Strabismus surgery in the setting of glaucoma drainage devices in the pediatric population

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PURPOSE To evaluate outcomes of strabismus surgery performed subequent to or concomitant with glaucoma drainage device (GDD) implantation for refractory childhood glaucoma.

METHODS The medical records of children who underwent strabismus surgery after or concomitantly with GDD implantation were reviewed retrospectively. Included were surgeries with motility and alignment data measured preoperatively and ≥3 months postoperatively. The following data were collected: demographics, visual acuity, glaucoma diagnosis, GDD type/location, pre- and postoperative sensorimotor/alignment measurements, and surgical details. Motor success was defined as $\leq 10^{\Delta}$ horizontal and $\leq 4^{\Delta}$ vertical residual heterotropia postoperatively.

RESULTS A total of 25 children were included: 11 in the post-GDD group and 14 in the concomitant-GDD group. In the former, peri-GDD capsule dissection was required in 9 of 11 patients (82%). All cases had preoperative motility restriction or intraoperative scarring. Mean preoperative deviation ($26.7^{\Delta} \pm 14.6^{\Delta}$) decreased by 41% postoperatively, with improved alignment in 7 patients (64%). No patients met strict motor alignment criteria for success. In the concomitant-GDD group, mean preoperative deviation ($28.5^{\Delta} \pm 10.0^{\Delta}$) decreased by 39% postoperatively, with improved alignment in 11 of 14 patients (79%). Four patients (29%) met strict criteria for success. There were no surgical complications in either group.

CONCLUSIONS Strabismus surgery in eyes with existing or planned GDDs for childhood glaucoma usually improves alignment but often does not result in success based on strict motor alignment criteria. Eyes with childhood glaucoma pose surgical technical challenges related to small orbits and exuberant GDD capsule–muscle scarring and postoperative challenges of poor vision and limited binocular function, that likely limit succcess. (J AAPOS 2019;23: 83.e1-8)

Strabismus and diplopia occur following glaucoma drainage device (GDD) implantation in adults, with reported rates from 1.4% to 77%.[1-6] Proposed mechanisms for the strabismus include surgical trauma to the extraocular muscles, muscle stretching by the bleb, fibrous capsule formation and expansion, fat adherence, and scarring of the extraocular muscles to the GDD, capsule, or sclera.[1,3,7,8] The resultant strabismus is usually incomitant, and suggested interventions have included aggressive dissection of the GDD capsule–muscle attachments with GDD plate modification or removal,[9] as well as capsule- and GDD-sparing procedures.[10] Reported success has been modest by strict criteria, with improvement in the majority of cases.[9,10] Less has been reported regarding the effect of GDDs on ocular motility in children.[11,12] One such study found motility restriction in 37% and strabismus in 40.3% of children following GDD implantation.[13]

Strabismus surgery in children with GDDs poses several challenges. First, the strabismus is often multifactorial with both restrictive and sensory components. The former frequently produces an incomitant strabismus, and the latter may reduce likelihood of postoperative fusion and stable long-term alignment.[14] Intraoperatively, significant scarring of the conjunctiva, extraocular muscles, GDD plate, and its surrounding capsule increases the difficulty of freeing and optimally positioning the extraocular muscle(s).[9,10] Further, children with refractory glaucoma frequently have strabismus even before GDD surgery.[13] We are not aware of any published data on the topic of

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strabismus management in the setting of prior or concurrent GDDs in refractory childhood glaucoma. The purpose of this study was to evaluate techniques and outcomes of strabismus surgery performed either subsequent to or concomitant with GDD implantation for refractory childhood glaucoma.

Subjects and Methods

Our study was approved by the Duke University Health System Institutional Review Board and complied with the US Health Insurance Portability and Accountability Act of 1996. The medical records of consecutive patients who underwent strabismus surgery subsequent to GDD placement (post-GDD group) or concomitant with GDD placement (concomitant-GDD group) for refractory childhood glaucoma from December 2005 to June 2016 under a single attending surgeon (SFF) were reviewed retrospectively.

Data collected included age at strabismus surgery, sex, glaucoma diagnosis, visual acuity, and history of prior strabismus surgery. Operative notes were reviewed for procedure type, intraoperative findings, technique, and complications. GDD implant type, size, and quadrant were recorded. Extraocular motility and alignment data were collected from a preoperative visit (≤12 months before surgery) and an early postoperative (3 to <6 months) and/or late postoperative (6-18 months) visit. Inclusion required motility data from preoperative, and an early and/or late postoperative visit.

Limitation in motility was recorded for each eye as present or absent in horizontal and vertical versions or ductions, and affected field(s) of gaze were noted. Alignment was recorded for near and distance measurements where present and standardly measured by alternate prism and cover testing, except where precluded by lack of fixation or cooperation. For those subjects, measurements were by Krimsky or Hirschberg estimation, based on cooperation. Alignment was categorized by horizontal (esotropia, exotropia) and vertical (hypertropia) deviations. Dissociated vertical deviations (DVDs) were considered vertical tropias if recorded consistently at different office visits. Phorias were not considered strabismus. Stereopsis and fusion (by Titmus testing and Worth four-dot, resp.) were recorded when documented. Visual acuity was measured by Snellen, HOTV, or Allen pictures in verbal children, and by fix-and-follow, Teller preferential looking testing, or central-steady-maintained in preverbal children.

Pre- and postoperative alignment measurements were compared to determine change in deviation and percentage of subjects demonstrating improvement. For subjects with both horizontal and vertical deviations, the deviation addressed by the surgery was analyzed. For instance, for surgery on horizontal rectus muscles, pre- versus postoperative horizontal deviations were compared. For subjects with measurements from both early and late postoperative periods, measurements from the late postoperative visit were chosen to best represent long-term outcomes. Motor success was evaluated using previously defined criteria of $\leq 10^{\Delta}$ horizontal[15] and $\leq 4^{\Delta}$ vertical residual heterotropia postoperatively.[16]

For patients with overcorrection (preoperative exotropia with postoperative esotropia or vice versa), the absolute value of the prism diopter deviation pre- and postoperatively was used for analysis.

Subjects were also excluded if they were ≥18 years of age at surgery or if clinical records lacked the data described above. Statistical analysis was performed using JMP Pro 13 (SAS, Cary, NC).

Surgical Techniques

Forced duction testing was routinely performed prior to surgery. When surgery was subsequent to GDD placement (Figure 1), a conjunctival fornix incision and meticulous dissection of Tenon's capsule and the rectus muscle adjacent to the GDD capsule allowed the muscle to be isolated without capsule rupture. Additional surgical recommendations for strabismus surgery following GDD placement are provided in Appendix A. When strabismus surgery was concomitant with GDD placement (Video 1), hang-back recession of the rectus muscle (usually the lateral rectus muscle) was performed by isolating and securing the muscle, placing and securing the GDD plate to sclera, then detaching and hanging the rectus muscle by scleral bites through the original insertion. GDD plate trimming was performed using scissors to remove the anterior or posterior aspect of the Baerveldt GDD plate wing to allow the recessed muscle direct scleral contact behind the plate. Additional surgical recommendations for strabismus surgery concomitant with GDD placement are provided in Appendix B.

Results

A total of 25 subjects met inclusion criteria: 11 in the post-GDD group and 14 in the concomitant-GDD group; mean age at strabismus surgery was 9.1 years (range, 1-17). The most common diagnoses were glaucoma following cataract surgery (10 [25%]) and primary congenital glaucoma (6 [24%]). Strabismus was horizontal only in 16 subjects (64%), vertical only in 1 (4%), and both horizontal and vertical in 8 (32%). Thirteen subjects (52%) had restrictive strabismus (positive forced ductions).

Descriptive statistics of both study groups may be found in Table 1. Of 23 subjects able to participate in optotype visual acuity testing, only 2 (9%) had visual acuity of 20/40 or better in both eyes. Only 1 subject (4%) had preoperative diplopia (subject 9 in Table 2, an expanded version of which is available as eSupplement 1 at jaapos.org), with sensory exotropia following blunt trauma requiring cataract removal, vitrectomy and Ahmed GDD (final visual acuity, 20/50).

In the post-GDD group (Table 2 and eSupplement 1), strabismus diagnoses and surgeries performed were heterogeneous. Diagnoses included exotropia (5/11 [45%]), esotropia (3/11 [27%]), and multiple/other (3/11 [27%]), and the most common procedure was a horizontal rectus two-muscle (recession and resection) procedure (6/11 [55%]). Of these 11 subjects, there were 15 previously placed GDDs: 7 Ahmed FP7/S2 (New World Medical,

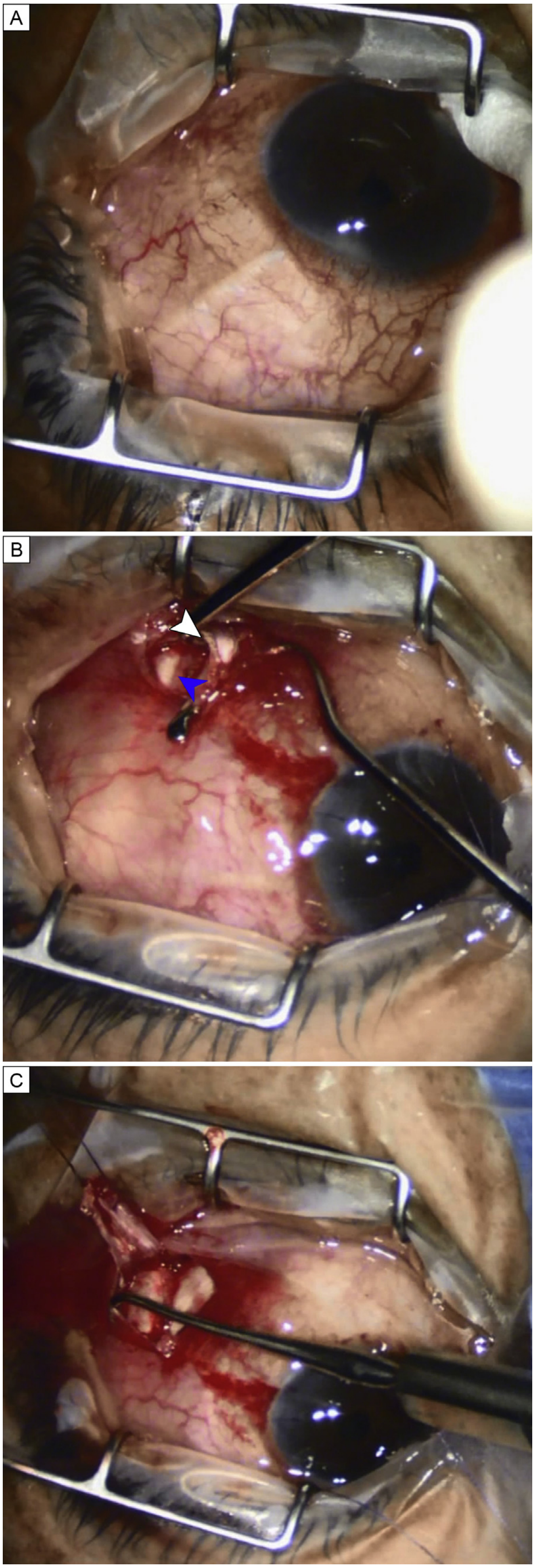

FIG 1. Right lateral rectus recession performed by hang-back in a representative exotropic patient with a previously placed superotemporal Baerveldt 350 mm^2. A, The superotemporal Baerveldt implant is visualized underneath the conjunctiva. B, Significant scarring of the lateral rectus muscle (white arrowhead) to the GDD capsule (blue arrowhead) required careful dissection in order to free the lateral rectus muscle and avoid perforating the GDD capsule. C, Lateral rectus was isolated and disinserted, revealing its close proximity to the GDD.

Rancho Cucamonga, CA), 7 Baerveldt 250 mm^2, and 1 Baerveldt 350 mm^2 (Johnson & Johnson Vision, Santa Ana, CA). Of the 2 subjects who had multiple GDDs, one (subject 1) had an Ahmed FP7 superotemporally in each eye, and the other (subject 7) had a Baerveldt 250 mm^2 superotemporally and inferotemporally in each eye.

The mean preoperative deviation of $26.7^\Delta \pm 14.6^\Delta$ decreased by a mean of 40.8% postoperatively, with improved alignment in 7 of 11 subjects (64%). No patients met strict criteria of $\leq 10^\Delta$ horizontal and $\leq 4^\Delta$ vertical residual heterotropia postoperatively. For subjects with preoperative strabismus that was both horizontal and vertical, statistical analysis was performed only on the deviation that was addressed surgically. After surgery, only 2 of 11 subjects were orthophoric, and 9 had residual deviations (with 4/11 unchanged). There was no clear relationship between GDD model or size and the type or magnitude of strabismus.

In the concomitant-GDD group (n = 14 subjects; Table 3 and eSupplement 2, available at jaapos.org), the most common surgery was unilateral lateral rectus recession for exotropia (12/14 [85.7%]). GDDs implanted were Baerveldt 250 mm^2 (5/14, 36%), Baerveldt 350 mm^2 (3/14 [21%]), and Ahmed FP7 (6/14 [43%]). All were placed superotemporally except 1 Baerveldt 250 mm^2 that was placed inferotemporally (subject 10) and 1 Ahmed FP7 placed inferonasally (subject 8). Both of these subjects had previously placed Baerveldt implants superotemporally. Preoperative restriction and intraoperative scarring were each noted in 2 of 14 subjects (14%).

The mean preoperative deviation of $28.5^\Delta \pm 10.0^\Delta$ and decreased by a mean of 38.9% postoperatively, with improved alignment in 11 (79%). Four subjects (29%) met strict alignment criteria for success. When analyzing the deviation that was surgically addressed (ie, only horizontal or only vertical), 4 subjects were orthophoric, 2 had consecutive horizontal deviation, and 8 had residual deviations (with 3/14 worsened). There was no clear relationship between GDD model or size and the type or magnitude of strabismus.

Hang-back recession of the lateral rectus muscle was performed in 12 of 14 subjects (86%) in the concomitant-GDD group, all of whom received a superior temporal GDD (Video 1); the Baerveldt wing was trimmed in 4 of 14 (29%).

Three patients (6 and 10 in the post-GDD group and 2 in the concomitant-GDD group) lacked quantification of their hypertropia or DVD and were included in descriptive

Table 1. Descriptive statistics of the post-GDD and concomitant-GDD groups

Group	No. subjects	Age, years, mean ± SD	Sex, no. (% male)	Preoperative restriction, no. (%)	Intraoperative scarring, no. (%)	Mean preoperative deviation, PD, mean ± SD	Mean % reduction in deviation	Subjects with improvement, no. (%)
All	25	9.1 ± 4.6	14 (56)	13 (52)	11 (44)	27.8 ± 11.8	39.6	18 (72)
Post-GDD surgery	11	9.7 ± 4.6	6 (55)	11 (100)	9 (82)	26.7 ± 14.6	40.8	7 (64)
Concomitant-GDD surgery	14	8.6 ± 4.7	8 (57)	2 (14)	2 (14)	28.5 ± 10.0	38.9	11 (79)

PD, prism diopter; *SD*, standard deviation.

Table 2. Post-GDD group: clinical characteristics

Subject	Age, years	GDD and location	Strabismus surgery	Alignment, PD	
				Pre-op	Post-op
1	17	Ahmed FP7 ST OD, Ahmed FP7 ST OS	Bilat-MR re-rec (OD 10 mm, OS 11 mm posterior to limbus) with half-tendon-width transposition superiorly	ET 12, R-HT 4, A pattern	No horizontal, RHT 8
2	11	BVT 350 ST OS	L-MR rec 5 mm, L-LR res 6 mm	ET 30	No horizontal, RHT 10
3	10	Ahmed FP7 ST OD	R-LR rec 6 mm, R-MR res 5 mm	XT 30	XT 12
4	1	BVT 250 ST OS	L-MR rec 6 mm, L-LR res 6 mm	ET 60, RHT 15	ET 30, RHT 30
5	15	Ahmed S2 ST OD	R-LR rec 7 mm, R-MR res 5 mm	XT 35, RHT 6	XT 20
6	6	BVT 250 ST OS	Excised capsule and trimmed BVT wings under SR and LR	XT 20, RHT not quantified	XT 16, no vertical
7	7	BVT 250 ST + IT OU	L-MR rec 6 mm, L-IR res res 6 mm	ET 14, LHT 12	ET 12, LHT 14
8	13	Ahmed FP7 ST OS	L-MR res 5 mm, L-LR rec 7 mm	XT 20	XT 20, LHT 5
9	12	Ahmed FP7 ST OD	R-MR res 4 mm, R-LR rec 5 mm	XT 20	XT 20
10	9	Ahmed S2 ST OS	L-IO anteriorization	L DVD	L DVD
11	6	BVT 250 ST OD	R-LR rec 10 mm	XT 20	XT 20

BVT, Baerveldt; *DVD*, dissociated vertical deviation; *ET*, esotropia; *GDD*, glaucoma drainage device; *HT*, hypertropia; *IO*, inferior oblique muscle; *IR*, inferior rectus muscle; *IT*, inferotemporal; *LR*, lateral rectus muscle; *MR*, medial rectus muscle; *OD*, right eye; *OS*, left eye; *OU*, both eyes; *PD*, prism diopter; *Rec*, recession; *Res*, resection; *SR*, superior rectus muscle; *ST*, superotemporal; *XT*, exotropia.

statistics but not in calculations involving prism diopters. Improvement was based on clinical documentation and whether or not the corresponding deviation was seen postoperatively.

There were no surgical complications or unintentional violations of the GDD capsule in either group. One subject in the post-GDD group had intentional GDD capsule resection for restrictive strabismus attributed to the large bleb underneath the superior rectus muscle.

In an attempt to identify patients not included in our study who needed GDD capsule violation/manipulation to treat strabismus after GDD, we reviewed all surgical records of GDD patients during the study period. Two additional patients not meeting inclusion criteria (lacking motility quantification) were identified who had strabismus following GDD placement. In one case restrictive esotropia was resolved by removal of the pediatric Ahmed GDD and huge overlying capsule without muscle manipulation (and with concurrent endocyclophotocoagulation). In the second case of restrictive esotropia and ipsilateral hypotropia from a large capsule over a superotemporal Ahmed FP7, surgery entailed capsule resection without manipulation of the GDD or surrounding muscles, again resulting in marked improvement.

Discussion

Strabismus surgery in children requiring GDDs for refractory glaucoma improved alignment in approximately 70% of cases, whether performed subsequent to or concomitant with GDD placement, despite lower success in both groups by strict motor alignment criteria (none in the former and 29% in the latter). There were no surgical complications, and, despite scarring and restrictive strabismus in most cases with preexisting GDDs, there was no unintentional GDD capsule violation.

Outcomes of strabismus surgery in children and adults are often assessed using specific quantitative criteria for postoperative alignment. Studies of pediatric esotropia have required residual deviation of $\leq 6^{\Delta}$ or $\leq 10^{\Delta}$,[17,18] whereas studies of adult strabismus have used limits of $\leq 10^{\Delta}$ horizontal and $\leq 4^{\Delta}$ or $\leq 5^{\Delta}$ vertical residual heterotropia.[15,16,19] Others have proposed goals-based assessments[20] and quality of life evaluations[21] to more accurately reflect subjective improvements in cases deemed unsuccessful by traditional motor outcomes.

Few cases in our study met traditional motor-based criteria for success. This may be explained by challenges in children requiring GDDs, including limited vision and binocularity, multiple mechanisms for strabismus, and

Table 3. Concomitant-GDD group: clinical characteristics

Subject	Age, years	GDD placed (type, quadrant, eye)	Strabismus surgery	Alignment, PD	
				Pre-op	Post-op
1	8	Ahmed FP7 ST OD	R-LR rec 8 mm	XT 25	Ortho
2	14	Ahmed FP7 ST OS	L-LR adv from 15 mm to 7 mm from limbus; L-SR adv from 15 mm to 8 mm from limbus	ET 20, R-HT	No horizontal; R-HT 10
3	16	BVT 350 ST OD	R-LR rec 8 mm	XT 20	Ortho
4	12	Ahmed FP7 ST OD	R-LR rec 10 mm	XT 20	No horizontal; L-HT 4
5	3	BVT 250 ST OD	R-LR exploration, rec 6 mm	XT 30	ET 10
6	10	Ahmed FP7 ST OS	L-LR rec 9 mm	XT 30	ET 12
7	1	BVT 250 ST OD	R-LR rec 10 mm	XT 45, R-HT 8	XT 20, R-HT 25
8	10	Ahmed FP7 IN OS	L-MR rec 5.5 mm	ET 20	ET 12
9	6	BVT 250 ST OD	R-LR rec 9 mm	XT 20	X(T) 14, L-HT small
10	11	BVT 250 IT OD	R-LR rec 8 mm	XT 35, R-HT 10	XT 25, R-HT 10
11	5	BVT 350 ST OD	R-LR rec 6 mm	XT 16	XT 14
12	15	BVT 250 ST OD	Bilat-LR rec (right 12 mm, left 10 mm)	XT 45	XT 55
13	5	BVT 350 ST OD	R-LR rec 10 mm	XT 40	XT 50
14	5	Ahmed FP7 ST OS	L-LR rec 9 mm	XT 25	XT 35

Adv, advancement; *Bilat*, bilateral; *BVT*, Baerveldt; *ET*, esotropia; *GDD*, glaucoma drainage device; *HT*, hypertropia; *IN*, inferonasal; *IT*, inferotemporal; *LR*, lateral rectus muscle; *MR*, medial rectus muscle; *OD*, right eye; *OS*, left eye; *OU*, both eyes; *PD*, prism diopter; *PPV*, pars plana vitrectomy; *Rec*, recessed, recession; *Res*, resection; *SR*, superior rectus muscle; *ST*, superotemporal; *XT*, exotropia.

the presence of scarring and GDD plates and surrounding capsules. Diplopia was rare in this study (4%), and most subjects had poor vision in at least one eye. Although these sensory challenges likely diminished our likelihood of achieving traditionally defined surgical success, these traditional standards may have also been of less significance for our study population than for patients with good fusional potential and preoperative diplopia.[3,6,16]

In the concomitant-GDD group, most subjects had surgery on only the lateral rectus adjacent to the GDD being implanted. Although usual surgical dose tables would have recommended two-muscle surgery for the full correction of these patients' strabismus, only the lateral rectus was recessed concomitantly with GDD placement, with the goal of improving preexisting strabismus while obviating later lateral rectus surgery after superior temporal quadrant placement of the GDD. Thus, the ipsilateral medial rectus muscle was preserved, if needed, for future strabismus surgery, and the surgical dose for the remaining muscle could be adjusted based on the residual strabismus after GDD placement.

Outcomes of strabismus surgery in eyes with GDDs have not been extensively reported, and no studies have specifically investigated these outcomes in children. In their study of 9 adults, Roizen and colleagues[9] noted that the GDDs' fibrous capsules were trimmed and opened to free the extraocular muscles from any restriction: 2 subjects had the GDD itself trimmed and repositioned, and 1 GDD was removed and replaced with a smaller device in a different quadrant. Postoperative results included no uncontrolled intraocular pressure, and resolution of diplopia in 5 of 9 subjects.[9] Osigian and colleagues[10] reported 16 patients (age range, 16-88 years) with GDD who underwent strabismus surgery, with a more conservative surgical approach aimed at preserving the GDD capsule: surgical success (defined as $\leq 10^{\Delta}$ horizontal or $\leq 4^{\Delta}$ vertical) was achieved in 42% of horizontal and 57% of vertical deviations, with a decrease of ≥50% in deviation magnitude in 74%. Unintended bleb perforation occurred in 1 case.[10] Our surgical approach tended to be conservative, more closely resembling that of Osigian and colleagues,[10] with similar success at GDD capsule preservation and no unintentional capsule perforation. As reported in adults having strabismus surgery subsequent to GDDs, various strabismus patterns presented in our post-GDD group (Table 2 and eSupplement 1).

To our knowledge, our study is the first to examine outcomes of strabismus surgery in children with GDDs for refractory glaucoma and the first to examine strabismus surgery performed concomitantly with GDD implantation. The latter approach offers improved alignment for children with preexisting strabismus facing GDD implantation, while minimizing future challenges of intraoperative scarring and fibrous capsule dissection. In concomitant strabismus surgery and GDD implantation, a hang-back recession facilitates placement of the operated extraocular muscle at its desired location once the GDD plate is positioned. This can be accomplished without plate trimming, especially with Ahmed or Baerveldt 250 mm^2 GDDs. But with Baerveldt 350 mm^2 GDDs, plate modification facilitates direct contact of the recessed muscle with the sclera and may improve bleb cosmesis and decrease risk of plate erosion (See Appendix B).

Regarding choice of surgical procedures for strabismus after GDDs in children, most cases required addressing the muscle adjacent to the GDD due to magnitude of strabismus and suspected capsule-muscle adhesions or scarring that limited eye movements. In this nonrandomized series, 9 of 11 subjects had surgery on muscles adjacent to the GDD, accomplished without damage to the GDD capsule except when capsule revision was intended. Therefore, strabismus surgery after GDD placement in children poses challenges but can be executed safely and with modest success.

Our study has several limitations. First, its retrospective nature limits the uniformity of data collection and decisions regarding surgical dosing and technique, which were made by surgeon preference. Some cases of combined horizontal and vertical strabismus were intentionally not fully addressed by the conservative surgical plan. Additionally, our relatively strict inclusion criteria requiring extensive motility data pre- and postoperatively excluded some cases because of incomplete follow-up data or motility documentation. Two cases of severe restrictive strabismus requiring capsule resection and/or plate removal were therefore excluded because quantitative measurements were lacking, but qualitative outcomes were good. Lastly, our study population was highly heterogeneous with respect to diagnoses, severity of glaucoma and strabismus, GDD type, and surgical technique. Although this heterogeneity demonstrates the many variables that merit consideration when developing a management strategy for strabismus in children requiring GDDs for refractory glaucoma, it also limits our ability to generalize regarding specific strabismus surgery dosing in childhood glaucoma patients with preexisting or impending GDDs.

Our study demonstrates that strabismus surgery in childhood involving GDDs, while challenging, can safely and substantially improve alignment in refractory childhood glaucoma, whether performed concomitant with, or subsequent to, GDD placement. The surgical approach should be tailored to the patient's motility restriction, scarring, and proximity of the extraocular muscle to the GDD plate and capsule.

Literature Search

PubMed was searched without date restriction on November 15, 2018, using the following terms: *strabismus surgery* AND *glaucoma drainage device* OR *glaucoma drainage implant* OR *Ahmed* OR *Baerveldt*. The results were reviewed and found to describe neither strabismus surgery in children with GDDs nor strabismus surgery performed concomitant with GDD implantation.

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Appendix A
Surgical technique recommendations for strabismus surgery subsequent to glaucoma drainage device (GDD) implantation

Step	Recommendations
Preoperative planning	• Review prior operative records. • Sensorimotor examination: assess for restriction of extraocular movements, incomitance. • Slit-lamp examination: assess for conjunctival scarring or thinning, visible signs of prior extraocular muscle surgery, and GDD location and any exposure. • Discuss case with glaucoma surgeon: obtain clearance for possible plate resection, implant removal, or tube ligation.
Prior to incision	• Forced duction testing. • Work under surgical microscope. • Consider creating a limbal paracentesis to allow access to anterior chamber if perforation of capsule and hypotony occur.
Incision	• Conjunctival fornix incision on side of extraocular muscle opposite GDD (ie, inferotemporal fornix incision if implant is superotemporal).
Isolation of extraocular muscle	• Avoid use of sharp or forceful instrumentation. • Utilize frequent cautery for hemostasis. • Identify insertion of muscle on opposite end from GDD. • Use slim muscle hook to gently isolate muscle away from GDD capsule. • Splitting the muscle is preferable to rupturing GDD capsule • Use a second muscle hook, and begin isolating the extraocular muscle at the edge adjacent to the GDD to lift muscle off capsule and GDD plate.
Scleral pass	• Consider hang-back technique for recession if difficulty with scleral exposure due to conjunctival scarring or small incision size
If perforation of GDD capsule occurs	• Inject viscoelastic and/or air bubble into anterior chamber to stabilize. • If nonvalved GDD implant, consider suture closure of small capsule rupture if feasible. If not feasible, or extensive capsule/plate resection is planned, consider ligation of tube. • If valved GDD implant, and capsule repair not possible, tube ligation may not be required.

Appendix B
Surgical technique recommendations for strabismus surgery concomitant with glaucoma drainage device (GDD) implantation

Step	Recommendations
Preoperative planning	• Review prior operative records. • Sensorimotor examination: assess for restriction of extraocular movements, incomitance.
Surgical steps	• Work under surgical microscope. • Forced duction testing. • Conjunctival fornix incision in the desired quadrant of the GDD (typically superotemporal). • Isolate and secure relevant extraocular muscle with 6-0 polyglactin suture (usually lateral rectus). • Trim/modify plate as appropriate (see below). • Place GDD in desired quadrant and secure to sclera. • Disinsert extraocular muscle to be recessed. • Reattach muscle to sclera at desired location, or use hangback technique.
Hangback technique	• Helpful when scleral exposure is limited due to conjunctival scarring or presence of GDD. • Place scleral bites at original insertion. • Use calipers to measure desired amount of recession on the extraocular muscle sutures. • Tie knot in extraocular muscle sutures at desired location • Allow muscle to hang back.
GDD plate trimming	• Either anterior or posterior aspect of the relevant wing of Baerveldt GDD plate can be trimmed, depending on desired location of extraocular muscle (eg, inferolateral wing for superotemporal GDD and lateral rectus recession). • This technique allows for direct contact of extraocular muscle to sclera. • Authors recommend anterior wing trimming to ensure bleb remains under/behind rectus muscles with possible lower risk of exposure and improved cosmesis. • Determine how much to trim from plate based on desired distance between anterior edge of GDD plate and limbus and desired location of recessed extraocular muscle. (eg, to place Baerveldt 350 mm^2 in superotemporal quadrant with anterior edge 8mm posterior to limbus, and to recess adjacent lateral rectus muscle 8mm from insertion to approximately 15 mm from limbus, recommend anterior plate trimming of inferolateral Baerveldt wing by 7 mm). • Use scissors to remove aspect of Baerveldt GDD plate prior to securing implant to sclera.