From Conventional Angle Surgery to 360-Degree Trabeculotomy in Pediatric Glaucoma

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• PURPOSE: To describe the transition from conventional angle surgery (CAS), trabeculotomy with rigid probe or goniotomy, to 360-degree trabeculotomy assisted with microcatheter (MCT).
• DESIGN: Retrospective comparative interventional case series.
• METHODS: Review of consecutive children with glaucoma undergoing angle surgery, including cases with previous surgery, from January 2012 until March 2018 at Moorfields Eye Hospital. Main outcome measure was success rate, defined as intraocular pressure (IOP) ≤21 mm Hg with a minimum of 20% of IOP reduction and no further glaucoma surgery (complete success: without the need of glaucoma drops; qualified success: drops were needed to keep the IOP under control).
• RESULTS: Among the 106 eyes (77 patients) included were 54 MCT and 52 CAS eyes. At last visit, after a single surgery, qualified success was 85% (46 eyes) in MCT and 37% (19 eyes) in CAS. Complete success was 69% (37 cases) in MCT and 23% (12 cases) in CAS. The mean (95% confidence interval) change in axial length after surgery was −0.03 mm (−0.34 to 0.40) for MCT and +1.35 mm (−0.64 to 1.62) for CAS ($P < .001$). The percentage of IOP reduction was 52.1% in MCT and 45.5% in CAS ($P = .1616$). Further glaucoma surgery was required in 5.5% (3) in MCT and 63.4% (33) in CAS. At 1 year, 94.3% of MCT cases achieved qualified success compared to 34.6% of CAS ($P < .0001$). No significant complications were found on either group.
• CONCLUSION: MCT achieved better results with significantly lower reoperation rates. The transition from CAS to MCT can be easily achieved, even in difficult cases or those previously operated. (Am J Ophthalmol 2020;219:77–86. Crown Copyright © 2020 Published by Elsevier Inc. All rights reserved.)

CHILDHOOD GLAUCOMA WAS CONSIDERED A devastating disease until Barkan first used the technique of goniotomy in 1938[1] to achieve unprecedented outcomes. Over the years, surgical techniques have been adopted from adult glaucoma surgery, such as glaucoma drainage devices[2] and trabeculectomy.[3] However, conventional angle surgery (CAS), which mainly includes goniotomy and traditional trabeculotomy with rigid Harms probe, has remained part of the surgical repertoire for childhood glaucoma, with similar success between these 2 techniques (especially if repeated), ranging from 47% to 90%.[4–11] The choice between these 2 approaches is mainly based on surgeon preference and corneal clarity. CAS is typically limited to a maximum incision of 120 degrees of the trabecular meshwork at a time, and for this reason, the literature suggests that success is lower compared with a full 360-degree approach.[7] For the same reason, it is often required to repeat CAS to achieve maximum success, necessitating exposing infants to repeated anesthesia, with potential consequences in their neurodevelopment.[12–15]

The idea of probing and opening 360 degrees of Schlemm canal was first described by Smith in 1960.[16] Then in 1988, 360-degree trabeculotomy was first performed in humans by Lynn and associates,[17] using a purse-string suture to incise the whole Schlemm canal; this procedure was further developed by Beck and Lynch.[4] However, this technique is not without some difficulties, mainly related to the nonvisualization of the tip of the suture, which may cause hyphema, iris tear, false passages, misdirection into the subretinal space, and prolonged hypotony, among other problems.[18–21] For this reason, Sarkisian in 2010 described the use of a flexible diode-illuminated microcatheter containing a flashing beacon for angle surgery.[22] This device is visible through the sclera and thus allows accurate location, avoiding some of the aforementioned complications. Despite this fact and the microcatheter-assisted trabeculectomy (MCT) having better outcomes compared with CAS, with success rates ranging from 83% to 91% with a single operation,[7,22–27] goniotomy or trabeculotomy with a rigid probe are still extensively performed as first-line treatment for primary congenital glaucoma (PCG). Large academic centers as

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well as experienced surgeons might feel comfortable with the success of a well-known intervention such as CAS.[28] Against the implementation of 360-degree trabeculotomy with the illuminated microcatheter are arguments of longer surgical time, high cost of the probe (between US$450 and $900),[29] and a longer surgical learning curve in identifying the Schlemm canal for those whose preferred technique was goniotomy. However, the improved results with a single operation and increasing evidence warning about potential risks to neurocognitive development in children following repeated anesthesia,[12–15] along with the introduction of new surgical instruments such as the iTrack microcatheter (Ellex, Fremont, California, USA), have convinced us to change our practice.

Moorfields Eye Hospital has a long tradition with CAS. Arthur Lister implemented it at Moorfields in 1947. He reported success with goniotomy in 63% of 181 patients.[30] His successor Noel Rice published the results of 335 eyes treated at Moorfields and reported a success rate with a single goniotomy of 71%.[31] Over the following years, the Moorfields Pediatric Glaucoma Service continued using goniotomy as first-line treatment for PCG.[32,33] After numerous reports of better outcomes compared to CAS, Moorfields adopted the MCT technique as the first-line surgical treatment for pediatric glaucoma. This publication shows the experience of a tertiary referral center in changing from CAS to MCT. All patients treated with 360-degree illuminated MCT were compared with the most recent consecutive patients having CAS.

METHODS

THIS IS A RETROSPECTIVE, SINGLE-CENTER, MULTIPLE-SURGEON (J.B., M.P., and J.M.N.) comparative interventional case series of consecutive patients with childhood glaucoma undergoing angle surgery, including previously operated cases, from January 2012 until March 2018 at Moorfields Eye Hospital, London, United Kingdom. The first cases underwent goniotomy and conventional trabeculotomy with rigid probe and from October 2013 MCT was gradually introduced as primary angle surgery. All subjects who underwent goniotomy or trabeculotomy were aged 18 years or under and had at least 12 months of follow-up.

This retrospective study adhered to the tenets of the Declaration of Helsinki and was approved by the Clinical Audit Assessment Committee of Moorfields Eye Hospital (271/CA14/GL/33).

The primary outcome was success at last visit, defined as intraocular pressure (IOP) ≤21 mm Hg with a minimum of 20% of IOP reduction, no further glaucoma surgery, and no devastating complications or loss of light perception. Complete success was achieved without the need for glaucoma drops and qualified success was achieved when drops were needed to keep the IOP under control. Patients in the CAS group that required a second CAS were considered a failure at the time the second CAS was required.

Secondary outcomes were complication rates, percentage of IOP reduction, number of medications needed, duration of surgery, and changes in axial length after the surgery.

All patients went through a complete baseline ophthalmologic examination in the pediatric glaucoma clinic that included case and family history, medication usage, IOP measured by Icare rebound tonometry (Icare Finland Oy, Helsinki, Finland), biomicroscopy, gonioscopy, and a fundus evaluation if possible. Axial length measurement was performed (Acuson Sequoia 512; Siemens, Erlangen, Germany) in the first visit and then in the first postoperative follow-up. During the examination under anesthesia (EUA) in theatre, patients went through IOP measurement pre-intubation under ketamine anesthesia with Perkins tonometry (Haag-Streit, Köniz, Switzerland), biomicroscopy with portable slit lamp, gonioscopy, and fundus examination with indirect ophthalmoscope and refraction. Data were obtained from preoperative and postoperative visits at 1, 6, and 12 weeks and at 6 and 12 months. Postoperative reviews included IOP measurements with Icare in clinic or Perkins in theatre, medication usage, slit-lamp examination, and complications. Angle and a fundus evaluation were performed whenever practical.

• **PATIENT SELECTION:** Cases were identified from theatre records between January 2012 and March 2018 searching for any type of angle surgery performed in that period for pediatric patients. We did not exclude cases of secondary glaucoma. Owing to the characteristics of the population referred from all regions in the UK to Moorfields Eye Hospital, some patients were treated surgically but had been followed up in local hospitals. Patients with follow-up less than 1 year are reported to identify complications but are not included in the survival analysis.

• **SURGICAL PROCEDURES:** CAS involved goniotomy or trabeculotomy with Harms probe. Goniotomy was performed through a clear corneal incision using a goniotomy knife. A tapered goniotomy knife was used to maximally incise the angle circumference (up to 120°) and it was preceded by viscoelastic to maintain the anterior chamber. The corneal incision was sutured with an interrupted 10-0 polyglactin 910. Antibiotic and corticosteroids were administered via subconjunctival injection. Topical pilocarpine/antibiotic/steroid regimen was given at a weaning dose for a month.

Trabeculotomy with a rigid probe was performed as follows: a small fornix-based conjunctival flap performed temporally was followed by a half-thickness scleral flap and then a radial incision was carefully deepened over the area of the Schlemm canal (blue-white junction) until it was identified. We try to avoid doing a thin scleral flap to maximize the visualization of the blue-white junction. This

TABLE 1. Clinical Characteristics of Eyes (Patients) Included in This Study

	MCT	CAS	*P*
Eyes	54 (40)	52 (37)	–
Unilateral cases	18	10	.1247
Mean age at surgery (days ± SD)	418 ± 714	245 ± 237	.1176
Male cases	32	28	.6954
Female cases	22	24	–
Baseline IOP (mm Hg ± SD)	30.5 ±7.4	31.8 ±11.9	.9686
Family history	3	10	–
Consanguinity	3	2	–
PCG	51	50	–
Other forms of glaucoma			
GFCS	1	2	–
SWS	1	–	
JOAG	1	–	
Previous surgery	6	7	–
Average preoperative axial length (mm) ± SD	23.3 ± 2.3	22.35 ± 1.9	.03
Average postoperative axial length (mm) ± SD	22.8 ± 1.8	23.3 ± 1.6	.36

CAS = conventional angle surgery (goniotomy or trabeculotomy with rigid probe; IOP = intraocular pressure; MCT = microcatheter-assisted trabeculotomy; PCG = primary congenital glaucoma, GFCS = glaucoma following cataract surgery; JOAG = juvenile open angle glaucoma; SWS = Sturge-Weber syndrome.

also requires less deepening of the radial cut, and facilitates a tight closure at the end of the surgery. To help us in identifying the Schlemm canal, we look for perforating vessels and the efflux of aqueous fluid/blood.

A Harms trabeculotomy probe was introduced and rotated internally until the internal wall of the canal was torn in both directions from the radial incision. The scleral and conjunctival flap are tightly closed with 10-0 polyglactin 910 or nylon and the conjunctival flap with 8-0 polyglactin 910. A subconjunctival injection of antibiotic and corticosteroids was given. Topical pilocarpine/antibiotic/steroid regimen was given at a weaning dose for a month. MCT was performed as previously described by other authors.[22,24] Once the Schlemm canal was identified and confirmed initially by a Harms rigid trabeculotome, a microcatheter (Glaucolight; Ufa Eye Research Institute, Ufa, Russia, or iTrack microcatheter; Ellex, Fremont, California, USA) was inserted and threaded circumferentially around the canal. If a blockage or deviation toward a collector channel is identified while inserting the microcatheter, rotational movements can make it return to the main canal. It is valuable to zoom out the microscope to keep simultaneous visualization of the scleral flap and the full circumference of the Schlemm canal. A corneal paracentesis was then made followed by acetylcholine chloride use to constrict the pupil and viscoelastic injection into the anterior chamber. After the microcatheter has navigated the 360 degrees of the Schlemm canal we keep introducing it until it crosses the radial incision. This will make its retrieval easier with a forceps or a Sinskey hook. Then the 2 ends of the microcatheter are pulled to incise the whole angle. In cases where the microcatheter encountered an obstruction within the Schlemm canal, it was removed and re-entered into the canal in the opposite direction, or if the catheter went down a collector channel it was withdrawn and external compression applied to the sclera in the area of the collector channel to encourage it to move forward in the canal past the collector channel. If the previous maneuvers were not successful and more than 180 degrees of Schlemm canal was cannulated, the conjunctiva was opened, and a scleral cut was done over the illuminated tip of the probe. The catheter was then grasped and reintroduced in the canal past the obstruction or misdirection. If this was not possible then the exposed ends of the catheter were grasped and pulled to incise the internal wall of the Schlemm canal. The microcatheter was then inserted in the opposite direction up until the point of cutdown, and the tip was exposed and then pulled to complete the circumferential incision. Alternatively, a Harms trabeculotomy probe was used for the incision in the opposite direction and effectively a subtotal trabeculotomy was performed. If the microcatheter is kinked during the attempts to introduce it, it can be cut with sharp scissors and it will continue flashing properly at its tip (extra care should be taken to avoid damage to the tissue because the cut microcatheter might have a sharp end). Finally, the scleral flap was closed with 10-0 polyglactin 910 or nylon sutures and the conjunctiva with 8-0 polyglactin 910 sutures. It is important to avoid leakage. Extra care was taken to avoid filtering flaps.

Antibiotics and corticosteroids were administered via subconjunctival injection. Pilocarpine and a combination of antibiotics and steroids were given at a weaning dose for a month.

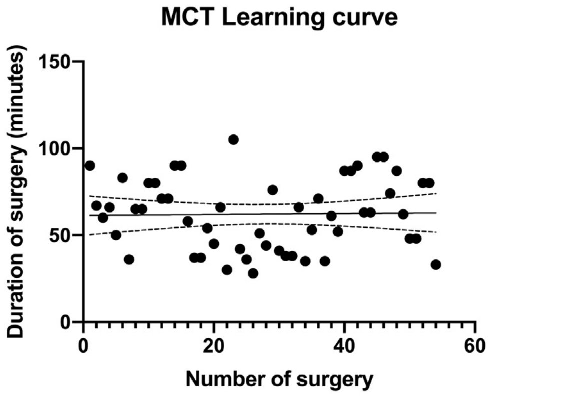


FIGURE 1. Linear regression graph between consecutive number of microcatheter-assisted trabeculotomy (MCT) cases and duration of surgery in minutes. The duration of surgery had no relationship with the number of angle surgeries performed by the surgeons. (y = 0.027 + 61.39, R2 < 0.001, *P* = .881.)

• **DATA COLLECTION:** Clinical notes were reviewed for the following information: maximum IOP before surgery, family history of glaucoma and consanguinity, preoperative diagnosis, surgeries performed, the extent in degrees of the angle incision, perioperative complications, postoperative IOP at each visit or in EUA, axial length measurements, and the number of glaucoma medications. Data were collected on an Excel spreadsheet and analyzed with GraphPad Prism 8 (GraphPad Software, La Jolla, California, USA). Normality was tested with Shapiro-Wilk normality test. Clinical characteristics between groups were compared using unpaired *t* test for parametric and Mann-Whitney test for nonparametric data. Fisher exact test was used for categorical variables. Data were summarized using the mean and standard deviation. The Kaplan-Meier test was used to estimate a curve of probability of intraocular pressure control (success) vs time after surgery. The differences between groups were analyzed with log-rank (Mantel-Cox) test. Significance for all analyses was set at .05 (2-tailed). For patients with both eyes eligible, a separate survival analysis was performed randomly selecting only 1 eye.

RESULTS

DURING THE STUDY PERIOD, 118 EYES (85 PATIENTS) WERE treated. Twelve eyes (8 patients) were excluded owing to no follow-up information (local follow-up) and 106 eyes (77 patients) were included in the analysis (Table 1). Fifty-four eyes (40 patients) received MCT and 52 eyes (37 patients) were treated with CAS (35 goniotomies and 17 trabeculotomies with the rigid probe). PCG was the most common diagnosis in 101 eyes (73 patients); the remaining participants are described in Table 1. The mean age of the patients at surgery was 418 (±717) days (13.7 months), with a minimum of 69 and a maximum of 5,156 days (14 years), in the MCT group; and 245 (±237) days (8 months), with a minimum of 42 and maximum of 1,667 days (4.5 years), in the CAS group (*P* = .1176). The baseline IOP, defined as the maximum pressure preoperatively, was very similar in both groups, 30.46 mm Hg in MCT (95% confidence interval [CI] 28.4-32.5) and 31.79 in CAS (95% CI 28.5-35.1), and consanguinity was established in 3 cases in MCT and 2 in CAS. In the MCT group, a third (18 eyes) of the cases were unilateral and two-thirds (36 eyes) bilateral; in the CAS group, 19% (10 eyes) were unilateral and 81% (42 eyes) were bilateral (*P* = .1247). Thirteen eyes had previous surgery, 6 of them in the MCT group (2 goniotomies, 3 conventional trabeculotomies, and 1 cyclodiode laser) and 7 in the CAS group (5 cyclodiode lasers and 2 goniotomies).

Duration of the surgery was 18.3 minutes longer on average in eyes treated with MCT compared with CAS (*P* < .0001). With the first technique, the average duration was 62.1 (±20.4) minutes while in CAS it was 43.8 (±13.9) minutes (41 for goniotomy and 49 trabeculotomy with rigid probe). The duration of surgery had no relationship with the number of surgeries performed per surgeon (y = 0.027 + 61.39, R2 < 0.001, *P* = .881) (Figure 1).

The mean (95% CI) change in axial length postoperatively was −0.03 mm (−0.34 to 0.40) for MCT and +1.35 mm (−0.64 to 1.62) for CAS, which was statistically significant (*P* < .001). Postoperative axial length measurement was done 183 ± 218 days on average. Figure 2A and B depicts the change between preoperative and postoperative axial length.

Qualified success at 1 year (IOP <21 mm Hg with or without medication) was significantly higher (*P* < .0001) in eyes treated with MCT than with CAS. Qualified success was achieved at 1 year in 85% (46 eyes) of the MCT group and 37% (19 eyes) of the CAS group. Complete success at 1 year (IOP <21 mm Hg without medication use) was achieved in 69% (37 cases) of the MCT and 23% (12 cases) of the CAS group (*P* < .0001).

The percentage of IOP reduction in all patients, regardless of additional surgery or medication use, from preoperative to 1 year follow-up, was 52.1% in the MCT group and 45.5% in eyes treated with CAS (*P* = .1616).

In eyes treated with MCT the baseline IOP (±standard deviation) was 30.5 ± 7.4 mm Hg and reduced to 13.9 ± 5.7 mm Hg at 1 year after surgery (*P* < .001). In the CAS group preoperative IOP was 31.8 ± 11.9 and was reduced to 15.6 ± 5.7 at 1 year (*P* < .001). At 6 weeks and 3 months, the IOP reduction was more significant in the MCT group than in CAS (*P* < .001 in both time periods) (Figure 3A and B, Supplemental Table 1; Supplemental Material available at AJO.com).

There was no difference in the number of glaucoma medications required at baseline between groups. At 1 year

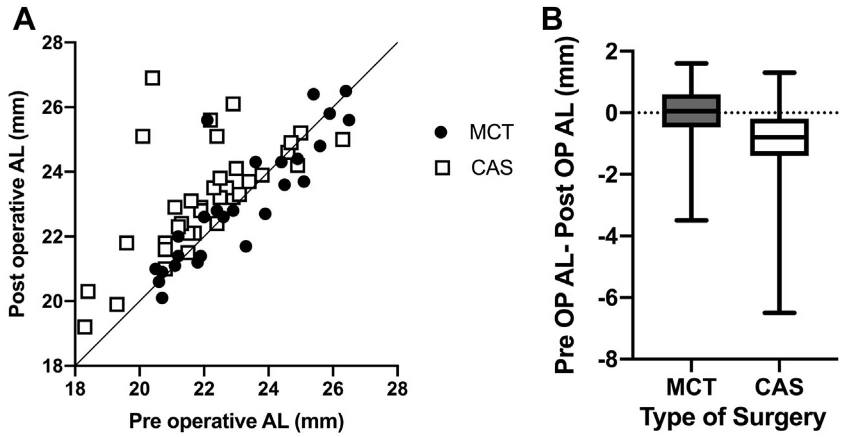


FIGURE 2. (A) Scatterplot of axial length (AL) difference in millimeters between preoperative and postoperative measurement. (B) Box-and-whiskers plot showing the average AL difference in millimeters between preoperative measurements minus postoperative. CAS = conventional angle surgery; MCT = microcatheter-assisted trabeculotomy. Values are expressed in mean and ranges (P < .001).

follow-up 1.5 medications were reduced in the MCT group and 0.98 in the CAS group (P = .0277). However, there was no significant difference between the CAS and MCT group at 1 year of follow-up in terms of the number of medications needed (P = .2890) (Figure 4 and Supplemental Table 2; Supplemental Material available at AJO.com). The survival analysis shows significant differences between both techniques. At 1 year, 94.3% (51) of the cases in the MCT group were still functioning (qualified success), compared to 34.6% (18) in the CAS group (P < .0001). The mean survival for CAS was 105 days (Figure 5). The analysis of 1 eye per patient shows similar results to those reported (Supplemental Figure; Supplemental Material available at AJO.com).

• **SUBGROUP ANALYSIS:** In the 7 MCT eyes with previous glaucoma surgery, success was seen in 6 PCG cases previously treated with cyclodiode, goniotomy, or conventional trabeculotomy. The failure eye had glaucoma following congenital cataract surgery (GFCS) treated with cyclodiode. In the CAS group, 7 eyes were previously treated and 2 GFCS eyes previously treated with cyclodiode were successful. The 5 failures were PCG treated previously with cyclodiode and goniotomy. Qualified success rates at 1 year were not different between patients with or without previous glaucoma surgery for MCT (P = .999) or for CAS (P = .1026). The mean (standard deviation) percentage of IOP reduction in these patients with previous glaucoma surgery was 44.3% (25.6) in the MCT group and 29.6% (17.1) in the CAS group (P = .1929). In the 5 patients with other forms of glaucoma, qualified success was achieved in 3 of them: in the juvenile open-angle glaucoma case treated with MCT and in 2 glaucoma following cataract surgery (GFCS) cases treated with goniotomy. The patient with Sturge-Weber syndrome and 1 case of GFCS in the MCT group failed. A 34% IOP reduction was seen at 1 year follow-up among these secondary glaucoma patients in both groups.

In 7 of the bilaterally treated patients, 1 eye was treated with MCT while the other was treated with CAS. Qualified success at 1 year follow-up was seen in all eyes treated with MCT and in 2 eyes treated with CAS. All CAS-treated cases in this group were failed MCT attempts. Furthermore, in another 7 bilateral patients, the outcome was different in each eye (ie, 1 eye was successful while the other was not), while in 18 bilateral patients treatment was successful in both eyes and in 11 patients it was unsuccessful. Finally, 81% of the bilateral patients had the same result (success or failure) in both eyes.

We had 9 cases of PCG of the neonate (onset <1 month old), 4 of them with success (3 treated with MCT and 1 with CAS) and 5 with failure (all treated with CAS).

• **COMPLICATIONS AND FURTHER SURGERY:** No significant complications were found. There were 8 cases of transient hyphema, 7 in the MCT group and 1 in the CAS group. Only 1 case in MCT required anterior chamber washout for hyphema. The rest of them resolved spontaneously during the first week of recovery. There was 1 case of peripheral anterior synechia in MCT and 1 case of transient hypotony in the goniotomy group. There were 3 cases of microcatheter misdirection and 1 case of iris dialysis in the MCT group. In all these cases conversion to rigid-probe conventional trabeculotomy was needed (Table 2). No cases of corneal trauma, cataract formation, endophthalmitis, retinal detachment, or other sight-threatening complications were detected.

In 43 eyes (79.6%) of the MCT group a complete 360-degree trabeculotomy was achieved. In the remaining 11 eyes (20.4%) in which less than a 360-degree

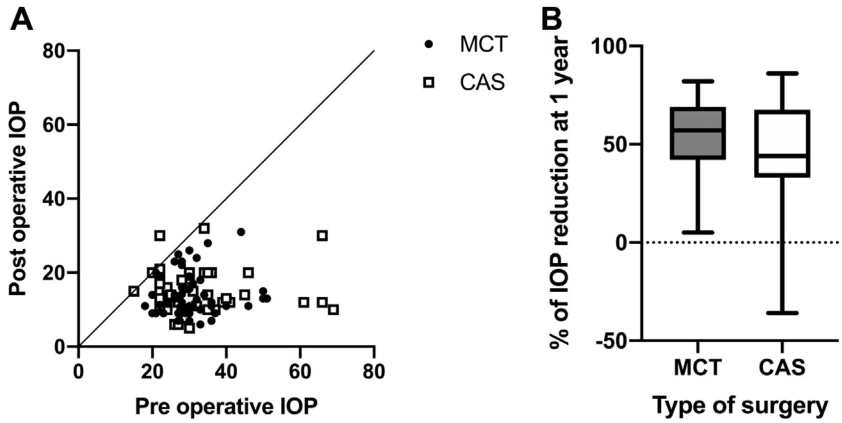


FIGURE 3. (A) Scatterplot of preoperative intraocular pressure (IOP) in mm Hg vs postoperative IOP in mm Hg. (B) Box-and-whiskers plots showing the average percentage of IOP reduction between preoperative baseline IOP and the 1-year follow-up visit: 52.1% in MCT and 45.5% in CAS group. CAS = conventional angle surgery; MCT = microcatheter-assisted trabeculotomy. Values are expressed in mean and ranges. There was no significant difference between groups (*P* = .1616).

trabeculotomy was achieved (mean 250 ± 48°), mean IOP was reduced by 49% and 90.9% of these eyes achieved qualified success, with no significant difference with the qualified success rate of complete 360-degree trabeculotomy ($P > .999$).

Further glaucoma surgery was required during the first year of follow-up in 5.5% (3 eyes) of MCT group and 63.4% (33 eyes) of the CAS group (Supplemental Table 3; Supplemental Material available at AJO.com).

DISCUSSION

THE TRANSITION TO MCT AS OUR FIRST-LINE TREATMENT for PCG and some secondary glaucomas from CAS at our institution is justified based on our results. In this retrospective study with similar groups, success rates at 1 year follow-up were higher with MCT than with CAS. The MCT group qualified and complete success was 85% and 69%, respectively. The CAS group qualified success considering a single angle surgery was 37%. This is at the lower end of the range of other publications, as we included previously treated eyes and secondary glaucomas known to be associated with a lower success rate compared to PCG: 31% by El Sayed and Gawdat in 2017,[7] 47.5% by Neustein and Beck in 2017,[34] 53.8% by Girkin and associates in 2012,[24] 50% by Mendicino and associates in 2000,[21] and 61.9% by Shi and associates in 2017.[27] However, our qualified success rate in MCT-treated eyes was similar to that previously reported in the literature: 83.3% by Girkin and associates in 2012,[24] 85.71% by Lim and associates in 2015,[26] 86.4% by Shi and associates in 2017,[27] 89% by El Sayed and Gawdat in 2017,[7] 91.6% by Girkin and associates in 2012,[25] 90% by Shakrawal and associates in 2017,[23] and 92% by Mendicino and associates in 2000.[21] The difference in success rates between our 2 groups is attributable to the greater extent of the incision achieved with MCT, even though in the 11 eyes (20.4%) a 360-degree incision was not achieved. However, these 11 eyes had 250 degrees of treatment on average, more than the standard CAS extension. Furthermore, 360-degree trabeculotomy is a more standardized technique, as the Schlemm canal must be successfully identified each time before it can be potentially cannulated in its entirety, whereas with goniotomy the position and depth of the knife can be variable[21] and so can the outcome.

We also noted 80% of qualified success rates (4 of 5) with 48% IOP reduction in MCT eyes that had previous angle surgery (goniotomy or conventional trabeculotomy) but among patients with secondary glaucoma a 25% qualified success rate (1 of 4 cases) and a 26% IOP reduction. These results are better than others previously reported for complex glaucoma[20,35] and similar to the 77.3% qualified success rate reported by Shi and associates[27] with MCT among previously operated PCG eyes.

The percentage reduction in IOP irrespective of the requirement of further glaucoma surgeries was similar in both groups: 52.1% in MCT and 45.5% in CAS, similar to the 42% in MCT reported by El Sayed and Gawdat in 2018,[29] 47% by Sarkisian in 2010,[22] 49% by Temkar and associates in 2015,[36] and 65% by Girkin and associates in 2012.[24] However, CAS failed more often, and these patients required more surgical procedures to have their IOP under control. The need for a second surgery, in agreement with previous reports,[24] was much lower with MCT (5.5%) than with CAS (63.4%) during the first year. In the CAS group there were 2 patients who required 5 surgeries and another 2 that required 6 surgeries during the first year, excluding the number of EUAs that some patients required. This is very important considering that there is evidence of abnormal neurodevelopment among

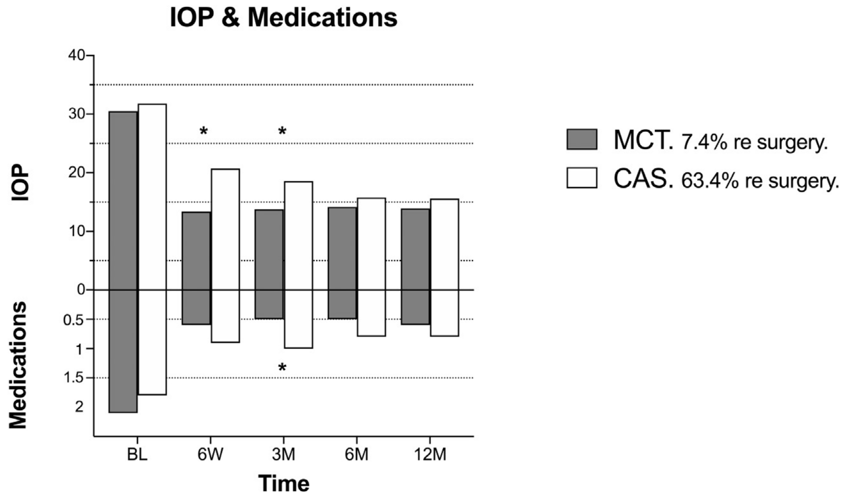


FIGURE 4. Double bar graph showing changes in mean intraocular pressure (IOP) and number of medications over the year of follow-up. In both groups there was a significant reduction in the IOP at 12 months compared to preoperative values ($P < .001$) and between groups, there was significant lower pressures in the microcatheter-assisted trabeculotomy (MCT) groups at 6 weeks (*$P < .001$) and 3 months (*$P < .001$) of follow-up. There was also a significant reduction in the number of medications used at 12 months compared to preoperative values ($P < .0001$) in both groups. These similar results in both groups were achieved with the need for 63.4% reoperation (re-surgery) in the conventional angle surgery (CAS) group and 7.4% in the MCT group. At 3 months of follow-up, eyes treated with MCT required a significantly smaller number of glaucoma medications compared with eyes treated with CAS (*$P = .0251$).

young children who receive repeated general anesthesia.[12–15] Our approach was to repeat the angle surgery in CAS, cyclodiode laser treatment, and trabeculectomy with mitomycin C, but recently we have adopted cyclodiode treatment and implant of glaucoma drainage device (GDD) as a more effective and safe approach for failed angle surgery in pediatric glaucoma patients.

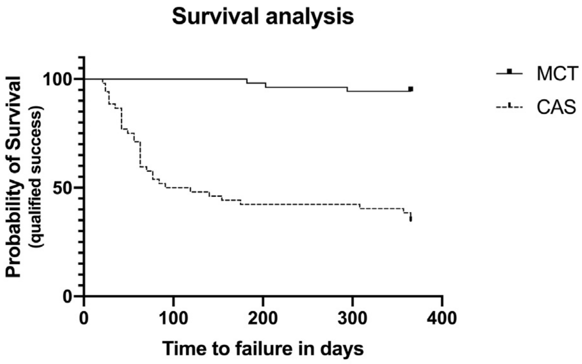
The need for medications was significantly lower in both groups after the surgery. However, between the groups there is a tendency of less medication needed among MCT patients than CAS patients, but this was only significant at 3 months of follow-up. This can be explained because in the CAS group more surgeries were needed to control the pressure while in MCT the majority of patients continue with just 1 surgery and in case the IOP was not controlled, the first step in the treatment strategy is topical treatment.

Evidence suggests that the superiority of MCT over CAS can still be seen at 2 years of follow-up.[7] Another long-term study shows that circumferential trabeculotomy with 6-0 polypropylene suture is more effective than single and multiple conventional angle surgery in both the short and long term of 10 years of follow-up.[34]

The number and type of complications were similar in both groups despite this new technique requiring a longer learning curve and despite that we included complex cases such as eyes with previous surgeries or secondary glaucoma. Only transient hyphema was more frequent in the MCT group (7 cases vs 1). Nonetheless, some peripheral anterior synechiae or self-limited hyphema may not have been detected because the routine follow-up was a week after the surgery, and gonioscopy was not routinely performed in the clinic and fewer patients required EUAs. Complications with MCT among aphakic patients has been described and includes hypotony, tears in the Descemet membrane, and hyphema with vitreous hemorrhage.[35] Also, a high rate of cataract formation of 9% was reported with the use of illuminated microcatheter.[29]

Another indirect way to determine if a child with glaucoma is stable is measuring the patient's axial length with ultrasound. In our study, the same operator did all axial length measurements with contact method in clinic. There is a correlation with patient's age.[37] However, when a treatment successfully reduces the intraocular pressure, we should expect an axial length reduction. MCT cases had an average of 0.03 mm reduction in axial length postoperatively, while patients in the CAS group increased their axial length by 1.35 mm after their surgery. This can also reveal that MCT is more effective than CAS. One limitation of this measure is that not all the patients had the same time gap between axial length measurements and in 2 cases, for example, this happened 2 weeks apart—not enough time, we think, to have a significant axial length change.

Visual acuity was not evaluated in this study because of the difficulty in objective measurements in young children and because of the short follow-up period. However, other authors have reported better visual acuity outcomes with 360-degree trabeculotomy with polypropylene suture than with CAS.[21,34]



	0	100	200	300	365 (days)
MCT	53	53	53	51	50
CAS	52	27	23	23	20

FIGURE 5. Kaplan-Meier survival analysis of microcatheter-assisted trabeculotomy (MCT) and conventional angle surgery (CAS) groups showing probability of qualified success among time after the surgery in days. The table indicates the number of participants at risk. Failure was defined if it was not possible to achieve pressures of 21 mm Hg or less, with or without drops and need for further surgery. A total of 94.34% of MCT and 34.62% of CAS treatments were successful at the year of follow-up. Comparison between the curves was significant ($P < .001$).

TABLE 2. Complications During Surgery

MCT	CAS
Hyphema = 7	Hyphema = 1
Microcatheter misdirection = 3	Transient hypotony = 1
Peripheral synechiae = 1	
Iris dialysis = 1	

CAS = conventional angle surgery group; MCT = microcatheter-assisted trabeculotomy group.

Surgical time was on average 43.8 minutes in CAS and 62.1 minutes in MCT. This means that this new technique takes 18.3 minutes (41.8%) more time but opens the complete 360 degrees of the Schlemm canal (360° in MCT vs 180° in CAS). In that case the time per degree treated is less in MCT (0.17 minutes per degree in MCT and 0.24 minutes in CAS). The duration of the surgery had no trend toward longer surgeries at the beginning of the transition period, suggesting that experienced surgeons should not expect a lengthy learning curve over the first cases.

Since the introduction of MCT the traditional management algorithm to treat childhood glaucoma has changed considerably.[28] The standard management for children with glaucoma was to perform a CAS first line. We traditionally preferred goniotomy over trabeculotomy because it was quicker, it had the same efficacy, and it did not violate the conjunctiva, and because of the long experience with this technique at our institution. These patients would undergo an examination under ketamine anesthesia 4-6 weeks later to assess IOP and to consider either repeating angle surgery or alternate surgery such as trabeculectomy with MMC or GDD surgery if the glaucoma was not under control. However, it is our impression that the introduction of MCT and the use of Icare in outpatient clinics have reduced the number of EUAs. The current standard management is to perform an MCT and then examine the patient during the postoperative period in the clinic without the need of EUA. Only if IOP is elevated or there are clinical signs of failure, the patient would be listed for EUA with a possible cyclodiode or GDD implant as a secondary surgical approach.

Despite the encouraging results with the MCT ab externo, it is important to mention that new instruments and techniques are evolving faster than ever before. Promising results have been reported from an ab interno approach with the Trab 360[38] or with gonioscopy-assisted transluminal trabeculotomy.[39] If over the years both approaches are equally safe, we would prefer a conjunctiva-sparing approach, when possible, that would preserve the conjunctiva for potential future glaucoma surgeries.

A final limitation to a universal implementation of this technique is the price of the microcatheter. We think that the price of the microcatheter could be reduced if it is a solid light-beaming catheter instead of a catheter with a lumen inside to use viscoelastic. With our technique we did not routinely inject viscoelastic into the Schlemm canal, yet we managed to complete 360° in 79.6% of the cases, similar to what has been previously reported: 50% by Girkin et al in 2012 (24), 67% by Sarkisian et al in 2010 (22), 75% by Girkin and associates in 2012,[25] 86.4% by Shi and associates in 2016,[27] 80% by Shakrawal and associates in 2017,[23] and 50% by El Sayed and Gawdat in 2017.[7]

Our study is limited by the short follow-up duration, its retrospective nature, and the analysis of both eyes of some participants. However, our principal aim was to show the real-life transition process from our last cases of conventional angle surgery to our first cases with MCT. We included different types of pediatric glaucoma, which could be considered a limitation, but we preferred to present a more pragmatic report of the transition to MCT. For instance, a case of juvenile open-angle glaucoma was included in MCT that increased the mean age in the MCT group, but with no statistically significant difference compared with CAS.

In summary, our results show that MCT is a more successful treatment than CAS, with a slightly prolonged operative time, but with longer survival time and much lower reoperation rate. We recommend the transition from conventional angle surgery to 360-degree trabeculotomy with illuminated microcatheter, especially in PCG cases.

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