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ORIGINAL PAPER

# Comparing the efficacy of trabeculectomy and diode laser cyclophotocoagulation in primary open-angle glaucoma

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**Abstract**

*Purpose* The aim was to compare the postsurgical outcomes of trabeculectomy (TET) and transscleral cyclophotocoagulation (CPC) in a similar cohort of eyes diagnosed with primary open-angle glaucoma (POAG).

*Materials and methods* For this monocentric non-randomized retrospective comparative trial, the records of eyes which underwent TET or CPC between 2013 and 2016 at our institution for the treatment of POAG were reviewed. Parameters analyzed before surgery as well as 1 and 2–3 years afterwards were visual acuity (VA), intraocular pressure (IOP), mean defect (MD) of the visual field, number of glaucoma medications and the objective refraction using which the surgically induced astigmatism (SIA) was calculated.

*Results* In total, 51 eyes of 51 patients underwent TET and 45 eyes of 45 patients underwent CPC. Mean VA dropped in both groups on the last follow-up after surgery (TET-group: 0.17 ± 0.17 to 0.23 ± 0.28 logMAR, $p = 0.01$/CPC-group: 0.22 ± 0.22 to 0.26 ± 0.27 logMAR, $p = 0.01$). In the TET- and CPC-groups IOP decreased significantly (TET: 24.9 ± 6.4 to 14.9 ± 3.1 mmHg, $p = 0.001$/CPC: 23.0 ± 6.5 to 16.0 ± 4.1 mmHg, $p = 0.001$) although more pronounced and less depending on IOP-lowering medication in eyes after TET. MD remained stable after TET (7.4 ± 4.8 and 8.1 ± 4.9 dB, $p = 0.1$) but further deteriorated in eyes after CPC (9.0 ± 4.9 and 10.7 ± 4.6 dB, $p < 0.001$). SIA was comparable in both groups on the last follow-up (TET: 0.83 ± 0.69 D; CPC: 0.91 ± 0.65 D, $p = 0.6$).

*Conclusion* The IOP reduction achieved without medication was more pronounced in the TET-group compared with the CPC-group. Visual field remained stable in the TET-group, while further deteriorating in the CPC-group during follow-up. Eyes undergoing CPC had a higher demand for additional medication to reach comparable success rates as TET. Due to this performing TET is favorable over CPC in POAG eyes.

**Keywords** Primary open-angle glaucoma · Trabeculectomy · Cyclophotocoagulation · Ophthalmic surgery

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## Introduction

Glaucoma is a widespread disease with an estimated global prevalence in the population over the age of 40 years of about 3–4% [1–3]. Following senile

cataract, glaucoma is the second leading cause of blindness worldwide [2–4]. Without treatment, glaucoma leads to apoptosis of retinal ganglion cells and optic nerve head atrophy. This leads to increasing visual field defects ultimately ending in blindness of one or both eyes. Lowering intraocular pressure (IOP) is the only known therapeutic option that can decelerate or at best stop further development of visual field defects.

IOP can be lowered by administration of medication or by surgical intervention. Basic principles of glaucoma surgery include relief of pupillary block mechanisms, external filtration into the subconjunctival space, internal filtration into the suprachoroidal space and cyclodestructive procedures. Trabeculectomy (TET) acts through external filtration into the subconjunctival space and was first introduced in the mid-1960s. Today, TET still remains the gold standard for the surgical management of glaucoma because of its distinct IOP-lowering potency [5]. However, TET has numerous limitations regarding the demanding technique, the necessity for frequent postoperative ophthalmic examinations and numerous occurring complications such as progression of lens opacification, drop of visual acuity, hypotony-induced maculopathy and bleb-associated infections [6–8]. In particular, the mild but sustained drop of visual acuity remains inexplicable in some cases treated with TET [9, 10]. Cyclodestructive procedures such as transscleral cyclophotocoagulation (CPC) act through the destruction of the ciliary body epithelium. The efficacy of the CPC was reported in many studies as well in complicated and refractory glaucomas [11, 12] as in eyes with good visual acuity [13], with eyes diagnosed with primary open-angle glaucoma (POAG) and receiving CPC as a primary option achieving better results [14, 15]. Various complications including pain, uveitis, IOP spikes, pigment dispersion, atonic pupil, hypotony and phthisis were reported after CPC [16, 17]. Because of the destructive nature, CPC classically serves as an alternative to TET in advanced glaucoma cases, cases with limited chances for success of TET or when other procedures already failed [18]. Still, the simplicity in performing this intervention combined with time spared compared with TET and the possibility of repeatable interventions and more controlled energy using the contact technique (mostly related to more control on the rates of complications) make this surgical option attractive compared to TET. In addition to this, many studies report the efficacy and the relatively low complication rate after CPC as a primary surgical option in POAG patients [14, 16, 19–23].

To our knowledge, there are no published data for a direct comparison of the postoperative efficacy and complications between TET and CPC in a comparable group of POAG patients, which is by far the most common form of glaucoma. Such a comparison is only reported in secondary glaucomas or in animal models [24–26]. A direct comparison of these two surgical methods in the POAG eyes could help in the decision-making process and patient counseling during the presurgical planning. Comparing IOP-lowering efficiency as well as functional parameters such as visual acuity, visual field indices and surgically induced refractive changes after TET and CPC in a similar population of patients suffering from POAG was the main goal of our investigations and thus being the first study to report this comparison in POAG patients. Special attention was paid to the postoperative change of refraction since this could be one of many possible reasons for the sustained drop of visual acuity noticed in many glaucoma cases.

## Materials and methods

For this monocentric retrospective comparative case analysis, the medical records of all POAG patients which underwent TET or CPC from January 2013 to December 2016 at the University Eye Hospital in Leipzig, Germany, were reviewed. The study was approved by the local ethics committee. Written informed consent was obtained from all individual participants. All procedures performed involving human participants were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. All surgical interventions were performed by the same ophthalmic surgeon (JDU). There are no conflicts of interest to declare for any of the authors.

Diagnosis of POAG was based on the presence of typical morphological optic diskc glaucomatous changes (increased cup to diskc ratio, notching of vessels, optic disk hemorrhage, defects of the nerve fiber layer, etc.). Further inclusion criteria were a patient age of $\geq$ 40 years, an untreated intraocular

pressure of $\geq$ 21 mmHg and the presence of typical glaucomatous visual field defects. All patients underwent a complete ophthalmic examination at first presentation. This included history taking, best-corrected visual acuity (BCVA) testing using Snellen charts (transformed to logMAR for statistical analysis), determination of the eye's objective refraction, slit-lamp examination of the anterior and posterior segments, evaluation of the optic nerve head by indirect ophthalmoscopy, static automatic visual field testing (Twinfield 2, Oculus, Wetzlar, Germany; 24-2 test strategy, 55 target points) and Goldmann applanation tonometry. A peripapillary-oriented optical coherence tomography scan (OCT; Spectralis, Heidelberg Engineering, Heidelberg, Germany) was also performed, and the RNFL thickness was measured and graded. Gonioscopy was performed in all cases prior to surgery. If evidence for a present angle closure glaucoma or secondary glaucoma (trabecular meshwork with neovascularization, heavy pigmentation or anterior synechiae) was found during gonioscopy, the case was excluded from further analysis.

Indications for glaucoma surgery were intraocular pressure under maximal tolerated local therapy of more than 21 mmHg (with or without progression of visual field defects) or intraocular pressure under 21 mmHg with progressing visual field defects. Eyes with pressure exceeding the target pressure under maximal tolerated local therapy (set by the examiner on the first visit and modified when needed according to the clinical findings) were also allocated for surgery. At the time of analysis of patients' records, follow-up results of at least one year after surgery had to be available. Exclusion criteria were a patient age of $<$ 40 years, necessity of any other intraocular surgeries during the follow-up period or existence of another glaucoma entity apart from POAG. Eyes that underwent any type of IOP-lowering surgery during the year before inclusion into the performed study were also excluded. The results of only one eye per patient were included into this analysis.

Patient demographics collected included: age, gender, laterality of the operated eye. Data concerning the performed surgical intervention were collected at three time points: the day before surgery, 1 year after surgery and at the last available follow-up examination. Collected data were BCVA, IOP, objective refraction, mean defect of the visual field test (MD), mean peripapillary RNFL thickness in the OCT scan and number of applied glaucoma medications. Apart from this, the surgically induced astigmatism (SIA) was calculated using the results of the objective refraction measurements performed at the follow-up examinations using customary programmed software utilizing the vector method by Jaffe and Clayman.

Data collection and statistical analysis were performed using Excel (version 2007, Microsoft; Redmond, USA) and SPSS (IBM version 22.0; Chicago, Illinois, USA) software. Patient characteristics, including patient age, BCVA, refraction, visual field indices and RNFL thickness, are given as mean and standard deviation. Student's *t* test, Mann–Whitney U test and Pearson's Chi-square test were performed where applicable with $p \leq 0.05$ indicating statistical significance. Definition of postoperative success after TET or CPC can be taken from Table 1. This definition followed the recommendations of the Guidelines on Design and Reporting of Glaucoma Surgical Trials of the glaucoma world association.

## Surgical technique

*TET with mitomycin C (MMC)* After disinfection of the ocular surface, the conjunctiva is opened at limbus using scalpel and scissors (fornix-based). Conjunctiva and Tenon's capsule are then elevated from the sclera creating a small pocket which will later become the blebs filtration zone. Bleeding vessels are coagulated. A sponge of approximately 5 $\times$ 5 mm in size is soaked with 0.05% MMC and left in the beforehand created conjunctival pocket for 2 min. After that, the MMC sponge is removed and the scleral bed and conjunctival pocket are meticulously rinsed with 20 ml of balanced salt solution. Afterwards, a scleral flap is created approximately 4 $\times$ 4 mm in size and a thickness aimed at ½ to ¾ of the sclera. Underneath this scleral flap, the eye's anterior chamber is entered aiming anteriorly the scleral spur and an iridectomy is created using forceps and scissors. The scleral flap is then re-approximated using 2–4 single-button sutures depending on the intraoperatively estimated IOP. The conjunctiva is then re-approximated to the limbus using 2–4 absorbable single-button sutures to assure water tightness of the resulting bleb. Postoperatively, suture lysis was performed when needed according to the intraocular pressure and the function of the bleb.

*CPC* For CPC, a diode laser (Oculight SL, Iris Medical, Santa Clara, USA) was utilized. Sixteen laser

**Table 1** Definition for operative success after TET or CPC depending on IOP, achieved IOP reduction from baseline and the necessity of application of IOP-lowering medication after surgery

| | IOP reduction (%) | IOP (mmHg) | IOP-lowering medication |
|---|---|---|---|
| Complete success (A) | > 20 | 6–21 | None |
| Qualified success (A) | > 20 | 6–21 | Yes |
| Complete success (B) | > 30 | 6–18 | None |
| Qualified success (B) | > 30 | 6–18 | Yes |

*IOP* intraocular pressure, *TET* trabeculectomy, *CPC* cyclophotocoagulation

spots were applied circumferentially 1.5–2 mm behind the limbus sparing the 12 o'clock position if further TET was necessary in the future. Laser application was started with a power of 2000 mW and 2 s of application time. When audible popping effects were heard, laser power was reduced in steps of 200 mW until no effects were noticed anymore.

## Results

Between January 2013 and December 2016, a total of 160 eyes received TET + MMC and 337 received CPC in our hospital for the treatment of POAG. The inclusion criteria were met by 51 eyes undergoing TET and 45 eyes treated with CPC. Mean follow-up time in the TET-group was 28.5 ± 9.4 months and 30.5 ± 10.0 months in the group of eyes receiving CPC ($p = 0.3$). The demographics of the treated POAG patients and eyes undergoing TET or CPC and the statistical comparison of both groups can be taken from Table 2. A survey of the eyes surgical history is summarized in Table 3. There was no difference in the previous surgical history between both groups when considering ALT, iridotomy, TET or CPC or the overall surgical history regardless of the intervention performed ($p$ for all > 0.05).

**Table 3** List of already performed glaucoma operations in the TET- and CPC-groups before inclusion into the performed analysis

| | TET | CPC | $p$ value |
|---|---|---|---|
| No pre-op | 32 | 24 | 0.1 |
| Argon laser trabeculoplasty (ALT) | 7 | 7 | 0.4 |
| Iridotomy | 2 | 1 | 0.6 |
| Cyclophotocoagulation (CPC) | 9 | 9 | 0.4 |
| Trabeculectomy (TET) | 1 | 3 | 0.16 |
| Vitrectomy | 0 | 1 | 0.4 |

*TET* trabeculectomy, *CPC* cyclophotocoagulation

There was no statistically significant difference between the two groups regarding age, gender, laterality of the operated eye, visual acuity, astigmatism, mean defect of visual field, number of prescribed glaucoma medications and OCT measurements of the RNFL (Table 2).

In the TET-group, mean visual acuity dropped significantly from 0.17 ± 0.17 preoperatively to

**Table 2** Baseline patient demographics and characteristics of eyes undergoing TET or CPC for the treatment of POAG

| | TET | CPC | $p$ |
|---|---|---|---|
| Age (years) | 70.18 ± 9.6 | 71.29 ± 7.4 | 0.53 |
| Gender (male:female) | 23:28 | 16:29 | 0.4 |
| Laterality (right:left) | 30:21 | 21:24 | 0.3 |
| Visual acuity (logMAR) | 0.17 ± 0.17 | 0.22 ± 0.22 | 0.24 |
| Astigmatism (D) | − 0.95 ± 0.74 | 1.12 ± 0.68 | 0.26 |
| Mean defect of visual field test (MD) (dB) | 7.40 ± 4.76 | 9.0 ± 4.9 | 0.11 |
| Intraocular pressure before surgery (mmHg) | 24.9 ± 6.4 | 23.0 ± 6.5 | 0.17 |
| Number of pressure-lowering agents prescribed ($n$) | 3.01 ± 1.12 | 3.07 ± 0.71 | 0.79 |
| Total RNFL thickness in OCT measurement (μm) | 58.33 ± 30.6 | 74.7 ± 19.0 | 0.1 |

*TET* trabeculectomy, *CPC* cyclophotocoagulation, *POAG* primary open-angle glaucoma

0.21 ± 0.24 after 1 year ($p = 0.03$) (Fig. 1). After that, visual acuity remained stable with a mean of 0.23 ± 0.28 at the last follow-up ($p = 0.34$). In the CPC-group, mean visual acuity dropped from 0.22 ± 0.22 preoperatively to 0.28 ± 0.23 ($p = 0.01$) at the follow-up examination after 1 year. At the last follow-up, mean visual acuity in the eyes undergoing CPC was 0.26 ± 0.27 which was not statistically different from the results 1 year after surgery ($p = 0.42$). At the last follow-up examination, BCVA was reduced by ≥ 2 Snellen lines in 19.6% of eyes after TET and 20.0% of eyes that were treated with CPC and there was no statistically significant difference between the results in both treatment groups ($p = 0.5$).

Mean IOP decreased in the TET-group from 24.9 ± 6.4 mmHg before surgery to 15.8 ± 3.4 mmHg after 1 year ($p = 0.001$), which equals an IOP reduction of 32.3% (Fig. 2). Thereafter, IOP remained stable with a mean of 14.9 ± 3.1 mmHg at the last examination ($p = 0.29$). In the CPC-group, mean IOP decreased significantly from 23.0 ± 6.5 to 17.8 ± 4.8 mmHg 1 year after surgery ($p = 0.001$) which equals a reduction of 22.6%. After that, mean IOP further decreased significantly to 16.0 ± 4.1 mmHg compared to the follow-up examination after 1 year ($p = 0.03$). When comparing the amount of IOP reduction between both groups 1 year after surgery, the difference was statistically significant with a lower mean IOP in the TET-group ($p = 0.004$). Comparing pressure reduction in between groups at the last follow-up examination did not show statistical significance ($p = 0.06$).

In the TET-group, mean MD 1 year after surgery did not show a statistical difference compared to before surgery with 7.4 ± 4.8 dB and 8.0 ± 5.0 dB, respectively ($p = 0.10$) (Fig. 3). At the last follow-up examination, mean MD in the TET-group remained stable with 8.1 ± 4.9 ($p = 0.74$). Parallel to this, the mean total RNFL thickness as measured using OCT also did not show statistically significant differences at the last follow-up examination where it was 60.9 ± 22.9 µm compared to before surgery with 58.6 ± 18.6 µm ($p = 0.46$). In the CPC-group, average MD increased from 9.0 ± 4.9 before to 10.7 ± 4.6 1 year after surgery which was statistically significant ($p = 0.001$). After that, MD remained stable with 10.7 ± 4.6 at the last follow-up examination ($p = 0.99$). OCT measurements also revealed a

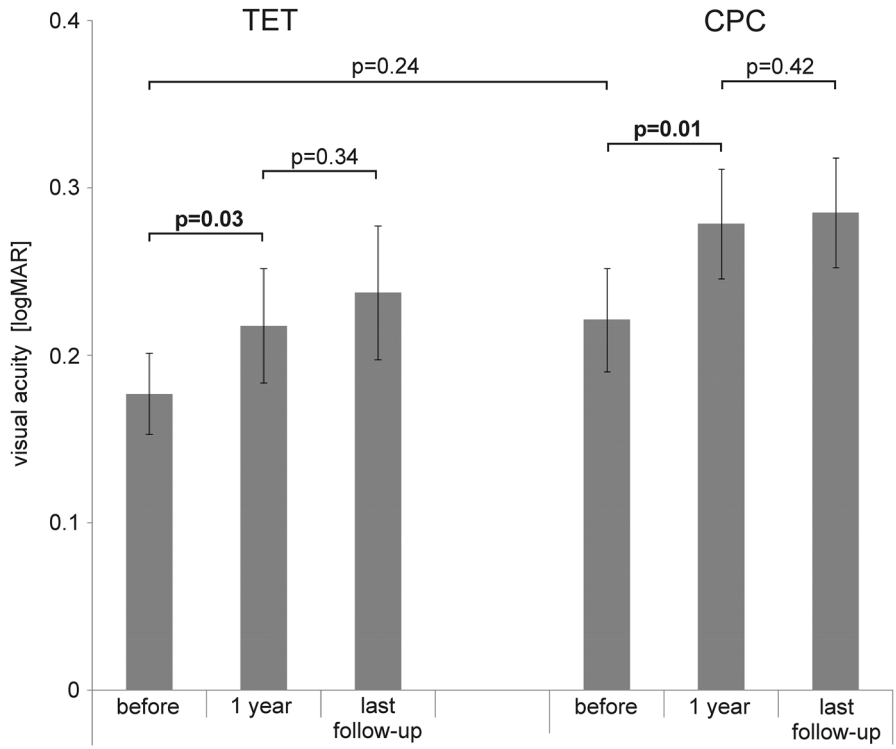


**Fig. 1** Development of mean visual acuity in the TET- and CPC-groups from before surgery until the last follow-up examination as well as the results for intra- and intergroup comparisons

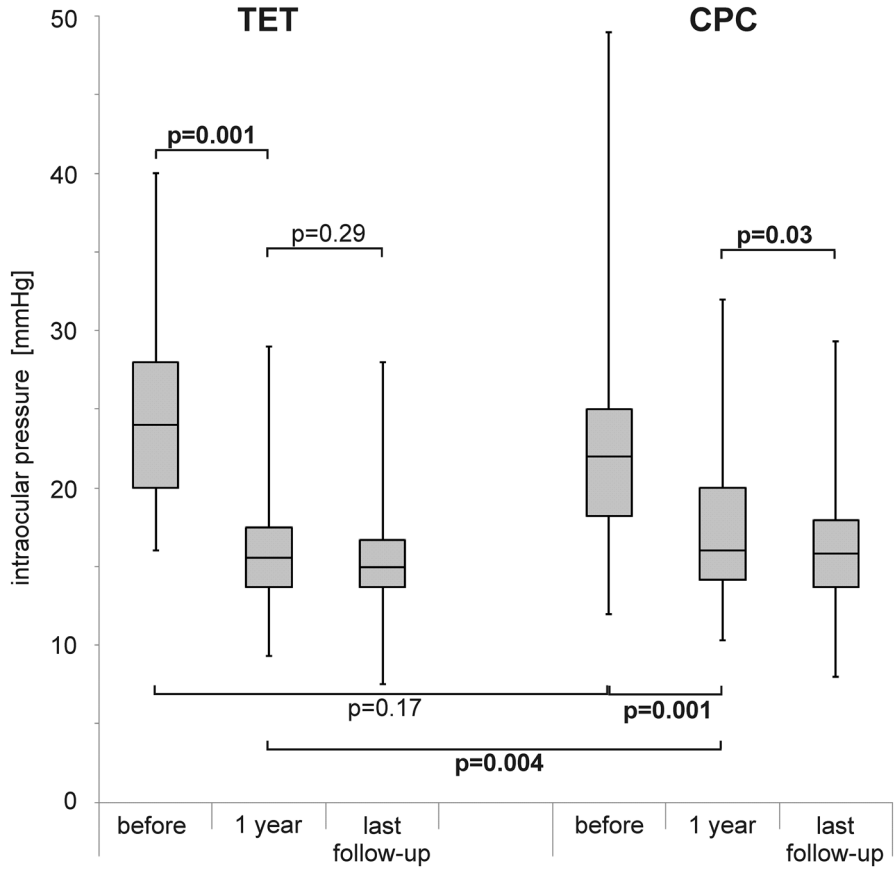


**Fig. 2** Course of mean intraocular pressure results in the TET- and CPC-groups from before surgery until the last follow-up examination

decrease in RNFL thickness from before surgery (74.7 ± 19.0 µm) to the last follow-up examination (67.6 ± 18.1 µm) which was statistically significant ($p = 0.001$).

The number of applied glaucoma drugs decreased significantly from 3.0 ± 1.1 preoperatively to 1.4 ± 1.3 at the 1-year follow-up examination ($p = 0.001$) and 1.5 ± 1.3 at the last examination ($p = 0.001$) in the TET-group (Fig. 4). In the CPC-group, the number of prescribed IOP-lowering agents was 3.0 ± 0.7 before surgery, 3.0 ± 0.8 at the one-year follow-up and 2.9 ± 0.9 at the last follow-up examination and showed no difference of statistical significance neither at the 1-year follow-up examination ($p = 0.8$) nor at the last follow-up ($p = 0.1$).

The exact rates for complete and qualified successes (A) and (B) can be taken from Table 4. Most success rates are higher for the group of eyes undergoing TET. But the success rates increased in the CPC-group between the follow-up examination 1 year after surgery and the last follow-up examination in case of qualified success (A) and (B), so that an initially present statistically significant difference disappeared during this time interval when considering success rates (A), but not for success rates (B).

The mean SIA in the TET-group was 0.82 ± 0.65 diopters (D) 1 year after surgery and 0.83 ± 0.69 D at the last follow-up examination. When comparing the SIA results measured at both time points, no statistically significant difference could be found ($p = 0.9$). In the CPC-group, the mean SIA was 0.72 ± 0.54 D 1 year after surgery and 0.91 ± 0.65 D at the last follow-up examination. This increase in SIA in the CPC-group was not statistically significant ($p = 0.06$). When comparing SIA of both treatment groups at both examinations, the difference in between groups was not statistically significant ($p = 0.6$ 1 year after operation; $p = 0.6$ at the last follow-up).

A statistically significant correlation between IOP and SIA was found in the TET-group 1 year after surgery where a lower IOP correlated with a higher

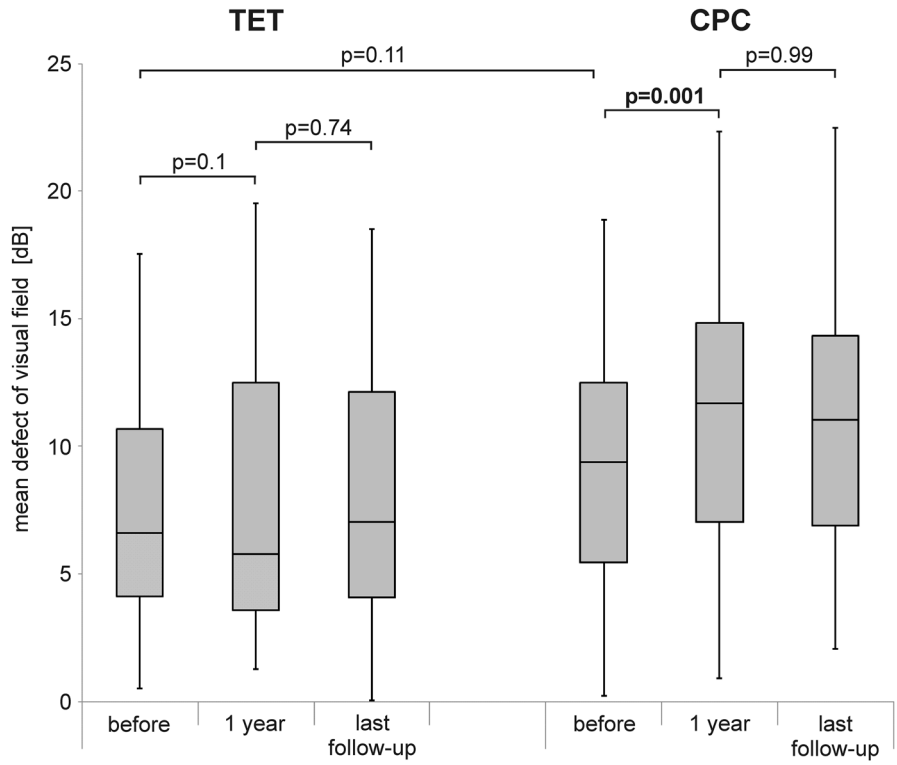


**Fig. 3** Development of the averaged visual field tests mean defect for all eyes included into the TET- and CPC-groups from before surgery until the last follow-up examination. The visual fields mean defect remained stable in the TET-group and further progressed in the CPC-group during the postsurgical follow-up period

SIA ($r = -0.29$, $p = 0.04$). This correlation however could not be found in the results determined at the last follow-up examination. Apart from these findings in the TET-group, the results found for the CPC-group did neither at 1 year after surgery nor at the last follow-up examination show a correlation of statistical significance between SIA and IOP.

Regarding complications, in the early postoperative period (first 6 weeks postsurgery) hypotony (defined as IOP < 6 mmHg with or without choroidal detachment or hypotonia-induced maculopathy) was seen in 4 patients (7.8%) of the TET-group and all resolved without long-term consequences. In the CPC-group, atonic pupil was found in 1 eye (2.2%) and an oval pupil in 1 eye (2.2%). One eye had hypotony with choroidal detachment (2.2%) in this group which resolved under medical management without other sequelae. On the long term, one eye which underwent CPC had a chronic uveitis (2.2%) and cystoid macular edema which did not respond to medical management in the first year of follow-up and caused visual loss (preoperative visual acuity of 0.1 logMAR and 0.3 logMAR after 1 year). This resolved until the last follow-up 17 months after surgery with visual acuity rising back to 0.1 logMAR. Another eye had herpes simplex stromal keratitis (2.2%) which was managed medically and resulted in vision loss from 0.7 logMAR preoperatively to 1.0 on the last follow-up 21 months after surgery. Whether this complication is directly related to the intervention is not clear. The total complication rate in the CPC-group was 11.1%. Considering all complications in both groups, 4 occurred out of 51 eyes in the TET-group and 5 out of 45 eyes in the CPC-group. The different complication rates of TET- and CPC-groups were not statistically significant ($p = 0.4$).

## Discussion

TET has been the gold standard for the surgical management of glaucoma for decades. TET offers a controlled reduction of IOP and thereby adds to the preservation of visual function in glaucomatous eyes [27–30]. However, disadvantages are numerous like occurring postsurgical complications and the partly demanding postsurgical care for the treating physician [6–8]. Hennis and Stewart [31] introduced transscleral

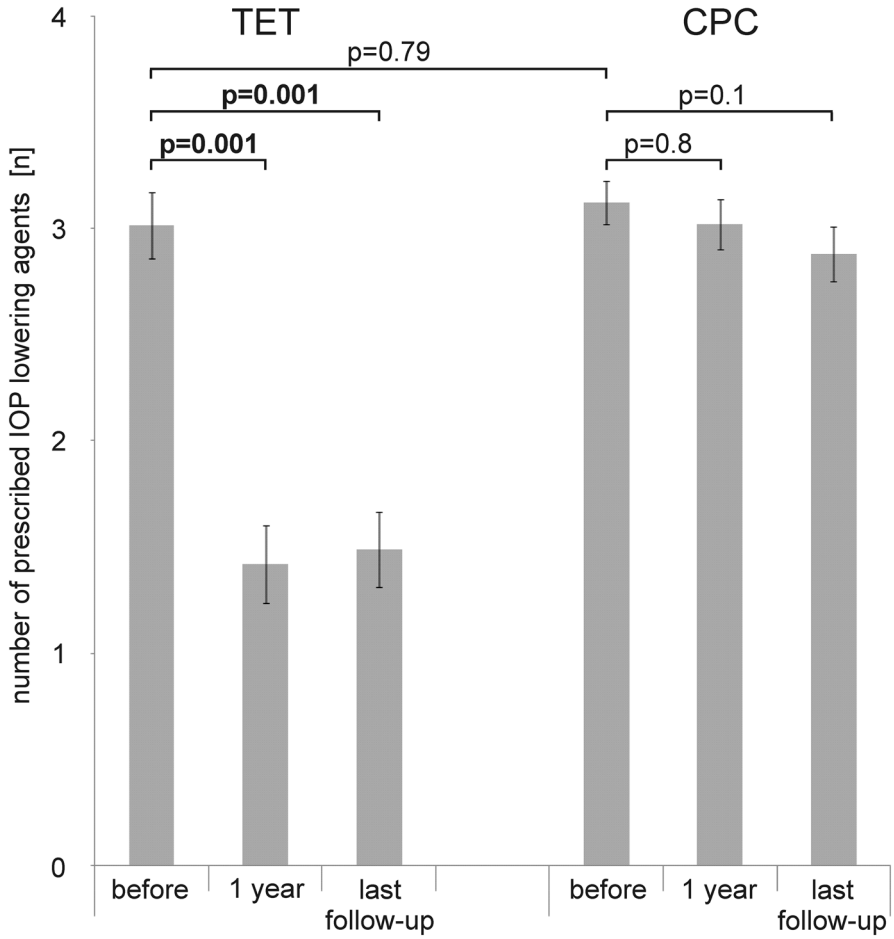


**Fig. 4** Mean number of IOP-lowering medications applied in the eyes of the TET- and CPC-groups before surgery as well as in the postsurgical course. The mean number of applied eye drops dropped in the TET-group after surgery and remained stable in the CPC-group

**Table 4** Achieved success rates of the eyes in the TET- and CPC-groups and the comparison between both

| | TET (%) | CPC (%) | *p* |
|---|---|---|---|
| Complete success (A) | | | |
| 1 year | 28.9 | 0 | 0.001 |
| Last follow-up | 23.5 | 4.4 | 0.01 |
| Qualified success (A) | | | |
| 1 year | 75.5 | 51.1 | 0.02 |
| Last follow-up | 70.6 | 64.4 | 0.14 |
| Complete success (B) | | | |
| 1 year | 24.4 | 0 | 0.001 |
| Last follow-up | 19.6 | 4.4 | 0.01 |
| Qualified success (B) | | | |
| 1 year | 66.7 | 26.7 | 0.003 |
| Last follow-up | 64.7 | 42.2 | 0.01 |

*TET* trabeculectomy, *CPC* cyclophotocoagulation

CPC using a diode laser in 1992 as an effective method for the reduction of IOP. CPC was widely adopted as a last-resort treatment for complicated glaucoma cases with anticipated limited success rates of TET. However, an increasing number of reports have been published recently suggesting CPC as a first-line surgical treatment for different types of glaucoma since it is faster and easier to perform than TET and reported a significant reduction of IOP and relatively low complication rates [16, 19–23, 32]. Due to a lack of direct comparative surveys between CPC and TET, we performed this monocentric retrospective comparative case analysis and strictly included only those cases where a complete follow-up of 1 and 2–3 years after surgery was available.

BCVA decreased significantly after both TET and CPC during the postsurgical follow-up period. At the last follow-up examination, BCVA was reduced by $\geq$ 2 Snellen lines in 19.6% of eyes after TET and

20.0% of eyes that were treated with CPC and there was no statistically significant difference between the results in both treatment groups. Similar results concerning a decrease in visual acuity after TET or CPC have been reported before. An increase in lens opacification, hypotony-induced maculopathy, progression of visual field defects affecting the central visual field and others are partly held responsible for this decrease [29, 33–35]. Since this is already well established, all patients planned for one of these procedures should be informed of a possible reduction of visual acuity after surgery.

But even when the above-listed reasons are ruled out, slight drops of visual acuity are observed in eyes after TET and CPC. Another reason for this decrease could lie in an induced change of the operated eyes refraction. In our patient population, both operations induced a distinct change of refraction which was still measureable years after surgery. The effect of both TET and CPC on the eyes refractive state and induced changes of refraction have been studied before in different patient groups of varying size [36–42]. When comparing penetrating and non-penetrating filtering glaucoma surgery outcomes, it was shown that both cause a significant change of refraction during the postoperative course. In case of TET, the induced change of refraction is probably due to the created scleral flap, the sutures keeping the scleral flap in place and the developing bleb pressing onto sclera and cornea. In eyes undergoing CPC, the induced change of refraction may in theory be due to scarring and reorganization of scleral fibers at the regions where the laser was applied to treat the underlying ciliary body epithelium and affection of the adjacent cornea. But histological proof confirming this hypothesis is lacking. Some lack of clarity also exists on how far the amount of refractive change differs between both techniques [37, 43]. That the amount of induced refractive change after TET is also drastically changing in the early postoperative course until 6–12 months after surgery has also been shown before [38].

On the last follow-up, we observed a SIA of $0.83 \pm 0.69$ in the TET-group and of $0.91 \pm 0.65$ in the CPC-group with no difference between both groups. This should be taken into consideration during the postsurgical follow-up, but still cannot fully explain the visual loss found in both groups in our study as visual acuity was measured as BCVA including a best correction in each visit, so that the effect of the SIA was compensated in the results. We also found a mild but still a significant negative correlation between the calculated SIA and the IOP in the TET eyes after 1 year ($r = -0.29$, $p = 0.04$) meaning that lower IOPs were reached in those eyes with larger amounts of SIA. Interestingly, this negative correlation disappeared in the further postoperative course possibly owing to further reorganization of the ocular tissues involved even after more than 12 months after surgery. The hereby presented results are to our knowledge the first dealing with long-term induced refractive changes of more than 12 months after TET and CPC and a direct comparison between both.

IOP reduction was statistically significant in both groups although more pronounced and less depending on additional IOP-lowering medications in the TET-group. This difference is illustrated in the different postsurgical success rates (Table 4). IOP reduction remained stable over the follow-up period in the TET- and CPC-groups. Eyes undergoing TET showed better complete success rates and comparable qualified success rates with CPC when considering the success rates (A). Regarding the success rates (B) TET eyes achieved higher complete and qualified success rates. A significant and sustained reduction of IOP and necessary glaucoma medications has been reported before in eyes which underwent TET and was also found in our results [27, 28, 30]. Long-term IOP reduction after CPC was also proven in different clinical studies [44, 45]. Our results are consistent with other reports concerning CPC results in POAG patients [14, 46]. A significant reduction of the number of necessary glaucoma medications after CPC to establish a certain IOP reduction has been reported before but was not detectable in our results [15, 45]. Schlote et al. found only a minimal reduction of medications (2.3 pre- to 2.0 medications post-op, $p = 0.049$) and used comparable energy settings to our study. Walland used a higher number of shots (40 shots in the first and 20 in the second group) compared to our study, still with lower energy settings (1500 mw and 1500 ms compared to 2000 mw and 2 s in ours), and this could partly explain the difference in the reduction of medication especially in the first group which was not found in our study. Of note, the reduction in the second group which received 20 shots was minimal (1.9 pre- to 1.5 post-op.), and the author

did not mention if this reduction was statistically significant or not.

Over the follow-up period, mean MD remained stable in the TET-group but not in the CPC-group where visual field defects further progressed. The efficacy of TET in lowering IOP and thereby slowing the progression of visual field decline has been described before in many reports [15, 26]. Contrary to this, an acceleration of visual field decline by 0.05 dB/year was demonstrated after CPC despite a potent IOP reduction of 38% [27]. Also the eyes undergoing CPC were more depending on application of additional IOP-lowering medications to meet the targeted IOP levels after surgery. Since adherence and persistence to therapy are known to be lower than expected in glaucoma patients, a discontinuation of glaucoma medication when IOP was not monitored could contribute to the increase in visual field defects during the follow-up period.

The complications in the early postsurgical period (6 weeks post-op) were minimal in our TET- and CPC-groups. Early hypotonia was observed in the TET-group in 4 eyes (7.8%), and this resolved under medical management without other sequelae. In the CPC-group, atonic pupil was observed in 1 eye (2.2%) and an oval pupil in 1 eye (2.2%). These remained unchanged until the last follow-up and did not cause subjective functional disabilities. On the mid- to long term, no sight-threatening complications were observed in the TET-group, while in the CPC-group one eye (2.2%) had a chronic macular edema causing vision loss until the first year post-op, and this resolved on the last follow-up with regain of visual acuity. This complication is known, still rare after CPC [22] and resulted in other reports only in temporary loss of visual acuity. One other eye suffered from herpes keratitis resulting in loss of visual acuity. No cases of phthisis bulbi were observed in both treatment groups during follow-up. Altogether, eyes undergoing CPC had a complication rate of 11.1%, which is comparable with that found for our TET-group and is in accordance with published data [14, 16, 32, 47].

## Conclusion

The main findings of this retrospective comparative analysis between TET and CPC in POAG eyes are that using both techniques IOP can be lowered effectively with few occurring complications. But only in eyes undergoing TET visual field decline was arrested effectively with application of fewer additional medication. However, performance of CPC did not stop visual field decline or reduce additional medication in POAG eyes. Both TET and CPC led to a comparable reduction of visual acuity and development of SIA.

Trabeculectomy remains the gold standard for glaucoma surgery today. Although new developments of surgical techniques, the effectiveness and availability of TET remains unrivaled. Transscleral diode laser CPC is effective in reducing intraocular pressure but does neither lead to a decrease in necessary medication to reach targeted IOP nor does it stop further visual field deterioration effectively. Due to these factors, TET is favorable over CPC in POAG eyes despite longer operating time and challenging technique.

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