

## Glaucoma drainage devices

## Dispositivos de drenagem para glaucoma

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## ABSTRACT

Glaucoma drainage devices are important therapeutic options for cases of refractory glaucoma, in which trabeculectomy with antimetabolites has shown high risk of failure. There are devices with different sizes, designs and materials, and several studies have been conducted to test their safety and effectiveness. Despite known complications, their use has progressively increased in recent years, and they are the primary surgical option, in some situations. The aim of this review is to discuss the importance, mechanisms, biomaterials, results and complications of glaucoma drainage devices.

## RESUMO

Os dispositivos de drenagem para glaucoma são importante opção terapêutica em casos de glaucomas refratários, nos quais a trabeculectomia com antimetabólitos tem alta chance de falência. Há dispositivos com diferentes tamanhos, desenhos e materiais, e muitos estudos foram realizados para testar sua segurança e eficácia. Apesar de suas conhecidas complicações, seu uso tem aumentado progressivamente nos últimos anos, inclusive como primeira opção cirúrgica, em algumas situações. O objetivo desta revisão foi discutir a importância, os mecanismos, os biomateriais, os resultados e as complicações dos dispositivos de drenagem para glaucoma.

## INTRODUCTION

Glaucoma is the main cause of irreversible blindness in the world, despite the growing innovation in its diagnosis and treatment.<sup>(1)</sup> Clinical treatment is the first approach in glaucoma; however, it might not reduce intraocular pressure (IOP) to appropriate levels in some patients; thus, surgery is required.<sup>(2)</sup>

Incisional glaucoma surgery basically consists of developing a complementary route of aqueous humor (AH) drainage, leading to the reduction of IOP. Trabeculectomy (TRAB) is the most common surgery.<sup>(2-4)</sup> Trabeculectomy failure generally occurs by a scarring mechanism, with fibrosis of the conjunctiva and episclera, with filtering bleb (FB) ceasing to exist.<sup>(5,6)</sup>

Historically, glaucoma drainage devices (GDD) have been reserved for patients at high risk of TRAB failure, such as eyes with scars in the conjunctiva due to incisional surgeries (previous TRAB, retinal surgeries with the use of explants for scleral buckling and *pars plana* vitrectomy – PPV); eyes with diseases causing conjunctival fibrosis; neovascular glaucoma (NVG), uveitic glaucoma, and post-penetrating keratoplasty (PK).<sup>(2-4,7,8)</sup>

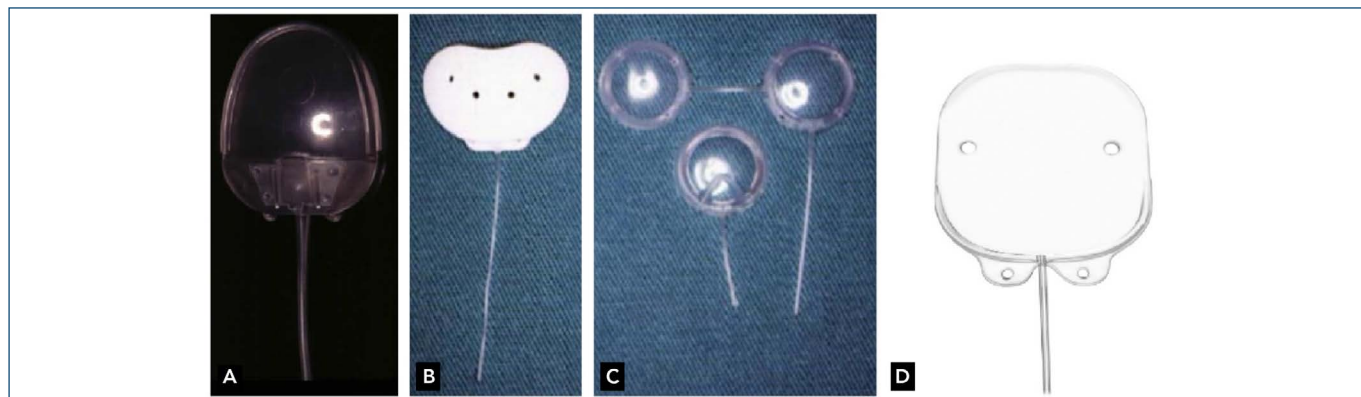
In 2002, the American Glaucoma Society (AGS) prepared a questionnaire for several of its members, to collect data on their preferences in glaucoma surgeries. A significant increase was observed in the use of GDD in cases of failed TRAB, uveitic glaucoma, NVG, and some secondary glaucomas (post-cataract surgery, post-PK, post-retinal surgery with scleral intropexion, and post-PPV).<sup>(3)</sup>

Data collected from Medicare (United States health insurance) fee-for-service paid claims, from 1994 to 2012, have shown the profile of glaucoma surgeries has been changing rapidly, with a sharp drop (77%) in the number of TRAB (as first surgeries in eyes without conjunctival scarring), and with a significant increase (410%) in GDD surgeries (in different types of glaucoma). In 1994,

the ratio between the number of TRAB and the number of GDD surgeries was 27:1, and then it dropped to 3:2, in 2012. With an increasing number of studies on GDD, better knowledge about their indications, more well-trained surgeons, as well as fear of TRAB failure or its FB complications, associated with the use of antimetabolites (leakage, endophthalmitis, dysesthesia), surgeries with GDD are more likely to be performed as early as possible.<sup>(2,4,9)</sup>

The use of GDD as a primary surgery has been discussed based on the fact that TRAB with antimetabolites might have higher risks of long-term intercurrent events, due to FB complications. The use of GDD as a primary glaucoma surgery is under study and might have better outcomes than their use after multiple surgeries, perhaps more advantageous than TRAB, since they present lower rates of complications than FB.<sup>(4)</sup> Some studies have shown similar outcomes between TRAB and GDD, when evaluating control of IOP and complications.<sup>(7,10-15)</sup> The Primary Tube Versus Trabeculectomy Study (PTVT) is an ongoing study comparing safety and efficacy of tube shunt implantation versus TRAB with mitomycin C (MMC) in eyes with uncomplicated open-angle glaucoma, with no previous incisional surgery. The three-year results showed that the TRAB group had lower IOP requiring fewer glaucoma medication.<sup>(16)</sup> Another study, Tube Versus Trabeculectomy (TVT), showed that, for eyes with previous cataract and/or glaucoma surgery, GDD showed slightly better results regarding reduction in IOP and number of hypotensive medications.<sup>(10)</sup>

The four most often used GDD are (Figure 1):<sup>(17,18)</sup> Ahmed glaucoma valve (AGV), New World Medical®, Rancho Cucamonga, CA; Baerveldt® glaucoma implant (BGI), Abbott Medical Optics®, Santa Barbara, CA; Molteno implant (MI) (Molteno Ophthalmic Limited®, Dunedin, New Zealand); and Implants de Susanna UF (Adapt, Brazil).



Source: pictures A to C were courtesy of Dr. João Antônio Prata Júnior, Universidade Federal do Triângulo Mineiro, Uberaba, MG, Brazil, and picture D was courtesy of Dr. Remo Susanna.

**Figure 1.** Glaucoma drainage devices. (A) Ahmed glaucoma valve; (B) Baerveldt® glaucoma implant; (C) double-plate and single-plate Molteno implant; (D) Susanna implant.

**Table 1.** Characteristics of the most commonly used glaucoma drainage devices

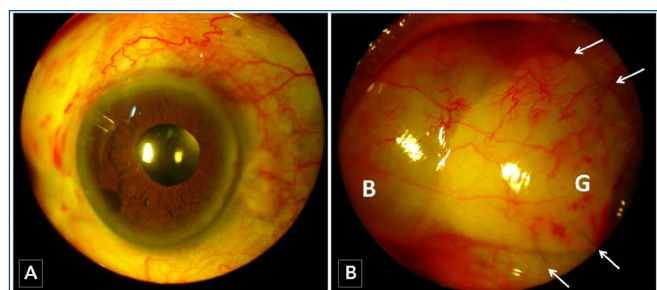
	Molteno <sup>(19, 20)</sup>	Baerveldt <sup>(21-24)</sup>	Ahmed <sup>(25, 26)</sup>	Susanna <sup>(27)</sup>
Year of release	1969	1992	1993	2017
Number of models	9	2	8	1
Surface area of the episcleral plate (mm <sup>2</sup> )	From 50 (pediatric) to 274 (double plate)	250 or 350	From 96 (pediatric) to 364 (double plate)	200
Material of the plate	Polypropylene and silicone	Barium-impregnated silicone	Polypropylene, silicone, polyethylene	Silicone
Presence of valve	No	No	Yes	No
Adaptation for <i>pars plana</i> insertion	No	Yes	Yes	No
Internal diameter of the silicone tube	300 µm	300 µm	300 µm	230 µm

Each device has different models and plate materials, according to Table 1.<sup>(19-27)</sup>

In 2016, Susanna implant was launched in Brazil, with a design similar to that of traditional GDD, also having a silicone tube and an episcleral plate, both thinner than the other three devices mentioned (Figure 1).<sup>(27)</sup>

## THE OPERATING MECHANISM OF GLAUCOMA DRAINAGE DEVICES MOST COMMONLY USED: MOLTENO®, BAERVELDT®, AND AHMED®

The reasoning behind the operating mechanism of GDD is to drive the AH from the anterior chamber through a silicone tube to a reservoir formed around the GDD plate, located posteriorly in the subconjunctival space and externally confined by a fibrous capsule. Aqueous humor crosses this capsule by passive diffusion, between the collagenous fibers, and is absorbed by capillaries and lymphatic vessels from the Tenon's capsule and conjunctiva. The capsule involving the plate is the most resistant site to AH flow.<sup>(8, 18, 28-33)</sup> The plate prevents the conjunctival adhesion to the sclera and its presence maintains the AH reservoir.<sup>(8)</sup> With adequate surgical technique, patients will have the aspect shown in Figure 2.



Source: courtesy of Dra. Heloisa Andrade Maestrini, Oculare Eye Hospital, Belo Horizonte, MG, Brazil.

**Figure 2.** Anterior segment biomicroscopy of implanted glaucoma drainage devices: (A) Aspect of the silicone tube in the periphery of the anterior chamber; (B) same eye with patch graft; G: sutured to underlying sclera (arrows) and B: bleb, overlying the glaucoma drainage device plate.

Molteno described three IOP oscillation phases, which occur after non-valved GDD implantation, when no tube

ligature is used: hypotonic, hypertensive, and controlled IOP phase (balance).<sup>(20)</sup> The first phase may last up to 30 days after implantation, and occurs because there is not enough time for the fibrous capsule to be formed around the plate, which is able to restrict the AH flow. Next, there is the hypertensive phase lasting from six to 12 weeks, when the capsule becomes thick, swollen and inflamed, with a low permeability to AH, reducing its reabsorption and causing increased IOP. In this phase, IOP rises and the pressure of AH on the capsule, together with proinflammatory substances present in it, contribute to fibrosis, thickening, and greater inflammation of the fibrovascular tissue. The third phase (balance) is characterized by a FB with no inflammatory reaction, with the implant capsule already remodeled and thinner, with more permeability to AH, establishing a stable control of IOP.<sup>(20, 30, 34-42)</sup>

## Area of the glaucoma drainage device and a successful control of intraocular pressure

Several studies have shown the IOP-lowering effect increases, but not proportionally, with the increase in plate size with areas over 170 mm<sup>2</sup> to 250 mm<sup>2</sup>. Thus, single-plate GDD have pressure effects that are little different from those of double-plate implants, as well as those with larger plates when compared to smaller plates.<sup>(18, 22, 34, 43-46)</sup> Possibly, larger implants might form a more fibrous capsule, by creating very large FB, since tension on the capsule's inner wall would be exponentially proportional to the diameter of FB, according to the Laplace law. Moreover, capsules with larger diameters experienced greater tension than those with smaller diameters, when submitted to the same pressure, as per the same law. Thus, thicker capsules would be more likely to nullify the benefit from a larger area of AH drainage.<sup>(44, 47)</sup> In cases in which implantation is difficult, such as in small eye sockets or in eyes submitted to previous conjunctival procedures, GDD with smaller plates seem to be a better option.<sup>(46)</sup>

## Valved and non-valved drainage devices

The purpose of the valve is to avoid postoperative hypotony and its complications. This idea was first introduced

by Krupin et al., in 1976, with a device that was a tube with a unidirectional valve mechanism. This device had a tip in the anterior chamber and was fixed under a scleral flap, without a plate in contact with the conjunctiva, and the AH was drained to subconjunctival space, as in a TRAB.<sup>(48)</sup> Modern GDD may be valved, such as the AGV (Figure 1A), or non-valved, such as BGI, MI, and Susanna (Figures 1B, 1C and 1D). In case of a non-valved implant, a temporary restriction of the AH flow is required, which may be placed by the tube ligation with an absorbable suture or by placing a suture thread in the tube lumen, and this suture thread may be removed some weeks after surgery, as required. Thus, a temporary restriction on AH flow occurs in the initial phase after the implantation, until a capsule is formed around the plate, restricting flow and preventing hypotony.<sup>(49, 50)</sup> As to the valved implant, there is already a flow restriction mechanism, with the advantage of having an immediate reduction in IOP in the postoperative period.<sup>(17, 51-53)</sup> In theory, the AGV is programmed to close the valve in cases of IOP of approximately 8 mmHg.<sup>(26)</sup> Nevertheless, the presence of a valve or the presence of tube ligation does not guarantee protection against hypotony, since these mechanisms may not work perfectly, in addition to a possible peritubular leakage in the scleral foramen.<sup>(26, 47, 54-59)</sup>

In the case of AGV, the AH reaches the tissues covering the device immediately after the surgery, stimulating the formation of a fibrous capsule due to proinflammatory substances in AH. This partially explains a more pronounced hypertensive phase of this GDD.<sup>(60-64)</sup>

Studies comparing valved devices (AGV) to non-valved devices (BGI) have not shown significant differences in IOP control nor in rate of complications, although the BGI group has required a smaller number of hypotensive drugs and has had a larger number of hypotony-related complications.<sup>(52, 58, 65)</sup> It is important to highlight that AGV S2 has a polypropylene plate, whereas BGI has a silicone one. Another important factor is that AGV is valved and is more likely to have encapsulation, with a longer hypertensive phase. Thus, more than one variable may have influenced the outcomes.<sup>(58)</sup> Compared to AGV, BGI has shown a slightly better IOP reduction, but it has higher incidence of complications, such as hypotony and evolution to no light perception.<sup>(66-68)</sup>

Hong et al. surveyed several studies with GDD and reported the incidence of encapsulation in patients who received AGV ranged from 40% to 80%, whereas in those who received BGI or MI with a double plate, it ranged from 20% to 30%.<sup>(37)</sup> Schwartz et al. reported a preference for using BGI, since a long-term IOP control was observed, always

employing the technique of ligation and fenestration of the silicone tube. Nevertheless, these authors informed preferring AGV in cases of uveitis and in those previously submitted to a cyclodestructive procedure, since the AH production may be reduced leading to hypotony.<sup>(18)</sup>

## Biomaterials

All synthetic materials cause an inflammatory response of the receptor tissue. The inflammatory reaction generally leads to material encapsulation by a fibrous layer rich in collagen.<sup>(69)</sup> An aggravated inflammatory process around the GDD plate results in a very thick fibrous capsule, being the main cause of failure of this therapeutic modality.<sup>(70)</sup> The inflammation around the plate is influenced by other characteristics in addition to the biomaterial it is made of, such as its size, shape and flexibility.<sup>(71)</sup> Thus, the ideal GDD should be made of a completely inert material or of relative biological inactivity.<sup>(71, 72)</sup>

Polypropylene is used in MI and in AGV. Silicone is used in Krupin, Schocket, Susanna, and Baerveldt® implants and in some models of AGV.<sup>(73, 74)</sup> Studies conducted using rabbits, with the implantation of biomaterials in the subconjunctival space, have shown that silicone induces less inflammatory reaction than polypropylene and PMMA.<sup>(71, 75)</sup> Most studies comparing polypropylene and silicone AGV have shown a better control of IOP with those using silicone.<sup>(76-79)</sup>

## Micromovement of the device and its influence on the thickness of the capsule

It is difficult for a GDD with a very smooth surface to be incorporated by the organism, since there are no holes for tissue growth in it, which prevents a perfect attachment to the implantation site. Thus, micromovements occur, which maintain an ongoing trauma, leading to a more intense inflammatory reaction, and to the formation of thicker capsules. Thus, some GDD surface roughness is desirable since it increases the adhesion of the device to its implantation site, reducing micromovements, with a subsequent formation of thinner capsules.<sup>(47, 73)</sup> Since the eyes move under extraocular muscles and under Tenon's connective tissue, GDD on the scleral surface may have micromovements that may maintain the low-grade chronic inflammatory reaction activated, which may cause an excessive scarring that forms a very thick collagenous capsule.<sup>(40, 47)</sup>

GDD have holes through which they may be attached to the sclera. BGI has fenestrations in its plate that allow for the formation of vertical fibrous bands connecting the

sclera to the roof of FB, avoiding a dramatic rise of the capsule of the implant.<sup>(18, 80)</sup> The MI has four fenestrations in its plate: two anterior ones and two posterior ones. The four holes may be used to attach GDD to the sclera, although only two anterior holes are usually used to attach the plate to the sclera.<sup>(81)</sup>

## POSTOPERATIVE COMPLICATIONS

Glaucoma drainage devices are some of the few therapeutic options in patients with glaucoma refractory to clinical and surgical treatment with TRAB. Although they have been effective to reduce IOP, their use is not free from complications. Applying the appropriate surgical technique with the proper patient selection are important factors that reduce the incidence of complications.<sup>(42)</sup> Early complications occur within the first postoperative month and late complications after the first month. Early complications include shallow or flat anterior chamber, choroidal detachment (CD), conjunctival leakage of AH, hyphema, wound dehiscence, endophthalmitis, and strabismus. Late complications include shallow or flat anterior chamber, CD, strabismus, endothelial cell loss and corneal decompensation, exposure of drainage device, endophthalmitis, retinal detachment, *phthisis bulbi*, and reduction of visual acuity (VA).<sup>(16)</sup>

### Hypotony, shallow anterior chamber and choroidal detachment

The presence of valve or ligature of the silicone tube with a nonabsorbable suture does not ensure protection against hypotony, which is generally caused by the excessive flow of AH through the fistula.<sup>(82-84)</sup> Another possible mechanism of hypotony is decreased AH production by an intense intraocular inflammation.<sup>(84)</sup> Some possible complications include shallow anterior chamber, serous or hemorrhagic CD, hypotony maculopathy, and worsening or development of cataract.<sup>(47, 82-84)</sup>

Extra care should be taken to perform sclerostomy, through which the silicone tube will pass into the inner eye. This foramen should be opened with a 22G or a 23G needle, so it is not too wide, predisposing peritubular leakage with a subsequent hypotony.<sup>(42, 85, 86)</sup> Regarding AGV, Sarkisian and Bailey et al. recommended to be careful, not vigorously performing priming of the valve, to avoid damaging it.<sup>(42, 85)</sup>

Glaucoma drainage devices with a larger drainage area have a greater success in controlling the IOP, with a major risk of hypotony. This applies both to comparisons among single-plate devices with different areas, and as well as the same GDD with a single plate versus a double plate.

Postoperative shallow anterior chamber may result from hypotony or, less frequently, from CD.<sup>(82)</sup> As a complication from shallow anterior chamber, an endothelial injury may occur resulting from the touch of the tube to the corneal endothelium, as well as from the touch of the iris or the iris with the crystalline lens.<sup>(47, 82)</sup> The formation of peripheral anterior synechiae may also result from iridocorneal touch. In cases of shallow anterior chamber with peripheral iridocorneal touch (grade 1 shallow AC), the clinical treatment is effective. In cases of flat AC (grade 3 shallow AC), with crystalline lens-corneal touch, an urgent surgery is required, with the purpose of reducing the flow of AH through the fistula. In cases of shallow anterior chamber with a total iridocorneal touch, with no crystalline lens-cornea touch (grade 2 shallow AC), it is recommended to reform the anterior chamber with a viscoelastic substance, although there is the option of clinical treatment or surgical drainage of CD.<sup>(82)</sup>

Serous CD, also called uveal effusion, is likely to occur because of the fluid transudation from the suprachoroidal capillaries, due to the change in the pressure gradient resulting from hypotony. In the hemorrhagic CD, also called suprachoroidal hemorrhage, a possible cause would be by rupture of posterior ciliary vessels, caused by a sudden drop in IOP and/or vessel stretching by a previously present small serous CD. Both types of CD may occur in the transoperative or postoperative period. Serous CD is usually benign and clinically treated, without causing VA loss. Hemorrhagic CD has the worst visual prognosis, particularly when it occurs during surgery, with expulsive hemorrhage. In CD, there may be an involvement of the ciliary body, with a decrease in AH production, which maintains and aggravates the hypotonic condition, creating a vicious cycle that perpetuates this condition and may lead to fistula failure, by a drastic reduction in the flow.<sup>(83)</sup> In the literature, the incidence of serous CD after GDD surgeries ranged from 0% to 22%. In few cases, serous CD was more severe, requiring drainage.<sup>(7, 14, 15, 17, 22, 26, 43, 45, 87-90)</sup> The occurrence of hemorrhagic CD after these surgeries ranged from 0% to 8%, with a larger number of cases requiring surgery for fluid drainage from the suprachoroidal space.<sup>(7, 17, 22, 26, 43, 65, 87-92)</sup>

Paysse et al. retrospectively studied hemorrhagic CD in 197 patients from two clinical studies with MI and observed this complication in 6% of cases. Most cases (67%) occurred up to one day after surgery, and virtually all cases (92%) occurred up to 5 days after surgery. No case occurred during surgery. Risk factors for this complication comprised the magnitude of IOP reduction after surgery; hypotony in the postoperative period; longer time with



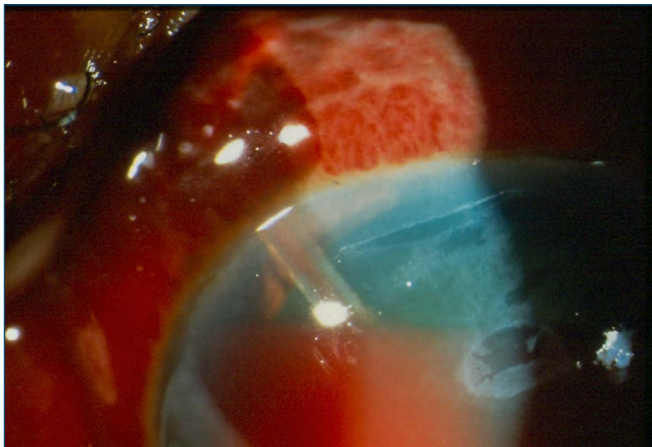
hypotony in the postoperative period; closed-angle glaucoma; and having been submitted to more than two previous surgeries.<sup>(91)</sup>

### Conjunctival leakage of aqueous humor

Conjunctival leakage has the potential to cause hypotony, with its consequent complications.<sup>(85, 93)</sup> Conjunctival leakage may be caused by erosion of the conjunctiva, which covers the GDD, and may be associated with endophthalmitis.<sup>(94)</sup>

### Hyphema

Hyphema in the postoperative period of TRAB or GDD seems to be due to iridectomy, ocular bulb decompression or bleeding from neovascularization, and it generally has a spontaneous resolution with conservative treatment (Figure 3).<sup>(95, 96)</sup> The incidence of this complication ranges from 2% to 25.9%.<sup>(7, 11, 15, 17, 23, 53, 87, 88, 90, 92, 97-101)</sup> Patients with NVG seem to face a higher risk of developing hyphema in the postoperative period.<sup>(23, 87, 92, 97, 100)</sup>



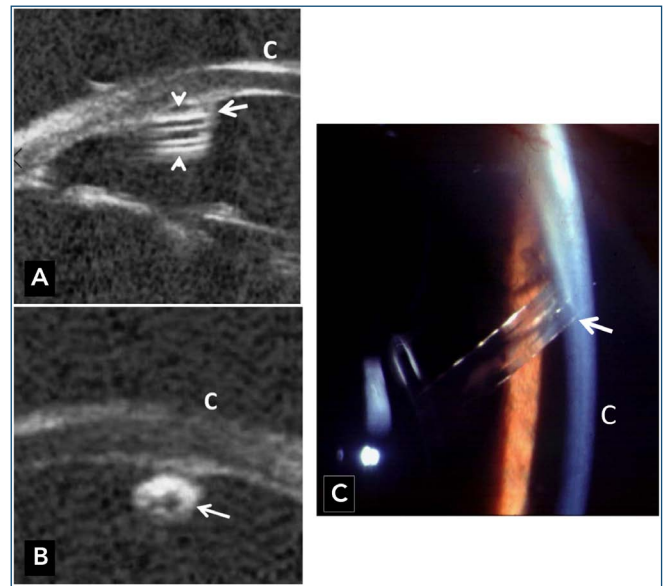
Source: courtesy of Dr. João Antônio Prata Júnior, Universidade Federal do Triângulo Mineiro, Uberaba, MG, Brazil.

**Figure 3.** Anterior segment biomicroscopy, showing hyphema.

### Endothelial loss and corneal decompensation

Hypotheses to explain endothelial injuries in patients with GDD include postoperative inflammation, the presence of an intraocular foreign body, endothelial trauma associated with surgery and the tube-endothelial touch during surgery and in the postoperative period (Figure 4). In the postoperative period, the tube-endothelial touch might be intermittent, occurring during eye movements, such as eye blinking and scratching.<sup>(38, 102-104)</sup>

A new surgery is recommended for tube repositioning, in case a tube-endothelial touch is detected, at risk of corneal decompensation.<sup>(38, 102)</sup> In children, the



Source: Images (A) and (B) were courtesy of Dr. Flávio A. Marigo, Instituto da Visão, Belo Horizonte, MG, Brazil; image (C) was courtesy of Dr. João Antônio Prata Júnior, Universidade Federal do Triângulo Mineiro, Uberaba, MG, Brazil.

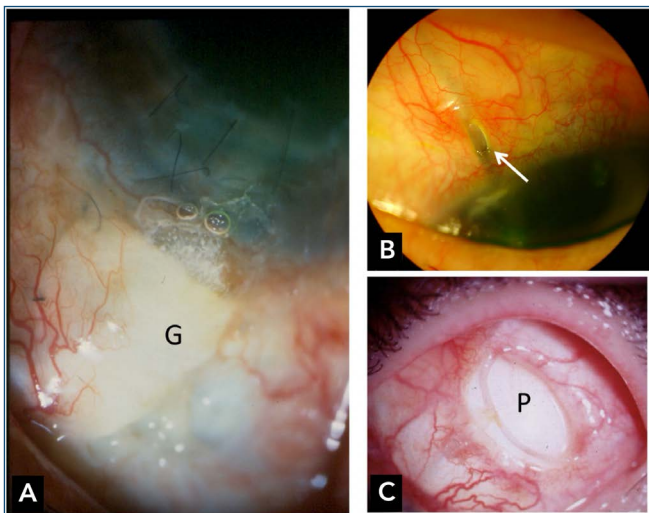
**Figure 4.** Tube-endothelial touch. Tube (arrow) in contact with cornea. (A) Ultrasound biomicroscopy, radial cut. (B) Ultrasound biomicroscopy, transversal cut through arrowheads in A. (C) Anterior segment biomicroscopy of another eye, also showing tube-endothelial touch (arrow).

tip of the tube may change its position over time, therefore, a tube-endothelial touch may occur. This is likely to occur because of eye growth. According to Budenz *et al.*, less experienced surgeons (less than 20 surgeries with GDD) were more likely to have tube-endothelial touch as complication.<sup>(17)</sup> *Pars plana* tube insertion into the vitreous cavity, after a complete PPV, has the advantage of preventing the tube-endothelial touch and of reducing endothelial trauma at the moment of the GDD surgery.<sup>(105)</sup>

McDonnell *et al.* suggested the presence of GDD may rupture the blood-aqueous barrier, which would lead to intraocular inflammation and corneal graft rejection.<sup>(106)</sup> Other situations that occurred prior to GDD implantation may have caused endothelial damage, with subsequent corneal decompensation in the postoperative period, such as: previous surgeries, inflammatory processes, acute or intermittent episodes of very elevated IOP. Thus, the state of the endothelium itself prior to surgery with GDD might explain the occurrence of corneal decompensation, which would be a mere reflection of the natural course of the disease, reducing the implant influence as the factor causing the problem.<sup>(37, 104, 107-109)</sup> Some studies evaluated the endothelium of patients submitted to surgery with GDD, in which endothelial cell loss was found to be more rapid in these patients, particularly in the site surrounding the silicone tube.<sup>(110-112)</sup>

## Exposure of drainage device

Glaucoma drainage device implantation involves risks to the patients, as it is a foreign body attached to the surface of the eye.<sup>(113)</sup> Exposure of tube or plate is a serious complication, which may require the GDD removal, because of its high risk of causing endophthalmitis.<sup>(54, 113-116)</sup> It is also important to consider leakage, which cause hypotony and shallow anterior chamber, with consequent tube-endothelial touch.<sup>(93)</sup> The silicone tube, which lies on the sclera, is covered with a graft (sclera, cornea, dura mater, *fascia lata* or pericardium) to prevent conjunctival erosion.<sup>(54, 85, 113-116)</sup> The exposure may be of the silicone tube, which is more frequent, or of the plate, located in the equator of the eye (Figure 5).<sup>(54, 113)</sup> Possible causes for erosion would be immune-mediated inflammation, poor tissue perfusion with conjunctival ischemia, excessive tissue tension, and mechanical eyelid trauma on the conjunctiva that covers the implant.<sup>(54, 116-118)</sup>



Source: pictures A and C were courtesy of Dr. João Antônio Prata Júnior; pictures B was courtesy of Dra. Heloisa Andrade Maestrini.

**Figure 5.** Conjunctival erosion, exposing: (A) patch graft: G; (B) silicone tube (arrow); (C) plate: P.

Two studies identified different risk factors, such as black race, number of topical ocular hypotensive medications before surgery with GDD; previous glaucoma laser surgery; and GDD surgery combined with another procedure at the same surgical time.

A meta-analysis analyzed 38 studies (total of 3,255 patients) and showed an incidence of exposure ranging from 0% to 12% (mean of  $2.0 \pm 2.6\%$ ), and a mean follow-up of  $26.1 \pm 3.3$  months. Follow-up time was the main risk factor, suggesting patients should be examined periodically.<sup>(119)</sup>

As for the site of GDD plate attachment, studies focused on the upper quadrants, particularly the upper

temporal.<sup>(117, 120-122)</sup> Pakravan et al. reported that the group of patients with devices placed inferiorly had a greater incidence of extrusion, endophthalmitis and worse esthetic outcome, since the implant is more visible.<sup>(117)</sup> Levinson et al. have shown that patients submitted to lower tube implantation were more likely to have exposure than those whose implant was placed superiorly (12.8% versus 5.8%;  $p=0.056$ ). They compared the incidence of endophthalmitis in cases of exposure of devices implanted inferiorly (41.7%) to those implanted superiorly (8.1%) with a statistically significant difference, probably due to the larger contact area between these exposed lower implants and the lacrimal fluid, rich in bacteria.<sup>(113)</sup>

## Endophthalmitis

Endophthalmitis is a serious complication that may cause a reduction of VA, which may lead to a complete loss of vision and atrophy of the eyeball. The exposure of the implant is the greatest risk factor for endophthalmitis, since the exposed GDD is a site of bacterial infection that may penetrate into the eye. Early endophthalmitis (before 1 month) may be caused by perioperative inoculation of conjunctival bacterial flora, whereas late endophthalmitis (after the first month) is virtually always caused by the exposure of the device. Gedde et al. suggested a surgical review should always be carried out in all cases of GDD exposure. The implant should be removed in virtually all cases, since the foreign body would serve as a means for bacteria to lodge and reinfect the eye after treatment with antibiotics.<sup>(115)</sup>

Studying the incidence of endophthalmitis and blebitis, Gedde et al. prospectively compared BGI versus TRAB for five years and found these complications in one case (1%) of BGI and in five cases (5%) of TRAB. Although this difference has not been statistically different, it still raises concern.<sup>(7)</sup>

Budenz et al. conducted a prospective study with patients submitted to surgery with AGV and with BGI, with a 1-year follow-up. Only one case of endophthalmitis was reported in the BGI group, which occurred in the first 3 months.<sup>(17)</sup> In this cohort, there was no case of endophthalmitis in a 5-year postoperative period; hence it raised the hypothesis late endophthalmitis should not be of concern in cases of GDD, in contrast with those of TRAB.<sup>(123)</sup>

## Retinal detachment

Retinal detachment (RD) is an important cause of visual loss, and if not treated, it virtually always progresses to blindness.<sup>(124)</sup> In addition to blindness, RD may cause *phthisis bulbi*.<sup>(125)</sup>

Waterhouse et al. carried out a survey on 350 patients submitted to antiglaucoma surgeries with MI. Sixteen patients (5%) were identified with RD. Out of these 16 patients, six (38%) developed *phthisis bulbi*, and one patient had to undergo enucleation. There is not just one mechanism explaining the origin of RD in these patients, since some of them had been submitted to other previous ocular surgeries, including PPV, ocular trauma repair, TRAB, PK, and lensectomy. They demonstrated the most frequent cause of retinal tears (origin of retinal detachment) is through the posterior vitreous detachment. Some patients had conditions in which the vitreous was abnormally adhered to the retina, which might cause tears (one case of *lattice* degeneration and one case with chorioretinal scar by a chronic uveitis condition). Only one patient was phakic (the others were aphakic or pseudophakic). The possibility that the GDD surgery has caused the retinal tears has not been excluded. In one of the cases, there was a vitreous obstruction of the tip of the tube situated in the *pars plana*. In this patient, peripheral retinal tears were in the same quadrant of the retina in which the tube was located.<sup>(126)</sup> Patients submitted to previous PPV may progress to RD, even after months, since iatrogenic retinal tears may occur in this procedure by vitreoretinal traction exerted by instruments in the sclera entry sites.<sup>(127)</sup> Patients submitted to cataract surgery also face a high risk of posterior vitreous detachment, with consequent formation of retinal tears, which may cause RD.<sup>(128)</sup> In other studies, the incidence of RD ranged from 0% to 10%.<sup>(7, 22, 44, 88, 90)</sup> These studies had different designs, follow-up periods, and populations.

### **Phthisis bulbi**

It occurs as the final stage of the severe eye disease and is characterized by soft eye (hypotony) with a limited size, containing atrophic and disorganized internal structures.<sup>(129, 130)</sup>

Studies have reported the incidence of *phthisis bulbi* ranging from 0% to 18% in patients submitted to surgery with GDD, with RD and NVG being the most common causes, and patients with NVG having the highest incidence of this complication.<sup>(23, 43, 45, 46, 88-90, 97, 99-101, 131, 132)</sup>

### **Strabismus**

Shwartz et al. reported that transient strabismus is not rare after GDD surgery and it usually improves with reduction of the edema of periocular tissues. These authors also informed BGI is more likely to cause strabismus and, for this reason, its manufacturer interrupted the production of the largest model, whose plate had an area of 500 mm<sup>2</sup>.

Another change was the addition of plate fenestrations, allowing for the growth of fibrous bands, which reduced the height of FB, and that might have reduced the incidence of this complication.<sup>(18)</sup> Rauscher et al. reported that in patients submitted to BGI surgery, the incidences of persistent strabismus ranged from 2.1% to 77%, and of diplopia, from 1.4% to 37%.<sup>(133)</sup> Hong et al. found a higher incidence of diplopia in the group of BGI (9%), when compared to AGV (3%) and MI (2%) ( $p < 0.01$ ). These authors suggested this higher incidence of ocular motility disorders in BGI would have occurred by the fact that its sides were implanted below two rectus muscles, causing local fibrosis and imbalance of extraocular muscles. There is a hypothesis that higher FB may cause strabismus in all models of GDD and that the higher the FB, the higher the chance of this complication to occur. Since BGI is the largest among all models, it would be more likely to have a very high FB, which would also explain a greater occurrence of disorders of extrinsic ocular motility. They have found the incidence of diplopia between 6% and 18%, excluding only one work in which the incidence was 77%.<sup>(37)</sup> In other studies, the incidence of strabismus ranged from 0% to 27%.<sup>(7, 14, 23, 26, 53, 87, 92, 101, 117, 133, 134)</sup>

Some studies have evaluated particularly strabismus after GDD, and the following disorders were described: paresis of the superior oblique muscle, acquired Brown syndrome (pseudo-Brown syndrome), exotropia, general restriction of the upward gaze, or another movement limitation of the quadrant where the device is implanted.<sup>(24, 135)</sup>

### **Reduction of visual acuity**

The review work conducted by Hong et al. did not find any difference in the reduction of VA, of at least two lines, among different GDD ( $p = 0.90$ ). Mean number of patients who had loss of VA was 33% for single-plate MI, 28% for double-plate MI, 27% for BGI, and 24% for AGV.<sup>(37)</sup>

Some studies have reported VA similar to (the same or with a difference of one line) or better than that of the preoperative period in 46% to 82% of patients. The worsening of VA, of two or more lines, was reported in 18% to 54% of patients.<sup>(17, 43, 44, 88, 92, 136)</sup> The worsening of VA may occur by progression of glaucoma and/or of other associated diseases, or by complications of GDD.<sup>(17, 44, 101)</sup> It is emphasized these studies had differences in follow-up period, design and populations. Patients with NVG had higher rates of loss of VA and of light perception, probably due to glaucoma progression and the ischemic retinal disease that caused glaucoma.<sup>(17, 101)</sup>



## DISCUSSION AND CONCLUSIONS

Glaucoma drainage implants are helpful in managing refractory glaucoma. They have been used more frequently and the results of scientific studies have proved its efficacy and safety are comparable with those of TRAB, being the preferred choice in cases of high risk of failure of standard surgery. These afore-mentioned trends toward increasing use of GDD, as well as toward choosing GDD as the first surgical option, reflect data mainly from the United States, and may not be the same in other countries, especially in developing countries, because of cost issues. Perhaps, economic reimbursement factors may also influence this trend. It is important to highlight that TRAB is a very important and established first option surgery and, in case of its failure, GDD could be performed. But, the inversion of this surgical sequence raises concern, because, after a GDD implantation, it would not make sense to “go back” to a TRAB. In addition, TRAB is no more possible in the same quadrant of the implanted GDD. The PTVT study supports TRAB as the first surgical option for uncomplicated open-angle glaucoma patients who had not undergone previous incisional ocular surgery, providing a better IOP control.

New designs of the traditional GDD should be tested to improve long-term IOP control and reduce complications, mainly those related to corneal endothelial cell loss, hypotony and exposure of device. The recent Molteno<sup>3</sup>® and Susanna implants have much thinner plates, when compared to traditional AGV and BGI. These thinner plates may reduce conjunctival complications and make the surgery easier. In the future, new biomaterials and better wound healing modulation may improve IOP results.

There is a trend toward non-bleb-formation procedures, probably trying to avoid bleb complications and making the surgery less invasive, with easier technique (minimally invasive glaucoma surgeries). So far, minimally invasive glaucoma surgeries have been indicated only in initial or moderate glaucoma, since their IOP reduction is limited. Therefore, for undetermined period, GDD will have their role in challenging cases and should not be compared with minimally invasive glaucoma surgery devices.

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