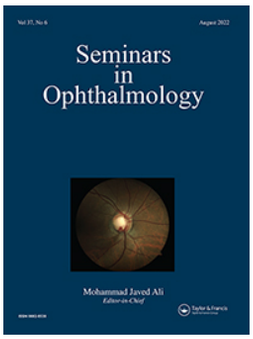

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Illuminated Microcatheter Passage Assisted Circumferential Trabeculotomy and Trabeculectomy (IMPACTT): An improved surgical procedure for Primary Congenital Glaucoma

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ABSTRACT

Purpose: To report an improved surgical procedure for primary congenital glaucoma (PCG).

Case report: An apparently healthy 4-month-old male child was referred by an ophthalmologist with the preliminary diagnosis of congenital glaucoma. Office examination followed by evaluation under anaesthesia confirmed the diagnosis of advanced PCG in both eyes. Horizontal corneal diameter was 13.5 mm in both eyes and intraocular pressure was 36 mmHg in both eyes. The child was operated on both eyes in the same session. An illuminated microcatheter passage assisted circumferential trabeculotomy and trabeculectomy (IMPACTT) was performed. Two months postoperatively, the IOPs were 12 and 10 mmHg in the right and left eye, respectively, and the cornea was clear except for the presence of Haab's striae in both eyes. The child's visual acuity (binocularly) was 4 cycles/degree as recorded with Teller acuity cards.

Conclusions: Illuminated microcatheter passage assisted circumferential trabeculotomy and trabeculectomy (IMPACTT) is safe and effective and may represent an improved surgical procedure for the management of advanced PCG.

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Combined trabeculotomy-trabeculectomy; Congenital glaucoma; goniotomy; Illuminated microcatheter passage assisted circumferential trabeculotomy and trabeculectomy; trabeculotomy

INTRODUCTION

Primary congenital glaucoma (PCG) is a potentially blinding disease and prompt surgical intervention is advocated.[1–3] Naturally, the question arises: What is the best primary surgical treatment?[4] Traditionally, goniotomy or trabeculotomy ab externo is the preferred initial surgical option depending on the corneal haze.[1–3] In more advanced forms of the disease, combined trabeculotomy-trabeculectomy (CTT) is one of the preferred surgical choice.[5–8] For the control of intraocular pressure (IOP), often multiple surgical interventions are required.[1–3,9]Circumferential trabeculotomy using a blue 6/0 polypropylene suture yielded a better success rate compared to goniotomy.[10,11] The possibility of creating a false passage is the downside of this technique.[12,13] Subsequently, the introduction of illuminated microcatheter markedly reduced the risk of misdirection as it enables continuous visualization of the device during circumferential trabeculotomy and several successful series have been reported.[14–16]

In search for the best surgical treatment for PCG, 360-degree trabeculotomy combined with trabeculectomy has been conceptualized as the new treatment modality. The aim of this communication is to report the microsurgical technique and outcome of illuminated microcatheter passage assisted circumferential trabeculotomy and trabeculectomy (IMPACTT) on a 4-month-old child with PCG.

CASE REPORT

The patient was a 4-month-old child, product of a normal pregnancy and his birth weight was 3 kg. The parents noticed gradual enlargement of the eyes with intolerance to light and tearing from the eyes since the second months of birth. They consulted a general ophthalmologist who referred the child to us with the provisional diagnosis of congenital glaucoma. His physical examination was unremarkable. Examination under anesthesia revealed horizontal corneal diameter of 13.5 mm with diffuse corneal edema with multiple Haab's striae in both eyes. His intraocular pressures were 36 mm Hg in both eyes and the lenses were clear. Gonioscopic view was hazy, but flat insertion of the iris over the poorly developed trabecular meshwork could be appreciated. Indirect ophthalmoscopy revealed asymmetric cupping of the optic of the optic nerves (0.6 OD and 0.4 OS). The posterior pole of both the eyes was otherwise normal with an incomplete view of the fundus. On ultrasound B-scan, both the eyes showed anechoic posterior segment. With this history and clinical findings, a diagnosis of bilateral primary congenital glaucoma was established, and the child underwent surgical intervention.

SURGICAL TECHNIQUE

The surgery was performed under general anaesthesia. The details of the surgical technique on the left eye (Figure 1A) are described below:

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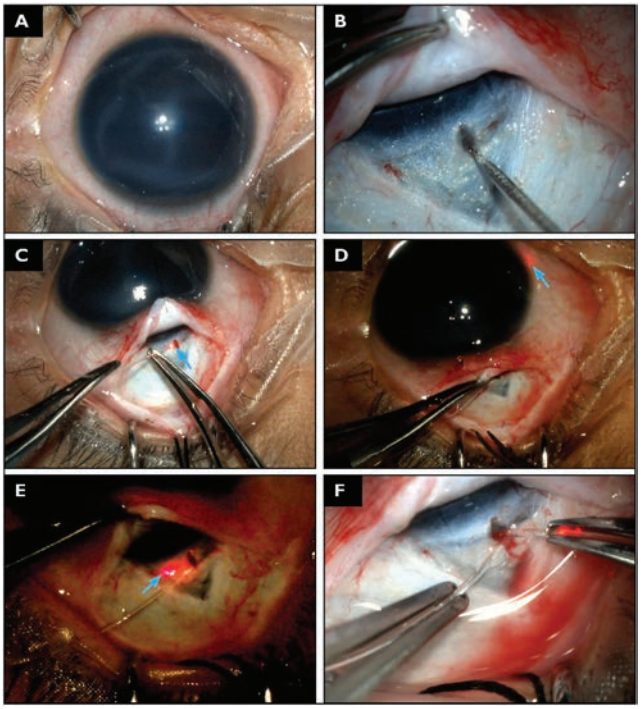

Figure 1. (**A**). Appearance of the left eye immediately before surgery. (**B**). Anatomy of the limbal region under a partial thickness superficial scleral flap. Note the radial incision to cut the superficial wall of the Schlemm's canal. **(C)**. The tip of the illuminated microcatheter is at the opening of the Schlemm's canal (Blue arrow). **(D)**. The illuminated tip in the canal just crossed ¼ of the circumference (Blue arrow). **(E)**. The illuminated tip (blue arrow) traversed almost 360-degrees and seen near the opening of the Schlemm's canal. **(F)**. The illuminated tip has been pulled out of the Schlemm's canal through the original incision.

- A limbus-based conjunctival flap was raised, and the dissection was done in the episcleral plane. Hemostasis was meticulously maintained with the help of bipolar underwater cautery.
- A one-half thickness triangular scleral incision was delineated, and the scleral flap was then dissected towards the limbus using a No. 15 Bard Parker blade. Surgical landmarks and the anatomy of the limbal region was carefully identified. A 2 × 2 mm trabeculectomy block was outlined without penetrating the anterior chamber. A central radial incision was then made just behind the junction of the bluish-grey band and the white band to cut the external wall of the Schlemm's canal (Figure 1B).
- A drop of viscoelastic material was placed in the opening of the Schlemm's canal. Two tying forceps were used to grasp the illuminated microcatheter (indigenously manufactured with outer diameter of 200 microns using optical fibre technology connected to the laser light source) placing the tip in alignment with the canal (Figure 1C) and the device was advanced into the canal (Figure 1D). The lighted tip allows for the surgeon to visualise the canulation of Schlemm's canal for 360 degrees as the catheter was advanced (Figure 1E).
- The catheter was grasped with a forceps when it emerged from the distal end of the canal and was pulled out a little bit (Figure 1F). Both exposed ends of the catheter were pulled in opposite directions using a tangential force like a purse-string (Figure 2A), thus garrotting all 360 degrees of the trabecular meshwork inward performing the circumferential trabeculotomy. There was minimal bleeding from the chamber angle forming clot over the peripheral iris and it was removed carefully with the help of Simcoe's irrigation and aspiration cannula.
- With the help of Vannas scissors, the 2 × 2 mm trabeculectomy block was removed (Figure 2B) and an iridectomy was then made (Figure 2C). The scleral flap was closed with one 10-o nylon suture at the apex of the triangular scleral flap and the knot was buried.
- The conjunctiva and Tenon's capsule were then closed in a single layer with a running suture of absorbable material using 8–0 polygalactin suture (Figure 2D). A subconjunctival injection of dexamethasone (0.3 ml) was given in the inferior fornix. A drop of antibiotic-steroid preparation was instilled into the conjunctival sac and a patch and shield was applied to the eye.

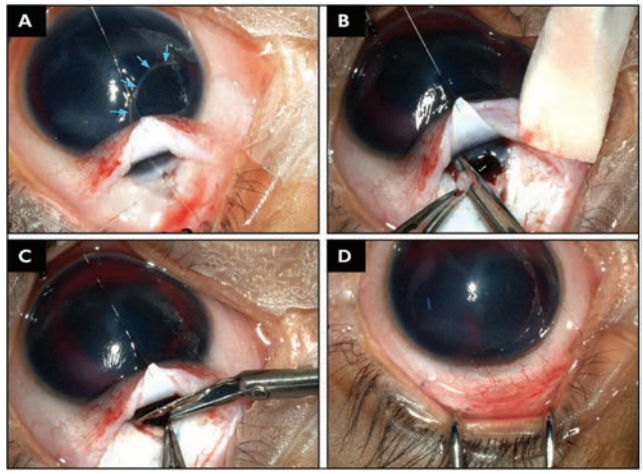

Figure 2. (**A**). Microcatheter seen in the anterior chamber (blue arrows) after trabeculotomy of the three quarters of the circumference. **(B)**. Trabecular block is being removed. **(C)**. Iridectomy is done. **(D)**. Appearance of the eye at the conclusion of the surgery.

POSTOPERATIVE CARE AND SURGICAL OUTCOMES

Postoperatively, the child was treated with antibiotic drop for a week, topical dexamethasone six times daily tapered over a period of 6-weeks and cyclopentolate drops three times daily for three weeks. EUA was done 2-months postoperatively when IOP recorded were 12 and 10 mmHg in the OD and OS, respectively, on no medications. The corneas were clear with multiple Haab's striae on both eyes. Figure 3A shows the preoperative appearance of the left cornea with diffuse corneal edema and Figure 3B shows clearance of corneal edema and multiple Haab's striae 2 months after surgery. The cupping of the optic was somewhat reversed (0.4OD and 0.2 OS). Figure 3C shows moderately elevated diffuse filtering bleb and Figure 3D shows Haab's striae on fundus

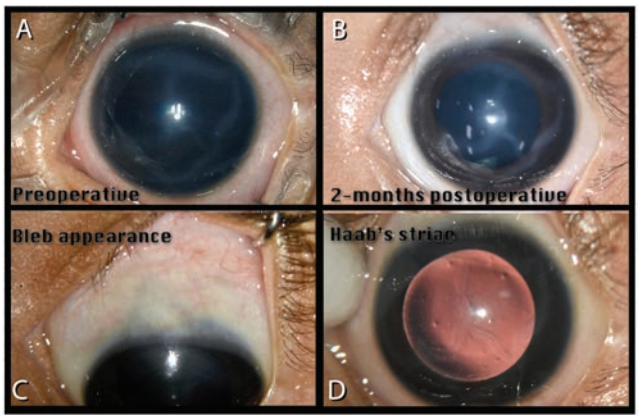

Figure 3. (**A**). Preoperative appearance of the left eye showing diffuse corneal edema. **(B)**. Two months postoperative appearance of the left eye showing complete clearance of corneal edema and the Haab's striae are seen. **(C)**. Two months postoperative appearance of the bleb. **(D)**. Fundus retro-illumination picture of the left eye showing clear cornea and Haab's striae.

retroillumination. Overall, the surgical outcome was excellent in both eyes. The parents were instructed to bring the child for follow-up after one month.

DISCUSSION

Primary congenital glaucoma (PCG) is a disease which occurs worldwide and poses a therapeutic challenge to the ophthalmologists. The mainstay of treatment for PCG involves incision on the abnormal trabecular meshwork that causes obstruction of aqueous humour drainage to Schlemm's canal, thus maintaining the physiological direction of flow. Goniotomy and trabeculotomy ab externo may be considered for primary surgery.[1–3] However, goniotomy requires clear cornea and was not suitable in this case that preclude proper visualization of angle structures. Trabeculotomy ab externo is a suitable alternative in such a situation.[17] Conventional trabeculotomy using metal trabeculotome can only open approximately one-third of the trabecular meshwork in a single surgery and may have to be attempted several times to achieve normal intraocular pressure. To increase the likelihood of success, two-site (superonasal and inferotemporal) rigid probe circumferential trabeculotomy has been attempted.[18,19] On the other hand, combined trabeculotomy with trabeculectomy (CTT) has emerged as one of the preferred surgical options for moderate-to-severe form of the disease particularly in Indian and Middle East populations.[5–8,20,21] Trabeculotomy with metal probe have some disadvantages: inability to open the full circumference and sometimes it can create false passage.

To maximize the IOP lowering effect, circumferential trabeculotomy was introduced with the ability to treat the entire angle in one surgery. Using a 6–0 polypropelene suture after blunting one end by cautery, Beck and Lynch described 360-degrees trabeculotomy for primary congenital glaucoma.[10] The main concern with this technique is that it is a blind procedure with the possibility of misdirection and associated complications.[12,13] With the introduction of illuminated microcatheter, the technique of circumferential trabeculotomy has been refined dramatically.[16] It enables continuous visualization of the device during Schlemm's canal canulation circumferentially. Initial results of circumferential trabeculotomy with illuminated microcatheter were promising.[14,16] Subsequently, several studies have shown superiority of microcatheter assisted circumferential trabeculotomy over conventional rigid probe trabeculotomy.[22–27] One study from India showed equivalent success rate between illuminated microcatheter-assisted circumferential trabeculotomy and combined trabeculotomy-trabeculectomy with mitomycin-C and recommended circumferential trabeculotomy as the initial surgical procedure for PCG.[28]

When isolated circumferential trabeculotomy is performed, the drainage of aqueous from the Schlemm's canal to the venous circulation is dependent on post-canalicular distal outflow pathway, which is assumed to be functioning normally. Studies have shown that about one-third of the outflow resistance lies distal to the juxtacanalicular meshwork.[29] Anatomically the aqueous veins are not distributed uniformly, and are present in the inferior nasal quadrants in the greatest numbers.[30] In patients with advanced PCG, the collector channels and the aqueous veins needed to carry the aqueous to the episcleral veins are more likely to be anomalous or atrophic in addition to the primary pathology, that is, trabeculodysgenesis. Assessment of the collector channels and functional efficiency of the distal outflow system is beyond the scope of clinical evaluation. In such a situation, angle surgery even in the form of circumferential trabeculotomy is bound to yield suboptimal results. A poorly functioning distal outflow pathway will necessitate an additional surgical step that bypasses it, like trabeculectomy. Hence, adding trabeculectomy to circumferential trabeculotomy as has been done in the present case will have theoretical advantage of dual-outflow pathway ensuring better drainage of aqueous and normalization of IOP. The case described herein is doing well and suggest that Illuminated Microcatheter passage Assisted Circumferential Trabeculotomy and Trabeculectomy (IMPACTT) is safe and effective. However, long-term follow-up is required. IMPACTT may represent the next step in the search for the best surgical treatment for primary congenital glaucoma. To the best of the author's knowledge, IMPACTT has not been reported earlier in the context of the management of PCG. While milder form of the disease may be treated successfully with goniotomy or trabeculotomy; IMPACTT is specifically indicated for moderate-to-severe form of the disease. The steep learning curve and the cost of the microcatheter are important considerations especially in the developing nation set-up. One of the sequelae of this technique is the theoretical possibility of over-filtration leading to shallow anterior chamber in the early postoperative period. Hence, an utmost precaution should be taken to maintain the chamber depth intraoperatively and manage the situation accordingly should it occur. Hyphema as has occurred in the present case is an intraoperative complication that should be borne in mind while performing IMPACTT. It was managed by letting the blood to form a clot over the iris and then was gently removed with the help of Simcoe's irrigation and aspiration cannula.

In conclusion, IMPACTT is safe and effective; and further prospective randomised studies are required to determine the perceived superiority of IMPACTT over the contemporary surgical techniques for the management of PCG.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

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References

1. deLuise VP, Anderson DR, deLuise VP. Primary infantile glaucoma (congenital glaucoma). *Surv Ophthalmol*. 1983;28:1–19. doi:10.1016/0039-6257(83)90174-1.
2. Mandal AK. Current concepts in the diagnosis and management of developmental glaucomas. *Indian J Ophthalmol*. 1993;41:51–70.
3. Mandal AK, Chakrabarti D. Update on congenital glaucoma. *Indian J Ophthalmol*. 2011;59:S148–57. doi:10.4103/0301-4738.73683.
4. Khaw PT. What is the best primary surgical treatment for the infantile glaucomas? *Br J Ophthalmol*. 1996;80:495–496. doi:10.1136/bjo.80.6.495.
5. Mandal AK, Gothwal VK, Nutheti R. Surgical outcome of primary developmental glaucoma: a single surgeon's long-term experience from a tertiary eye care centre in India. *Eye (Lond)*. 2007;21:764–774. doi:10.1038/sj.eye.6702324.
6. Mandal AK, Matalia JH, Nutheti R, Krishnaiah S. Combined trabeculotomy and trabeculectomy in advanced primary developmental glaucoma with corneal diameter of 14 mm or more. *Eye (Lond)*. 2006;20:135–143. doi:10.1038/sj.eye.6701817.
7. Al-Hazmi A, Awad A, Zwaan J, Al-Mesfer SA, Al-Jadaan I, Al-Mohammed A. Correlation between surgical success rate and severity of congenital glaucoma. *Br J Ophthalmol*. 2005;89:449–453. doi:10.1136/bjo.2004.047761.
8. Mandal AK, Gothwal VK, Khanna R. Combined trabeculotomy-trabeculectomy for primary congenital glaucoma: long-term experience from a tertiary referral centre in a developing nation. *Acta Ophthalmol*. 2022;100:e439–e447. doi:10.1111/aos.14984.
9. Biglan AW, Hiles DA. The visual results following infantile glaucoma surgery. *J Pediatr Ophthalmol Strabismus*. 1979;16:377–381. doi:10.3928/0191-3913-19791101-10.
10. Beck AD, Lynch MG. 360 degrees trabeculotomy for primary congenital glaucoma. *Arch Ophthalmol*. 1995;113:1200–1202. doi:10.1001/archopht.1995.01100090126034.
11. Mendicino ME, Lynch MG, Drack A, et al. Long-term surgical and visual outcomes in primary congenital glaucoma: 360 degrees trabeculotomy versus goniotomy. *J AAPOS*. 2000;4:205–210. doi:10.1067/mpa.2000.106201.
12. Neely DE. False passage: a complication of 360 degrees suture trabeculotomy. *J AAPOS*. 2005;9:396–397. doi:10.1016/j.jaapos.2005.05.003.
13. Verner-Cole EA, Ortiz S, Bell NP, Feldman RM. Subretinal suture misdirection during 360 degrees suture trabeculotomy. *Am J Ophthalmol*. 2006;141:391–392. doi:10.1016/j.ajo.2005.08.038.
14. Girkin CA, Marchase N, Cogen MS. Circumferential trabeculotomy with an illuminated microcatheter in congenital glaucomas. *J Glaucoma*. 2012;21:160–163. doi:10.1097/IJG.0b013e31822af350.
15. Girkin CA, Rhodes L, McGwin G, Marchase N, Cogen MS. Goniotomy versus circumferential trabeculotomy with an illuminated microcatheter in congenital glaucoma. *J AAPOS*. 2012;16:424–427. doi:10.1016/j.jaapos.2012.05.013.
16. Sarkisian SR Jr. An illuminated microcatheter for 360-degree trabeculotomy [corrected] in congenital glaucoma: a retrospective case series. *J AAPOS*. 2010;14:412–416. doi:10.1016/j.jaapos.2010.07.010.
17. Luntz MH. The advantages of trabeculotomy over goniotomy. *J Pediatr Ophthalmol Strabismus*. 1984;21:150–153.
18. Saltzmann RM, Reinecke S, Lin X, Cavanagh HD, Whitson JT. Long-term outcomes of a pseudo 360-degree trabeculotomy ab externo technique for congenital glaucoma at children's medical center. *Clin Ophthalmol*. 2012;6:689–698. doi:10.2147/OPTH.S29898.
19. El Sayed YM, Gawdat GI. Microcatheter-assisted trabeculotomy versus 2-site trabeculotomy with the rigid probe trabeculotome in primary congenital glaucoma. *J Glaucoma*. 2018;27:371–376. doi:10.1097/IJG.0000000000000892.
20. Sood NN, Aggarwal HC, Kalra BR. Evaluation of surgery for congenital glaucoma. *Indian J Ophthalmol*. 1983;31:609–611.
21. Agarwal HC, Sood NN, Kalra BR, Dayal Y. Microsurgery in congenital glaucoma. *Indian J Ophthalmol*. 1983;31:777–779.
22. Celea C, Dragosloveanu S, Pop M, Celea C. Comparison of 360-degree circumferential trabeculotomy and conventional trabeculotomy in primary pediatric glaucoma surgery: part 1. *J Pediatr Ophthalmol Strabismus*. 2016;53:357–364. doi:10.3928/01913913-20160809-01.
23. El Sayed Y, Gawdat G. Two-year results of microcatheter-assisted trabeculotomy in paediatric glaucoma: a randomized controlled study. *Acta Ophthalmol*. 2017;95:e713–e719. doi:10.1111/aos.13414.
24. Lim ME, Neely DE, Wang J, Haider KM, Smith HA, Plager DA. Comparison of 360-degree versus traditional trabeculotomy in pediatric glaucoma. *J AAPOS*. 2015;19:145–149. doi:10.1016/j.jaapos.2015.01.008.
25. Neustein RF, Beck AD. Circumferential trabeculotomy versus conventional angle surgery: comparing long-term surgical success and clinical outcomes in children with primary congenital glaucoma. *Am J Ophthalmol*. 2017;183:17–24. doi:10.1016/j.ajo.2017.08.008.
26. Shakrawal J, Bali S, Sidhu T, Verma S, Sihota R, Dada T. Randomized trial on illuminated-microcatheter circumferential trabeculotomy versus conventional trabeculotomy in congenital glaucoma. *Am J Ophthalmol*. 2017;180:158–164. doi:10.1016/j.ajo.2017.06.004.
27. Shi Y, Wang H, Yin J, et al. Microcatheter-assisted trabeculotomy versus rigid probe trabeculotomy in childhood glaucoma. *Br J Ophthalmol*. 2016;100:1257–1262. doi:10.1136/bjophthalmol-2015-307880.
28. Temkar S, Gupta S, Sihota R, et al. Illuminated microcatheter circumferential trabeculotomy versus combined trabeculotomy-trabeculectomy for primary congenital glaucoma: a randomized controlled trial. *Am J Ophthalmol*. 2015;159:490–7 e2. doi:10.1016/j.ajo.2014.12.001.
29. Schuman JS, Chang W, Wang N, de Kater Aw, Allingham RR, de Kater AW. Excimer laser effects on outflow facility and outflow pathway morphology. *Invest Ophthalmol Vis Sci*. 1999;40:1676–1680.
30. Stepanik J. Measuring velocity of flow in aqueous veins. *Am J Ophthalmol*. 1954;37:918–922. doi:10.1016/0002-9394(54)91933-9.

AMERICAN ACADEMY OF OPHTHALMOLOGY®

Long-term Outcomes in Patients Undergoing Surgery for Primary Congenital Glaucoma between 1991 and 2000

A Single-Center Database Study

Anil K. Mandal, MD,[1,2] *Vijaya K. Gothwal, PhD,*[3,4] *Ashik Mohamed, PhD*[5,*]

Purpose: To estimate the long-term surgical and visual outcomes in patients with primary congenital glaucoma (PCG) who completed at least 20 years of follow-up.

Design: Retrospective study.

Participants: Two hundred twenty eyes of 121 patients undergoing surgery for PCG between January 1991 and December 2000 and who returned for a follow-up visit from January 2021 through January 2022.

Methods: Retrospective review of medical records of patients who underwent primary combined trabeculotomy–trabeculectomy (CTT) without mitomycin C as an initial procedure. Success was defined as complete when intraocular pressure (IOP) was $\geq$ 6 mmHg and $\leq$ 21 mmHg without glaucoma medication and as qualified when up to 2 glaucoma medications were required. Failure was defined as uncontrolled IOP with more than 2 glaucoma medications, need for a second IOP-lowering procedure, chronic hypotony (IOP $<$ 6 mmHg on 2 consecutive visits), or any sight-threatening complication. A mixed-effects model using maximum likelihood estimation was used in estimation of eye-based variables and to make comparisons between different visits. Kaplan–Meier survival analysis was used to estimate the probabilities of surgical and functional successes. Cox proportional hazards regression using sandwich clustered estimation was used to evaluate risk factors for failure and poor visual outcome.

Main Outcome Measures: Primary outcome measure was the proportion of patients who demonstrated complete success over the 20-year follow-up. Secondary outcome measures included rate of surgical failure and need for reoperation for glaucoma, visual acuity, refractive errors, risk factors for poor outcome, and complications.

Results: Kaplan–Meier survival analysis revealed 1-year, 10-year, and 20-year complete success rates of 90.7%, 78.9%, and 44.5%, respectively. In univariate analysis, surgical failure was higher among patients with any additional non-glaucoma intraocular surgery. None of the clinical parameters were associated significantly with failure in multivariable analysis. Overall, the proportion of eyes with good, fair, and poor visual outcomes was 33.2%, 16.4%, and 50.4%, respectively. Myopia was seen in 68.9% eyes. Twenty-eight eyes of those who underwent primary CTT (14.4%) required second surgery for IOP control. No significant intraoperative complications occurred. Six eyes required enucleation because of painful blind eye.

Conclusions: In this large cohort of patients with PCG, CTT is a useful procedure. It provides good IOP control and moderate visual recovery that remained over a 20-year follow-up after surgery.

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Primary congenital glaucoma (PCG) is a rare disease, but it is the most common form of primary childhood glaucoma.[1–3] Typically bilateral, PCG may be unilateral in 25% to 30% of patients.[4–6] Primary congenital glaucoma results from an isolated developmental abnormality of the angle called trabeculodysgenesis. The diagnosis of PCG is based on clinical criteria that include elevated intraocular pressure (IOP), cloudy corneas, increased corneal diameter, enlargement of the globe, abnormally deep anterior chamber, and typical breaks in the Descemet membrane called Haab striae.[1] The prevalence of PCG varies worlwide,[7] with relatively higher prevalence in South India, where it is estimated to be 1 in 3300 live births, accounting for 4.2% of childhood blindness in this population.[8,9]

Primary congenital glaucoma can lead to blindness or, alternatively, a lifetime of normal visual acuity (VA) with

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early diagnosis and prompt treatment for successful control of IOP. The mainstay of management of PCG is surgery, and intervention should be carried out as early as possible. Life-long monitoring is essential to ensure control of IOP. The technique and the type of surgery often are decided by the severity of the disease and the surgeon's skills and experience. Traditionally, angle-incision surgery is the primary choice in Western populations.[10–15] Some surgeons prefer to perform trabeculotomy, which can be carried out without a clear cornea by an ab externo approach.[7,16–19] Conventional trabeculotomy using a metal trabeculotome opens about one-third of the angle, and it is technically easier and anatomically more precise even when the cornea is not clear.[2–22] Recently, 360° trabeculotomy using an illuminated microcatheter improved success rates in PCG, and the investigators postulated that more angle opening is the reason for improved success rates.[23–25] In a randomized controlled trial from India, illuminated microcatheter-assisted circumferential trabeculotomy achieved comparable surgical outcomes as primary combined trabeculotomy–trabeculectomy (CTT) with mitomycin C (MMC) in PCG.[26] We prefer to perform CTT without MMC as the primary surgical procedure in PCG because of the possibility of bleb-related infections and endophthalmitis resulting from the use of MMC in young children.[1,27]

A few short and intermediate-term studies have reported outcomes of PCG, including from our center.[28–30] Previous studies had some limitations. First, they combined all subtypes of PCG in a single cohort. Second, a paucity of information is available on the long-term outcomes and sight-threatening complications. Furthermore, some of the published literature on long-term studies of PCG have not included data on visual outcomes.[15,31,32] Although the long-term follow-up care of patients with PCG is fraught with challenges worldwide,[33] it is even more difficult in the developing world because of limited resources in terms of access to care, lower levels of health literacy, lower socioeconomic status, and the small number of specialized pediatric glaucomatologists.[34] Therefore, the primary aim of the present study was to evaluate long-term surgical outcomes and VA in patients undergoing surgery for different subtypes of PCG. The secondary aim was to investigate the factors that influence surgical outcomes and reoperation rates over the course of follow-up.

Methods

This was a retrospective cohort study of children with PCG in the original L V Prasad Eye Institute congenital glaucoma registry[35] who underwent glaucoma surgery at a single center by a single surgeon (A. K. M.) from January 1991 through December 2000. The registry included all children, regardless of age at surgery, laterality, or subtype of PCG and those who reached adulthood (≥ 18 years) at the follow-up visit at our center from January 2021 through January 2022. The study was approved by the Ethics Committee for Human research of L. V. Prasad Eye Institute, and all study procedures adhered to the tenets of the Declaration of Helsinki. All participants provided informed consent.

Primary congenital glaucoma was defined according to the 9th Consensus Report of the World Glaucoma Association and further by the Childhood Glaucoma Research Network classification system for childhood glaucoma.[36,37] The age at onset was classified according to the Childhood Glaucoma Research Network guidelines: neonatal or newborn onset (0–1 month), infantile onset (1–24 months), and late onset or late recognition for children after 24 months of age. Patients with glaucoma associated with nonacquired ocular and systemic disease or syndromes and secondary glaucoma were excluded.

Information about sex; age at presentation; date, type, and number of surgeries performed (glaucoma and nonglaucoma procedures); surgical outcomes such as IOP (with handheld Perkins applanation tonometry or Goldmann applanation tonometry as appropriate); need for glaucoma medications; VA (in logarithm of the minimum angle of resolution [logMAR]); refractive error (in spherical equivalent [SE]); cup-to-disc ratio; and visual fields (VFs) were retrieved from the medical records. Snellen VA was converted to logMAR units for the purposes of analysis. We considered a good visual outcome as VA of 20/40 or better (≤ 0.30 logMAR), fair as 20/50 to 20/200 (< 0.30–1.00 logMAR), and poor as worse than 20/200 (> 1.00 logMAR). Severity of PCG was classified based on the severity index published by us earlier.[38] The cup-to-disc ratio was graded based on the recent classification by Sihota et al.[39] It included 3 categories: mild (< 0.6), moderate (0.6–0.8), and severe (> 0.8). The severity of VF defects was graded using the standard Hoddap-Anderson-Parrish grading system.[40–43] In this, the mean deviation (measured in decibels) was used as the VF measurement representing overall VF loss. Patients were categorized into 3 groups of VF loss: mild (≥ −6 dB), moderate (> −6 dB and ≥ −12 dB), and severe (< −12 dB).

All patients underwent suitable glaucoma procedures (described later) within 1 week of presentation to us and confirmation of glaucoma. The choice of surgical technique was based on a combination of factors such as corneal diameter and clarity, level of IOP, severity of glaucoma, and history of prior surgical intervention (if any).

Surgical Procedure

The surgical technique of CTT was performed as a primary procedure in most patients.[1,27,30] This technique was described previously in detail by us.[1,27,30] Trabeculectomy was performed in patients with severe PCG in whom the Schlemm's canal could not be identified. However, we performed trabeculectomy with MMC (0.2 mg/ml for 1 minute) in patients in whom prior surgery failed and who required a second surgical intervention.[44,45] In patients with refractory glaucoma, we performed transscleral cyclophotocoagulation (TSCPC) with a diode laser using a G-probe.[46] The power used was 1500 to 2000 mW with a soft pop, limiting the treatment to 180°, and 20 to 25 shots were applied to prevent hypotony and phthisis.

Success Criteria

Surgical success and failure were defined a priori. Complete and qualified surgical success were evaluated at each study interval. In our definition of surgical success using IOP as the criteria, we considered a cutoff value of 16 mmHg when it was recorded while the patient was under anesthesia and 21 mmHg when it was recorded while the patient was in the office. We defined complete surgical success as control of IOP without the use of glaucoma medications or need for additional IOP-lowering surgery. Qualified surgical success was defined as control of IOP with the use of up to 2 glaucoma medications. Failure was defined as uncontrolled IOP with > 2 glaucoma medications, need for a second IOP-lowering procedure, chronic hypotony (IOP < 6 mmHg on 2 consecutive visits), or any sight-threatening complication.

Statistical Analysis

Patients' demographics and baseline characteristics were summarized by mean ± standard deviation (SD) for normally distributed continuous data, the median (interquartile range) for skewed distributed data, and counts and percentages for categorical data. The mixed-effects model using maximum likelihood estimation was used in the estimation of eye-based variables and to make comparisons between different visits. Random intercept at the patient level was used to account for correlation between fellow eyes of the same patient during analysis of IOP. Kaplan–Meier survival analysis was used to estimate the probabilities of success, and the log-rank test was used to evaluate the equality of survival functions among the 3 subtypes of PCG. Cox proportional hazards regression using sandwich clustered estimation was used to assess the effect of risk factors on survival. Specifically, univariable and multivariable Cox proportional hazards models were used to measure subgroup hazard ratios (HRs) to determine predictors of success and poor visual outcome including age at surgery, type of PCG (neonatal, infantile, or late onset), sex, laterality, preoperative IOP (as continuous and as categorical with cutoff of 35 mmHg), severity of PCG (mild, moderate, or severe), preoperative horizontal corneal diameter (HCD), preoperative corneal clarity (clear, edema, or scar), and any additional intraocular surgery. Separate Cox proportional hazards models were used to evaluate predictors of success and poor visual outcome. Cox proportional hazards regression was carried out by including 1 variable at a time in univariable analysis. Results are expressed as HR with 95% confidence intervals (CIs). Spherical equivalent (in diopters [D]) was used to analyze the refractive errors. An SE value ≥ -0.50 D was considered to be myopia, and an SE of > 0.50 D was considered to be hyperopia. Any SE of < 0.50 D and of < -0.50 D was considered emmetropia. A P value of < 0.05 was considered statistically significant. All statistical analyses was performed using Stata software version 14.2 (StataCorp).

Table 1. Baseline Characteristics of Patients with Primary Congenital Glaucoma

Characteristic	Results
No. of patients	121
No. of eyes	220
Age	
Mean ± SD	25.7 ± 46.7 mos
Range	1 day to 267.7 mos
Median	6 mos
Sex	
Male	55 (45)
Female	66 (55)
Laterality	
Unilateral	22 (18)
Bilateral	99 (82)
Type of glaucoma	
Neonatal	27 (22)
Infantile	70 (58)
Late onset	24 (20)
Corneal diameter at presentation, mm	
Mean ± SD	13.25 ± 1.19
Range	10.5–18
Corneal edema at presentation*	120 (54.5)
Corneal scar at presentation*	43 (19.5)
Clear cornea at presentation*	57 (25.9)
Preoperative IOP, mmHg	
Mean ± SD	26.9 ±7.7
Range	16–59
Use of glaucoma medications at presentation*	
Mean ± SD	1 ± 0.8
Range	0–4

IOP = intraocular pressure; SD = standard deviation.
Data are presented as no. (%) or no., unless otherwise indicated.
*Number of eyes.

Results

Participant Characteristics

The study group included 121 patients (220 eyes) who underwent surgery for PCG. Table 1 summarizes the demographics of our study population. The median age at surgery was 181 days (interquartile range, 62–730 days). Most patients had infantile-onset PCG (n = 70 [58%]) and included a slight female preponderance. Ninety-nine patients (82%) had bilateral disease. Follow-up averaged 21.3 years (median, 21 years). Most eyes had a severe form of PCG (155 eyes [70.5%]) followed by moderate PCG (59 eyes [26.8%]) and mild PCG (6 eyes [2.7%]). Primary CTT comprised the most common initial surgical procedure for control of IOP (n = 97 [80.2%]), followed by trabeculectomy (n = 19 [15.7%]) and TSCPC (n = 5 [4.1%]). Adjuvant MMC during primary trabeculectomy was used in 3 patients who had undergone prior failed primary surgery elsewhere.

Intraocular Pressure

In the entire cohort, the mean ± SD preoperative IOP was 26.9 ± 7.7 mmHg (range, 16–59 mmHg), and the mean ± SD number of glaucoma medications was 1 ± 0.8. At the last follow-up visit, the mean ± SD IOP was 17.6 ± 6.5 mmHg (range, 5–58 mmHg; $P < 0.0001$, paired t test), and the mean ± SD number of glaucoma medications was 0.8 ± 0.9 ($P < 0.0001$, Wilcoxon signed-rank test). The level of IOP at 5-year intervals is shown in Figure 1. Before surgery, 157 eyes (71.4%) were receiving glaucoma medication, whereas, at the last follow-up, 100 eyes (45.4%) required antiglaucoma medication. The rationale to perform glaucoma surgery in eyes with normal IOP was based on comprehensive ocular examination to confirm the diagnosis of glaucoma and that the patients already were receiving glaucoma medications.

In those eyes that underwent CTT as the primary surgical procedure, the mean ± SD preoperative IOP was 26.5 ± 8.4 mmHg (range, 8–59 mmHg), and the mean ± SD number of glaucoma medications was 0.96 ± 0.8. At the last follow-up visit, the mean ± SD IOP was 17.7 ± 9.3 mmHg (range, 6–58 mmHg; $P < 0.0001$, paired t test), and the mean ± SD number of glaucoma medications was 0.8 ± 1.1 ($P < 0.0001$, Wilcoxon signed-rank test). Before surgery, 135 eyes (66.6%) were receiving glaucoma medication, whereas, at the last follow-up, 86 eyes (44%) required antiglaucoma medication.

Corneal Diameter and Clarity

At presentation, mean ± SD HCD was 13.25 ± 1.19 mm (range, 10.5–18.0 mm). Before surgery, one-quarter of the

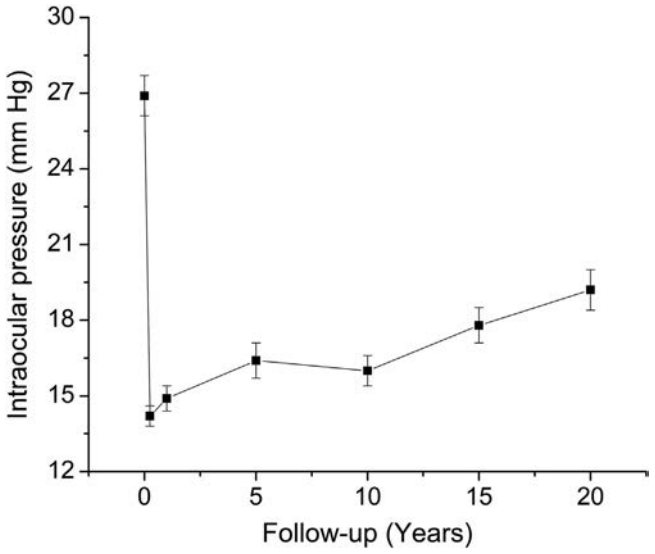

Figure 1. Line graph showing postoperative intraocular pressure distribution at 5-year intervals in primary congenital glaucoma. Results represent mean ± standard error of the mean.

eyes (n = 57 [25.9%]) showed normal corneal transparency, and the decision for surgery in these eyes was based on high IOP, enlarged corneal diameter, and gonioanamoly suggestive of developmental glaucoma. One hundred twenty eyes (54.5%) showed varying degrees of corneal edema. Of these, 51 eyes (42.5%) showed clear corneas at the last follow-up visit. Forty-three eyes (19.5%) showed corneal scarring. Of the eyes with preoperative corneal edema, 51 eyes (23.2%) showed a clear cornea at the last visit (P = 0.0003). Overall, one-half of the eyes (n = 100 [45.4%]) showed normal corneal transparency at the last visit. At the final follow-up visit, 46 eyes (20.9%) showed corneal scarring. The preoperative and postoperative clinical photographs of congenital, infantile, and juvenile-onset developmental glaucoma are depicted in Figure 2.

Visual Acuity

Overall, the proportion of eyes with good visual outcome was 73 (33.2%), the proportion of those with fair visual outcome was 36 (16.4%), and the proportion of those poor visual outcome was 111 (50.4%). We found no significant difference in the proportion of eyes with good visual outcome across the 3 subtypes of PCG ($P > 0.05$). However, when we assessed the visual outcomes by laterality, we found that the proportion of those with good visual outcome among the bilaterally affected PCG eyes was significantly greater than among those with unilaterally affected eyes (P = 0.02). Glaucomatous optic atrophy followed by corneal scar from Haab striae resulting in meridional amblyopia (resulting from high irregular astigmatism) were the leading causes of poor visual outcome.

Refractive Errors

Refractive status assessment was available for 103 eyes at the last follow-up (46.8%). The mean ± SD SE was −3.93 ± 4.38 D, and 36 eyes (34.9%) had high myopia (SE ≥ 6 D). The median SE was −2.00 D at the last follow-up visit. Overall, 71 eyes (68.9%) demonstrated myopia ranging from −0.50 to −18.75 D. Twelve eyes demonstrated hyperopia ranging from 0.50 to 18.00 D. Of these, 8 eyes demonstrated hyperopia of between 0.50 and 2.50 D, 4 eyes demonstrated hyperopia of between 3.50 and 6 D, and 2 eyes demonstrated hyperopia of 7 D and 18.00 D (both were phakic). The high hyperopia was the result of corneal scar and a flatter cornea.

Cup-to-Disc Ratio and Visual Field Findings

Cup-to-disc ratio could be assessed in 163 eyes (67.3%). Of these, 69 eyes (42.3%) showed mild, 52 eyes (31.9%) showed moderate, and 42 eyes (25.8%) showed severe degree of changes in the cup-to-disc ratio. Visual field testing was possible in 165 eyes (68.2%), but the data were not available for 40 eyes. Visual field data were unreliable for 21 eyes, and the final VF data were analyzed for 104 eyes. Thirty-nine eyes (37.5%) showed mild VF loss, 39 eyes (37.5%) showed moderate VF loss, and 36 eyes (34.6%) showed severe VF loss.

Surgical Success

For the entire cohort, Kaplan−Meier curves illustrated that, overall (complete success [Fig 3A] and complete plus qualified success [Fig 3B]), surgical success declined from 89.1% and 91.8% at 1 year to 76.8% and 80.9% at 10 years and to 43.1% and 64.0% at 20 years. Overall, complete success was achieved in 80 eyes (36.4%), and complete plus qualified success was achieved in 132 eyes (60.0%). The success rates at different follow-up visits for complete and complete plus qualified success are provided in Table 2. The success rate was not significantly different across the 3 PCG subtypes. At the 20-year follow-up, complete surgical success was 40%, 36.9%, and 31.7% in the neonatal, infantile, and late-onset groups, respectively.

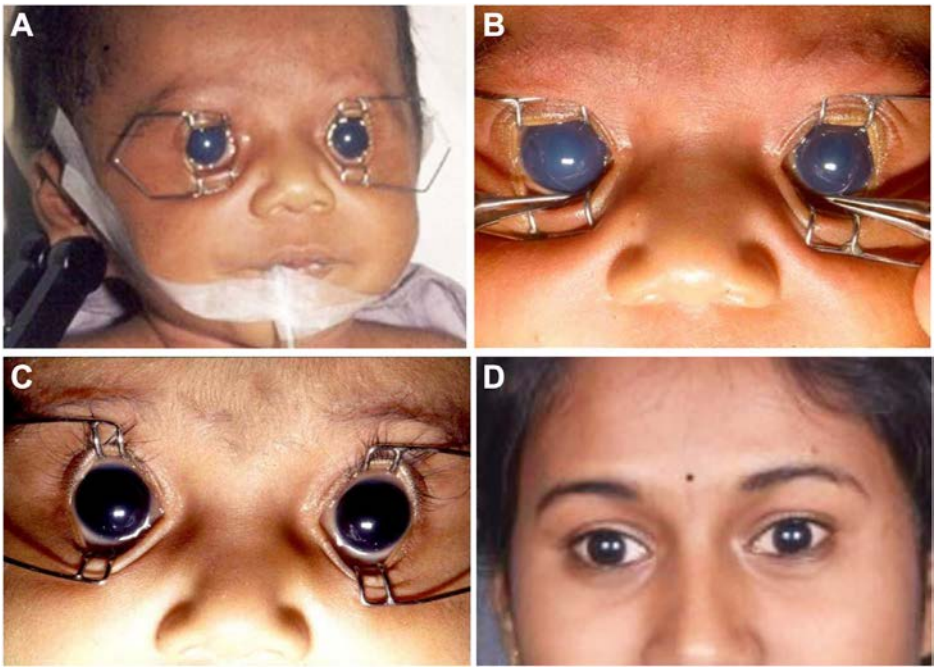

Figure 2. Photographs showing appearance of a patient with bilateral congenital glaucoma (**A**, **B**) before surgery and (**C**) 6 months after surgery who underwent surgery at 2 weeks of age and (**D**) the long-term postoperative (27 years) appearance of the cornea showing normal corneal transparency. Informed consent was obtained from all patients to include these images.

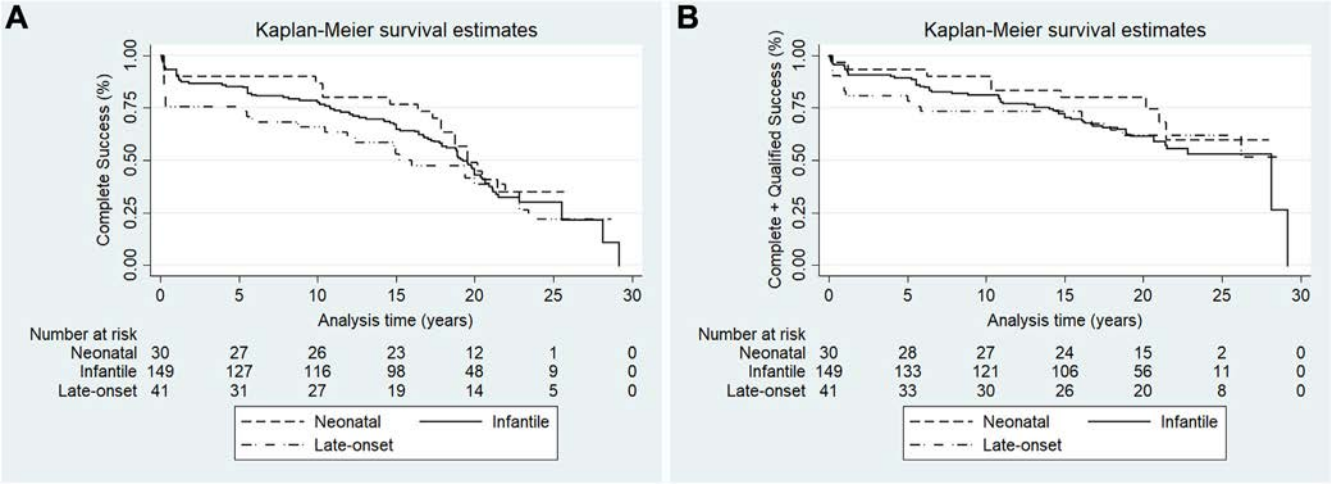

Figure 3. **A**, Kaplan–Meier survival analysis of the entire cohort showing probability of complete success for 3 subtypes (neonatal, infantile, and late onset) of primary congenital glaucoma (n = 220 eyes). Note no statistically significant difference was found in the success rates across the subtypes ($P = 0.63$). **B**, Kaplan–Meier survival analysis of the entire cohort showing probability of complete plus qualified success for 3 subtypes (neonatal, infantile, and late onset) of primary congenital glaucoma (n = 220 eyes). Note no statistically significant difference was found in the success rates across the subtypes ($P = 0.51$).

Additionally, complete plus qualified surgical success was 70%, 57.7%, and 61% in the neonatal, infantile, and late-onset groups, respectively.

In those eyes that underwent CTT as the primary surgical procedure, Kaplan–Meier curves illustrated that, overall (complete success [Fig 4A] and complete plus qualified success [Fig 4B]), surgical success declined from 90.7% and 93.3% at 1 year to 78.9% and 83.0% at 10 years and to 44.5% and 66.6% at 20 years. Overall, complete success was achieved in 113 eyes (58.2%), and complete plus qualified success was achieved in 133 eyes (68.6%). The success rates at different follow-up visits for complete and complete plus qualified success are provided in Table 2. The complete and complete plus qualified success rates were not significantly different across the 3 PCG subtypes. At the 20-year follow-up, complete surgical success was 48.8%,

Table 2. Surgical Success Rates of Patients with Primary Congenital Glaucoma at 5-Year Intervals

Visit Duration (yrs)	Entire Cohort	
	Success Rate % (95% CI)	
	Complete	*Complete + Qualified*
0.25	92.7 (88.4, 95.5)	95.0 (91.2, 97.2)
1	89.1 (84.2, 92.6)	91.8 (87.3, 94.8)
5	83.6 (78.1, 87.9)	87.7 (82.6, 91.4)
10	76.8 (70.2, 81.4)	80.9 (75.1, 85.5)
15	65.3 (58.6, 71.2)	72.6 (66.2, 78.0)
20	43.1 (36.1, 49.8)	64.0 (57.1, 70.1)

Visit Duration (yrs)	Primary Combined Trabeculotomy-Trabeculectomy	
	Success Rate % (95% CI)	
	Complete	*Complete + Qualified*
0.25	92.8 (88.1, 95.7)	95.4 (91.3, 97.6)
1	90.7 (85.7, 94.1)	93.3 (88.7, 96.1)
5	85.6 (79.8, 89.8)	89.7 (84.5, 93.2)
10	78.9 (72.4, 84.0)	83.0 (76.9, 87.6)
15	67.9 (60.8, 74.0)	74.1 (67.3, 79.7)
20	44.5 (37.0, 51.7)	66.6 (59.3, 72.9)

CI − confidence interval

42.9%, and 48.8% in the neonatal, infantile, and late-onset groups, respectively. Additionally, complete plus qualified surgical success rates were 80.0%, 62.0%, and 77.5% in the neonatal, infantile, and late-onset groups, respectively.

Risk Factors

In univariable analysis of the entire cohort (Table 3), the surgical failure rate was higher among patients who underwent any additional nonglaucoma intraocular surgery (HR, 2.92; 95% CI, 1.76−4.85; $P < 0.0001$). When adjusted for intereye correlation with factors such as age at surgery, sex, laterality, baseline IOP, PCG severity, baseline HCD, baseline corneal clarity, and additional intraocular surgery in survival analyses, none of these factors were associated significantly with failure in the multivariable analysis. The results remained unchanged when the CTT group was analyzed separately (data not shown).

In the Cox multivariable model of the entire cohort (Table 4), predictors of poor visual outcome (VA worse than 1.00 logMAR) were male sex (HR, 0.60; 95% CI, 0.41−0.86; $P = 0.006$), bilateral affliction (HR, 0.52; 95% CI, 0.31−0.87; $P = 0.01$), presence of corneal edema at presentation (HR, 0.45; 95% CI, 0.27−0.72; $P < 0.001$), preoperative IOP (HR, 1.04; 95% CI, 1.02−1.06; $P < 0.0001$), and any additional nonglaucoma intraocular surgery (HR, 2.41; 95% CI, 1.51−3.85; $P < 0.001$). The results remained unchanged when the CTT group was analyzed separately (data not shown).

Additional Glaucoma and Nonglaucoma Surgeries

Of the patients who underwent primary CTT (194 eyes of 97 patients), 28 patients (28 eyes [14.4%]) required a second glaucoma procedure for control of IOP over the course of follow-up. The details are provided in Figure 5. Of these 28 patients, 2 patients (2 eyes) required a third glaucoma procedure; 1 eye of each underwent trabeculectomy and TSCPC. Trabeculectomy with or without MMC and TSCPC were the commonly performed additional glaucoma procedures in the cohort. Twenty-nine eyes (13.2%) underwent nonglaucoma surgeries such as

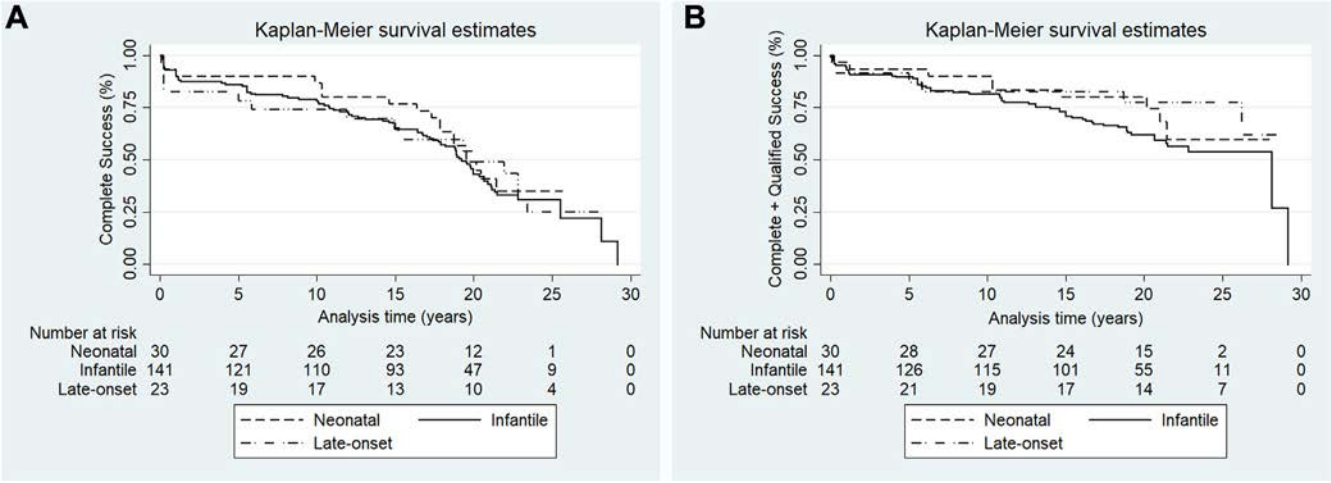

Figure 4. A, Kaplan−Meier survival analysis showing probability of complete success for 3 subtypes (neonatal, infantile, and late onset) of primary congenital glaucoma who underwent primary combined trabeculotomy−trabeculectomy (n = 194 eyes). Note that no statistically significant difference was found in the success rates across the subtypes ($P = 0.82$). **B**, Kaplan−Meier survival analysis showing the probability of complete plus qualified success for 3 subtypes (neonatal, infantile, and late onset) of primary congenital glaucoma who underwent primary combined trabeculotomy−trabeculectomy (n = 194 eyes). Note that no statistically significant difference was found in the success rates across the subtypes ($P = 0.17$).

Table 3. Results of Cox Proportional Hazards Analysis for Assessing Risk Factors on the Survival Estimates of Complete Success

Variable	Bivariate Analysis	
	P Value	Hazard Ratio ± Robust Standard Error (95% Confidence Interval)
Age at surgery (mos)	0.70	0.999 ± 0.003 (0.994–1.004)
Age at surgery (neonatal, infantile, late-onset PCG)	0.44	1.16 ± 0.22 (0.80–1.67)
Sex (male)	0.13	0.73 ± 0.15 (0.49–1.09)
Laterality	0.29	1.36 ± 0.39 (0.77–2.38)
Preoperative IOP*	0.17	1.01 ± 0.01 (0.99–1.04)
Preoperative IOP > 35 mmHg	0.56	1.18 ± 0.32 (0.69–2.01)
PCG severity	0.22	1.23 ± 0.21 (0.88–1.73)
Preoperative horizontal corneal diameter	0.61	1.05 ± 0.09 (0.88–1.24)
Preoperative corneal edema	0.34	0.80 ± 0.19 (0.50–1.27)
Any additional surgery	**< 0.0001**	2.92 ± 0.76 (1.76–4.85)

IOP = intraocular pressure; PCG = primary congenital glaucoma.
Boldface values indicate statistical significance.
*Continuous variable.

penetrating keratoplasty for persistent corneal edema (12 eyes [41.4%]), cataract surgery with intraocular lens implantation (8 eyes [27.6%]), Descemet's stripping endothelial keratoplasty (DSEK) (1 eye [3.4%]), pars plana lensectomy with vitrectomy (1 eye [3.4%]), and evisceration (7 eyes [24.1%]).

Complications

Early postoperative complications were encountered in 26 of 194 eyes (13.4%) that underwent primary CTT. These included shallow anterior chamber (AC; 8 eyes) and hyphema (12 eyes). Four eyes with shallow AC required surgical reformation of the AC, and in the remaining 4 eyes, the AC deepened spontaneously. None of the eyes required surgical drainage of the postoperative hyphema. No sight-threatening intraoperative complications occurred during primary CTT. However, 1 patient experienced expulsive choroidal hemorrhage during the second intervention (penetrating keratoplasty) and required evisceration. Six eyes required evisceration because of painful blind eye secondary to absolute glaucoma. One eye demonstrated choroidal detachment that was managed successfully conservatively. Rhegmatogenous retinal detachment occurred in 2 highly myopic eyes and both underwent vitreoretinal procedures.

Anesthetic Complications

Apnea occurred in 6 patients (4.9%) who were resuscitated successfully. An anesthetic complication in the form of bleeding from the trachea occurred in one patient. This was observed during the recovery phase from anesthesia and was managed successfully. The most serious anesthetic complication was cardiopulmonary arrest that occurred 5 hours after surgery, after aspiration and during feeding in 1 child who could not be resuscitated. Two children demonstrated delayed recovery (2 and 4 hours) because of prematurity (weight at surgery was 2.2 and 2.3 kg, respectively). Both children were shifted to the pediatric intensive care unit. The

Table 4. Results of Cox Proportional Hazards Analysis for Assessing Risk Factors for Poor Visual Outcome*

Variable	Bivariate Analysis		Multivariable Analysis	
	P Value	HR ± Robust SE (95% CI)	P Value	HR ± robust SE (95% CI)
Age at surgery (mos)	0.65	1.001 ± 0.002 (0.997–1.006)		NI
Type of glaucoma (neonatal/infantile/late onset)	0.11	1.41 ± 0.30 (0.92–2.15)		NI
Male sex	**0.02**	0.65 ± 0.12 (0.45–0.94)	**0.006**	0.60 ± 0.11 (0.41–0.86)
Laterality	**0.03**	0.63 ± 0.13 (0.41–0.96)	0.01	0.52 ± 0.14 (0.31–0.87)
Preoperative IOP	**< 0.0001**	1.05 ± 0.01 (1.02–1.07)	**< 0.001**	1.04 ± 0.01 (1.02–1.06)
Disease severity	**0.07**	1.45 ± 0.29 (0.97–2.16)		NI
Preoperative horizontal corneal diameter	**0.005**	1.24 ± 0.10 (1.07–1.44)	0.15	Step 1 elimination
Preoperative corneal edema	**0.007**	0.54 ± 0.12 (0.35–0.85)	**< 0.001**	0.45 ± 0.11 (0.27–0.72)
Any additional surgery	**0.007**	1.91 ± 0.46 (1.20–3.06)	**< 0.001**	2.41 ± 0.58 (1.51–3.85)

CI = confidence interval; HR = hazard ratio; IOP = intraocular pressure; NI = not included; SE = standard error.
Boldface values indicate statistical significance.
*Visual acuity worse than 1.00 logarithm of the minimum angle of resolution.

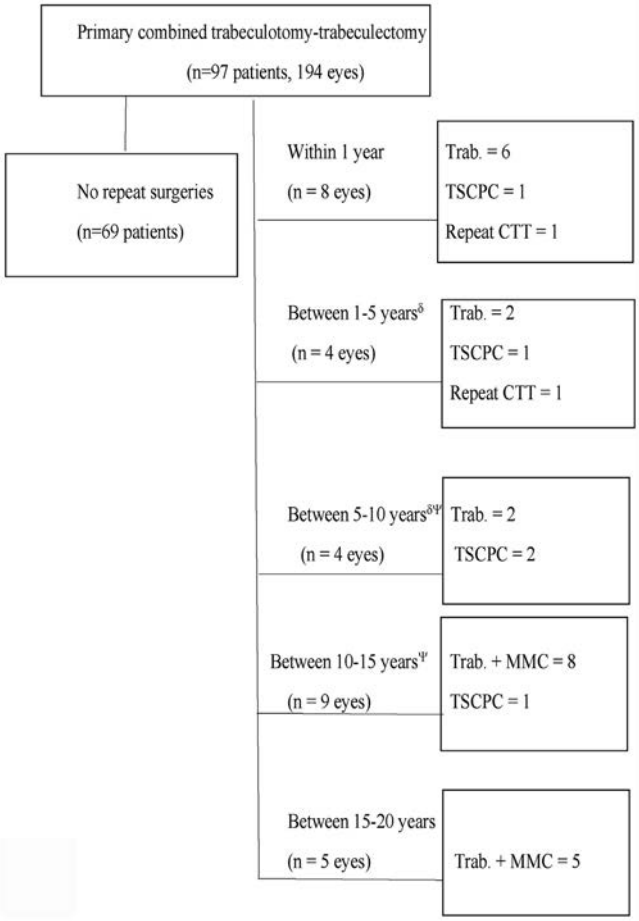

Figure 5. Flowchart showing distribution of additional glaucoma surgeries (n = 28 patients) over the entire follow-up period in the study for only those who underwent primary combined trabeculotomy–trabeculectomy (n = 97 patients [194 eyes]). Two patients underwent repeated surgeries: $^{\delta}$one at the 5-year and 10-year follow-up and the other at the $^{\Psi}$10-year and 15-year follow-up. The timeline is shown in years in chronological order. CTT = combined trabeculotomy–trabeculectomy; MMC = mitomycin C; TSCPC = transscleral cyclophotocoagulation; Trab = trabeculectomy.

child with a 2-hour delayed recovery responded well and completed 20 years of follow-up; the other child died 48 hours later.

Discussion

Our results from this large Asian cohort study of children with PCG operated during early infancy and followed up for at least 20 years at a single tertiary eye care center indicate that good surgical success can be achieved in the long term by modern microsurgical technique in these patients. The major highlight of the present study was that long-term IOP control (< 21 mmHg) could be achieved with a first glaucoma procedure in most patients with PCG (36.4% without medication and 60.0% if medication was added). This finding is in accordance with published literature regarding the fact that the chances of success are highest with the first surgical procedure in children with PCG.[1,7] Some authors have reported use of antifibrotic agents such as MMC during the initial glaucoma surgery to improve the success rate.[47,48] As mentioned previously, it is not a standard practice in our center to use antifibrotic agents during primary glaucoma surgery, given the potential for bleb-related complications and hypotony in these young children over their lifetimes.[4] Based on our results, we believe that primary CTT can be considered as the initial glaucoma procedure in children with PCG, even without using any antifibrotic agent. It should be noted that, in 19 patients (15.7%), CTT could not be performed given the inability to locate the Schlemm's canal. Consequently, only trabeculectomy was performed as the initial procedure in these patients. Theoretically, this conversion may have impacted the surgical success rate adversely. However, separate analysis of the success rate for the CTT group did not reveal any significant difference from the entire cohort. Perhaps the smaller number of the patients who underwent trabeculectomy and TSCPC compared with the CTT group could explain the lack of significant difference in the success rates. Recently, Khairy et al,[49] in a triple-armed randomized controlled trial, demonstrated that CTT is a useful procedure without the need for augmentation and that augmented procedures should be reserved for patients with recalcitrant disease.

Superior results of CTT compared with angle surgeries have been reported from other Asian and Middle Eastern countries.[49–54]

Owing to the rarity of PCG, only a limited number of long-term studies have been published, and, therefore, possible comparisons among studies are limited (Table S5, available at www.aaojournal.org). To the best of our knowledge, long-term surgical results in children with PCG beyond a mean follow-up of 20 years are scarce.[55,56] The study by de Silva et al[55] had a mean follow-up of 33.8 years, and the study by Sood et al[56] had a mean follow-up of 28.8 years. The present study is the only third such study with a mean follow-up of more than 20 years (mean, 21.3 years). However, a few studies have had a maximum follow-up of more than 20 years.[13,57–59] In a review spanning a 30-year period of PCG treated by goniotomy, Russell-Eggitt et al[15] reported higher surgical success in patients whose symptoms developed in first 3 months of life compared with those whose symptoms developed at birth. They reported that eyes continued to relapse over the 30-year period, but the number of eyes followed up over 10 years was very low, making statistical analysis and comparisons inappropriate.

In the present study, using CTT as the primary procedure, we did not find a significant variation in the success rate among the 3 subtypes of PCG (Fig 4A, B). This is not a novel finding given that similar observations have been reported by us earlier.[29] The clinical manifestations of PCG in an Asian population tend to be more advanced because of the high rate of consanguinity, genetic basis, and delay in accessing care.[34,47,60] In the present series, 22% of the children showed neonatal-onset PCG with severe phenotypical manifestations at presentation. However, most of the patients in our study (58%) demonstrated infantile-onset PCG at presentation. It is well established that neonatal-onset PCG tends to have a relatively poor prognosis.[15,54] In patients with neonatal-onset glaucoma, the collector channels and the aqueous veins needed to carry the aqueous to the episcleral veins are more likely to be anomalous,[61–63] in addition to the primary pathologic feature of trabeculodysgenesis. This poorly functioning distal outflow system perhaps contributes to worse surgical outcomes of goniotomy or trabeculotomy in early-onset PCG. The addition of trabeculectomy to trabeculotomy as has been performed in the present series has the advantages of a dual-outflow pathway to ensure better drainage of aqueous and normalization of IOP.[5,47,56,64]

Primary congenital glaucoma is difficult to treat, and patients often require multiple procedures during their lifetime for control of IOP.[1,7,15,27,65] The present study bears significance, given its very long-term mean follow-up of over 20 years (median, 21 years). It is of note that most of our patients (60%) achieved good IOP control with a single surgical procedure over the course of the long-term follow-up. The distribution of patients who underwent repeat glaucoma procedures in the CTT group is depicted in the flow chart (Fig 5). Twenty-eight patients (28 eyes) required a second glaucoma procedure for control of IOP over the course of follow-up. Of these, 2 patients underwent a third glaucoma procedure: one of them at the 5-year and 10-year follow-up and the other at the 10-year and 15-year follow-up. The steady decline in success rate over time in the present study is in agreement with several other studies worldwide.[31,32,55,56,59,66–68] These results highlight the need for long-term dedicated follow-up in children with PCG to identify the time for further surgical intervention. It should be borne in mind that glaucoma progression may occur even after several years of good IOP control and quiescence. In cases of repeat surgery, we performed MMC-augmented trabeculectomy, and this provided improved outcomes.[30,45] We did not perform glaucoma drainage implantation in this series of patients during the observation period, but it was been added later to the armamentarium of surgical methods for treatment of refractory congenital glaucoma.[69] However, we performed TSCPC for patients with refractory cases whose visual potential was poor, and some patients with refractory cases required multiple sessions of TSCPC. In the present study, the need for any additional intraocular surgery such as cataract surgery or vitreoretinal procedures was a risk factor for surgical failure in univariable analysis. However, this was not observed in the multivariable analysis.

One of the aims of our study was to assess the long-term visual outcomes in patients who underwent surgery for PCG. Good visual outcomes are linked to better quality of life.[35,70] Precise assessment of VA is technically challenging for infants in the preoperative period. For this reason, we did not have measurements of preoperative VA for comparison; rather, we analyzed the VA outcomes at the last follow-up. Visual outcomes differ across different regions of the world in patients with PCG, and this variation can be attributed to the severity of the disease, age at onset, type of surgical intervention, delay in presentation, overall level of IOP control, and length of follow-up. In accordance with previous studies having longer follow-up[32,55,56,66,71] (mean, 10 years) that reported a larger proportion of eyes with poorer VA, we also found a similar trend. This finding in our study could be attributed to the late presentation and longer duration of follow-up coupled with clinical factors such as amblyopia and glaucomatous optic atrophy. One-third of the eyes (33.2%) maintained good VA at the end of the 20-year follow-up. This result is better than that reported from the North India, where the overall probability of having a VA of 20/60 or better declined to only 5% after 30 years.[66] de Silva et al[55] followed up 16 patients (30 eyes) for $>$ 20 years and reported VA of better than 20/60 in 45% of the eyes. Furthermore, they attributed glaucomatous progression as one of the main causes of poor outcomes.[55] In a large series reported by Shaffer,[13] 577 goniotomies were performed over 40 years, and 287 of these patients were followed up for long enough to assess success rate. However, VA results were available for only 52 eyes, and VA of 20/40 or better was achieved in 28 eyes (53.8%).

Visual field data were analyzed for almost one-half of the eyes (47%). We found generalized reduction of sensitivity in most eyes with PCG using automated perimetry.

However, de Souza et al[72] and O'Reilly et al[73] reported localized VF defects in 37% and 28% of eyes, respectively.

Data on refractive status at the last follow-up visit were available for 103 eyes (46.8%). Most patients (68.9%) showed myopia ranging from −0.50 to −18.75 D. The mean ± SD SE was −3.93 ± 4.38 D, and 36 eyes (34.9%) demonstrated high myopia (SE ≥ 6 D). Twelve eyes demonstrated hyperopia ranging from 0.50 to 18.00 D. These results are in accordance with our previous reports of long-term follow-up outcomes of PCG[4,5] as well as with results reported by Sood et al[56] from India. Often, despite a timely surgical intervention, the visual prognoses of patients with PCG are quite poor, especially if accompanied by amblyopia. Therefore, correction of refractive errors using glasses along with occlusion treatment are important to improve vision in such patients.[71,74]

It was encouraging to note no intraoperative complications in our study. However, expulsive choroidal hemorrhage occurred in 1 eye of a child while undergoing penetrating keratoplasty. Adverse events in the form of serious anesthesia-related complications occurred in 2 children resulting in their death, and this was documented in our earlier report.[75] Although the surgical technique is different, the long-term complications of the present series are comparable with those reported by Litinsky et al[76] and Shaffer.[13] The treating ophthalmologist ought to bear in mind the long-term complications as well as the long-term drift in IOP control when counseling the parents before surgery.

Our study has several strengths. First, to our knowledge, this study included the largest cohort of patients with PCG who underwent surgery and were followed up for at least 20 years by the same surgeon at a single tertiary eye care center. Thus, this study provides a unique and realistic view of the outcomes of primary CTT in PCG. Second, this study provided the visual and refractive outcomes over a 20-year period. However, the study has some limitations. As with any long-term follow-up study, we encountered increasing losses to follow-up over time. Therefore, our long-term results (such as VA) may be influenced by factors related to this dropout rate. For example, if patients who had good VA (20/40 or better) and were doing well but failed to attend a follow-up visit, our survival estimates may be lower than actual rates. Other limitations include the nonrandomized, retrospective design and the variability in the timing of the surgery that depended on the clearance for anesthesia and variability in the age at presentation. Also, the lack of serial measurements of axial length in the follow-up assessments is an important consideration. Finally, the relatively uniform population of patients with PCG from a phenotypic and genetic basis in our study should be borne in mind, such that these results may not be applicable widely to patients with PCG in other parts of the world.

In conclusion, we found primary CTT to be a useful procedure in a large cohort of patients with PCG. It provided good IOP control and moderate visual outcomes that remained over a long term (up to 20 years after surgery), which is encouraging for parents of children with PCG who are considering whether their children should undergo the procedure. Although not frequent, the need for repeat surgery in the long term should be borne in mind by both the glaucomatologists as well as the parents of children with PCG. This study contributes to the scant literature on long-term surgical outcomes of a pure cohort of patients with PCG. Surgical management of these complex eyes with PCG often is challenging and requires an experienced surgical and multidisciplinary team to maximize the chance of surgical success and good long-term visual outcomes.

Footnotes and Disclosures

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AUTHOR CONTRIBUTIONS:

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Analysis and interpretation: Mandal, Gothwal, Mohamed

Data collection: Mandal, Gothwal

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Abbreviations and Acronyms:
AC = anterior chamber; **CI** = confidence interval; **CTT** = combined trabeculotomy−trabeculectomy; **D** = diopter; **HR** = hazard ratio; **IOP** = intraocular pressure; **logMAR** = logarithm of the minimum angle of resolution; **MMC** = mitomycin C; **PCG** = primary congenital glaucoma; **SD** = standard deviation; **SE** = spherical equivalent; **TSCPC** = transscleral cyclophotocoagulation; **VA** = visual acuity; **VF** = visual field.

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References

1. Mandal AK, Chakrabarti D. Update on congenital glaucoma. *Indian J Ophthalmol*. 2011;59(Suppl):S148−S157.
2. Hoguet A, Grajewski A, Hodapp E, Chang TC. A retrospective survey of childhood glaucoma prevalence according to Childhood Glaucoma Research Network classification. *Indian J Ophthalmol*. 2016;64:118−123.
3. Senthil S, Badakere S, Ganesh J, et al. Profile of childhood glaucoma at a tertiary center in South India. *Indian J Ophthalmol*. 2019;67:358−365.
4. Mandal AK, Gothwal VK, Khanna R. Combined trabeculotomy-trabeculectomy for primary congenital glaucoma: long-term experience from a tertiary referral centre in a developing nation. *Acta Ophthalmol*. 2022;100(2):e439−e447. https://doi.org/10.1111/aos.14984. Epub 2021 Jul 28.
5. Mandal AK, Gothwal VK, Nutheti R. Surgical outcome of primary developmental glaucoma: a single surgeon's long-term experience from a tertiary eye care centre in India. *Eye (Lond)*. 2007;21:764−774.
6. Pedersen KB, Kappelgaard P, Kessel L, et al. Primary congenital glaucoma in Denmark, 1977−2016. *Acta Ophthalmol*. 2020;98:182−189.
7. deLuise VP, Anderson DR. Primary infantile glaucoma (congenital glaucoma). *Surv Ophthalmol*. 1983;28:1−19.
8. Dandona L, Williams JD, Williams BC, Rao GN. Population-based assessment of childhood blindness in southern India. *Arch Ophthalmol*. 1998;116:545−546.
9. Kaur K, Mandal AK, Chakrabarti S. Primary congenital glaucoma and the involvement of CYP1B1. *Middle East Afr J Ophthalmol*. 2011;18:7−16.
10. Barkan O. Surgery of congenital glaucoma; review of 196 eyes operated by goniotomy. *Am J Ophthalmol*. 1953;36:1523−1534.
11. Lister A. The prognosis in congenital glaucoma. *Trans Ophthalmol Soc U K*. 1966;86:5−18.
12. Rice N. The surgical management of the congenital glaucomas. *Aust J Ophthalmol*. 1977;5:174−179.
13. Shaffer RN. Prognosis of goniotomy in primary infantile glaucoma (trabeculodysgenesis). *Trans Am Ophthalmol Soc*. 1982;80:321−325.
14. Shaffer RN, Hoskins HD. Montgomery lecture. Goniotomy in the treatment of isolated trabeculodysgenesis (primary congenital [infantile] developmental glaucoma). *Trans Ophthalmol Soc U K*. 1983;103(Pt 6):581−585.
15. Russell-Eggitt IM, Rice NS, Jay B, Wyse RK. Relapse following goniotomy for congenital glaucoma due to trabecular dysgenesis. *Eye (Lond)*. 1992;6(Pt 2):197−200.
16. Harms H, Dannheim R. Epicritical consideration of 300 cases of trabeculotomy 'ab externo.'. *Trans Ophthalmol Soc U K*. 1970;89:491−499.
17. Luntz MH, Livingston DG. Trabeculotomy ab externo and trabeculectomy in congenital and adult-onset glaucoma. *Am J Ophthalmol*. 1977;83:174−179.
18. Luntz MH. Congenital, infantile, and juvenile glaucoma. *Ophthalmology*. 1979;86:793−802.
19. Quigley HA. Childhood glaucoma: results with trabeculotomy and study of reversible cupping. *Ophthalmology*. 1982;89:219−226.
20. Luntz MH. The advantages of trabeculotomy over goniotomy. *J Pediatr Ophthalmol Strabismus*. 1984;21:150−153.
21. McPherson Jr SD, Berry DP. Goniotomy vs external trabeculotomy for developmental glaucoma. *Am J Ophthalmol*. 1983;95:427−431.
22. Esfandiari H, Basith SST, Kurup SP, et al. Long-term surgical outcomes of ab externo trabeculotomy in the management of primary congenital glaucoma. *J AAPOS*. 2019;23:222 e1−222 e5.
23. Girkin CA, Rhodes L, McGwin G, et al. Goniotomy versus circumferential trabeculotomy with an illuminated microcatheter in congenital glaucoma. *J AAPOS*. 2012;16:424−427.
24. Mendicino ME, Lynch MG, Drack A, et al. Long-term surgical and visual outcomes in primary congenital glaucoma: 360 degrees trabeculotomy versus goniotomy. *J AAPOS*. 2000;4:205−210.
25. Neustein RF, Beck AD. Circumferential trabeculotomy versus conventional angle surgery: comparing long-term surgical success and clinical outcomes in children with primary congenital glaucoma. *Am J Ophthalmol*. 2017;183:17−24.
26. Temkar S, Gupta S, Sihota R, et al. Illuminated microcatheter circumferential trabeculotomy versus combined trabeculotomy-trabeculectomy for primary congenital glaucoma: a randomized controlled trial. *Am J Ophthalmol*. 2015;159:490−497 e2.
27. Mandal AK. Current concepts in the diagnosis and management of developmental glaucomas. *Indian J Ophthalmol*. 1993;41:51−70.
28. Mandal AK, Bhatia PG, Bhaskar A, Nutheti R. Long-term surgical and visual outcomes in Indian children with developmental glaucoma operated on within 6 months of birth. *Ophthalmology*. 2004;111:283−290.
29. Mandal AK, Gothwal VK, Bagga H, et al. Outcome of surgery on infants younger than 1 month with congenital glaucoma. *Ophthalmology*. 2003;110:1909−1915.
30. Mandal AK, Naduvilath TJ, Jayagandan A. Surgical results of combined trabeculotomy-trabeculectomy for developmental glaucoma. *Ophthalmology*. 1998;105:974−982.
31. Kessel L, Pedersen KB, Siersma V, et al. Long-term success after trabeculotomy in primary congenital glaucoma—a study with up to 35 years follow-up. *Acta Ophthalmol*. 2021;99:362−368.
32. Yassin SA, Al-Tamimi ER. Surgical outcomes in children with primary congenital glaucoma: a 20-year experience. *Eur J Ophthalmol*. 2016;26:581−587.
33. Ghate D, Wang X. Surgical interventions for primary congenital glaucoma. *Cochrane Database Syst Rev*. 2015;1:CD008213.
34. Mandal AK, Sulthana SS, Gothwal VK. Primary congenital glaucoma: trends in presentation over 3 decades at a tertiary eye care center in India. *J Glaucoma*. 2020;29:1095−1100.
35. Gothwal VK, Seelam B, Mandal AK. Quality of life following surgery for congenital glaucoma: findings of the LVPEI congenital glaucoma registry. *Eye (Lond)*. 2019;33:659−667.
36. Beck A, Chang TCP, Freedman S. Definition, classification, differential diagnosis. In: Weinreb R, Grajewski A, Papadopoulos M, et al., eds. *Childhood Glaucoma: The 9th*

Consensus Report of the World Glaucoma Association. Amsterdam: Kugler; 2013:3–10.
37. Thau A, Lloyd M, Freedman S, et al. New classification system for pediatric glaucoma: implications for clinical care and a research registry. *Curr Opin Ophthalmol*. 2018;29:385–394.
38. Panicker SG, Mandal AK, Reddy AB, et al. Correlations of genotype with phenotype in Indian patients with primary congenital glaucoma. *Invest Ophthalmol Vis Sci*. 2004;45:1149–1156.
39. Sihota R, Selvan H, Sharma A, et al. Severity of visual field defects in primary congenital glaucoma and their risk factors. *Graefes Arch Clin Exp Ophthalmol*. 2020;258:1483–1491.
40. Anderson DR. *Automated Static Perimetry*. St. Louis, MO: Mosby; 1992.
41. Hodapp E, Parrish RKI. *Clinical Decisions in Glaucoma*. St. Louis, MO: Mosby-Year Book; 1993.
42. Sponsel WE, Arango S, Trigo Y, Mensah J. Clinical classification of glaucomatous visual field loss by frequency doubling perimetry. *Am J Ophthalmol*. 1998;125:830–836.
43. Sponsel WE, Ritch R, Stamper R, et al. Prevent Blindness America visual field screening study. The Prevent Blindness America Glaucoma Advisory Committee. *Am J Ophthalmol*. 1995;120:699–708.
44. Mandal AK, Prasad K, Naduvilath TJ. Surgical results and complications of mitomycin C-augmented trabeculectomy in refractory developmental glaucoma. *Ophthalmic Surg Lasers*. 1999;30:473–480.
45. Mandal AK, Walton DS, John T, Jayagandan A. Mitomycin C-augmented trabeculectomy in refractory congenital glaucoma. *Ophthalmology*. 1997;104:996–1001. discussion 1002–1003.
46. Mandal AK, Senthil S. Childhood glaucoma surgery in developing countries. In: Grajewski AL, Bitrian E, Papadopoulos M, Friedman SF, eds. *Surgical Management of Childhood Glaucoma*. Switzerland: Springer; 2018:159–171.
47. Al-Hazmi A, Awad A, Zwaan J, et al. Correlation between surgical success rate and severity of congenital glaucoma. *Br J Ophthalmol*. 2005;89:449–453.
48. Mullaney PB, Selleck C, Al-Awad A, et al. Combined trabeculotomy and trabeculectomy as an initial procedure in uncomplicated congenital glaucoma. *Arch Ophthalmol*. 1999;117:457–460.
49. Khairy MA, Kenawy S, Fawzi KM, Al-Nashar HY. Combined trabeculotomy-trabeculectomy with and without augmentation in primary congenital glaucoma: triple-armed randomized controlled trial. *Int Ophthalmol*. 2023;43(5):1591–1600.
50. Chen TC, Chen PP, Francis BA, et al. Pediatric glaucoma surgery: a report by the American Academy of Ophthalmology. *Ophthalmology*. 2014;121:2107–2115.
51. Essuman VA, Braimah IZ, Ndanu TA, Ntim-Amponsah CT. Combined trabeculotomy and trabeculectomy: outcome for primary congenital glaucoma in a West African population. *Eye (Lond)*. 2011;25:77–83.
52. Gagrani M, Garg I, Ghate D. Surgical interventions for primary congenital glaucoma. *Cochrane Database Syst Rev*. 2020;8:CD008213.
53. Yu Chan JY, Choy BN, Ng AL, Shum JW. Review on the management of primary congenital glaucoma. *J Curr Glaucoma Pract*. 2015;9:92–99.
54. Khairy MA, Kenawy S, Fawzi KM, Al-Nashar HY. Factors affecting final surgical outcome of combined trabeculotomy-trabeculectomy in primary congenital glaucoma. *Clin Ophthalmol*. 2022;16:43–49.
55. de Silva DJ, Khaw PT, Brookes JL. Long-term outcome of primary congenital glaucoma. *J AAPOS*. 2011;15:148–152.
56. Sood D, Rathore A, Sood I, et al. Long-term outcome of combined trabeculotomy-trabeculectomy by a single surgeon in patients with primary congenital glaucoma. *Eye (Lond)*. 2018;32:426–432.
57. Ikeda H, Ishigooka H, Muto T, et al. Long-term outcome of trabeculotomy for the treatment of developmental glaucoma. *Arch Ophthalmol*. 2004;122:1122–1128.
58. Robin AL, Quigley HA, Pollack IP, et al. An analysis of visual acuity, visual fields, and disk cupping in childhood glaucoma. *Am J Ophthalmol*. 1979;88:847–858.
59. Zagora SL, Funnell CL, Martin FJ, et al. Primary congenital glaucoma outcomes: lessons from 23 years of follow-up. *Am J Ophthalmol*. 2015;159:788–796.
60. Debnath SC, Teichmann KD, Salamah K. Trabeculectomy versus trabeculotomy in congenital glaucoma. *Br J Ophthalmol*. 1989;73:608–611.
61. Ramirez JM, Ramirez AI, Salazar JJ, et al. Schlemm's canal and the collector channels at different developmental stages in the human eye. *Cells Tissues Organs*. 2004;178:180–185.
62. Schuman JS, Chang W, Wang N, et al. Excimer laser effects on outflow facility and outflow pathway morphology. *Invest Ophthalmol Vis Sci*. 1999;40:1676–1680.
63. Lewczuk K, Jablonska J, Konopinska J, et al. Schlemm's canal: the outflow 'vessel.'. *Acta Ophthalmol*. 2022;100:e881–e890.
64. Elder MJ, De Cock R. Childhood blindness in the West Bank and Gaza Strip: prevalence, aetiology and hereditary factors. *Eye (Lond)*. 1993;7(Pt 4):580–583.
65. Biglan AW, Hiles DA. The visual results following infantile glaucoma surgery. *J Pediatr Ophthalmol Strabismus*. 1979;16:377–381.
66. Chaudhary RS, Gupta A, Sharma A, et al. Long-term functional outcomes of different subtypes of primary congenital glaucoma. *Br J Ophthalmol*. 2020;104:1288–1292.
67. Ozawa H, Yamane M, Inoue E, et al. Long-term surgical outcome of conventional trabeculotomy for childhood glaucoma. *Jpn J Ophthalmol*. 2017;61:237–244.
68. Wagner FM, Schuster AK, Grehn F, et al. Twenty-years of experience in childhood glaucoma surgery. *J Clin Med*. 2021;10(24):5720. https://doi.org/10.3390/jcm10245720.
69. Senthil S, Turaga K, Mohammed HA, et al. Outcomes of silicone Ahmed glaucoma valve implantation in refractory pediatric glaucoma. *J Glaucoma*. 2018;27:769–775.
70. Gothwal VK, Sharma S, Mandal AK. Beyond intraocular pressure: visual functioning and quality of life in primary congenital glaucoma and secondary childhood glaucoma. *Am J Ophthalmol*. 2020;209:62–70.
71. Kargi SH, Koc F, Biglan AW, Davis JS. Visual acuity in children with glaucoma. *Ophthalmology*. 2006;113:229–238.
72. de Souza EC, Berezovsky A, Morales PH, et al. Visual field defects in children with congenital glaucoma. *J Pediatr Ophthalmol Strabismus*. 2000;37:266–272.
73. O'Reilly J, Lanigan B, O'Keefe M. Long-term visual results following primary trabeculectomy for infantile glaucoma. *Acta Ophthalmol Scand*. 2001;79:472–475.
74. Khitri MR, Mills MD, Ying GS, et al. Visual acuity outcomes in pediatric glaucomas. *J AAPOS*. 2012;16:376–381.
75. Mandal AK, Bhatia PG, Gothwal VK, et al. Safety and efficacy of simultaneous bilateral primary combined trabeculotomy-trabeculectomy for developmental glaucoma. *Indian J Ophthalmol*. 2002;50:13–19.
76. Litinsky SM, Shaffer RN, Hetherington J, Hoskins HD. Operative complications of goniotomy. *Trans Sect Ophthalmol Am Acad Ophthalmol Otolaryngol*. 1977;83:78–79.