

Trends in operating room-based glaucoma procedures at a single eye center from 2016–2020

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Abstract

• **AIM:** To evaluate trends in glaucoma procedures at the Peking University Eye Center in 2016–2020.

• **METHODS:** A retrospective search of all glaucoma procedures performed at our institution were performed. Data were analyzed by calculating the absolute numbers and relative weightage of each procedure per year.

• **RESULTS:** The average age of glaucoma patients undergoing surgical procedures was 62.33 ± 17.87 y, and 55% were women. From 2016 to 2019, the number of surgical procedures performed in glaucoma patients showed an overall upward trend from 749 to 1460, although it decreased slightly in 2020 ($n=1393$), probably due to the COVID-19 pandemic. The number of trabeculectomies did not change significantly in 2016 ($n=161$) to 2018 ($n=164$) but decreased in 2019 ($n=139$) to 2020 ($n=121$), indicating a reduction in its relative weightage among glaucoma procedures (from 21.50% to 8.69%). The number of glaucoma drainage device implantations and minimally invasive glaucoma surgeries both increased (50 and 58 respectively in 2019), except in 2020. The number of transscleral cyclophotocoagulation procedures was relatively stable, increasing until 2017 ($n=218$) and then decreasing. Cataract surgeries with or without glaucoma procedures accounted for a large number of the total surgeries, increasing from 247 (32.97%) in 2016 to 967

(69.42%), among which cataract extraction combined with goniosynechialysis was the most frequent.

• **CONCLUSION:** The overall increase in the number of operating room-based surgical procedures is significant. Trabeculectomy is one of the most commonly performed procedures, despite the relative decline in its weightage. Other procedures, including use of glaucoma drainage devices and mini shunts and minimally invasive glaucoma surgeries, are gaining greater acceptance. Notably, lens-related surgery plays an important role in glaucoma management.

• **KEYWORDS:** glaucoma surgery; trends; minimally invasive glaucoma surgery

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INTRODUCTION

Glaucoma is the leading cause of irreversible blindness, and its global prevalence is expected to increase to 111.8 million in 2040, with Asia having the highest prevalence of primary angle-closure glaucoma (PACG)^[1-2]. As the population expands and ages, the demand for glaucoma treatments is expected to increase accordingly.

Intraocular pressure (IOP) is the only confirmed risk factor that is directly related to glaucomatous optic nerve damage. The treatment of glaucoma is mainly aimed at decreasing IOP, which is the principle of currently available therapies. The target IOP is established according to many factors, and the American Academy of Ophthalmology recommends that the initial IOP-lowering treatment in primary open angle glaucoma (POAG) patients should aim to reduce 25% of the baseline^[2]. Several IOP-lowering options are available: medications, laser therapy, and surgeries. According to the European Glaucoma Society Guidelines, patients taking ≥ 3 different pharmacological agents are likely to be considered surgical candidates for improved treatment efficacy^[3].

Table 1 The characteristics of glaucoma patients who underwent surgical procedures in 2016–2020

| Year | Patients, <i>n</i> | Eyes, <i>n</i> | Age (y) | Gender, <i>n</i> (%) | | Laterality of eyes, <i>n</i> (%) | |
|-------|--------------------|----------------|-------------|----------------------|--------------|----------------------------------|--------------|
| | | | | Male | Female | Right eye | Left eye |
| 2016 | 470 | 790 | 59.53±18.98 | 248 (52.8) | 222 (47.2) | 375 (47.5) | 415 (52.5) |
| 2017 | 621 | 987 | 59.04±18.75 | 313 (50.4) | 308 (49.6) | 479 (48.5) | 508 (51.5) |
| 2018 | 713 | 1124 | 62.05±18.38 | 310 (43.5) | 403 (56.5) | 545 (48.5) | 579 (51.5) |
| 2019 | 1059 | 1520 | 64.40±16.83 | 421 (39.8) | 638 (60.2) | 737 (48.5) | 783 (51.5) |
| 2020 | 1078 | 1482 | 63.56±17.08 | 452 (41.9) | 626 (58.1) | 766 (51.7) | 716 (48.3) |
| Total | 3941 | 5903 | 62.33±17.87 | 1744 (44.25) | 2197 (55.75) | 2902 (49.16) | 3001 (50.84) |

The data included all surgical procedures, whether glaucomatous or lens-related.

Trends in glaucoma management have been affected by advances in topical IOP-lowering agents and technological improvements. With the introduction and wide application of prostaglandin analogs and carbonic anhydrase inhibitors, trabeculectomy rates decreased dramatically in the late 1990s^[4-5]. Additionally, the results of a 5-year tube versus trabeculectomy study provided evidence that glaucoma drainage devices and aqueous shunts have a higher success rate and fewer complications than trabeculectomy in eyes that have undergone previous surgeries^[6]. Few studies have reported the impact of these developments on the rates of glaucoma laser treatment and surgical procedures in China.

Recently, the emergence of minimally invasive glaucoma surgery (MIGS) has potentially changed surgical trends^[7]. EXPRESS mini-shunt implantation (Alcon, Geneva, Switzerland, approved by Health Canada in 2005) and iTrack 250 canaloplasty (iScience Interventional Corp., Menlo Park, CA, USA) procedures, as well as trabectome (NeoMedex, Corp., Tustin, CA, USA), Kahook Dual Blade (KDB; New World Medical, Rancho Cucamonga, CA, USA), iStent (Glaukos Corp., San Clemente, CA, USA), and other MIGS devices have significantly broadened the available surgical options^[8-10]. Although studies regarding the efficacy of these procedures in lowering IOP have started to emerge, there are no current data on the trends in their practical usage.

In this study, we aimed to provide an update on the changes in operating room-based glaucoma procedure trends at a Chinese eye center from 2016 to 2020.

SUBJECTS AND METHODS

Ethical Approval Ethical approval was obtained from the Peking University Third Hospital Ethics Committee (the approval number: 2022IRB712-01), and exemption of informed consent was approved as this is a retrospective study.

Data Source We performed a retrospective search of all glaucoma procedures carried out in the operating room of the Peking University Eye Center from January 1, 2016, to December 31, 2020, including those performed on both inpatients and outpatients.

Data Selection The characteristics of patients with glaucoma, such as age and sex, and the procedures they underwent were

collected in the dataset. Further analysis was conducted only in glaucomatous and lens-related procedures, excluding vitreous or other surgeries.

Glaucoma surgeries at our center included glaucoma filtration surgeries (trabeculectomy, glaucoma drainage device implantation, and EXPRESS mini-shunt implantation), transscleral cyclophotocoagulation (TSCPC), bleb needling, Trabectome procedures, iTrack-assisted Schlemm’s canal surgery (AB-interno canaloplasty and gonioscopy-assisted transluminal trabeculotomy), and KDB procedures. A growing number of glaucomatous patients underwent cataract surgeries, either alone or combined with glaucoma procedures, due to their effectiveness in lowering IOP in patients with or without angle closure^[11-13]. Therefore, lens-related surgeries were included in this study. Procedures performed outside the operating room were not registered in the dataset, including laser procedures [laser peripheral iridotomy (LPI), laser peripheral iridoplasty, and selective laser trabeculoplasty (SLT)], as well as procedures performed at the slit lamp, such as anterior chamber paracentesis.

Statistical Analysis Microsoft Excel software was used for data collection, and SPSS software (IBM SPSS Statistics for Macintosh, version 24.0; IBM Corp., Armonk, NY, USA) was used for descriptive statistical analysis. Data were analyzed by calculating the number of times the different procedures were performed and the proportion of each procedure per year.

RESULTS

Patient Characteristics From 2016 to 2020, 3941 patients diagnosed with glaucoma underwent surgical procedures in the operating room, with a male-to-female ratio of approximately 4.5:5.5. A total of 5903 eyes were operated upon, without a significant difference in the laterality of the eyes. The average age of the patients was 62.33±17.87y (Table 1).

Changes in Surgical Procedures Performed in Glaucoma Patients Further analysis was only performed using data regarding glaucomatous or lens-related surgeries. The total number of antiglaucoma surgeries increased gradually over the first 4y, from 749 eyes in 2016 to 1460 eyes in 2019, and then decreased slightly in 2020 (Table 2).

Table 2 The number and percentage of surgical procedures performed in glaucoma patients from 2016 to 2020

| Year | Eyes, <i>n</i> | Glaucoma filtration procedures | | | | | Lens-related surgeries | | | MIGS | | Other surgeries ^b | | | <i>n</i> (%) ^a |
|------|----------------|--------------------------------|-----------------------------|---------------------|--------------------|-----------------------------|------------------------|--------|-------------|-------------|---------------|------------------------------|--|--|---------------------------|
| | | Trabeculectomy | Ex-PRESS mini-shunt implant | Ahmed valve implant | Cataract surgeries | Combined cataract surgeries | Trabectome | iTrack | KDB | TSCPC | Bleb needling | Others | | | |
| 2016 | 749 | 161 (21.50) | 20 (2.67) | 9 (1.20) | 75 (10.01) | 172 (22.96) | 9 (1.20) | | 181 (24.17) | 96 (12.82) | 26 (3.47) | | | | |
| 2017 | 913 | 163 (17.95) | 22 (2.42) | 28 (3.07) | 111 (12.16) | 211 (23.11) | 26 (2.85) | | 218 (23.88) | 110 (12.05) | 24 (2.63) | | | | |
| 2018 | 1058 | 164 (15.50) | 19 (1.80) | 28 (2.65) | 114 (10.78) | 372 (35.16) | 34 (3.21) | | 213 (20.13) | 84 (7.94) | 30 (2.84) | | | | |
| 2019 | 1460 | 139 (9.52) | 18 (1.23) | 32 (2.19) | 181 (12.40) | 731 (50.07) | 58 (3.97) | | 188 (12.88) | 91 (6.23) | 22 (1.51) | | | | |
| 2020 | 1393 | 121 (8.69) | 5 (0.36) | 21 (1.51) | 227 (16.30) | 740 (53.12) | 40 (2.87) | | 146 (10.48) | 69 (4.95) | 24 (1.72) | | | | |

^aThe relative weightage of each procedure; ^bOther procedures included goniosynechialysis, peripheral iridectomy, drainage device adjustment, anterior chamber filling/evacuation, and drainage device removal. MIGS: Minimally invasive glaucoma surgery; KDB: Kahook Dual Blade; TSCPC: Transscleral cyclophotocoagulation.

Glaucoma filtration surgeries As the main method of glaucoma filtration surgery, the number of trabeculectomies remained stable in 2016–2018 and then decreased in 2019–2020. However, with the rapid increase in the total number of procedures, the rate of trabeculectomy has decreased annually from 21.50% in 2016 to 8.69% in 2020. The number of glaucoma drainage device procedures, such as Ahmed valve implantation, and other filtration surgeries, such as ExPRESS mini-shunt implantation, were relatively small and decreased in 2020.

Cataract extraction surgery The rate of cataract extraction combined with primary intraocular lens implantation in glaucomatous patients increased significantly from 10.01% in 2016 to 16.30% in 2020. However, the total number of surgeries performed showed an almost 3-fold increase during the study.

Surgical procedures for glaucoma combined with cataract surgery Glaucoma surgical procedures commonly combined with cataract extraction included trabeculectomy, goniosynechialysis (GSL), and bleb needling. The rate of antiglaucoma procedures combined with cataract surgery increased dramatically from 22.96% (172/749) in 2016 to 53.12% (740/1393) in 2020. Among these, GSL combined with cataract extraction was the most common. The proportion of trabeculectomies combined with cataract extraction decreased in 2016–2018 and then increased in 2019–2020 (Figure 1).

Based on above two kinds of surgeries, the overall lens-related surgeries increased from 247 (32.97%) in 2016 to 967 (69.42%) in 2020.

Minimally invasive glaucoma surgery MIGSs at our center mainly included Trabectome procedures, iTrack-assisted Schlemm's canal surgery, and KDB-assisted trabeculotomy. The rate of MIGS increased to 3.97% (58/1460) from 2016 to 2019 and then decreased in 2020. The distribution of the different MIGS procedures is shown in Figure 2. Among them, iTrack-assisted Schlemm's canal surgery and KDB procedures first became available in 2018 and 2019, respectively.

Other surgeries TSCPC and bleb needling accounted for a large proportion of the procedures but gradually decreased in 2016–2020, accounting for 10.48% (146/1393) and 4.95% (69/1393) of the procedures, respectively, in 2020. Other rarely used surgical methods included GSL, peripheral iridectomy, drainage device adjustment, anterior chamber filling or evacuation, and drainage device removal. The number of these procedures was stable in 2016–2020, while the rate showed a gradual downward trend.

Glaucoma subtypes The subtypes of glaucoma patients who underwent different surgeries are displayed in Figure 3. Trabeculectomy was applied to all kinds of glaucoma, mainly including POAG and PACG, as well as including

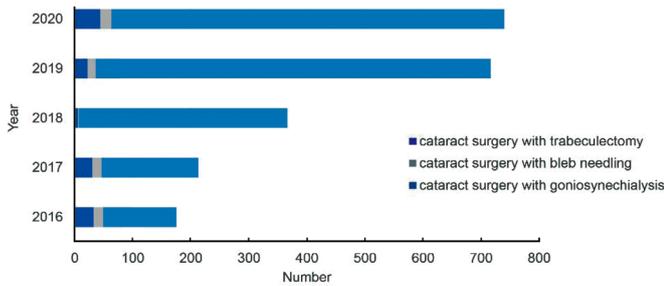


Figure 1 The distribution of combined glaucoma and cataract surgeries.

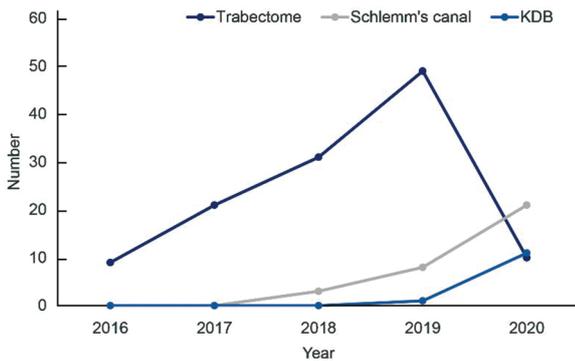


Figure 2 The trend in minimally invasive glaucoma surgery in 2016–2020 KDB: Kahook Dual Blade.

secondary glaucoma and other glaucoma such as infantile glaucoma or juvenile glaucoma. Other glaucoma filtration surgeries (including EXPRESS mini-shunt and Ahmed valve implantation) were mainly used in open angle glaucoma and secondary glaucoma. Schlemm's canal-related surgery was mostly used in infantile glaucoma and juvenile glaucoma. The Trabectome and KDB were applied to open angle glaucoma. The lens-related surgery mainly incorporated cataract extraction combined with GSL, which was applied mostly to PACG. TSCPC was used for controlling IOP in advanced glaucoma and refractory glaucoma, which are not shown in the figure as the primary type of glaucoma was not clear in the surgery system.

DISCUSSION

Recently, a variety of newly developed glaucoma surgical procedures have emerged, especially MIGS, which has potentially influenced the distribution and trends in glaucoma surgery. This study demonstrated that the proportion of conventional trabeculectomy at the Peking University Eye Center showed a declining trend in the late 2010s. The IOP-lowering efficacy of conventional trabeculectomy can be attenuated by low postoperative IOP, a shallow anterior chamber, or filtering bleb scarring. It was therefore inevitable that the operation would show a downward trend.

Previous studies on the rates of glaucoma procedures in other countries reported different results^[14-19]. In Portugal, trabeculectomy had a stable surgical rate nationwide in 2000-

2015 and remained the most frequently performed surgical glaucoma procedure^[17]. However, its relative weightage among all ophthalmic and glaucoma procedures has decreased. Recent studies in Australia^[15], Scotland, England, Wales^[14], and Ontario^[19] have also reported stable trabeculectomy rates in the 2000s. In contrast, despite being the most commonly performed glaucoma surgery in France, the trabeculectomy rate decreased continuously from 2005–2014^[16]. This is in agreement with the persistent downward trend reported in the United States^[18]. In our study, it was notable that bleb needling played an important role in glaucomatous procedures, and therefore trabeculectomies could be revitalized^[20].

The rate of surgery using glaucoma drainage devices (such as aqueous shunts) remained relatively stable during the study period, except in 2020, although the total number was extremely low compared to that of trabeculectomy. The frequency of Ahmed valve implantation increased significantly in 2017 and remained stable in 2017–2019. The number of EXPRESS mini-shunt implantations was small and showed little change in 2016–2019. Both these surgeries were rarely performed in 2020, which was partly attributed to the COVID-19 pandemic. Nevertheless, the overall trend of glaucoma drainage device surgeries increased continuously in several countries throughout the 2000s^[14-15,17-18].

A 5-year multicenter study confirmed that tube shunts are at least as effective as conventional trabeculectomy with mitomycin C in eyes with previous surgery and reported no significant difference in late postoperative complications, reoperation for complications, or cataract extraction^[6]. The eligible criteria of tube-shunt surgery have expanded beyond refractory glaucoma, accounting for its increased use.

There was an upward trend in the total number of MIGS in 2016–2019. The Trabectome was more widely used and surgery using this device showed a 4-fold increase in 2016–2019, while canaloplasty using the iTrack microcatheter and goniotomy using the KDB were introduced in the late study period and showed a slightly upward trend. As MIGS aims to lower IOP with a higher safety profile than fistulating surgery and is non-penetrating, minimally invasive, and/or bleb-independent, it has been gaining popularity among ophthalmologists, patients, and especially non-subspecialists^[21-22]. However, some comparative studies have reported that MIGS results in limited IOP reduction compared to that of trabeculectomy^[23-25]. In several studies that recently reported trends in glaucoma surgeries, MIGSs were not included in the analysis because the specific code was not yet available^[16-17]. A further investigation into the application of MIGS in different countries or eye centers is needed to understand the extent to which these new techniques have changed the distribution of glaucoma surgeries.

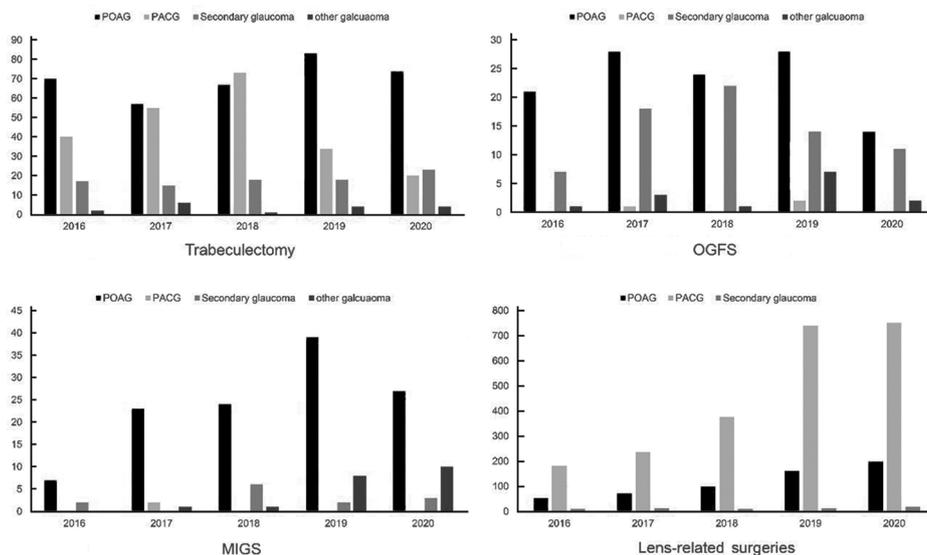


Figure 3 The distribution of glaucoma types in different surgical procedures POAG: Primary open angle glaucoma; PACG: Primary angle-closure glaucoma; OGFS: Other glaucoma filtration surgeries; MIGS: Minimally invasive glaucoma surgery.

TSCPC was the most commonly performed cyclodestructive procedure to reduce aqueous humor production at our center and is an option reserved for patients with end-stage glaucoma. Ultrasound cycloplasty (UCP) using high-intensity focused ultrasound was performed a few times, yet the number was too small to be incorporated into the analysis. Both TSCPC and UCP are invasive and easy to perform. Studies have reported the efficacy of transscleral diode laser cyclophotocoagulation in patients with good visual acuity, thus broadening its acceptance and supporting its early use in patients with less advanced glaucoma and poor management^[26-27]. Other cyclodestructive procedures, such as endoscopic cyclophotocoagulation, which ablates the ciliary body under direct vision, were rarely performed, likely due to the cost of the materials used. However, as the coding system could not differentiate between endoscopic and TSCPC procedures in several recent reports, the number and trend of each approach remain unclear^[14-15,17]. Regarding other laser procedures, LPI showed a significantly increasing trend in Australia from 1994 to 2014 and laser trabeculoplasty showed a marked increase upon the marketing of SLT in 2006^[15]. In this study, these laser procedures performed in the outpatient clinic were not incorporated, while the number did not show an increasing trend, which may be associated with the remarkably increasing cataract surgeries and the introduction of MIGS.

The number of cataract surgeries performed at our center increased 3-fold during the study period. This rapidly increasing trend is similar to that in Australia, France, and Portugal^[15-17]. By 2019, the number of cataract extraction surgeries exceeded that of trabeculectomies at our center. Similarly, in Portugal, cataract surgery had become the most commonly performed eye procedure in glaucoma patients

by 2015, followed by trabeculectomy^[17]. Notably, there was a 4-fold increase in the number of combined glaucoma and cataract surgeries performed at our center, far more than that of cataract surgeries alone, and combined GSL and cataract surgery became the most commonly performed procedure. This change can be mostly attributed to the increasing demand of an aging population with growing health expectations. As a developing country, the rate of cataract surgery in China is rapidly increasing. As there is growing evidence that cataract surgery has confirmed efficacy in lowering IOP in patients with angle closure, the significance of cataract surgery in the management of glaucoma is now gaining more attention^[12,28]. The Effectiveness of Early Lens Extraction for the Treatment of PACG study was a landmark randomized controlled trial, which reported that clear-lens extraction showed greater efficacy and was more cost-effective than LPI^[29]. Azuara-Blanco *et al*^[29] suggested that it be considered as an option for first-line treatment. Additionally, phacoemulsification typically results in small-to-moderate reductions in IOP and the administration of medications for patients with POAG and pseudoexfoliation glaucoma^[30]. However, the effectiveness of cataract surgery for POAG remains controversial^[31], and a study reported that the rate of glaucomatous visual field defect progression did not decrease despite reduced IOP after cataract surgery^[13].

Although the number of combined cataract extractions with GSL was remarkably large in this study, this procedure showed no-to-moderate additional benefit for PACG^[32-33]. GSL physically opens the anterior chamber angle and separates peripheral anterior synechia (PAS) from it; however, this is an inflammatory process, and PAS can recur^[28]. The possible complications of trabeculectomy may also prevent doctors

from performing combined cataract and glaucoma surgeries^[16], although postoperative IOP is comparable between that of phacotrabeculectomy and trabeculectomy^[34]. At our center, the number of combined glaucoma and cataract surgeries is increasing. We believe that safer glaucoma procedures such as MIGS could lead doctors to perform combined surgery more often.

Overall, the number of glaucoma procedures performed was much lower than that of cataract surgeries. The decrease in the rate of conventional glaucoma filtration surgery has been attributed to the increased medical and laser options. However, Fraser and Wormald^[4] found no increase in the diagnosis of angle-closure glaucoma and speculated that the increase in cataract extraction may be partially responsible for the reduction in trabeculectomy. The results from the Liwan Eye Study also indicated that as the cataract surgery rate increases, the angle-closure prevalence could decrease remarkably, especially in the older population^[35].

In China, with the outbreak of the COVID-19 pandemic in 2020, many glaucoma patients chose conservative therapy rather than undergoing surgery, especially in the operating room. Consequently, the overall volume of operating room procedures did not increase in 2020, which differs from the trend in 2016–2019. However, most IOP-lowering procedures declined, while lens-related surgeries continued to increase in 2020.

This study had some limitations. First, we focused on procedures requiring an operating room environment, excluding laser procedures such as LPI, laser peripheral iridoplasty, and SLT, which were performed in the clinic. Second, confounding factors regarding surgeons, such as personnel changes and preferences, affected the study results. Third, this was a single-center study that was representative of only large-scale Chinese hospitals. Fourth, due to the COVID-19 pandemic, the number of outpatients and overall surgical procedures decreased significantly in 2020. Fifth, some of the procedures were not approved by the National Medical Products Administration; for example, the Xen gel stent was not approved until March 2021. Sixth, the study period of 5y may not have been long enough to fully validate the trend. Given the continued trend of moving away from conventional trabeculectomy and toward alternative IOP-lowering procedures such as ExPRESS MicroShunt implantation, UCP, and iTrack canaloplasty, more well-designed randomized controlled trials are needed to compare the efficacy and safety of new procedures for glaucoma management.

This is a descriptive study that reflected the change in surgical procedures over 5y at a single eye center in China. In glaucoma patients, trabeculectomy is one of the most commonly performed procedures, despite the decline in its weightage.

Other procedures, including use of glaucoma drainage devices and mini shunts and MIGS, are gaining increasing acceptance. TSCPC remains a widely used cyclodestructive procedure. In addition, lens-related surgery plays an important role in glaucoma management. These results can be important for the allocation of health resources and the planning of medical care.

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