenal of drug therapy and the improvement of antiglaucoma surgery methods, the search, development and implementation of new technologies that can provide a higher safety profile combined with maximum efficiency continue to arouse increased interest of ophthalmic surgeons.

We analyzed relevant available publications for a 131-year period on the issue of modern methods of surgical treatment of glaucoma. This review is devoted to the topic of drainage devices widely used in clinical practice for glaucoma. Particular attention is paid to the actively developing technologies of drainage antiglaucoma surgery in the last decade as an alternative to traditional treatment for initial and advanced forms of glaucoma. The article considers the history of the use of drains, their classification, characteristics of models and methods of their implantation. The presented results of clinical studies on various aspects of the application of surgical methods using drainage devices not only clearly demonstrate their compliance with modern concepts in the treatment of glaucoma, but also dictate the expediency of expanding the indications for their use. There is no doubt that further research is needed for more advanced, pathogenetically substantiated technologies in order to minimize surgical trauma and achieve a stable hypotensive effect. However, we can confidently say that drainage surgery already today occupies a worthy place in the algorithm of modern glaucoma treatment.

Key words: *glaucoma, glaucoma drainage devices, Baerveldt implant, Ahmed valve, Molteno implant, PAUL implant*

A comprehensive literature search was conducted in the PubMed, e-library, Scopus, Google Scholar databases using primary and secondary keywords: “glaucoma”, “glaucoma drainage devices”, “GDD”, “Baerveldt implant”, “Ahmed valve”, “Molteno implant”, “PAUL implant”. A total of 250 articles published between 1894 and 2025 were identified.

Titles, summaries, and keywords were pre-screened for relevance to the topic, resulting in 187 articles being selected for full-text assessment. The remaining 120 relevant publications were included in the final review and cited. They consisted of 56 randomized controlled trials (RCTs), 12 retrospective meta-analyses, and a number of additional observational and experimental studies, as well as national protocols and guidelines, which provide a comprehensive overview of the Glaucoma Drainage Device (GDD) theoretical justifications and clinical implementation.

Purpose

This review was conducted to highlight the current situation and trends in glaucoma drainage surgery, to evaluate the efficacy, safety and sustainability of various GDDs, to inform about innovative technologies and development trends in this segment of glaucoma treatment. Data of 12 major meta-analyses were presented to qualify the practical effectiveness of GDD as the very important and significant part of glaucoma management.

Glaucoma, as a chronic progressive neurodegenerative disorder, has been one of the leading causes of irreversible blindness worldwide for many decades [1]. In 2010, 4,5 million people were diagnosed with bilateral blindness due to glaucoma and by 2020, this number had increased to 5.9 million [2, 3]. According to the World Health Organization, various types of glaucoma have caused blindness to approximately 8 million people globally [4]. The global prevalence of glaucoma is estimated at 3.54%, with the number of cases projected to increase from 64.3 million in 2013 to 111,8 million in 2040 [5, 6].

The irreversible consequences of glaucoma highlight its significance in both medical and social contexts. In Russia, glaucoma is the leading cause of primary disability due to eye disease, being the cause of 31% of all disability cases, depending on the region [7]. In the United States glaucoma affects about 2% of adults over 40 with incidence rates increasing significantly in older population [8, 9]. In Azerbaijan, the burden of glaucoma averages 14.2 ± 1.3% of all eye and adnexa diseases, recorded between 2010 and 2019, with a prevalence rate of 14.5 ± 18.7% [10].

Early detection of glaucoma is the cornerstone of combating this serious disease, which has irreversible consequences and a high disability rate. Aggressive proactive screenings and prioritizing the etiopathogenetic features of glaucoma when choosing treatment strategies are crucial for its effectiveness and play a decisive role in reducing its impact. However, according to some studies, even with an adequate treatment, about 10% of patients still lose their vision [11, 12].

Drug therapy remains relevant and is recommended by various protocols as a first-choice or starting treatment. Considering the serious expansion of pathogenetically targeted antiglaucoma medicines and their increased effectiveness, the therapeutic approach has become a vector-forming in the arsenal of modern ophthalmologists [13, 14, 15, 16]. Prostaglandin analogues, beta-blockers, rho kinase inhibitors (ROCK), diuretics, carbonic anhydrase inhibitors, cholinergic agonists, alpha agonists represent the main groups of medications using for the treatment of several types of glaucoma [17, 18, 19, 20].

However, some authors argue that the shift toward an active observational therapeutic strategy has led to negative consequences, resulted in deterioration in surgical outcomes [21]. Thus, a large-scale study on the clinical and epidemiological

characteristics of glaucoma in the CIS countries and Georgia revealed that surgical treatment was performed in 19.3% of cases at the initial stage of the disease, and in 37.2% and 37.4% of cases at advanced and severe stages, respectively [22]. Considering the late diagnostic of glaucoma, surgical treatment remains the primary method for achieving long-term reduction of intraocular pressure (IOP) to target levels necessary to maintain visual function [23, 24, 25].

Another important risk factor in glaucoma progression is the IOP fluctuations and controlling it is crucial for glaucoma treatment due to destructive effect on the optic nerve. [26]. However, the clinical polymorphism of glaucoma doesn't allow us to consider any of the many actual surgical techniques as universal and most effective.

Currently, the only reliable way to stabilize the glaucoma process is to reduce the level of ophthalmotonus to target IOP in the range of 12-21 mmHg, which is confirmed by the results of several large multicenter studies [27, 28]. Thus, based on the main indicator – targeting low IOP, the criteria for qualifiying the stabilization of glaucoma process are the absence of additional instillations, need for re-surgery and availability of vision-threatening complications [29].

The first-choice surgery – trabeculectomy, remains the "gold standard" in glaucoma filtration surgery, but obtained results are temporary, unpredictable and unstable due to fibrosis and scarring. Almost 60% of filtration blebs cause to function within 15 years, often a much shorter period, and subsequent treatment is limited to cyclodestructive procedures [30, 31].

This is why the revolutionary idea of implanting drainage systems in glaucoma treatment has become increasingly popular in recent years and is considered as a full-fledged alternative to trabeculectomy and cyclodestruction [32]. Modern models of implants made from intact materials, as well as the latest surgical techniques based on innovational approaches, have brought to significant increase of number of drainage surgeries even in the early stages of glaucoma [33, 34].

Drainage surgery in the treatment of glaucoma has become much more relevant in most cases. Implantation of the Glaucoma Drainage Device (GDD) is the main treatment tactic for drug-uncontrolled glaucoma and the most common penetrating surgery for glaucoma in the world. Its advantages include a long-lasting hypotensive effect and a relatively controlled IOP level. Originally intended for the treatment of secondary glaucoma and ineffective trabeculectomy, it is now becoming the first-choice surgery type for refractory glaucoma [35, 36, 37, 38].

Previously, GDD was used when fistulizing surgeries were considered to be low-effective or impossible for technical reasons. These included patients with excessive postoperative scarring of the conjunctiva or its pronounced pathology, active neovascularization of the iris or anterior chamber angle. However, subsequent observations have demonstrated more positive results compared with trabeculectomy in medically uncontrolled glaucoma with a lower risk of filtration impairment [39, 40]. These devices have been shown to be successful in controlling IOP in eyes that have previously undergone trabeculectomy, as well as in uveitic, neovascular, pediatric, and progressive glaucoma [41, 42].

Thus, neovascular glaucoma as the main type of refractory glaucoma is pathogenetically associated with severe ischemic eye diseases, such as proliferative diabetic retinopathy and ischemic occlusion of the central retinal vein. Panretinal photocoagulation and intravitreal anti-VEGF injections are used in the treatment of neovasular glaucoma to reduce ischemia and angiogenic factors, but they are not sufficient for sustainable IOP control. Currently, the main surgical treatment for neovascular glaucoma is the implantation of antiglaucomatous drainage devices, and in cases of pars plana vitrectomy, it is the only effective option [43, 44, 45, 46, 47].

Main indications for GDD implantation:

- Neovascular glaucoma
- Traumatic glaucoma
- Uveitic glaucoma
- Pseudoexfoliative glaucoma
- Pigmentary glaucoma
- Pediatric glaucoma
- Iridocorneal endothelial syndrome
- Post-penetrating keratoplasty glaucoma
- Post-vitreoretinal surgery glaucoma
- Aphakic/Pseudophakic glaucoma
- Failed trabeculectomies
- Sturge-Weber's syndrome

The main criteria to qualify the GDD:

- IOP control
  1. *Target range 6-18 mmHg*
  2. *IOP reduction from the baseline ≥20-30%*
  3. *Sustained IOP control without significant fluctuations*
- Medication reduction
- Stability of the visual field and optic nerve
- Maintenance or improvement of Visual Acuity (VA)
- Endothelial cell density
- Safety profile
  1. *Minimal or manageable complications: hypotony, tube exposure, endophthalmitis, corneal decompensation*
  2. *No device-related severe adverse events*
- Surgical success rate
  1. *Complete success (target IOP achieved without medications or reoperation)*
  2. *Qualified success: (target IOP achieved with or without medications, but no reoperation)*
  3. *Failure: (IOP>defined upper limit, IOP <5 mmHg on ≥ 2 visits, vision loss from complications, or device removal)*

The idea of using drainage to reduce intraocular pressure dates back over 100 years. In 1886, French ophthalmologist Wecker proposed using a gold wire as a drainage device. However, trauma of the tissues caused by its movement led to the abandonment of this revolutionary idea [48]. The use of setons for aqueous humor drainage began in 1906 when silk threads were implanted in anterior chamber via paracentesis [49]. Zorab used horsehair to drain the anterior chamber during the treatment of hypopyon and, a year later, to enhance aqueous humor outflow in glaucoma surgery [50]. However, the postoperative period was often complicated by active formation of connective tissue. Bick experimented with magnesium wire and tantalum foil, but these attempts failed due to poor material fixation, leading to frequent extrusion and ocular infections [51]. One study described the use of platinum drains. Kuljaca et al. implanted a Teflon drain in 12 patients, achieving a positive hypotensive effect in 75% of cases. However, Teflon induced significant connective tissue formation and this is limiting its clinical use [52].

Various materials, including vanadium steel, nickel-titanium alloy, stainless steel, and even gold, were tested as alternatives. Analysis of these studies revealed that the overall effectiveness of drainage devices directly depends on the material used. The material's characteristics determine the inflammatory and reparative response of surrounding tissues. While this response is a protective function of connective tissue, it can lead to scar tissue formation, obstructing outflow pathways and reducing the hypotensive effect. Minimizing this risk requires materials with high biocompatibility and low toxicity [53].

The first antiglaucomatous drainage device, the Molteno Implant **(Figure 1)**, was introduced over 50 years ago by Professor Anthony Molteno (1938–2023). His pioneering GDD work started in University of Cape Town, South Africa, and then prolonged at the University of Otago, Dunedin, New Zealand.

Figure 1. *Graphic image of Molteno Implant.*

This valveless device allowed aqueous humor to flow from the anterior chamber through a silicone tube to an end plate, where it was absorbed in the sub-Tenon's space. Fibrous capsule formation around the plate was expected within 4-6 weeks postoperatively, regulating the outflow of aqueous humor [54, 55]. Molteno developed several modifications of the device, including a pediatric version. In 1981, he introduced a double-plate implant but later returned to single-plate designs with larger (175 or 230 mm²) and more flexible configurations. Nowadays, the Molteno drainage device line is widely used worldwide and is manufactured by Innovative Ophthalmic Products Inc. (Costa Mesa, CA, USA) and Molteno Ophthalmic Limited (Dunedin, New Zealand). Newest models of Molteno GDD are: Molteno3 Single Plate (Molteno3 S), Molteno3 Double Plate (Molteno3 D) and Molteno3 Mini. Improvements include lower profile design, flexible biocompatible silicone tube, sutureless plate fixation system and integrated ripcord ligature for flow control [56 - 59].

Figure 2. *Graphic image of Krupin Valve*

In 1979, Professor Theodore Krupin from Northwestern University Medical School (Chicago, USA) introduced the first valved antiglaucomatous drainage device, where the valve provided resistance to aqueous outflow. The valve automatically opened at an IOP of 11-16 mmHg and closed at 1-3 mmHg. Krupin Valve played a significant role in the evolution of GDD and in common glaucoma surgery (**Figure 2**). It rarely used today due to more effective and predictable alternatives [60, 61, 62].

In early 1980s, Dr. Stephen S. Shocket conceived and developed the idea of using a tube connected to a 360-degree encircling band as a drainage for glaucoma treatment with initial cases dating to around 1983-1985. The ACTSEB (Anterior Chamber Tube Shunt to an Encircling Band) remained a niche technique used in some unpredictable situations, but it has historical value in the development of latest GDDs as non-valved and biologically modulated procedure. Later, in association with Dr Ahmed was created the Shockmed valve, which combined the ACTSEB procedure with Ahmed Valve implantation [63, 64, 65].

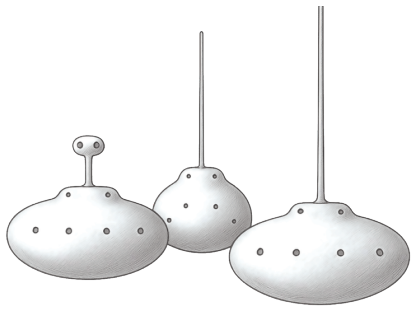

Figure 3. *Graphic image of Baerveldt® Glaucoma Implant*

Professor George Baerveldt supported the concept of non-restrictive drainage and, in 1990, (FDA approved in 1995) introduced his model of the GDD in California, USA, which quickly gained global popularity. The American Glaucoma Society awarded him the Innovator Award for his extraordinary

contributions to glaucoma research and surgical innovations [66 – 70]. The new drainage device used softer silicone, but the plate size was significantly larger (250 and 350 mm²). Over the years, numerous modifications of the Baerveldt implant (**Figure 3**), including pediatric versions, have been developed. But generally, it stays relatively unchanged due to well-established performance. These are manufactured by Johnson & Johnson Vision Care, Inc., and distributing by Advanced Medical Optics, Inc. (Santa Ana, CA, USA) [71, 72, 73].

Figure 4. *Graphic image of Ahmed® Glaucoma Valve*

In 1993, Abdul Mateen Ahmed introduced the Ahmed® Glaucoma Valve, a valved device with self-regulating silicone membranes that open automatically when IOP exceeds 8-10 mmHg. The device has undergone numerous modifications, significantly improving its effectiveness and ease of use **(Figure 4)**. These modifications have focused on simplifying implantation techniques, enhancing IOP control, and reducing acute postoperative hypotony [74, 75, 76]. Pressure-sensitive venture valve opens when IOP exceeds 8-10 mmHg. This GDD, as well as its newest versions, are manufactured by New World Medical Inc., USA.

It should be noted that despite the large numbers of GDD models from different manufacturers, the implantation of the device has common similar technical principles and treatment regulations. The superotemporal quadrant is the gold-standard site for GDD implantation. It provides the easiest surgical access, avoids superior oblique tendon, minimizes risk to long posterior ciliary nerves and provides a large surface area for bleb formation. If superotemporal placement is not available due to scarring, conjunctival fibrosis or previous surgery, GDD can be implanted in different locations. Thus, superonasal quadrant is more difficult for exposure due to being near superior oblique tendon and nasal structures, inferonasal – more technically challenged and higher risk of tube-corneal touch because of inferiorly shallower AC, inferotemporal – harder exposure and higher risk of plate extrusion and patient discomfort. GDD's plate should be sutured 8-10 mm posterior to the limbus on sclera and must be placed under Tenon's capsule and conjunctiva to reduce the risk of exposure.

The tube of GDD can be positioned in several anatomical sites depending on the patient's ocular status and surgical goals. Anterior chamber is most common position, when tube passes through peripheral cornea into AC. It is the easier technique with predictable results, suitable for standard eyes with adequate chamber depth. Creates the risks of endothelial cells loss and corneal decompensation. Ciliary sulcus or Posterior Chamber position is useful in pseudophakic eyes, in eyes with shallow AC and high risk of corneal damage. It's more difficult technically and can create the iris contact and pigment dispersion.

After vitrectomy, the GDD plate is placed as usual on sclera, but the tube is directed into the pars plana, 3-3.5 mm posterior to limbus, and covered with a patch graft. Complete vitrectomy is essential to avoid vitreous blocking the tube.

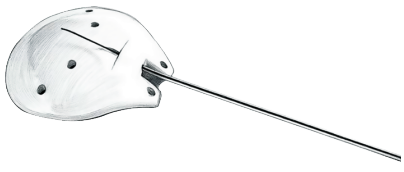

Figure 5. *Graphic image of Ahmed ClearPath®*

Pars plana tube placement is preferable after corneal transplantation, when shallow anterior chamber, extensive peripheral anterior synechiae, pediatric eyes with corneal risk and in patients undergoing combined PPV+GDD implantation [77-81].

Today, antiglaucomatous drainage devices come in various sizes, materials, and designs, with or without valves to regulate IOP. The non-valved **Ahmed ClearPath®** was developed as part of Ahmed family of implants and has the pre-threaded tube design to reduce the error in tube positioning, rounded posterior plate to minimize the conjunctival stress and low-profile plate to avoid the erosion risk **(Figure 5)**. It requires the intraoperative ligature, stenting and fenestartions to manage the flow [82, 83]. Newest ClearPath® ST offers a smaller profile tube of 127 μm and a 457 μm outer diameter. This option allows surgeons for more flexibility to accommodate different patient needs and surgical preferences.

Figure 6. *Graphic image of Aurolab Aqueous Drainage Implant*

The non-valved **Aurolab Aqueous Drainage Implant** is a GDD developed by Aurolab, the manufacturing division of Aravind Eye Care System, India **(Figure 6)**. It was modeled to offer a low-cost alternative for managing refractory glaucoma. It is made from medical-grade silicone, with the plate size – 350 mm² and ligature and intraluminal stenting to prevent postoperative hypotony. Aurolab creates a subconjunctival filtering bleb by draining aqueous humor through a silicone tube into episcleral plate, which allows for gradual absorption into surrounding tissue. The mechanism is very similar to Baerveldt GDD, but due to significantly lower cost is suitable for the large-scale use in public health systems [84-87].

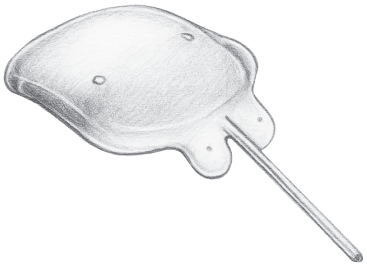

Figure 7. *Graphic image of Susanna GDD*

The **Susanna Glaucoma Drainage Device** was developed by Dr. Remo Susanna, Brazil, designed as a non-valved implant intended as a low-cost alternative for managing the refractory glaucoma **(Figure 7)**. It follows up the successful design principles of other large-plate GDDs, but its thinner plate with fenestrations enhances stability, making it less mobile comparing with other GDDs. Some authors presented 86.4% success rate with very few severe complications (4.5%), another publication states that at 6 months successful rate were 73% for neovascular and 86% for refractory glaucoma [88 - 90].

Figure 8. *Graphic image of Virna GDD*

Virna GDD is the newest non-valved implant designed to lower the IOP. This device was developed by Rohto Corp., Indonesia, to cover the local need for glaucoma drainage implants (**Figure 8**). Virna designed for use in advanced or uncontrolled glaucoma cases [91, 92].

The **Paul® Glaucoma Implant** is a newer generation non-valved glaucoma drainage implant designed to lower the IOP in patients with refractory or advanced glaucoma **(Figure 9)**. It was developed by Advanced Ophthalmic

Innovations, France, in collaboration with Dr. Paul Chew and designed to improve the safety and efficacy while minimizing complications associated with the earlier devices.

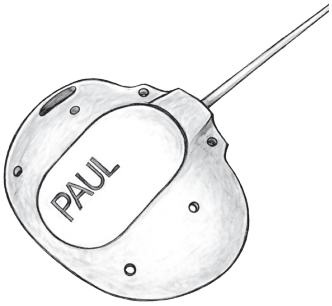

Figure 9. *Graphic image of Paul® Glaucoma Implant*

Main advantages are thinner and more flexible tube to decrease corneal endothelial cells loss, smaller inner diameter (0.127 mm) to lower the risk of postoperative hypotony, lower-profile plate made from biocompatible medical-grade silicone to minimize the conjunctival erosion. In accordance with some clinical studies IOP reduction after Paul GDD implantation is 50-60%, medication burden reduced by 2-3 medications in average and lower complications rate [93 - 98].

It should be noted that pediatric versions of drainage devices have recently begun to be actively used in the treatment of glaucoma [83]. The most recognized GDD for implantation in children are Ahmed FP8, Molteno, Baerveldt and Paul usually with some modifications. The choice depends on the child's age, eye size, glaucoma type and surgeon preference. Here are more risks for encapsulation and fibrosis due to stronger healing response in children. Tubes may need revisions or repositioning as the eye grows [99 - 102].

Non-valved devices include:

- Molteno (IOP Inc., USA, and Molteno Ophthalmic Limited, New Zealand),
- Baerveldt (Advanced Medical Optics, Inc., USA),
- Eagle Vision implants (Eagle Vision, Inc., USA),
- Ahmed ClearPath (New World Medical, Inc., USA)
- Aurolab Aqueous Drainage Implant (Aurolab, Aravind Eye Care System)
- Paul Glaucoma Implant (PGI, Advanced Ophthalmic Innovations, Singapore).

Valved devices include:

- Krupin Eye Valve with Disk (Hood Laboratories, Pembroke, MA),
- Ahmed Glaucoma Valve (AGV, New World Medical, USA),
- Schockmed valve (a modified Ahmed valve using the Shocket's ACTSEB technique)

Figure 10. *Graphic image of Eye Watch System*

Some newly designed GDDs can be adjusted post-operatively to reduce the incidents of hypotony and hypertension and thus creates a 3rd group: GDD with adjustable valve. These devices include the eyeWatch (eW, Rheon Medical, Switzerland) **(Figure 10)**. The eyePlate has a deformable silicone tube that can undergo targeted compression to alter its cross-sectional area and thereby change fluidic resistance. Post-operatively IOP may be changed non-invasively by moving the position of an internal magnetic rotor with an external control unit – the eyeWatch Pen. A pilot study announces a complete success rate of 40%. Adjustable GDDs may reduce the need for intra-operative measures, such as tube ligation, and enable better postoperative IOP control. Some clinics used the part of EyeWatch system – eyePlate-300 and eyePlate-200 – as a stand-alone GDD [103, 104, 105].

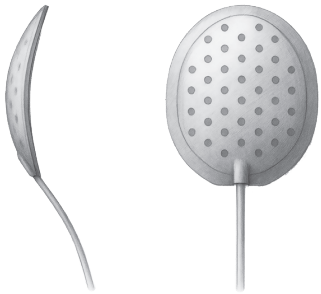

Figure 11. *Graphic image of GORE Glaucoma Drainage Implant*

The **GORE Glaucoma Drainage Implant** (GORE GDI) is an investigational non-valved glaucoma drainage device developed by W.L.Gore & Associates, Inc., USA, (www.gore.com) using expanded polytetrafluoroethylene (ePTFE), a biocompatible, microporous material to prevent the excessive scarring **(Figure 11)**. This device demonstrates an improved tissue integration than silicone- or propylene-based GDDs and allow to expect potentially lower rates of encapsulation [106, 107]. Considering modern trends in development of drainage surgery, it should be noted that many scientists in different medical centers and countries work on the creation of new GDD. It is noteworthy that these developments do not modify current devices, but carry fundamentally new ideas and methods.

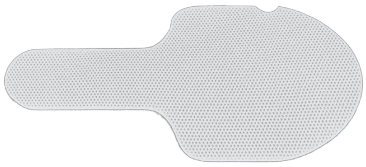

Figure 12. *Graphic image of VisiPlate*

VisiPlate is a next-generation anti-glaucomatouse device classified as a hybrid – minimally invasive GDD developed by Avisi Technologies, USA. It is an ultra-thin (≈20 μm), extremely low-profile, multi-layer nanostructure made of titanium. It is biocompatible and designed to reduce the inflammation and scarring (**Figure 12**). The device made from 400 nm aluminum oxide plate coated with a 2-μm layer of parylene-C and consists of multiple hexagons with intervening channels to provide slow outflow. Thus, prevent hypotony and create comfortable for the patient less-elevated bleb [108].

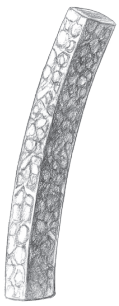

Figure 13. *Graphic image of Alloflo Uveo*

IANTREK, White Plains, USA, and Dr. T. Ianchulev with colleagues introduced new **Alloflo Uveo** uveoscleral dual bio-spacers micro interventional biostent-reinforced cyclodialysis technique to enhance supraciliary aqueous drainage **(Figure 13)**. Biostent comprised decellularised sclera allograft tissue microtrephined into a polymer tubular implant [109, 110].

Figure 14. *Graphic image of Calybreye® TGT® Surgical*

The **Calybreye® Titratable Glaucoma Therapy® (TGT) Surgical System's,** Myra Vision Inc., USA, is engineered to put control in the hands of ophthalmologists through unprecedented adjustable outflow **(Figure 14)**. The Calibreye Shunt's 10.0×1.6 mm overall dimensions and very low profile (0.30 mm thick) intended to provide posterior bleb

formation to increase aqueous drainage. has 3 distinct outflow channels: the standard is open in all settings, medium and large channels are valve controlled. In accordance with press release of Myra Vision, they secured FDA Approval to initiate US IDE Study in Glaucoma. (www.myravision.com)

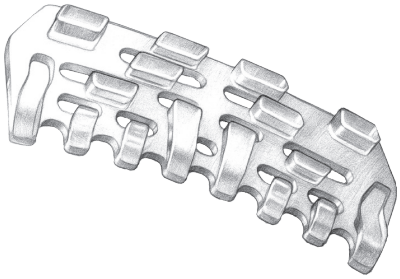

Figure 15. *Graphic image of Intercil® Uveal Spacer*

The **Intercil® Uveal Spacer,** Ciliatech SAS, France, is the first ever Ciliioscleral Interpositioning Device (CID), belongs to a new category of glaucoma procedure known as the Ciliioscleral Interpositioning. Intercil® doesn't enter the anterior chamber, is ab-externo implanted and bleb frees **(Figure 15).** Ciliatech engineered it to create the localized gap between the ciliary muscle and the sclera. This spacing decreases the resistance to the passage of aqueous humour into this area and will lead to a physiological reduction of IOP by re-establish the natural uveo-scleral flow to the choroidal circulation. Trapezoidal shaped implant (7 × 3.4 × 0.6 mm) is a non-resorbable one-piece device made of hydrophilic acrylic and characterized by high biocompatibility. It designed with grooves and corrugations to maximize the outflow from the anterior chamber to the suprachoroidal space [111]. Ciliatech are currently working with key regulatory bodies around the world in order to obtain formal licenses in preparation for formal commercialization. Intercil® received CE mark approval in August 2025 (www.cilia.tech).

Market Scope (www.market-scope.com) recently published the 2025 Glaucoma Surgical Device Market Report, which provides an analysis based on six years of global sales data and evaluates emerging trends for future projections. According to the report, microstents represent the largest share of utilization (44.8%), followed by canal surgery devices (23.5%), laser-based procedures (12.3%), tube shunts (10.9%), and subconjunctival shunts (8.4%). This information is extremely important for understanding the prevalence of certain devices and, accordingly, surgical techniques. It impartially demonstrates the preferences of surgeons, based on the results of their clinical practice and highlights the further development **(Table 1).**

Narrative review of meta-analysis

There is a vast number of studies dedicated to the GDDs, their advantages and disadvantages, implantation techniques, efficacy and complications. In this review we would like to present the results of latest large multicenter meta-analysis of GDDs. Thus, typically refers to comprehensive research studies that combine data from multiple clinical centers and trials to evaluate the common information in managing of glaucoma. This improves the accuracy of conclusions about treatment efficacy, safety and risk factors.

The meta-analysis performed by Serhan H.A. and co-authors reviewed 8 studies (474 eyes) for comparison between GDD (Ahmed valve and Baerveldt) implanted and trabeculectomy underwent eyes condition. It revealed no significant difference in IOP reduction, but GDDs were associated with higher rates of complications: cystoids macular edema (15% vs 4%, P<0.001), need for revision surgery (11% vs 6%, P = 0.04), and uveitic flare (5% vs 0%, P = 0.001). However, trabeculectomy had a higher risk of cataract progression (7% vs 1%, P<0.001) [112].

3 studies comprised by Dr. Raja S. and team, a total of 176 individuals with refractory glaucoma, with 107 patients received the AADI and 69 patients received the BGI. This meta-analysis, using a random-effects

Table 1. *Main characteristics of GDD*

Type	*GDD name*	*Manufacturer*	*Dimensions*	*Inner Diameter*	*Outer Diameter*	*Material*	*IOP reduction*	*Flow control*
Valved	Ahmed® Glaucoma Valve FP7/FP8, S2	New World Medical, Inc., USA	184 mm²/ 96 mm², 184 mm²	0.305 mm	0.635 mm	Flexible silicone/Rigid polypropylene	40-50%	Venturi-based valve mechanism
	Krupin Valve with Disk	Alcon Inc., Switzerland/ USA	183 mm²	0.30 mm	0.64 mm	Medical –grade silicon	40-55%	Pressure-sensitive valve
Adjustable valve	EyeWatch® System with EyePlate	Rheon Medical, Switzerland	250 mm²	0.30 mm	0.64 mm	Titanium housing/silicon plate	40-55%	External magnetically adjustable valve
Non-valved	Molteno3® Glaucoma Drainage Device S150/D270	Molteno Ophthalmic Ltd, NZ/IOP inc., USA	150 mm² 270 mm²	0.305 mm	0.635 mm	Medical-grade polypropylene or silicone	55-60%	Ligatura/ Ripcord/ venting slits
	Baerveldt® Glaucoma Implant	Johnson & Johnson Surgical Vision	250 mm² 350 m²/ 0.84mm	0.3 mm	0.63 mm	Medical-grade silicone	40-60%	Ligatura/ ripcord/ staged opening
	Ahmed ClearPath®	New World Medical, Inc., USA	250 m² 350 mm²/ 1.9mm	0.305 mm	0.635 mm	Medical-grade silicon	45-50%	Ligatura/ intraluminal stenting
	Paul® Glaucoma Implant	Advanced Ophthalmic Innovations, Switzerland	342 mm²	0.127 mm	0.467 mm	Silicone	50-60%	Ligatura/ venting slits
	Aurolab Aqueous Drainage Implant	Aurolab, Aravind Eye Care System, India	350 mm²	0.3 mm	0.63 mm	Medical-grade silicon	50-65%	Ligatura/ intraluminal stenting
	Susanna Glaucoma Drainage Implant	Kinner Silicone Rubber Industria Comercio Ltda., Brazil	200 mm² /0.5 mm	230 µm	530 µm	Medical grade, soft silicon	55-65%	Ligation/ fenestration
	Virna® Glaucoma Drainage Device	Virna S.p.A., Italy	350 mm²	0.30 mm	0.60 mm	Medical-grade silicon	60-70%	Ligation/ stenting/ fenestration
	GORE® Excluder® Glaucoma Drainage Implant	W.L. Gore & Associates, USA	200-230 mm²	0.30 mm	0.60 mm	Expanded Polytetrafluoro-ethylene (ePTFE, Gore-Tex®)	35-50%	Ligation/ stenting/ fenestration
Non-Valved Hyb	VisiPlate® Glaucoma Drainage Device	Avisi Techno-logies, USA	96 mm²	0.07-0.1 mm	0.25-0.3 mm	Composition of alumina and Parylene-C	30-40%	Gradual flow control due to very small inner lumen

model, demonstrated a statistically borderline significant reduction in postoperative IOP in patients with the AADI compared to the BGI group at 3 months (MD: -2.74; 95% CI [-5.47; -0.01]; p = 0.05; I^2 = 0%), while at 6 months, the decrease was not statistically significant (MD: -3.77; 95% CI [-8.42; 0.88]; p = 0.11; I^2 = 68%). By the 12 months follow-up, no significant difference in postoperative IOPs was observed between the 2 groups (MD:

-1.19; 95% CI [-3.90; 1.53]; p = 0.39; I^2 = 0%). Surgical success rate in 2 groups had a statistically nonsignificant difference and similar overall complication incidence rate [113].

The meta-analysis performed by Raja A. et al. earlier indicates that the Molteno implants demonstrate greater success in sustaining low IOP, however the Ahmed valve exhibits fewer overall complications [114].

Dr. Hong M. included 825 eyes (820 patients) from 6 studies to his meta-analysis comparing the results of Aurolab Aqueous Drainage Implant and Ahmed Glaucoma Valve implantations. Weighted mean difference of the IOP reduction between those implants were 0.58 (95% CI: 0,07 - 1.09) at 3 months, 0.44 (95% CI: 0,11 - 0.77) at 6 months, 2.20 (95% CI: 0.63 - 3.77) at 12 months, and 3.24 (95% CI: 1.73 - 4.75) at the follow-up endpoint; of the reduction in antiglaucoma medication were 0.87 (95% CI: 0.61 - 1.13) at 6 months, 1.04 (95% CI: 0.66-1.42) at 12 months and 0.93 (95% CI: 0.52 - 1.34) at the follow-up endpoint. The pooled odds ratio comparing AADI and AGV were 3.64 (95% CI: 2.44 - 5.45) for the complete success rate and 1.72 (95% CI: 1.24 - 2.39) for qualified success rate [115].

18 studies (946 eyes) follow-up the Paul Glaucoma Implant (PGI) implantation were analised by Dr. Carla M. and colleagues. The PGI demonstrated mean IOP reduction ranged from 14,8 mmHg to 19,1 mmHg, depending on follow-up duration and patient characteristics. Complete success rates ranged from 38.4% to 75%, while qualified success rates were consistently high, reaching up to 93.2% [116].

32 studies (1221 eyes, 885 patients) were included in the study hold by Dr. Stallworth J. and colleagues. The findings show that Ahmed and Baerveldt shunts substantially reduced IOP for at least 24 months of childhood glaucoma, with similar findings among device types and glaucoma etiologies [117].

Dr. Ramdas W.D. and co-authors from Erasmus Medical Center, Netherlands, performed the meta-analysis to compare their own results with the 24 studies from PubMed database. It showed no significant differences between patients with and without uveitis in the IOP reduction (44.9% vs 42.8% respectively), postoperative weighted mean difference of - 17.8 mmHg and 2.2 lower number of IOP-lowering medications in uveitic glaucoma compared to -13.2 mmHg and 3.5 in current study, respectively [118].

13 cohort studies (562 eyes) were included in meta-analysis performed by Dr. Pan S.Y. and his team. The effects of trabeculectomy with or without antifibrotic agents, valved or non-valved GDDs and medical treatment were compared. According to their results, valved GDD was more effective in controlling IOP and preserving the corneal grafts. UTherefore, they assume the valved GDD as the preferred surgical approach for the treatment of post-PKP glaucoma [119].

One of the latest reviews Dr. Garg A. stated, that the future of glaucoma surgery lies in balancing the safety and efficacy of traditional GDDs with the minimally invasive nature of MIGS. While GDDs still crucial for advanced cases, MIGS are expected to expand their reach. Innovations in materials, smart technologies, and personalized treatment approaches will shape the future landscape, offering patients safer, more effective options to manage their glaucoma [120].

Conclusion

Summarizing, we can estimate the GDDs as a pathogenetically justified and clinically essential modality in the modern management of glaucoma. The active development of MIGS as another modern method of glaucoma treatment in no way diminishes the role of GDD, forming and expanding a specific niche for each of them. An analysis of current trends indicates that the future modernization of GDDs will focus on three key domains: enhancing safety, improving efficacy, and maximizing patient comfort.

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REFERENCE

1. McMonnies, C.W. Glaucoma history and risk factors // J. Optom., – 2016. 10(2), – p. 71-78. https://doi.org/10.1016/j.optom.2016.02.003
2. Quigley, H.A. The number of people with glaucoma worldwide in 2010 and 2020 / H.A.Quigley, A.T.Broman // Br. J. Ophthalmol., – 2006. 90(3), – p. 262-267. https://doi.org/10.1136/bjo.2005.081224
3. Kang, J.M. Glaucoma / J.M.Kang, A.P.Tanna // Med. Clin. North Am., – 2021. 105(3), – p. 493-510. https://doi.org/10.1016/j.mcna.2021.01.004
4. Allison, K. Epidemiology of Glaucoma: The Past, Present, and Predictions for the Future / K.Allison, D.Patel, O.Alabi // Cureus, – 2020. 12(11), – p. 11686. https://doi.org/10.7759/cureus.11686
5. Cioffi, G.A. American Academy of Ophthalmology. Glaucoma // American Academy of Ophthalmology, – 2011.
6. Tham, Y.C. Global prevalence of glaucoma and projections of glaucoma burden through 2040: a systematic review and meta-analysis / Y.C.Tham, X.Li, T.Y.Wong [et al.] // Ophthalmology, – 2014. 121(11), – p. 2081-2090. https://doi.org/10.1016/j.ophtha.2014.05.013
7. Козина, Е.В. Первичная инвалидность вследствие глаукомы в Красноярском крае / Е.В.Козина, М.В.Терехович, И.А.Кох [и др.] // Национальный журнал Глаукома, – 2023. 22(3), – с. 3-13. https://doi.org/10.53432/2078-4104-2023-22-3-3-13
8. Friedman, D.S. Prevalence of open-angle glaucoma among adults in the United States / D.S.Friedman, R.C.Wolfs, B.J.O´Colmain [et al.] // Arch. Ophthalmol., – 2004. 122(4), – p. 532-538. https://doi.org/10.1001/archopht.122.4.532
9. Friedman, D.S. The prevalence of open-angle glaucoma among blacks and whites 73 years and older: the Salisbury Eye Evaluation Glaucoma Study / D.S.Friedman, H.D.Jampel, B.Munoz [et al.] // Arch. Ophthalmol., – 2006. 124(11), – p. 1625-1630. https://doi.org/10.1001/archopht.124.11.1625
10. Касимов, Э.М. К изучению современных эпидемиологических особенностей распространения глаукомы в Азербайджане / Э.М.Касимов, Р.Б.Агаева, Н.М.Рустамова [и др.] // Азербайджанский Офтальмологический Журнал, – 2022. 3(42), – p. 51-57.
11. Ramulu, P. Glaucoma and disability: which tasks are affected, and at what stage of disease? // Curr. Opin. Ophthalmol., – 2009. 20(2), – p. 92-98. https://doi.org/10.1097/ICU.0b013e32832401a9
12. Wierzbowska, J. Evaluation of ocular blood flow in glaucoma – possibilities and barriers. Klinika Oczna // Acta. Ophthalmol. Polonica, – 2020. 122(4), – p. 139-146. https://doi.org/10.5114/ko.2020.101649
13. Glaucoma: diagnosis and management. Methods, evidence and recommendations // NICE, – London: – 2017. – p. 324.
14. Gedde, S.J. American Academy of Ophthalmology Preferred Practice Pattern Glaucoma Panel. Primary Open-Angle Glaucoma Preferred Practice Pattern® / S.J.Gedde, K.Vinod, M.M.Wright [et al.] // Ophthalmology, – 2021. Jan; 128(1), – p. 71-150. https://doi.org/10.1016/j.ophtha.2020.10.022
15. Basic and Clinical Science Course 2022-2023. Section 10 Glaucoma. Ed. A.P.Tanna // AAO, – San Francisco: – 2022. – p. 319.
16. Национальное руководство по глаукоме для практикующих врачей. Изд. 4-е, испр. и. доп. Под ред. Е.А.Егорова, В.П.Еричева // ГЭОТАР-Медиа, – М.: – 2019. – с. 384.
17. Lusthaus, J. Current management of glaucoma / J.Lusthaus, I.Godberg // Med. J. Aust., – 2019. 210, – p. 180-187. https://doi.org/10.5694/mja2.50020
18. Schuster, A.K. The diagnosis and treatment of glaucoma / A.K.Schuster, C.Erb, E.M.Hoffmann [et al.] // Dtsch. Arztebl. Int., – 2020. 117, – p. 225-234. https://doi.org/10.3238/arztebl.2020.0225
19. Wang, J. Rho-Kinase inhibitors as Emerging Targets for Glaucoma Therapy / J.Wang, H.Wang, Y.Dang // Ophthalmol. Ther., – 2023. Oct; 14. 12(6), – p. 2943-2957. https://doi.org/10.1007/s40123-023-00820-y
20. Lee, H.P. Glaucoma: Current and New Theraupetic Approaches / H.P.Lee, T.H.Tsung, Y.C.Tsai [et al.] // Biomedicines, – 2024. Sep; 3. 12(9), – p. 2000. https://doi.org/10.3390/biomedicines12092000
21. Montolio, F.G.J. Influence of glaucoma surgery on visual function: a clinical cohort study and meta-analysis / F.G.J.Montolio, R.P.H.M.Mueskens, N.M.Jansonius // Acta. Ophthalmologica, – 2019. 97(2), – p. 193-199. https://doi.org/10.1111/aos.13920
22. Егоров, Е.А. Отдельные клинико-эпидемиологические характеристики глаукомы в странах СНГ и Грузии. Результаты многоцентрового открытого ретроспективного исследования (часть 2) / Е.А.Егоров, А.В.Куроедов // РМЖ. Клиническая офтальмология, – 2012. 1. – p. 19-22.
23. Еричев, В.П. О переходе к хирургическому этапу лечения глаукомы / В.П.Еричев, С.Н.Басинский,

А.В.Куроедов // Национальный журнал глаукома, – 2023. 22(1), – p. 92-102. https://doi.org/10.53432/2078-4104-2023-22-1-92-102
24. Shaarawy, T. Reducing intraocular pressure: is surgery better than drugs? / T.Shaarawy, J.Flammer, I.O.Haefliger // Eye, – 2004. 18(12), – p. 1215-1224. https://doi.org/10.1038/sj.eye.6701374
25. Gusarevich, A.A. Trends in the surgical treatment of glaucoma in recent decades / A.A.Gusarevich, A.V.Kuroyedov, A.Y.Brezhnev // National Journal of Glaucoma, – 2024. 23(1), – p. 75-87. https://doi.org/10.53432/2078-4104-2024-23-1-75-87
26. Guo, Z.Z. Intraocular pressure fluctuation and the risk of glaucomatous damage deterioration: a Meta-analysis / Z.Z.Guo, K.Chang, X.Wei // Int. J. Ophthalmol., – 2019. Jan; 18. 12(1), – p. 123-128. https://doi.org/10.18240/ijo.2019.01.19
27. Куроедов, А.В. Аддитивная и комбинированная терапия глаукомы: принципы и практика / А.В.Куроедов, З.М.Нагорнова, З.У.Тибиева [и др.] // Российский офтальмологический журнал, – 2018. 11(2), – с. 71-81. https://doi.org/10.21516/2072-0076-2018-11-2-71-81
28. Gazizova, I.R. Additive Therapy for Advanced Stages of Glaucoma / I.R.Gazizova, V.E.Korelina, E.P.Goncharuk // Ophthalmology in Russia, – 2023. 20(3), – p. 523-527. https://doi.org/10.18008/1816-5095-2023-3-523-527
29. Maier, P.C. Treatment of ocular hypertension and open angle glaucoma: meta-analysis of randomized controlled trials / P.C.Maier, J.Funk, G.Schwarzer [et al.] // BMJ, – 2005. 331(7509), – p. 134-136. https://doi.org/10.1136/bmj.38506.594977.E0
30. Wilensky, J.T. Long-term results of trabeculectomy in eyes that were initially successful / J.T.Wilensky, T.C.Chen // Trans. Am. Ophthalmol. Soc., – 1996. 94, – p. 147-159. https://doi.org/10.1016/S0002-9394(14)70163-1
31. Ndulue, J.K. Evolution of Cyclophotocoagulation / J.K.Ndulue, K.Rahmatnejad, C.Sanvicente [et al.] // J. Ophthalmic. Vis. Res., – 2018. Jan-Mar; 13(1), – p. 55-61. https://doi.org/10.4103/jovr.jovr_190_17
32. Minckler, D.S. Aqueous shunts in glaucoma: a report by the American Academy of Ophthalmology / D.S.Minckler, B.A.Francis, E.A.Hodapp [et al.] // Ophthalmology, – 2008. Jun; 115(6), – p. 1089-1098. https://doi.org/10.1016/j.ophtha.2008.03.031
33. Poelman, H.J. The Baerveldt Glaucoma Drainage Device: Efficacy, Safety and Place in Therapy / H.J.Poelman, R.C.W.Wolfs, W.D.Ramdas // Clin. Ophthalmol., – 2020. 14, – p. 2789-2797. https://doi.org/10.2147/OPTH.S219271
34. Qin, Q. Development and material characteristics of glaucoma surgical implants / Q.Qin, Ch.Zhang, N.Yu [et al.] // Adv. Ophthalmol. Pract. Res., – 2023. 3(4), – p. 171-179. https://doi.org/10.1016/j.aopr.2023.09.001
35. Ashburn, F.S. The Evolution of Glaucoma Drainage Implants / F.S.Ashburn, P.A.Netland // J. Ophthalmic. Vis. Res., – 2018. 13(4), – p. 498-500. https://doi.org/10.4103/jovr.jovr_26_18
36. Agrawal, P. Glaucoma drainage implants / P.Agrawal, P.Bhardwaj // International Journal of Ophthalmology, – 2020. 13(8), – p. 1318-1328. https://doi.org/10.18240/ijo.2020.08.20
37. Dawson, E.F. Comparison of Outcomes Following Glaucoma Drainage Tube Surgery Between Primary and Secondary Glaucomas, and Between Phakic and Pseudophakic eyes / E.F.Dawson, B.E.Culpepper, Ch.A.Bolch [et al.] // Asia Pac. J. Ophthalmol., – 2021. (6), – p. 553-563. https://doi.org/10.1097/APO.0000000000000452
38. Bettis, D.I. Trabeculectomy with mitomycin C or Ahmed valve implantation in eyes with uveitic glaucoma / D.I.Bettis, R.G.Morshedi, C.Chaya [et al.] // J. Glaucoma, – 2015. 24, – p. 591-599. https://doi.org/10.1097/IJG.0000000000000195
39. Luo, N. Comparison of tube shunt implantation and trabeculoectomy for glaucoma: a systematic review and meta-analysis / N.Luo, M.Liu, M.Hao [et al.] // BMJ Open, – 2023. 13(4), – p. 065921. https://doi.org/10.1136/bmjopen-2022-065921
40. Lee, N. Surgical results of trabeculectomy and Ahmed valve implantation following a previous failed trabeculectomy in primary congenital glaucoma patients / N.Lee, K.T.Ma, H.W.Bae [et al.] // Korean J. Ophthalmol., – 2015. 29(2), – p. 109-114. https://doi.org/10.3341/kjo.2015.29.2.109
41. Wagdy, F. An Ex-Press implant versus trabeculectomy in a fibrotic bleb with late failure after previous trabeculectomy / F.Wagdy, T.H.Mokbel, H.Elsorogy [et al.] // Int. J. Ophthalmol., – 2021. 14(3), – p. 383-387. https://doi.org/10.18240/ijo.2021.03.08
42. Miglani, T. A review of the Surgical Management of Neovascular Glaucoma / T.Miglani, S.Ullah // Curr. Surg. Reports, – 2023. 11, – p. 162-167. https://doi.org/10.1007/s40137-023-00358-9
43. Drinkwater, O.J. Diagnosis and Management of Neovascular Glaucoma / O.J.Drinkwater, J.Panarelli // Eye Net. Magazine., – 2018. – p. 39-41.

44. Tang, Y. The mechanism and therapeutic strategies for neovascular glaucoma secondary to diabetic retinopathy / Y.Tang, Y.Shi, Z.Fan // Front Endocrinol., – 2023. 14, – p. 1102361. https://doi.org/10.3389/fendo.2023.1102361
45. Medert, C.M. The influence of etiology on surgical outcomes in neovascular glaucoma / C.M.Medert, C.Q.Sun, E.Vanner [et al.] // BMC Ophthalmol., – 2021. 21(1), – p. 440. https://doi.org/10.1186/s12886-021-02212-x
46. Chang, E.K. Combined pars plana glaucoma drainage device placement and vitrectomy using a vitrectomy sclerotomy site for tube placemenbt: a case series / E.K.Chang, S.Gupta, M.Chachanidze [et al.] // BMC Ophthalmol., – 2021. 21, – p. 106. https://doi.org/10.1186/s12886-021-01872-z
47. Karapapak, M. Evaluation of the Efficacy of Pars Plana Ahmed Glaucoma Valve Implantation with Vitrectomy in Uncontrolled Neovascular Glaucoma Secondary to Proliferative Diabetic Retinopathy: A Retrospective Analysis / M.Karapapak, C.Gül, D.Özcan [et al.] // Hamidiye Med. J., – 2024. 5(2), – p. 67-72. https://doi.org/10.4274/hamidiyemedj.galenos.2024.03371
48. Wecker, L. de. Sclerotomie simple et combine // Ann. d´ocul., – 1894. №25, – p. 112.
49. Rollett, M. Treatment of the hypopyon by capillary drainage of the anterior chamber / M.Rollett, M.Moreau // Rev. Gen. Ohthalmol., – 1906. 25, – p. 481.
50. Zorab, A. The reduction of tension chronic glaucoma // Ophthalmoscope, – 1912. 10, – p. 258-261.
51. Bick, M.W. Use of tantalum for ocular drainage // Arch. Ophthalmol., – 1949. 42(4), – p. 373-388. https://doi.org/10.1001/archopht.1949.00900050381003
52. Kuljaca, Z. Draining implant for neovascular glaucoma / Z.Kuljaca, V.Ljubojevic, D.Momirov // Am. J. Ophthalmol., – 1983. 96(3), – p. 372-376. https://doi.org/10.1016/S0002-9394(14)77830-4
53. Ходжаев, Н.С. Базовые характеристики антиглаукоматозных дренажей / Н.С.Ходжаев, А.В.Сидорова, М.Н.Коломейцев // Офтальмохирургия, – 2017. 4, – p. 80-86. https://doi.org/10.25276/0235-4160-2017-4-80-86
54. Molteno, A.C. New implant for drainage in glaucoma. Animal trial // Br. J. Ophthalmol., – 1969. 53(3), – p. 161-168. https://doi.org/10.1136/bjo.53.3.161
55. Molteno, A.C., Luntz M.H. The use of plastics in glaucoma surgery // Proceedings of the First South African International Ophthalmological Symposium. – London: – Butterworths: – 1969.
56. Molteno, A.C. Long tube implants in the management of glaucoma / A.C.Molteno, J.L.Straughan, E.Ancker // S. Afr. Med. J., – 1976. 50, – p. 1062-1066.
57. Molteno, A.C. Implants for draining neovascular glaucoma / A.C.Molteno, M.M.Van Rooyen, R.S.Bartholomew // Br. J. Ophthalmol., – 1977. 61, – p. 120-125. https://doi.org/10.1136/bjo.61.2.120
58. Molteno, A.C. Long tube implants in the management of glaucoma / A.C.Molteno, J.L.Straughan, E.Ancker // Trans. Ophthalmol. Soc. N. Z., – 1981. 33, – p. 39-41.
59. Molteno, A.C. The optimal design of drainage implants for glaucoma // Trans. Ophthalmol. Soc. N. Z. – 1981. 33, – p. 39-41.
60. Krupin, T. Valve Implants in Filtering Surgery / T.Krupin, S.M.Podos, B.Becker [et al.] // American Journal of Ophthalmology, – 1976. (2), – p. 232-235. https://doi.org/10.1016/0002-9394(76)90737-6
61. Krupin, T. A Long Krupin-Denver Valve Implant Attached to a 180° Scleral Explant for Glaucoma Surgery / T.Krupin, R.Ritch, C.Camras [et al.] // Ophthalmology, – 1988. 95(9), – p. 1174-1180. https://doi.org/10.1016/S0161-6420(88)33030-7
62. Krupin, T. Posterior Tube Shunt Implants for Glaucoma Surgery / T.Krupin, M.E.Feitl // Seminars in Ophthalmoogy, – 1991. 6(2), – p. 87-94. https://doi.org/10.3109/08820539109060186
63. Fleischman, D. Schockmed Valve: a novel surgical option for uncontrolled glaucoma in eyes with poor conjunctiva and encircling bands / D.Fleischman, B.Kim // J. Curr. Glaucoma Pract., – 2017. 11(3), – p. 120-124. https://doi.org/10.5005/jp-journals-10028-1236
64. Schocket, S.S. Anterior chamber tube shunt to an encircling band in the treatment of neovascular glaucoma / S.S.Schocket, V.Lakhanpal, R.D.Richards // Ophthalmology, – 1982. 89(10), – p. 1188-1194. https://doi.org/10.1016/S0161-6420(82)34671-0
65. Schocket, S.S. Anterior chamber tube shunt to an encircling band in the treatment of neovascular glaucoma and other refractory glaucomas: a long-term study / S.S.Schocket, V.S.Nirankari, V.Lakhanpal [et al.] // Ophthalmology, – 1985. 92(4), – p. 553-562. https://doi.org/10.1016/S0161-6420(85)34009-5
66. Lloyd, M.A. Initial clinical experience with the Baerveldtimplant in complicated glaucomas / M.A.Lloyd, G.Baerveldt, D.K.Heuer [et al.] // Ophthalmology, – 1994. 101(4), – p. 640-650. https://doi.org/10.1016/S0161-6420(94)31283-8
67. Fellenbaum, P.S. Experience with the Baerveldt Implant in young patients with complicated glaucomas

/ P.S.Fellenbaum, P.A.Sidoti, D.K.Heuer [et al.] // J. Glaucoma, – 1995. 4(2), – p. 91-97. https://doi.org/10.1097/00061198-199504000-00005
68. Sidoti, P.A. Experience with the Baerveldt glaucoma implant in treating neovascular glaucoma / P.A.Sidoti, T.R.Dunphy, G.Baerveldt [et al.] // Ophthalmology, – 1995. 102(7), – p. 1107-1118. https://doi.org/10.1016/S0161-6420(95)30904-9
69. Sidoti, P.A. Glaucoma drainage implants / P.A.Sidoti, G.Baerveldt // Curr. Opin. Ophthalmol., – 1994. 5(2), – p. 85-98. https://doi.org/10.1097/00055735-199404000-00013
70. Britt, M.T. Randomized clinical trial of the 350-mm² versus the 500-mm² Baerveldtimplant: longer term results: is bigger better? / M.T.Britt, L.D.LaBree, M.A.Lloyd [et al.] // Ophthalmology, – 1999. 106(12), – p. 2312-2318. https://doi.org/10.1016/S0161-6420(99)90532-8
71. Iwasaki, K. Long-term outcomes of Baerveldt glaucoma implant surgery in Japanese patients / K.Iwasaki, R.Komori, Sh.Arimura [et al.] // Sci. Rep., – 2023. 13(1), – p. 14312. https://doi.org/10.1038/s41598-023-41673-6
72. Manako, K. Risk factors for Baerveldt glaucoma drainage implantation for uveitic glaucoma / K.Manako, E.Takahashi // Sci. Rep., – 2023. 13, – p. 4473. https://doi.org/10.1038/s41598-023-29244-1
73. Tan, A.N. Outcome and safety of the Baerveldt glaucoma implant. (Doctoral Thesis, Maastricht University). Maastricht University, – 2023. https://doi.org/10.26481/dis.20230310at
74. Coleman, A.L. Initial Clinical Experience With the Ahmed Glaucoma Valve Implant / A.L.Coleman, R.Hill, M.R.Wilson [et al.] // American Journal of Ophthalmology, – 1995. 120, 1, – p. 23-31. https://doi.org/10.1016/S0002-9394(14)73755-9
75. Riva, I. Ahmed glaucoma valve implant: surgical technique and complications / I.Riva, G.Roberti, F.Oddone [et al.] Clin. Ophthalmol., – 2017. Feb; 17. 11, – p. 357-367. https://doi.org/10.2147/OPTH.S104220
76. Kang, Y.K. Long-term surgical outcomes of Ahmed valve implantation in refractory glaucoma according to the type of glaucoma / Y.K.Kang, J.P.Shin, D.W.Kim // BMC Ophthalmol., – 2022. 22, – p. 270. https://doi.org/10.1186/s12886-022-02493-w
77. Qin, Q. Development and material characteristics of glaucoma surgical implants / Q.Qin, C.Zhang, N.Yu [et al.] // Advances in Ophthalmology Practice and Research, – 2023. 3(4), – p. 171-179. https://doi.org/10.1016/j.aopr.2023.09.001
78. Al-Lozi, A. Outcomes of inferonasal glaucoma drainage device surgery in the management of childhood glaucoma / A.Al-Lozi, A.C.Umfress, S.Stinnett [et al.] // Journal of American Association for Pediatric Ophthalmology and Strabismus, – 2022. October; 26(5), – p. 1-7. https://doi.org/10.1016/j.jaapos.2022.06.003
79. Kumar, H. Pars plana implantation of glaucoma drainage devices – The way to succeed in refractory glaucoma / H.Kumar, M.Thulasidas // Indian J. Ophthalmol., – 2021. Jul; 69(7), – p. 1650-1651. https://doi.org/10.4103/ijo.IJO_688_21
80. Samuel, S. Outcomes of Anterior Chamber, Sulcus, and Pars Plana Glaucoma Drainage Device Placement in Glaucoma Patients / S.Samuel, E.K.Chang, S.Gupta [et al.] // Journal of Ophthalmology, – 2022. (1), – p. 5947992. https://doi.org/10.1155/2022/5947992
81. Гасанов, Д.В. Ранние результаты эффективности глаукомных дренажей Ахмеда и Бервельдта при рефрактерной глаукоме в Азербайджане / Д.В.Гасанов, Э.М.Касимов, Х.И.Рамазанова [и др.] // Azərbaycan Ohalmologiya Jurnalı, – 2020. 33, – s. 39-49.
82. Shalaby, W.Sh. Ahmed ClearPath® vs Baerveldt Glaucoma Implant: A Retrospective Noninferiority Comparative Study / W.Sh.Shalaby, R.Reddy, B.Wummer [et al.] // Ophthalmol. Glaucoma, – 2024. 7(3), – p. 251-259. https://doi.org/10.1016/j.ogla.2023.12.006
83. Boopathiraj, N. 36-Month Outcomes of Ahmed ClearPath® Glaucoma Drainage Device in Severe Primary Open Angle Glaucoma / N.Boopathiraj, I.V.Wagner, P.C.Lentz [et al.] // Clinical Ophthalmology, – 2024. 18, – p. 1735-1742. https://doi.org/10.2147/OPTH.S467894
84. Sisodia, V.P.S. Aurolab Aqueous Drainage Implant (AADI): Review of Indications, Mechanism, Surgical Technique, Outcomes, Impact and Limitations // Seminars in Ophthalmology, – 2022. 37, 7-8, – p. 856-868. https://doi.org/10.1080/08820538.2022.2082254
85. Aref, A.A. Safety and Efficacy outcomes of low-cost glaucoma drainage implants // Glaucoma Today. Peer Review, – 2021. March/April; – p. 32-33.
86. Gnanavelu, S. Intermediate-term outcomes of the Aurolab aqueous drainage implant in neovascular glaucoma / S.Gnanavelu, G.V.Puthuran, K.P.Chiranjeevi [et al.] // British Journal of Ophthalmology, – 2023. 107, – p. 355-360. https://doi.org/10.1136/bjophthalmol-2021-319999
87. Həsənov, C.V. Azərbaycanda refrakter qlaukoma zamanı klapansız qlaukoma implantın uzaq nəticələri /

C.V.Həsənov, G.D.Əfəndiyev, N.A.Həsənova // Azərbaycan Ohalmologiya Jurnalı, – 2023. 47, – s. 3-15. https://doi.org/10.30546/2709-4634.2023.47.001.
88. Susanna, F.N. Efficacy and Safety of the Susanna Glaucoma Drainage Device after 1 year of Follow-up / F.N.Susanna, B.N.Susanna, C.N.Susanna [et al.] // J. Glaucoma, – 2021. 30(5), – p. 231-236. https://doi.org/10.1097/IJG.0000000000001802
89. Biteli, L.G. Evaluation of the Efficacy and Safety of the New Susanna Glaucoma Drainage Device in Refractory Glaucomas: Short-term Results / L.G.Biteli, T.S.Prata, C.P.Gracitelli [et al.] // J. Glaucoma, – 2017. 26(4), – p. 356-360. https://doi.org/10.1097/IJG.0000000000000620
90. Ruppert, A.D.P. Outcomes of Susanna UF implants in refractory congenital glaucoma / A.D.P.Ruppert, N.G.Ogata, L.E.O.Barbosa [et al.] // Clinics (Sao Paulo), – 2025. May; 1. 80, – p. 100619. https://doi.org/10.1016/j.clinsp.2025.100619
91. Supatra, P. Bilateral Glaucoma Drainage Device (GDD) Implantation in Steroid Induced Glaucoma / P.Supatra, R.Suryaningrum, I.Kusumadjaja // Intisari. Sains. Medis., – 2023. 14(3), – p. 1053-1058. https://doi.org/10.15562/ism.v14i3.1884
92. Virna, A. Low-Cost New Glaucoma Drainage Device in Indonesia: One Year Follow-Up of 252 Subjects / A.Virna, W.Morgan // Clin. Exp. Ophthalmol., – 2025. 53(5), – p. 493-501. https://doi.org/10.1111/ceo.14509
93. Koh, V. Treatment outcomes using the PAUL Glaucoma Implant to control intraocular pressure in eyes with refractory glaucoma / V.Koh, P.Chew, G.Triolo [et al.] // Ophthalmol. Glaucoma, – 2020. 3(5), – p. 350-359. https://doi.org/10.1016/j.ogla.2020.05.001
94. Vallabh, N.A. Surgical technique, perioperative management and early outcome data of the PAUL glaucoma drainage device / N.A.Vallabh, F.Mason, J.T.S.Yu [et al.] // Eye, – 2022. 36(10), – p. 1905-1910. https://doi.org/10.1038/s41433-021-01737-1
95. Jose, P. One-year efficacy and safety of the PAUL Glaucoma Implant using a standardized surgical protocol / P.Jose, R.C.Barao, F.J.Teixeira [et al.] // J. Glaucoma, – 2022. 31(3), – p. 201-205. https://doi.org/10.1097/IJG.0000000000001969
96. Tan, M.C.J. Two-year outcomes of the PAUL Glaucoma Implant for Treatment of Glaucoma / M.C.J.Tan, H.Y.C.Choy, V.K.T.Chang [et al.] // J. Glaucoma, – 2022. 31(6), – p. 449-455. https://doi.org/10.1097/IJG.0000000000001998
97. Ang, B.C.H. Recent Advancements in Glaucoma Surgery – A Review / B.C.H.Ang, S.Y.Lim, B.K.Betzler [et al.] // Bioengineering, – 2023. 10(9), – p. 1096. https://doi.org/10.3390/bioengineering10091096
98. Hasanov, J., Hasanova N., Kasimov E. Paul glaucoma implant in refractory glaucoma: short-term results in Azerbaijan. 11th World Glaucoma Congress // Honolulu, – Hawaii: – USA: June; – 2025.
99. Elhusseiny, A.M. Long-term outcomes of Ahmed ClearPath in childhood glaucoma: four-year results / A.M.Elhusseiny, M.S.Sayed, M.M.Khodeiry [et al.] // J. AAPOS, – 2025. 29(2), – 1041-1072. https://doi.org/10.1016/j.jaapos.2025.104172
100. Həsənova, N.A. Pediatrik afakik qlaukoma (ədəbiyyət icmalı) / N.A.Həsənova, C.V.Həsənov, E.M.Qasımov // Azərbaycan Ohalmologiya Jurnalı, – 2023. 46, – s. 71-79. https://doi.org/10.30546/2709-4634.2023.46.0271.
101. Hasanova, N., Hasanov J., Kasimov E. Outcomes of the Ahmed Glaucoma valve versus Aurolab aqueous drainage implant for refractory paediatric glaucoma in Azerbaijan. 11th World Glaucoma Congress // Honolulu, – Hawaii: – USA: June; – 2025.
102. Vasconelos, A.T. Glaucoma drainage devices in children: an updated review / A.T.Vasconelos, J.A.Massote, C.Senger [et al.] // Arq. Bras. Oftalmol., – 2024. 20, 87(6), – p. 2021. https://doi.org/10.5935/0004-2749.2021-0338
103. Roy, S. Initial Clinical Results of the eyeWatch: a New Adjustable Glaucoma Drainage Device Used in Refractory Glaucoma Surgery / S.Roy, A.Villamarin, C.Stergiopulos [et al.] // J. Glaucoma, – 2019. 28(5), – p. 452-458. https://doi.org/10.1097/IJG.0000000000001209
104. Roy, S. Comparison Between the eye Watch Device and the Ahmed Valve in Refractory Glaucoma / S.Roy, A.Villamarin, C.Stergiopulos // J. Glaucoma, – 2020. 29(5), – p. 401-405. https://doi.org/10.1097/IJG.0000000000001471
105. Ahmed, F. Evaluating the Safety and Efficacy of a Novel Glaucoma Drainage Device in High-Risk Adult Glaucoma Patients: A One-Year Pilot Study / F.Ahmed, E.Normando, S.Ahmed [et al.] // J. Clin. Med., – 2024. 13(7), – p. 4996. https://doi.org/10.3390/jcm13174996
106. Bicket, A.K. A novel bilayered expanded polytetrafluoroethylene glaucoma implant creates a permeable thin capsule independent of aqueous humor exposure / A.K.Bicket, J.Szeto, P.Roeber [et al.] // Bioeng.

Transl. Med., – 2021. 6(1), – p. 10179. https://doi.org/10.1002/btm2.10179
107. GORE Glaucoma Drainage Implant Clinical Study // Clinical Trials. https://gov/show/NCT055570580
108. Kao, B.W. Biocompatibility and feasibility of VisiPlate, a novel ultrathin, multichannel glaucoma drainage device / B.W.Kao, E.Meer, T.A.Barbolt [et al.] // J. Mater. Sci. Mater. Med., – 2021. 32(12), – p. 141. https://doi.org/10.1007/s10856-021-06613-8
109. Ianchulev, T. Biotissue stent for supraciliary outflow in open-angle glaucoma patients: surgical procedure and first clinical results of an aqueous drainage biostent / T.Ianchulev, R.N.Weinreb, G.Kamthan [et al.] // Br. J. Ophthalmol., – 2023. 108(2), – p. 217-222. https://doi.org/10.1136/bjo-2022-322536
110. Calvo, E. Bio-Interventional Uveoscleral Outflow Enhancement Surgery for Primary Open Angle Glaucoma: 2-year results of cyclodialysis with scleral allograft reinforcement / E.Calvo, T.De Francesco, L.Vera [et al.] // Ophthalmol. Sci., – 2025. Feb; 3. 5(4), – p. 100727. https://doi.org/10.1016/j.xops.2025.100727
111. Droste, A.P. Emerging glaucoma treatments: are we seeing an improvement in adherence? / A.P.Droste, P.A.Newman-Casey // Expert Rev. Ophthalmol., – 2023. Apr; 12. 18(2), – p. 101-111. https://doi.org/10.1080/17469899.2023.2199981
112. Serhan, H.A. Effectiveness and Safety of Trabeculectomy Versus Tube Shunt Implantation for Uveitic Glaucoma: A Systematic Review and Meta-Analysis / H.A.Serhan, S.A.Ba-Shammakh, A.K.Hassan [et al.] // Am. J. Ophthalmol., – 2024. 268, – p. 319-328. https://doi.org/10.1016/j.ajo.2024.08.045
113. Raja, S. Efficacy and Safety of Aurolab Aqueous Drainage Implant Compared With Baerveldt Glaucoma Implant for Refractory Glaucoma at One Year: A Systematic Review and Meta-Analysis / S.Raja, U.Nisar, O.Khan [et al.] // J. Ophthalmol., – 2024. 2024(1), – p. 8617959. https://doi.org/10.1155/2024/8617959
114. Raja, A. Meta-analysis of Molteno glaucoma implants and Ahmed glaucoma valves: insights into efficacy and safety for complex glaucoma / A.Raja, S.Bhimani, H.A.U.Rahman [et al.] // Front. Ophthalmol., – 2023. 3, – p. 1307439. https://doi.org/10.3389/fopht.2023.1307439
115. Hong, M. Comparison of Aurolab Aqueous Drainage Implant with Ahmed Glaucoma Valve for Refractory Glaucoma: A Meta-Analysis / M.Hong, Y.Peng, Y.Lai [et al.] // Ophthalmic. Res., – 2023. 66(1), – p. 457-464. https://doi.org/10.1159/000529039
116. Carla, M.M. The Paul Glaucoma Implant: a systematic review of safety, efficacy, and emerging applications / M.M.Carla, G.Gambini, F.Boselli [et al.] // Graefes Arch. Clin. Exp. Ophthalmol., – 2025. https://doi.org/10.1007/s00417-025-06861-2
117. Stallworth, J.Y. Efficacy of Ahmed and Baerveldt glaucoma drainage device implantation in the pediatric population: A systematic review and meta-analysis / J.Y.Stallworth, K.S.O'Brien, Y.Han [et al.] // Surv. Ophthalmol., – 2023. 68(4), – p. 578-590. https://doi.org/10.1016/j.survophthal.2023.01.010
118. Ramdas, W.D. Efficacy of glaucoma drainage devices in uveitic glaucoma and a meta-analysis of the literature / W.D.Ramdas, J.Pals, A.Rothova [et al.] // Graefes Arch. Clin. Exp. Ophthalmol., – 2019. 257(1), – p. 143-151. https://doi.org/10.1007/s00417-018-4156-9
119. Pan, S.Y. A systematic review and network meta-analysis of surgical interventions for glaucoma following penetrating keratoplasty / S.Y.Pan, Y.Y.Chen, Y.A.Lu [et al.] // Scientific Reports, – 2025. 15(1), – p. 13783. https://doi.org/10.1038/s41598-025-95997-6
120. Garg, A. Comprehensive study of traditional glaucoma drainage devices and emerging Micro Invasive Glaucoma Surgery (MIGS) devices: A review / A.Garg, G.Singh, S.Gupta [et al.] // Biomedical Engineering Advances, – 2025. 9, – p. 100140. https://doi.org/10.1016/j.bea.2024.100140