RESEARCH ARTICLE

Retrospective evaluation of two-year results with a filtering trabeculotomy in comparison to conventional trabeculectomy by exact matching [version 1; peer review: 1 approved]

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Abstract

Background: To compare two-year results of a filtering trabeculotomy (FTO) to conventional trabeculectomy (TE) in open-angle glaucoma by exact matching.

Methods: 110 patients received an FTO and 86 a TE. FTO avoided the need for an iridectomy due to a preserved trabeculo-descemet window anterior to the scleral flap. TE employed a trabecular block excision and iridectomy. Mitomycin C was used in both. FTO and TE were exact matched by baseline intraocular pressure (IOP) and the number of glaucoma medications. Complete and qualified success (IOP ≤18 mmHg and IOP reduction ≥ 30%, with or without medication) were primary endpoints. IOP, visual acuity (BCVA), complications and intervention were secondary endpoints.

Results: 44 FTO were exact matched to 44 TE. The IOP baseline in both groups was 22.5±4.7 mmHg on 3±0.9 medications. At 24 months, complete success was reached by 59% in FTO and 66% in TE, and qualified success by 59% in FTO and 71% in TE. In FTO, IOP was reduced to 12.4±4.3 mmHg at 12 months and 13.1±4.1 mmHg at 24 months. In TE, IOP was 11.3±2.2 mmHg at 12 months and 12.0±3.5 mmHg at 24 months. Medications could be reduced at 24 months to 0.6±1.3 in FTO and 0.2±0.5 in TE. There were no significant differences between the two groups in IOP, medications, complications or interventions at any point.

Conclusion: Modifying aqueous flow through a limited trabeculotomy in FTO yielded clinical outcomes similar to traditional TE but allowed to avoid an iridectomy.

Keywords
trabeculectomy, mitomycin C, trabeculotomy, exact matching, open-angle glaucoma, iridectomy
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Introduction
Since the first description of a guarded filtering procedure in enucleated eyes by Grant in 1958, performance of this surgery in patients in 1961 by Sugar, popularization of the term “trabeculectomy” in 1968 by Cairns, and introduction of mitomycin-C as an antifibrotic to make it more effective, trabeculectomy (TE) has remained a primary surgery in the treatment of glaucoma. Over the years, multiple modifications of this surgery have been explored to improve its effectiveness, to make outcomes more predictable and to reduce postoperative complications and need for interventions. These modifications include, among others, variations in size, localization, and thickness of the scleral flap, different suture techniques, variable intra- and postoperative treatment with antifibrotics or a combination of these approaches with one another.

In this study, we combined elements of deep sclerectomy and trabeculotomy with TE in an attempt to improve conventional outflow as well as subconjunctival aqueous humor drainage. Encouraged by a pilot study of filtering trabeculotomy (FTO) with a complete success rate of 79%, we hypothesized that FTO had a higher success rate and lower complication rate than TE. We applied advanced statistics, exact matching, to enable a highly balanced comparison of our retrospective data with two-year follow-up.

Methods
Study design
This retrospective study was approved by the ethics committee of the University of Würzburg, Germany (#2019101601AS). Because of its retrospective nature, informed consent was waived.

All primary open angle glaucoma (POAG) patients at the University Eye Hospital Würzburg who underwent a modified FTO with mitomycin C (MMC) or TE with MMC by a single surgeon (FG) between 2007 and 2014 were analyzed. The indication for surgery was a failure to control intraocular (IOP) pressure, flat or shallow chamber, an IOP relatively high for surgery, carbonic anhydrase inhibitors, and trabecular outflow as well as subconjunctival aqueous humor drainage.

Inclusion criteria
- Hyphema
- Hypotony
- Mitomycin C
- Cataract
- Glaucoma medications (including a glaucoma medication score [logMAR])
- IOP (Goldmann tonometry [mmHg])
- Topical glaucoma medications
- Visual field defect
- Best corrected visual acuity

Categorical variables were described as the frequency with percentage, whereas continuous and discrete variables as mean with standard deviation (SD) or median with range. The chi-squared test or Fisher’s exact test was used for the analysis of categorical variables. Continuous variables were compared using Student’s t-test or Mann–Whitney U test, whereas discrete variables were compared using Mann-Whitney U test. The distribution of continuous variables was determined by the
Shapiro-Wilk test, equality of variances by Levene’s test. Assessment of repeated measures for IOP was performed using repeated measures MANOVA and Tukey’s test, while visual acuity (logMAR) and medications were examined using the Friedman test and Wilcoxon signed-rank test. The success of treatment was expressed by a Kaplan-Meier curve and compared between treated groups using the log-rank test. The success of treatment at particular a given time point was determined by odds ratio (OR) with respective 95% confidence intervals and p-values. P-values below 0.05 were considered statistically significant.

Results
A total of 196 patients were included. The unmatched demographic data of FTO and TE had significant differences in preoperative IOP (p=0.017), glaucoma medication score (p=0.001), and pseudophakia (p=0.012). In total 88, eyes (44 in each group) could be matched as exact pairs eliminating key differences in IOP and medications. The IOP at baseline was 22.6±4.7 mmHg in FTO and 22.6±4.7 in TE while on 3.0±0.9 medications in both (Table 1). There were no significant differences between FTO and TE in gender, age, best-corrected visual acuity, type of glaucoma, or surgical side. In FTO, 13 eyes were pseudophakic compared to 3 in TE (p=0.006). Two patients in FTO had a pars plana vitrectomy and one a retinal cryopexy. In TE, there were no prior ocular surgeries other than phacoemulsification.

There were no statistically significant inter-group differences in complete or qualified success at any time (p=0.403 for complete success; p=0.204 for qualified success at 24 months; Figure 1 and Figure 2). The complete success rate in FTO ranged from 79% to 6 to 78% at 12 months, and 59% at 24 months. In TE, it was 81%, 85%, and 66%, respectively. Similarly, IOPs of FTO and TE were not significantly different at any time (12 months: p=0.983, 24 months: p=1.000, Figure 3). At one year, the IOP had declined to 12.4±4.3 mmHg in FTO and 11.3±2.2 mmHg in TE with medications (qualified success). At two years, IOP remained at 13.1±4.1 mmHg in FTO and 12.0±3.5 mmHg in TE (qualified success), respectively. The postoperative visual acuity was not significantly different in FTO and TE at any time (p=0.894 after 12 months; p=0.443 after 24 months; Figure 4 and Figure 5).

There was a reduction in glaucoma medication from 3±0.9 to 0.6±1.3 in FTO and from 3±0.9 to 0±0.5 in TE after 24 months. There was no significant difference between the two groups in glaucoma medications at 24 months with 19% of patients in

<table>
<thead>
<tr>
<th>Table 1. Demographic data of both groups after matching.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FTO n=44</strong></td>
</tr>
<tr>
<td>Female (n, (%))</td>
</tr>
<tr>
<td>Male (n, (%))</td>
</tr>
<tr>
<td>Age, years (mean±SD)</td>
</tr>
<tr>
<td>BCVA, logMAR (mean±SD)</td>
</tr>
<tr>
<td>Preoperative IOP, mmHg (mean±SD)</td>
</tr>
<tr>
<td>Glaucoma medication (mean±SD)</td>
</tr>
<tr>
<td>Type of glaucoma (n, (%))</td>
</tr>
<tr>
<td>POAG</td>
</tr>
<tr>
<td>PXG</td>
</tr>
<tr>
<td>PG</td>
</tr>
<tr>
<td>Right</td>
</tr>
<tr>
<td>Left</td>
</tr>
<tr>
<td>Pseudophakia (n, (%))</td>
</tr>
<tr>
<td>Prior ocular surgery excluding phaco (n, (%))</td>
</tr>
<tr>
<td>Type of prior laser (n, (%))</td>
</tr>
<tr>
<td>ALT</td>
</tr>
<tr>
<td>SLT</td>
</tr>
<tr>
<td>CPC</td>
</tr>
<tr>
<td>nd:YAG capsulotomy</td>
</tr>
</tbody>
</table>

Figure 1. Kaplan-Meier curve for complete success in filtering trabeculotomy (FTO) and trabeculectomy (TE).

Figure 2. Kaplan-Meier curve for qualified success in FTO and TE.
Figure 3. Mean preoperative vs postoperative intraocular pressure (IOP) of filtering trabeculotomy (FTO) and trabeculectomy (TE) (mean±SD).

Figure 4. Preoperative versus postoperative visual acuity of both groups (mean±SD). FTO: filtering trabeculotomy; TE: trabeculectomy.

FTO and 12% of patients in TE using glaucoma drops (p=0.471, Figure 6 and Figure 7).

Postoperative complications in FTO included 5 eyes (12%) with a high IOP, hyphema in 5 cases (11%) and hypotony (IOP ≤ 5 mmHg) with choroidals in 4 eyes (9%). The most common postoperative challenge in TE was a flat bleb in 6 eyes (14%), hyphema in 3 eyes (7%), high IOP in 2 eyes (5%), bleb leakage in 2 eyes (5%), and hypotony in 1 eye (2%). A total of 16, mostly reversible, complications occurred in each group (37%; Table 2).

The number of postoperative interventions was the same in the two groups (p=0.087). Bleb needling, conjunctival suture, and scleral flap suture were the most common interventions. There was no statistically significant difference between both groups in early or late interventions (Table 3), except 5-FU and laser suture lysis, which was performed more often in FTO.

Discussion
TE with MMC remains a primary surgery in the management of advanced glaucoma despite its potential for serious complications that include choroidal effusions, maculopathy, blebitis, endophthalmitis, and suprachoroidal hemorrhage. Numerous modifications have been explored over the years to reduce the rate of these. They include a smaller scleral flap, limbus-versus fornix-based conjunctival closure, releasable flap sutures, a combination of trabeculectomy with deep sclerectomy, different concentrations and exposure times of MMC or sutureless tunnel trabeculectomy without iridectomy. The iridectomy, which
is part of traditional trabeculectomy with a trabecular block excision, can cause hyphema, inflammation, posterior synechiae, iris-dialysis, and cataracts\textsuperscript{25,26}. FTO addresses some of these issues by creating a more spread-out intake of aqueous humor, thereby reducing iris aspiration and avoiding the need for an iridectomy. The trabeculotomy and sclerectomy\textsuperscript{8,27,28}, that are part of the FTO, were meant to remove some of the post trabecular outflow resistance\textsuperscript{29,30}.

We used matching, a nonparametric method of controlling the confounding influence of pretreatment variables in observational data\textsuperscript{31}. Before matching, FTO and TE had significant
Figure 7. Scatter plots of IOP of both groups. Few patients required medications postoperatively.

Table 2. Postoperative complications and challenges.

<table>
<thead>
<tr>
<th></th>
<th>FTO, n (%)</th>
<th>TE, n (%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypotony with choroidals</td>
<td>4 (9)</td>
<td>1 (2)</td>
<td>0.360</td>
</tr>
<tr>
<td>Hypotony maculopathy</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>1.000</td>
</tr>
<tr>
<td>Shallow or flat chamber</td>
<td>4 (9)</td>
<td>4 (9)</td>
<td>1.000</td>
</tr>
<tr>
<td>High IOP</td>
<td>5 (12)</td>
<td>2 (5)</td>
<td>0.266</td>
</tr>
<tr>
<td>Bleb leakage</td>
<td>0 (0)</td>
<td>2 (5)</td>
<td>0.494</td>
</tr>
<tr>
<td>Flat bleb</td>
<td>1 (2)</td>
<td>6 (14)</td>
<td>0.110</td>
</tr>
<tr>
<td>Hyphema</td>
<td>5 (12)</td>
<td>3 (7)</td>
<td>0.713</td>
</tr>
<tr>
<td>Iris incarceration</td>
<td>0 (0)</td>
<td>1 (2)</td>
<td>1.000</td>
</tr>
<tr>
<td>Need for cataract surgery</td>
<td>1 (1)</td>
<td>1 (1)</td>
<td>1.000</td>
</tr>
</tbody>
</table>

FTO: filtering trabeculotomy; TE: trabeculectomy; IOP: intraocular pressure.

We have previously used coarsened exact matching, propensity score matching, and, more recently, exact matching. Coarsened exact matching applies multiple imputations to fill in missing data to not distort any relationships contained in the data while enabling the inclusion of all observed data from moderately uneven groups. Such was the case when we compared patients with a primary IOP indication to patients with a mixed indication for both cataract removal and IOP reduction. Propensity score matching is helpful to compare even more divergent groups, for instance, patients undergoing tube shunt surgery with patients undergoing trabectome surgery. By contrast, exact matching is well suited to compare similar pathological conditions and similar treatments, for instance, phaco-iStent or phaco-trabectome. A downside of exact matching is that a certain number of datasets must be excluded from the analysis because the algorithm accepts only identical primary criteria matches. Overall, our data loss was acceptable because of the high similarity that already existed at baseline. We were able to retain a large number of eyes (about 45%) as identical pairs of preoperative IOP and medication to focus on the preeminent questions of success in IOP and medication reduction. We found that FTO was as successful as TE with a similar reduction of IOP and medications. Both had a similar intervention and complication rate, notwithstanding numerical hypotony within the first six weeks after surgery. We observed a remarkably low rate of hyphema compared to ab interno trabeculecctomy that occurs when the IOP is at or below episcleral venous pressure allowing blood to reflux into the anterior chamber. This could indicate reduced patency of collector channels in advanced glaucoma that qualifies for filtering surgery, which has been observed ex vivo.

Trabeculotomy ab externo has been applied to adult POAG before but, compared to TE, was noted to have a lower success rate of 70% at one year, presumably due to a reapproximation
Table 3. Postoperative interventions in FTO and TE.

<table>
<thead>
<tr>
<th>Early postoperative interventions</th>
<th>FTO (n, (%))</th>
<th>TE (n, (%))</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of interventions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>26 (59)</td>
<td>35 (80)</td>
<td>0.087</td>
</tr>
<tr>
<td>1</td>
<td>15 (34)</td>
<td>8 (18)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2 (5)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0 (0)</td>
<td>1 (2)</td>
<td></td>
</tr>
<tr>
<td>5-FU (mean±SD)</td>
<td>2.1±2.4</td>
<td>0.8±0.9</td>
<td>0.023</td>
</tr>
<tr>
<td>Bleb needling</td>
<td>11 (25)</td>
<td>6 (14)</td>
<td>0.280</td>
</tr>
<tr>
<td>Conjunctival suture</td>
<td>4 (9)</td>
<td>3 (7)</td>
<td>1.000</td>
</tr>
<tr>
<td>Scleral flap revision (high IOP)</td>
<td>2 (5)</td>
<td>0 (0)</td>
<td>0.494</td>
</tr>
<tr>
<td>Scleral flap suture (hypotony)</td>
<td>2 (5)</td>
<td>2 (5)</td>
<td>1.000</td>
</tr>
<tr>
<td>nd:YAG laser goniopuncture</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>1.000</td>
</tr>
<tr>
<td>Cyclodestruction</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>1.000</td>
</tr>
<tr>
<td>Iris repositioning</td>
<td>1 (2)</td>
<td>1 (2)</td>
<td>1.000</td>
</tr>
<tr>
<td>Laser suture lysis (average±SD)</td>
<td>1.5±1.5</td>
<td>0.8±0.9</td>
<td>0.026</td>
</tr>
</tbody>
</table>

Late postoperative interventions

<table>
<thead>
<tr>
<th>No. of interventions</th>
<th>FTO (n, (%))</th>
<th>TE (n, (%))</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>35 (80)</td>
<td>42 (95)</td>
<td>0.147</td>
</tr>
<tr>
<td>1</td>
<td>6 (14)</td>
<td>2 (5)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3 (7)</td>
<td>0 (0)</td>
<td>0.241</td>
</tr>
<tr>
<td>Bleb needling</td>
<td>1 (2)</td>
<td>2 (5)</td>
<td>1.000</td>
</tr>
<tr>
<td>Conjunctival suture</td>
<td>3 (7)</td>
<td>0 (0)</td>
<td>0.241</td>
</tr>
<tr>
<td>Scleral flap revision (high IOP)</td>
<td>3 (7)</td>
<td>0 (0)</td>
<td></td>
</tr>
<tr>
<td>Scleral flap suture (hypotony)</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>**</td>
</tr>
<tr>
<td>nd:YAG laser goniopuncture</td>
<td>4 (9)</td>
<td>0 (0)</td>
<td>0.116</td>
</tr>
<tr>
<td>Cyclodestruction</td>
<td>1 (2)</td>
<td>0 (0)</td>
<td>1.000</td>
</tr>
<tr>
<td>Re-TE</td>
<td>0 (0)</td>
<td>0 (0)</td>
<td>**</td>
</tr>
</tbody>
</table>

** not calculated. FTO: filtering trabeculotomy; TE: trabeculectomy; IOP: intraocular pressure

or regeneration of the disrupted trabecular meshwork. A study by Chihara et al. was in agreement with this, finding that a modified trabeculotomy ab externo lowers IOP to an average near 16 mmHg in a safe fashion, by not as much as TEs. Ogawa et al. compared a nonpenetrating trabeculectomy with or without trabeculotomy using a technique that was very similar to the one applied in our study, except without MMC. Despite the absence of this antifibrotic, the authors achieved a two-year IOP of 13 mmHg, not unlike our patients.

Our two-year TE results match Kirwan et al.’s multicenter study of TE with an iridectomy in 428 eyes well. These eyes achieved an IOP of 12.4±4 mmHg and 80% did not have to use glaucoma medications anymore, slightly more than in our study population. The authors performed needling in 17% of patients, not unlike our rates, and numerical hypotony during the first six months occurred in 7.2% of patients, which is in a similar range as our 9% in FTO and 2% in TE. Leakage was observed in 14% compared to 9% in our FTO and 2% in our TE. However, Kirwan et al.’s cataract surgery rate was 31%, much higher than our 1% in both FTO and TE, which might represent a difference in practice pattern or simply easier access to this elective procedure, which is done as an outpatient surgery in the UK.

It is interesting to note that TEs in the Tube Versus Trabeculotomy (TVT) study were performed without an iridectomy. In that study, IOP reduced from 25.6±5.3 mm Hg to 12.7±5.8 mm Hg at one year while the number of glaucoma medications declined from 3.0±1.2 to 0.5±0.9, which is also relatively similar to our results although these investigators included eyes with prior...
In all of these studies, TE was performed as an outpatient patient procedure, a practice that emerged in the late 1980s\textsuperscript{49,50} and became a standard for most types of eye surgeries and countries\textsuperscript{51–54}. Even before the now-common use of antifibrotics, there was no significant difference in success or complication rates between inpatients and outpatients\textsuperscript{51}, an observation that has been confirmed with antifibrotics as well\textsuperscript{55}. In the country of our study, TE and FTO are only reimbursable as inpatient procedures. It has been argued that meticulous micromanagement after TE for several days may be associated with better long-term outcomes of TE. However, this hypothesis is challenged by the present study and by the findings of others\textsuperscript{49,50,53,55}. One could argue that the considerably lower cataract surgery rate in our data compared to Kirwan et al.\textsuperscript{52} might indicate a higher threshold for cataract surgery. These would have typically also been done as inpatient procedures to better handle post-cataract surgery bleb care.

Our study was limited by its retrospective nature and nonrandomized design. We determined that we had a testing power above 80% to detect a difference of more than 2 mmHg 1 year (alpha= 0.05), yet no significant difference was found. Certainly, randomized controlled trials are a more sophisticated tool to reduce bias when trying to detect differences. However, given that exact matching already allows for a highly balanced comparison of retrospective data, such an effort might be difficult to justify. The indication for postoperative interventions and length of hospitalization was at the discretion of the treating physicians and was not standardized for both groups. Despite reducing confounding through the exact matching of IOP and medications, other confounding factors might have contributed to small differences in early postoperative patient management, as reflected by the fact that FTO patients received more 5-FU injections. Although these patients had a higher rate of numerical hypotony they were hospitalized for a slightly shorter time and experienced results that were not significantly different.

In conclusion, our results are largely in line with other FTO and TE outpatient studies. Combining elements from both yields reasonable two-year rates of surgical success, postoperative complications, and interventions while avoiding an iridectomy.

**Data availability**

**Underlying data**

Open Science Framework: Retrospective evaluation of 2-year results with a filtering trabeculotomy in comparison to conventional trabeculectomy by exact matching, https://doi.org/10.17605/OSF.IO/KDYF3\textsuperscript{56}.

Data are available under the terms of the Creative Commons Zero “No rights reserved” data waiver (CC0 1.0 Public domain dedication).

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A previous version of this article is available on medRxiv: https://doi.org/10.1101/2020.01.17.20017913.

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Marc Töteberg-Harms
Department of Ophthalmology, University Hospital Zurich, Zurich, Switzerland

The authors present a retrospective study comparing two surgical interventions for the management of glaucoma. The use of exact matching is a major advantage of their study design.

It is unclear if only one eye per patient was included and, if not, if a statistical model to account for two-eye-effect was used.

A post-hoc power analysis could further improve this excellent paper to prove that the sample size of 44 eyes per group was sufficient to find a difference or no difference between the two study arms.

Is the work clearly and accurately presented and does it cite the current literature?
Yes

Is the study design appropriate and is the work technically sound?
Yes

Are sufficient details of methods and analysis provided to allow replication by others?
Yes

If applicable, is the statistical analysis and its interpretation appropriate?
Partly

Are all the source data underlying the results available to ensure full reproducibility?
No

Are the conclusions drawn adequately supported by the results?
Yes
**Competing Interests:** No competing interests were disclosed.

**Reviewer Expertise:** Glaucoma, cataract.

I confirm that I have read this submission and believe that I have an appropriate level of expertise to confirm that it is of an acceptable scientific standard.

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