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Current approaches to glaucoma surgery in children – glaucoma drainage devices and minimally invasive procedures

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ABSTRACT

Glaucoma is one of the leading causes of visual impairment and irreversible loss of vision in children worldwide. Taking into account prolonged treatment, the condition should be diagnosed as early as possible, so that an appropriate therapeutic strategy can be implemented. The choice of treatment should be guided by factors including the type of glaucoma, the patient's age, the condition of the anterior segment of the eye, the course of treatment to date, and the child's general health. In many glaucoma cases in pediatric patients, surgery (goniotomy, trabeculotomy) is the first-line treatment, but in recent years more and more importance has been attached to surgical procedures involving the implantation of filtration and drainage valves as well as novel surgical techniques, including minimally invasive glaucoma surgery (MIGS) via the ab interno approach. They may provide additional or alternative solutions to traditional surgical procedures in the treatment of childhood glaucoma.

KEY WORDS: minimally invasive glaucoma surgery, glaucoma drainage devices, glaucoma in aphakic eyes, childhood glaucoma.

INTRODUCTION

Glaucoma is a major cause of visual impairment and irreversible loss of vision in children worldwide [1-4]. The disease leads to progressive damage to visual function, while high intraocular pressure (IOP) causes corneal opacity and the development of vision loss more commonly than in adult patients [5]. The primary pathomechanism of childhood glaucoma is dysgenesis of the iridocorneal angle *in utero*. Abnormal anatomical development of the angle causes a gradual increase in IOP and rapid disease progression. Glaucoma in pediatric patients represents a diverse group of disorders, each of which requires attention and understanding to prevent vision loss over the lifetime of young patients [6].

Childhood glaucoma is generally divided into primary congenital glaucoma (from birth to two years of age), late -onset primary congenital glaucoma (from two years of age to adolescence) – juvenile glaucoma, secondary congenital glaucoma (associated with congenital ocular anomalies including congenital aniridia, Peters anomaly; associated with congenital syndromes and systemic disorders such as trisomy 21, Marfan syndrome, homocystinuria, mucopolysaccharidosis, congenital rubella syndrome), as well as acquired secondary glaucoma (after cataract surgery, post-traumatic, post-inflammatory, associated with retinopathy of prematurity) [5, 6].

Considering the fact that childhood glaucoma requires prolonged treatment, the condition should be diagnosed as early as possible, so that proper therapeutic management can be initiated [7]. The choice of therapy should be guided by factors such as glaucoma type, patient's age, corneal clarity, prior course of treatment, and the child's general health. The management strategies include surgery and pharmacotherapy [6, 8]. Treatment and monitoring of pediatric glaucoma entails a number of challenges, for example clinical presentation evolving over time, problems with performing ocular examinations, lack of a normative database, and the need for close cooperation with young patients' caregivers [8-10].

In many cases of glaucoma in pediatric patients, surgery is the first-line treatment [11]. The aim of traditional surgical treatment (goniotomy, trabeculotomy) is to open the iridocorneal angle, which results in improved outflow of aqueous humor from the eye [12, 13]. However, over 20% of such procedures are ultimately unsuccessful [14-16]. The success rates for angle surgery in cases of secondary childhood glaucoma (including those associated with Peters anomaly, Sturge–We-

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ber syndrome, and aniridia) are also low [14, 17]. Pharmacological treatment can be used only during patient preparation for surgery, and as postoperative adjunctive therapy aimed to maintain normal IOP levels [18]. When surgery within the filtration angle cannot be performed or fails for various reasons, drainage devices and novel surgical techniques can be employed. Among the latter, minimally invasive glaucoma surgery (MIGS) done via the ab interno approach deserves particular attention [19]. MIGS procedures may be considered as the first step towards lowering the IOP in special circumstances (e.g. in monocular patients or in cases with a high predicted risk of postoperative complications).

In recent years, surgical procedures involving the implantation of glaucoma drainage devices have become increasingly important in the management of pediatric glaucoma [11]. This is due to the continuous improvement of surgical techniques with a view to reducing the number and severity of postoperative complications, particularly hypotony. Drainage systems have the advantage of being associated with potentially fewer postoperative interventions necessary to achieve well-controlled normal IOP compared to trabeculectomy (including suture removal or adjustment, anti-scarring injections), but the potential for postoperative complications must also be considered [8, 20].

The number of reports of randomized trials comparing various methods of surgical treatment of childhood glaucoma available in the medical literature worldwide is scarce. Considering the broad spectrum of disease severity and different operative techniques preferred by surgeons [19], interpreting and drawing conclusions from relatively small case series becomes even more difficult.

GLAUCOMA IMPLANTS

Glaucoma drainage devices

The first surgeon to report the use of a glaucoma drainage device in the pediatric population was Molteno (1973) [21]. Since then, other types of devices have been proposed, including Ahmed and Baerveldt implants, which are now most commonly used, also in children [8, 22]. The Ahmed implant is a flow-restrictive device, which theoretically reduces the risk of early hypotony, whereas the Baerveldt implant has a free flow design and thus requires additional measures to minimize the risk of early hypotony following surgery [23]. Their success rates in the studies published to date are difficult to compare in view of multiple study limitations [8, 24]. However, a common feature of both drainage devices is declining efficacy over time and the need for pharmacotherapy to support surgical treatment [25]. At one- to two-year follow-up, the success rate is approximately 80%, declining to about 50% at longer follow-up after the procedure [8]. It is not easy to determine which types of drainage devices are more widely used in the treatment of the pediatric population. The application of the Ahmed glaucoma valve is associated with fewer reported short-term complications, while the Baerveldt implant may provide superior long-term IOP control [8, 25]. Studies comparing different materials used in the Ahmed valves (polypropylene/silicone) indicate that silicone implants provide superior long-term control of IOP in children [8, 26]. The tables below list the results of studies analyzing the effects of Molteno type (Table I), Baerveldt type (Table II) and Ahmed type (Table III) glaucoma drainage devices in the treatment of childhood glaucoma [20].

Complications associated with the use of glaucoma drainage devices in children

A severe complication related to the implantation of glaucoma drainage devices in the pediatric population is postoperative hypotony. There have been reports on the external ligation of implants with restricted and unrestricted flow in order to reduce the risk of hypotony [8, 56]. The procedure can be performed either with sutures made of absorbable material which allow spontaneous flow release after a specific time or with non-absorbable sutures that are released after a defined time interval by laser lysis or surgical removal [57, 58]. Regardless of using the above solutions, the risk of postoperative hypotony is still high. Alternative strategies to avoid hypotony directly after the surgery involve the administration of a viscoelastic to the drainage tube or drainage device implantation via a two-stage procedure in which the end plate is attached to the sclera during the first stage, and then a drainage tube is implanted a few weeks later [8].

Other complications of using drainage devices in children include abnormalities related to the contact of the implant with ocular structures, such as corneal decompensation (a complication often seen in children because of their highly elastic cornea and sclera), cataract, chronic iritis, and migration of the drainage device, which may occur both within and beyond the anterior chamber [8, 59]. Most of these complications do not occur after drainage device implantation into the posterior chamber. There have also been reports of drainage device obstruction by the vitreous/hemorrhage/fibrin, as well as erosion of the artificial fistula, potentially leading to endophthalmitis. In addition, displaced device components may look unesthetic and result in impaired ocular motility [8].

A major problem involved in drainage device implantation in children is device malalignment and the ensuing complications (11% to 32% of cases) [60, 61]. Obstruction by iris tissue, inflammatory membrane or the vitreous has been reported in 3-13% of cases [60]. Possible causes of such complications include children's eye growth with the enlargement of the globe, resulting in a change in the length and position of the drainage tube, and vigorous rubbing of the eye (device displacement leading to touching the cornea). The incidence of such complications can be reduced by appropriate planning of the procedure, proper implant placement, long-term follow-up of patients, and active contact and counseling of children's caregivers [62, 63]. It the pediatric population, it is important to take into account patients' eye growth, and consequently use a longer drainage device. In such cases, an increased risk

Tabela I. Using of Molteno type glaucoma drainage devices in the treatment of childhood glaucoma [20]

Authors	Study	Molteno implant type	Mean follow-up time (months)	Glaucoma type	Mean age at surgery	Number of eyes	Mean preoperative IOP	Mean postoperative IOP	Success criteria	Success rate
Molteno *et al*. [27]	R	SP	66	Advanced juvenile glaucoma (PCG, GFCS, aniridia, SWS, post-uveitis, post-traumatic, Marfan syndrome, NVG) (≤ 24 y/o)	30-288 months	83	NA	NA	IOP < 21 mmHg with or without medications	83% (61 eyes without medications, 18 eyes with antiglaucoma medications)
Munoz *et al*. [28]	R	SP	18	PCG, aniridia, Peters anomaly (< 12 y/o)	34.04 ±34.42 months	53	In successfully treated eyes (36 out of 53); 30.7 ±5.7	In successfully treated eyes (36 out of 53); 16.3 ±5.3 over 24 months	IOP ≤ 21 mmHg	68%
Hill *et al*. [29]	R	SP + DP	22.7	Other than neovascular childhood glaucoma (< 21 y/o)	109.2 ±78 months	70	NA	NA	5 < IOP < 22 mmHg	62%
Lloyd *et al*. [30]	R	SP	49.1 ±25.3	PCG, GFCS, aniridia, Rieger's anomaly, congenital rubella syndrome, JIA-related glaucoma in children (< 13 y/o)	81.5 ±52.3 months	16	NA	NA	5 < IOP < 21 mmHg without the need for further glaucoma surgeries or serious postoperative complications	44%
Billson *et al*. [31]	R	DP	41.3	PCG, GFCS, aniridia, secondary angle-closure glaucoma (≤ 4 y/o)	6-48 months	23	NA	NA	IOP < 21 mmHg with antiglaucoma medications	78%
Nesher *et al*. [32]	R	SP+DP	20	PCG, SWS, aniridia, GFCS, congenital rubella syndrome, Peters anomaly (≤ 13 y/o)	47 ±55 months	27	34 ±4	19 ±6	IOP < 21 mmHg with or without antiglaucoma medications	57%
Cunliffe *et al*. [33]	R	DP	134.4	PCG, post-uveitis, SWS, GFCS, microphthalmia, aniridia	6-24 years	34	NA	NA	IOP < 22 mmHg with or without antiglaucoma medications	85%

PCG – primary congenital glaucoma; SWS – Sturge-Weber syndrome; GFCS – glaucoma following congenital cataract surgery; NVG – neovascular glaucoma; JIA – juvenile idiopathic arthritis; CACG – chronic angle closure glaucoma; OAG – open angle glaucoma; PFV – persistent fetal vasculature; PK – penetrating keratoplasty; ASD – anterior segment dysgenesis; SP – single-plate; DP – dual-plate; NA – not available; IOP – intraocular pressure; R – retrospective

Tabela II. Using of Baerveldt type glaucoma drainage devices in the treatment of childhood glaucoma [20]

Authors	Study	Baerveldt implant size	Mean follow-up time	Glaucoma type	Mean age at surgery	Number of eyes	Mean preoperative IOP	Mean postoperative IOP	Success criteria	Success rate
Fellenbaum *et al*. [34]	R	200, 350, 500 mm^2	15 months	PCG, GFCS, ASD, SWS, post-uveitis, aniridia, post-traumatic, NVG, associated with RD and SOI (< 21 y/o)	79.2 ±76.8 months	30	35.5 ±13.1	13.5 ±4.2	6 < IOP ≤ 21 mmHg with or without antiglaucoma medications	93% in 6 months, 86% in a year
Donahue *et al*. [35]	R	350 mm^2 (except for one case of 200 mm^2)	19 months	PCG, SWS, GFCS, Peters anomaly, juvenile glaucoma	8–182 months	20	33,6	15.5 mmHg in 8 eyes with complete postoperative success, 16 mmHg in 6 eyes with partial success	IOP ≤ 21 mmHg with or without antiglaucoma medications	61%
Budenz *et al*. [36]	R	NA	23.4 ±21.7 months	GFCS, SWS, post-traumatic, aniridia, Rieger's anomaly, JIA-related glaucoma, Peters anomaly, congenital rubella syndrome, associated with Lowe syndrome, associated with coloboma (< 18 y/o)	78 ±67.2 months	62	35 ±8.7	17.6 ±8.4	6 < IOP ≤ 21 mmHg with or without antiglaucoma medications	85% in 6 months, 67% in 24 months, 60% in 28 months
Rolim de Mura *et al*. [37]	R	NA (depending on operator preferences)	21 months (median)	PCG, aniridia, SWS, GFCS, post-traumatic, ACG, inflammatory glaucoma, mixed mechanism	49.2 ±58,8 months	48	31.2 ±25.7	16.4 ±4.9	IOP ≤ 21 mmHg with or without antiglaucoma medications	90% in 12 months, 58% in 48 months
Van Ovrdam *et al*. [38]	R	350 mm^2	32 months	PCG, aniridia, GFCS, PFV, SWS, post-traumatic, post-uveitis (< 16 y/o)	39.6 ±43,2 months	55	27.2	15.5	IOP < 22 mmHg with or without antiglaucoma medications on the last two follow-up measurements or IOP reduced by at least 20% with or without antiglaucoma medications compared to baseline in eyes with preoperative IOP < 22 mmHg	94% in 12 and 24 months

Tabela II. Cont.

Authors	Study	Baerveldt implant size	Mean follow-up time	Glaucoma type	Mean age at surgery	Number of eyes	Mean preoperative IOP	Mean postoperative IOP	Success criteria	Success rate
El Gendy *et al.* [39]	R	BGI 101–350	46 ±29 months	PCG, GFCS, aniridia, post-steroid, NVG, CHED (< 18 y/o)	67,2 months	20	33.8 ±5.7	19.6	8 < IOP < 24 mmHg (with or without antiglaucoma medications), without the need for another glaucoma surgery after valve implantation and without significant postoperative complications	80%
Tai *et al.* [40]	R	NA	NA	PCG, aniridia, SWS, GFCS, Rieger's syndrome, post-steroid, post-uveitis, associated with iris coloboma (5-19 y/o)	5-19 years	45	31.6 ±5	18.3 ±4.8	24-30 months	IOP ≤ 21 mmHg without the need for another glaucoma surgery or severe postoperative complications
Vinod *et al.* [41]	R	*Pars-plana* BGI	Complications 6.5 ±3.4 years	86.7% in 24-30 months, PCG, GFCS, post-uveitis, Rieger's syndrome (< 16 y/o)	6 ±4.7 years	37	30.8 ±8.1	13.8 ±4.1 (after successful surgery)	5 < IOP < 21 mmHg with or without antiglaucoma medications	94.5% in 12 months
Banitt *et al.* [42]	R	*Pars-plana* BGI (250 mm^2 in 5 patients, 350 mm^2 in 21 patients, 425 mm^2 in 4 patients)	29.8 ±26.4 months	PCG, GFCS, aniridia, PFV, post-traumatic, post-uveitis (< 18 y/o)	6.9 ±5 years	30	32.9 ±7.9	15.2 ±5 (after successful surgery)	5 ≤ IOP ≤ 21 mmHg with or without antiglaucoma medications, without the need for another glaucoma surgery, and without losing the sense of light	72% in 36 months

PCG – primary congenital glaucoma; SWS – Sturge-Weber syndrome; GFCS – glaucoma following congenital cataract surgery; NVG – neovascular glaucoma; JIA – juvenile idiopathic arthritis; CACG – chronic angle closure glaucoma; OAG – open angle glaucoma; PFV – persistent fetal vasculature; PK – penetrating keratoplasty; ASD – anterior segment dysgenesis; RD – retinal detachment; SOI – silicone oil implantation; CHED – congenital endothelial corneal dystrophy; NA – not available; IOP – intraocular pressure; R – retrospective

Tabela III. Using of Ahmed type glaucoma drainage devices in the treatment of childhood glaucoma [20]

Authors	Study	Mean follow-up time	Glaucoma type	Mean age at surgery	Number of eyes	Mean preoperative IOP	Mean postoperative IOP	Success criteria	Success rate
Coleman *et al.* [43]	P	16.3 ±11.2 months	(PCG, SWS, post-traumatic, associated with congenital rubella syndrome, post-uveitis, associated with osteogenesis imperfecta, Peters' anomaly) < 18 y/o	4.8 years	24	30.7	15.6 ±4.9 during months 7-12	- IOP < 22 mmHg - without the need for further glaucoma surgeries and risk of vision loss	77.9 ±8.8% in 6 months, 60.6 ±13.7% in 12 months
Englert *et al.* [44]	R	12.6 ±8.2 months	(PCG, GFCS, SWS, NVG, post-uveitis, aniridia) < 18 y/o	4.8 years (0.3-16.8 years)	27	32.8 ±7.5	16.7 ±5.4 in 18 months	IOP < 22 mmHg without the need for further glaucoma surgeries and risk of vision loss	90.6% in 12 months, 58.3% in 24 months
Hamush *et al.* [45]	R	30.35 months	SWS	10 days – 25.5 years (over 10 years in only three patients)	11	27.7 ±4.6	18.5 ±4.4 at the last measurement	IOP < 21 mmHg without the need for additional anti-glaucoma surgeries, and risk of retinal detachment and displacement-causing choroidal hemorrhage	79% in 24 months, 59% in 42 months, 30% in 60 months
Djodeyre *et al.* [46]	R	12.6 ±10.8 months	(PCG, SWS, PFV, GFCS, post-uveitis, associated with PK) < 15 y/o	2.4 years (0-14.8 years)	35	28.8 ±4.5	18.1 ±2.4 in 18 months	- complete success: IOP < 22 mmHg without further glaucoma surgeries and vision loss - partial success: glaucoma medications or implant revision needed	70.1 ±8.5% in 12 months, 63.7 ±9.9% in 24 months
Kafkala *et al.* [47]	R	36.8 months	Post-uveitis	11 years (9-13 years)	7	37 ±8	12.1 ±4 at the last measurement	4 mmHg < IOP < 22 mmHg with or without glaucoma medications	IOP reduction ratio – 69.9%
Balekudaro *et al.* [48]	R	37.8 ±32.1 months	(PCG, JOAG, post-traumatic, post-uveitis, SOAG, SOI) < 18 y/o	82.07 ±58.31 months	71	35.86 ±9.57	16.38 ±8.7 at the last measurement	6 mmHg < IOP < 22 mmHg without (complete) or with (partial) glaucoma medications	97% in 12 months, 80% in 24 months
Razeghinejad *et al.* [49]	R	32.6 ±18.3 months	PCG	2.7 ±3.1 years	33	32.8 ±7.3	16.8 ±4.0 at the last measurement	IOP 6-21 mmHg with not more than three glaucoma medications	97±3% in year 1, 85±7% in year 2, 56±4.8% in year 5

Tabela III. *Cont.*

Authors	Study	Mean follow-up time	Glaucoma type	Mean age at surgery	Number of eyes	Mean preoperative IOP	Mean postoperative IOP	Success criteria	Success rate
Chen *et al.* [50]	R	6.1 ±3.3 years	(PCG, post-uveitis, secondary glaucoma) < 18 y/o	6.8 ±5.7 years	119	29.2 ±9.7	15.2 ±3.5 in year 10	5 mmHg < IOP < 21 mmHg with or without glaucoma medications	55% in 5 years
Dave *et al.* [51]	R	17.9 ±9.3 months	PCG after previous unsuccessful trabeculotomy-trabeculectomy	15.4 ±4.9 months	11	28 ±5.7	13.6 ±3.4 at the last measurement	5 mmHg < IOP ≤ 18 mmHg without (complete) or with (partial) glaucoma medications and without serious postoperative complications and additional glaucoma surgery	10 out of 11 eyes achieved partial success within a year
Eksioglu *et al.* [52]	R	64.46±33.56 months	Associated with uveitis	14.19±3.25 years	16	33.5±7.3	12.69±3.20	5 mmHg < IOP ≤ 21 mmHg without (complete) or with (partial) glaucoma medications and without serious postoperative complications and additional glaucoma surgery	68.8% in 6 months, 56.3% in 12 months, 49.2% in 36 months, 35.2% in 84 months
Parkavan *et al.* [53]	R	51 ±33 months in PCG patients and 49 ±41 months in GFCS patients	PCG, GFCS	94.7 ±77.8 months	95	PCG: 33.1 ±8.6 GFCS: 28.9 ±6.1	PCG: 18.5 ±6.4 GFCS: 16.0 ±5.9 in year 3	IOP ≤ 21 mmHg and decrease by ≥ 20% without the need for another glaucoma surgery	90% in both groups in year 1, 52.5% in the PCG group and 71.5% in the GFCS group at 5 years
Morad *et al.* [54]	R	24.3 ±16 months	PCG, GFCS, ASD, SWS, associated with uveitis, aniridia, juvenile)	6 ±4.9 y/o (1.5 months – 16 years)	66	32.8 ±6.2	16.6 ±8.0 at the last measurement	5 < IOP < 22 mmHg with or without glaucoma medications	93% in a year
Speiss and Calvo [55]	R	85.41 ±56.24 months	GFCS associated or non-associated with PFV	91 ±48.3 months	29	32.66 ±6.73	16.5 ±2.75	IOP ≤ 21 mmHg with or without glaucoma medications and without serious postoperative complications	37.5% in patients with PEV-associated glaucoma, 88.2% in patients with non-PEV-associated glaucoma during 12 months

PCG – primary congenital glaucoma; SWS – Sturge-Weber syndrome; GFCS – glaucoma following congenital cataract surgery; NVG – neovascular glaucoma; CACG – chronic angle closure glaucoma; OAG – open angle glaucoma; PFV – persistent fetal vasculature; PK – penetrating keratoplasty; ASD – anterior segment dysgenesis; SOI – silicone oil implantation; JOAG – juvenile open angle glaucoma; IOP – intraocular pressure; R – retrospective; P – prospective

of complications arising from contact between the drainage device and the cornea (and thus corneal edema and decompensation) must be considered. The complication can be prevented by leaving a 2 mm section of the drainage tube in the anterior chamber, and placing it parallel to the limbus and at an appropriate distance from the posterior corneal surface [64]. In aphakic eyes, anterior vitrectomy is recommended to prevent the vitreous from clogging the drainage device. Oblique opening at the exit of the external drainage tube, as well as appropriate length of the tube and its proper positioning, make it possible to avoid obstruction by the protruding iris [60].

Glaucoma drainage devices consist of a tube draining the aqueous humor from the anterior/posterior/vitreous chamber to the surface of a plate attached to the sclera. One of the main reasons for implantation failure is fibrosis developing around the device plate [8, 59, 65]. Anti-scarring agents have not found application in drainage device surgery in adult patients, while the results published for pediatric patients are inconclusive [8].

Some surgeons prefer the use of drainage devices as the primary surgical procedure in aphakic or pseudophakic children with uveitis, in children with glaucoma developing as a complication of cataract surgery, and in children who are expected to undergo cataract surgery in the near future [1]. Primary drainage device implantation surgery may also be considered in children diagnosed with choroidal hemangiomas secondary to Sturge-Weber syndrome, as the technique is associated with a lesser risk of postoperative hypotony than trabeculectomy, after which early IOP values may be difficult to predict [8]. An additional indication is severe disease course, especially in primary congenital glaucoma which is associated with high treatment failure rates even in patients undergoing trabeculectomy with mitomycin C [8].

Where the IOP level cannot be normalized after drainage device surgery, the simplest solution, associated with the least risk, is the introduction of topical pharmacotherapy [66, 86]. Other options include needling or surgical revision to manage the bleb, however, published studies show that the outcomes of these procedures are inferior to additional implantation of a drainage device, which increases the incidence of corneal complications. In such situations, surgery in a different quadrant of the eye should be considered [8, 67]. However, satisfactory IOP control after needling and surgical revision is frequently short-lived [8, 67, 68]. Studies show that between 9% and 50% of pediatric patients with an implanted drainage device require another surgical intervention to control intraocular pressure or manage surgery-associated complications during the follow-up period [20].

Primary congenital glaucoma

Primary congenital glaucoma (PCG) is a rare disease that affects 4.8/100,000 live births [24]. The disease is caused by anomalous development of the filtration angle and the trabecular meshwork, which causes physical blockage of the outflow of aqueous humor in the filtration angle [24]. The appearance of classic PCG symptoms can be explained by an increased IOP level leading to corneal edema with associated Descemet's membrane tears (Haab's striae), increased corneal diameter, impaired fixation, and the onset of nystagmus secondary to compromised visual acuity. The gold standard of management in PCG is surgical treatment [24, 69]. Pharmacotherapy is routinely used to lower the IOP in the pre-surgery period. The most widely used procedures include goniotomy and trabeculectomy [70-72]. The efficacy of IOP reduction associated with surgical treatment varies from country to country, ranging from 19.4% to 91% [73, 74].

The success rates for the implantation of glaucoma drainage devices in cases of primary congenital glaucoma is reported to be between 31% and 97% [75, 76]. The results of these studies are difficult to compare because they apply to different patient populations and types of glaucoma, various surgical techniques, drainage devices, and follow-up periods. Whether Ahmed valve implantation is associated with a higher success rate in patients with PCG compared to other types of glaucoma in children remains controversial. Djodeyre *et al.* reported that the period of therapeutic efficacy of Ahmed glaucoma valves implanted in 17 eyes with PCG was shorter compared to 18 eyes with other glaucoma diagnoses [77]. Similarly, Chen *et al.* in their study found that the PCG group had a lower success rate (24.4%) compared to other diagnoses (72% for glaucoma with uveitis and 52.1% in cases of other secondary glaucoma). Morad *et al.* and O'Malley *et al.* have not identified any correlation between glaucoma type and surgical failure [77].

In a study by Pakravan *et al.*, the success rate of Ahmed valve implantation in refractory PCG was 82.1% at one year, subsequently decreasing to 55.1% at the follow-up visit five years after the procedure [77]. Approximately 12% of PCG patients required a second implant, and the cumulative success rate was 20% at 30 months of follow-up [77]. Contrary to promising reports of second implant placement in adult patients, there are few available studies evaluating this type of treatment in children with PCG. The most common complications noted in that study were abnormalities associated with drainage device migration. They were more common in PCG patients than in aphakic individuals. Approximately 13% of patients required surgery to reposition the drainage system [77]. This relatively high complication rate is comparable to reports from previous studies. Most likely, the device is positioned properly during surgery, but as the IOP decreases, it migrates, necessitating another surgical intervention. Furthermore, the same researchers have not observed the migration of glaucoma drainage devices among aphakic children [77]. The ocular volume is known to increase during the first two years of life, and high intraocular pressure further stretches the eye in all planes, resulting in scleral thinning. During the postoperative period of significant decrease in IOP, the ocular volume decreases and the drainage device migrates forward. This does not apply to glaucoma in aphakic patients, as the dimensions of the eye remain less enlarged and thus the eye is more resistant to IOP fluctuations [77]. The migration of the drainage device towards the endothelium can also be caused by vigorous rubbing

of the eyes as well as normal ocular development and changes in the filtration angle. Based on the above findings, Pakravan *et al*. recommend that the device is placed 1 mm posterior to the corneal limbus and closer to the iris [77].

Post-cataract surgery glaucoma

Esfandiari *et al*. evaluated long-term safety and efficacy of surgical procedures using Ahmed and Baerveldt implants in the treatment of childhood glaucoma after cataract surgery in 28 eyes in 28 patients (16 eyes were implanted with Ahmed glaucoma valves, and 12 with Baerveldt implants). The reported incidence of glaucoma developing after congenital cataract surgery varies from 15% to 45% [79, 80]. The risk factors include small corneal diameter, young age at surgery and the presence of nuclear cataract. The pathophysiological mechanism underlying glaucoma development in these children remains in most cases unclear [81]. The researchers determined the mean time interval to glaucoma diagnosis to be 3.6 ±1.5 years. The mean age at implantation surgery was 4.1 ±1.0 years (4.4 ±2.1 years for the Ahmed glaucoma valve and 4.1 ±1.5 years for the Baerveldt implant) [79].

The mean time from the implantation of the drainage device to the loss of its efficacy was 41.9 ±2.1 months: 42.8 ±2.7 months for Ahmed glaucoma valve and 41.2 ±3.1 months for Baerveldt glaucoma implant (Kaplan-Meier curve) [79]. Three eyes (17.6%) required second valve implantation to control intraocular pressure [79]. A review of the literature covering a period of up to 2020 identified a small number of studies evaluating long-term outcomes of valve reimplantation in the population of children with glaucoma secondary to congenital cataract surgery [79].

In view of unsuccessful outcomes and the development of post-trabeculectomy complications (related primarily to the presence of the filtration bleb and associated complications, mostly due to the overgrowth of the bleb), drainage valves are increasingly implanted in aphakic children with glaucoma [77, 78]. The success rate for glaucoma drainage devices is 87% ±5.0% versus 36% ±8.0% for trabeculectomy at one-year follow-up. After six years, the difference increased to 53%, compared to 19% (post-trabeculectomy) [77]. In a randomized clinical trial comparing Ahmed valve implantation with mitomycin C-enhanced trabeculectomy in glaucoma associated with aphakia, the success rate was 66.7% in the Ahmed valve implantation group, compared to 40% in the trabeculectomy group [77].

MINIMALLY INVASIVE GLAUCOMA PROCEDURES

Recent years have seen the development of new techniques in glaucoma treatment which are increasingly used in pediatric patients. The techniques include minimally invasive glaucoma surgery (MIGS) procedures done via the ab interno approach. MIGS does not require conjunctival incision, which reduces the risk of scarring and, consequently, secondary surgical failure [80]. The procedure involves making an incision in the clear cornea, which protects the conjunctiva from damage and allows future corneal surgeries to be performed. It also facilitates the visualization of anatomical landmarks, and thus correct positioning of the implant. The small incision increases the safety of the operation, preserves the anatomical structure of the eye, and minimizes the risk of postoperative refractive errors. Significant advantages of MIGS include fast patient recovery, and short duration and ease of the procedure. The procedures can be divided into three categories based on anatomical characteristics: procedures increasing the outflow of aqueous humor from the eye by the conventional route via Schlemm's canal (i-Stent, Hydrus, Trabectome); procedures performed within the suprachoroidal space to improve the uveoscleral outflow of aqueous humor (iStent Supra, Cy Pass); and procedures that create an alternative route for the outflow of aqueous humor into the subconjunctival space (XEN Gel Stent) [81]. They demonstrate an exceptionally favorable safety profile but their efficacy is often inferior to traditional surgical glaucoma treatments (trabeculectomy with mitomycin C, drainage devices) [80]. The effects of minimally invasive glaucoma procedures in the pediatric population have not, as yet, been fully characterized in the available literature reports.

Smith *et al*. reported a series of three eyes in three children with congenital glaucoma who were implanted XEN Gel Stents. In two children, the stent was implanted following unsuccessful trabeculotomy, and in one case, primary gel stent implantation was performed [82]. One eye received two implants. Three procedures were performed using the ab interno technique, and the fourth one with the ab externo technique [82]. No complications related to the drainage device were observed in any of the cases. The IOP was controlled without topical pharmacotherapy for a period from 6 to 24 months. In three out of four procedures, pre- or intraoperative subconjunctival injection of mitomycin C was administered. In the fourth procedure (second stent in the eye), the eye was exposed to mitomycin C during the first operation, but during the second it was not applied [82]. The researchers highlighted that the routine use of mitomycin C during procedures done in children is controversial, and may lead to complications related to filtration bleb formation. The technique of XEN Gel Stent implantation in children is the same as in adult patients. The device should preferably be placed in the subconjunctival space, so the ab externo approach seems to be a more attractive option. An important factor that needs considering is increased scleral elasticity in pediatric patients [82]. On the first day post-implantation, two younger children (four and seven months old) had low IOP values and a large, raised bleb with slightly shallowed anterior chamber. During the first week of follow-up, the size of both blebs decreased and the intraocular pressure increased. Topical pharmacotherapy was then started for a few weeks. The observation may suggest that there is an additional outflow route, which is interrupted during subsequent weeks following the stabilization of the filtration bleb [82]. Oluwatosin *et al*. argue that XEN stent implantation in children is not associated with an increased risk compared to the group of adult patients [82]. None of the patients in the study required needling, which may be due to the fact that their conjunctiva was in a good condition, and had not been exposed to long-term topical antiglaucoma drug therapy.

The procedure of XEN gel stent implantation proved safe, and successfully lowered IOP values in three cases of pediatric glaucoma. XEN gel stents can be used as an adjunct or alternative to traditional angle surgery [82].

Techniques such as Trabectome, i-Stent, and Hydrus implants provide new treatment options in adult patients with mild to moderate glaucoma [11, 83]. They are considered safer, and show fewer complications and faster recovery times than invasive methods (including trabeculectomy) [19, 84]. However, they may not be an appropriate treatment modality for childhood glaucoma, as many young patients have moderate to advanced glaucoma with uncontrolled IOP values and corneal opacities, which preclude surgery [19]. Also, potential developmental anomalies in the aqueous humor outflow pathway rule out the MIGS option. The techniques might prove to be a potentially effective therapeutic option for children with mild glaucoma or minor angle abnormalities [85]. MIGS has the advantage of preserving the conjunctiva for any future glaucoma surgeries, which are likely to be performed later in the patients' lives [19, 85].

CONCLUSIONS

Surgical treatment of childhood glaucoma is extremely challenging because of the risk of therapeutic failure and potential complications. In recent years, a number of treatment options have been introduced and modified. Approaches to the treatment of childhood glaucoma vary around the world. Even though new procedures have a better safety profile, they are frequently inferior in efficacy to invasive glaucoma surgeries such as trabeculectomy with mitomycin C which consistently remains the gold standard for patient management.

Following glaucoma surgery, intraocular pressure is often seen to increase over time, which is also accompanied by an elevated risk of postoperative complications. This is particularly important in children who are expected to have a long life after undergoing the surgical procedure. It must also be noted that pediatric patients may require multiple surgeries throughout their lifetime. Consequently, it is critical to leave the conjunctiva intact for as long as possible to facilitate subsequent procedures that may be needed.

A limitation of the cited study outcomes is the small number of patients included in the analysis. In many cases, valve implantation or MIGS may prove to be an effective alternative to classic glaucoma surgeries. The application of advanced surgical techniques in the pediatric population carries multiple complications. To prevent them, long-term follow-up and proper ophthalmic consultations must be provided to the child's caregivers. However, it should be expected that additional pharmacological or surgical treatment will be necessary in pediatric patients because of the lifetime need for glaucoma treatment and monitoring.

Currently, there is no sufficiently large pool of studies for analysis – and high-quality evidence – that would support minimally invasive glaucoma surgery as a treatment modality for childhood glaucoma. However, a number of advanced glaucoma therapies may offer advantages over traditional surgical approaches.

DISCLOSURE

The authors declare no conflict of interest.

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