Graefes Arch Clin Exp Ophthalmol
DOI 10.1007/s00417-010-1507-6

GLAUCOMA

Non-penetrating intracanalicular partial trabeculectomy via the ostia of Schlemm's canal

Alexey V. Dashevsky · Ines M. Lanzl · Konstantin E. Kotliar

Received: 26 March 2010 / Revised: 25 July 2010 / Accepted: 29 August 2010

Abstract
Background In order to distinguish a more pronounced and sustained hypotensive effect of non-penetrating glaucoma surgery, a modified surgical procedure is proposed, which provides enlargement of the filtration membrane area with maximal maintenance of natural aqueous outflow pathways.
Methods In 21 eyes of 17 patients with open-angle glaucoma (intraocular pressure: 32.4±4.7 mmHg; age: 69.2±4.4 years) the following non-penetrating surgery was performed. After the excision of the outer wall of Schlemm's canal, outer layers of the trabecular meshwork were removed with a trabecular spatula (Geuder AG, G-16240) at the site of the open area of Schlemm's canal. A cannula-harpoon (Geuder AG, G-S02199) was introduced through both Schlemm's canal ostia, between the less permeable and well-permeable trabecular layers and separating them. Due to the harpoon configuration of the cannula, the superficial less permeable trabecular layers were removed within Schlemm's canal adjacent to its ostia during the retracting movement of the cannula. Thus, the filtration zone became extended using the outflow pathways into Schlemm's canal.
Results A postoperative intraocular pressure of 13.4± 2.3 mmHg after 2 years of follow-up was measured. In all 21 eyes the hypotensive effect was absolute (without medications). In seven cases (33%) a hyphema had occurred during surgery, which dissolved in all cases within 2-3 days postoperatively.
Conclusions The results of the study demonstrate a pronounced and sustained effect of the modified surgery technique, and show that this surgery can be applied successfully in patients with therapy-resistant open-angle glaucoma. Further randomized prospective studies with larger case numbers are needed for generalized conclusions for a large population.

Keywords Non-penetrating glaucoma surgery · Trabecular meshwork · Schlemm's canal · Intraocular pressure

Authors have full control of all primary data, and agree to allow Graefe's Archive for Clinical and Experimental Ophthalmology to review their data upon request.

There exists no financial relationship with any organization that sponsored the research, neither in the form of grants, nor in the form of equipment or drugs.

A. V. Dashevsky
Private Eye Clinic,
Sendlinger Str, 29,
80331 Munich, Germany

I. M. Lanzl · K. E. Kotliar (✉)
Department of Ophthalmology, Munich University of Technology,
Ismaninger Str. 22,
81675 Munich, Germany
e-mail: kotliar@lrz.tum.de

Introduction

Trabeculectomy is nowadays a routine procedure whenever incisional glaucoma surgery is indicated. It represents the gold standard with which all other procedures are compared [18, 24]. Trabeculectomy is associated with complications, even if a stable IOP decrease and visual field maintenance can be achieved [1]. Complications include persistent hypotony, maculopathy, hyphema, increased cataract formation, bleb failure and late endophthalmitis.

Attempts to make the procedure safer have been made by employing different means to recreate the natural outflow path, instead of fashioning a fistula with its inherent problems of too much or too little outflow. Trabeculotomy has been advocated with various success rates for that purpose [25]. Non-penetrating glaucoma surgery (NPGS) was introduced more than 20 years ago [7, 10, 26, 27], increasing in popularity over recent years. A relatively low rate of intraoperative as well as of postoperative complications represents the main advantage of this type of glaucoma surgery. NPGS has been proved to be a safer technique than other available types of glaucoma surgery including trabeculectomy [2, 14, 15, 20, 21]. The sparing character of this surgical procedure allows for the quick recovery of eye functions as well as for the establishing of more natural persistent postoperative aqueous outflow without marked filtering bleb, even after years [2].

The present work aimed to develop a modified NPGS technique named non-penetrating intracanalicular partial trabeculectomy via the ostia of Schlemm's canal (NPIT), which keeps the advantages of NPGS and overcomes its two main disadvantages, which are inadequate hypotensive effect [5, 12] and the relative complexity of the surgical technique compared to trabeculectomy [20]. The results of NPIT were observed in a pilot study with long-term postoperative follow-up. Two surgical instruments were developed in order to standardize the surgical technique and to help a surgeon to avoid prevailing intraoperative failures.

Patients and methods

In 21 eyes of 17 patients with open-angle glaucoma (IOP: 32.4±4.7 mmHg [mean ± standard deviation], range 22.0–43.0 mmHg; age: 69.2±4.4 years, range 61.0–76.0 years), non-penetrating intracanalicular partial trabeculectomy via the ostia of Schlemm's canal (NPIT) was carried out.

Goldmann applanation tonometry was used for IOP measurements. Tonometry data were corrected using pachymetry data and the Dresden correction table [9]. The IOPs of all the glaucoma patients were measured repeatedly before the decision for surgery. These served for the decision-making for the surgical treatment. Mean preoperative IOP value was used as baseline value. The following criteria had to be met for the glaucoma surgery: baseline IOP >22 mmHg with optimized medical therapy, and decrease in visual field parameters in the previous year.

The study was designed as a prospective pilot study to reveal the hypotensive effect of the non-penetrating intracanalicular partial trabeculectomy via the ostia of Schlemm's canal, developed and performed by the authors [3]. In all patients, postoperative IOP was measured 1 day after surgery, 1 month, 1 year and 2 years after surgery. Thirteen of 17 patients in the NPIT group were controlled more frequently: once every 3 months in the first year after the first month following the surgery, and once every 6 months a year thereafter. These additional examinations were not included in the prospective schedule. All 21 eyes of 17 subjects were evaluated during the follow-up.

Informed consent was obtained from all the subjects. The study followed the guidelines for clinical investigations required by the Ethics Committee of Medical Faculty at Munich University of Technology. All procedures adhered to the tenets of the Declaration of Helsinki.

Detailed surgical technique

The less permeable layers of the trabecular meshwork: the inner wall of SC, the juxtacanalicular and the corneoscleral trabecular meshwork (Fig. 1) are removed at the site of the open area of SC with an atraumatic trabecular spatula developed by the authors.

Through both ostia of SC, the cannula-harpoon developed by the authors (Geuder AG, Heidelberg, Germany, G-S02199) is introduced between the less permeable layers of the trabecula meshwork (presumably corneoscleral and juxtacanalicular meshwork and the inner wall of SC) and the well-permeable uveal trabecular layer. The layers are separated with this maneuver. The superficial less permeable trabecular layers are removed via SC through its ostia during the retraction of the cannula. Thus, the post-operative filtration zone becomes extended using the natural outflow pathways as SC, providing sufficient postoperative aqueous outflow. Neither penetration into the anterior chamber (as in trabeculectomy) nor exposing a substantial part of Descemet's membrane (as in the classic non-penetrating deep sclerectomy) is performed (Fig. 1). After the extended filtration membrane is thus created a collagen drainage device (STAAR Surgical Company, Monrovia, CA, USA) is implanted at the site of filtration.

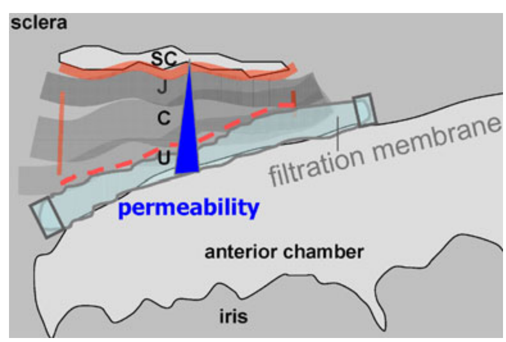

Fig. 1 Anatomical scheme of the classic NPGS procedure. The permeability of the trabecular meshwork decreases towards Schlemm's canal. Less impermeable layers of the trabecular meshwork (area bounded with the *red line*) need to be removed during the surgery. The remaining filtration membrane consists of the more permeable part of the TM. Additionally, the filtration membrane is extended towards Descemet's membrane. *SC* — Schlemm's canal; *J* — juxtacanalicular, *C* — corneoscleral, *U* — uveoscleral layers of the trabecular meshwork. A *continuous red line* adjacent to SC represents the inner wall of SC

The initial part of the surgery follows the classic technique of non-penetrating deep sclerectomy (NPDS) described by Kozlov [10], which is modified and standardized as follows.

A fornix-based conjunctival flap is prepared from limbus. A superficial scleral flap~4×4 mm is separated deeply into the corneal stroma, approximately 1.5 mm in corneal tissue. Its thickness reaches about 1/3 of the sclera, which is approximately 270-300 μm (Fig. 2). The flap is elevated parallel to the surfaces of the sclera and the cornea.

For easier handling during the following separation of the deep flap in the region of Schlemm's canal and Descemet's membrane, as well as for the final excision of the flap, the flap is designed as a pentagon with two parallel sides. The deep flap is fashioned with a thickness of 2/3 of the sclera (Fig. 3) so that during separation of the flap towards the cornea the lumen of Schlemm's canal is entered automatically.

The deep scleral flap is separated in deep sclera very close to the ciliary body, which can be observed by a change in scleral color. In order to provide a correct orientation in the scleral layers, the sclera is perforated at the apex of the deep scleral flap up to the ciliary body. This orientational local sclerotomy in one place is small, and does not represent a cyclodialysis because there is no contact of the instrument to the ciliary body.

Next, preparation is performed moving away from the apex "flying at zero altitude" with only a thin semi-transparent scleral layers left under the knife (Fig. 4). Thereby, an opening to Schlemm's canal is created.

Figure 4 shows the preparation field in NPIT. In the classic NPGS, a relatively large part of Descemet's membrane is exposed to filtration additionally. If the lumen of Schlemm's canal has been entered at once and the deep flap has been separated well into the cornea, the trabecular tissue becomes visible and a thin film on the surface of the inner wall of Schlemm's canal can be easily removed with a microsponge. This film represents the less permeable trabecular layers (corneoscleral TM, juxtacanalicular TM and the inner wall of SC), while the more permeable layer (uveal TM) remains intact (Fig. 1). In other versions of NPDS, this stage is usually performed with a forceps only. When grasping the superficial film, perforation is not unusual.

In the NPIT technique, the superficial less permeable trabecular layers are separated with an atraumatic trabecular spatula (Fig. 5) in order to prevent microperforation of the uveal trabecular layer and Descemet's membrane. This spatula is inserted along the tangent to the surface of Descemet's membrane between the trabecular layers. Then, the superficial layers are separated from the less permeable layers with a motion from below upwards (Fig. 5, *right panel*). Finally, the dissected layers are removed with a forceps. Any acute contact of the instrumentation to the remaining trabecular layer and Descemet's membrane is avoided. The deep scleral layer is then excised.

In classic NPDS, the formation of the filtration membrane is usually finished at this step. In the NPIT technique, an additional stage is added before the insertion of the collagen implant in order to improve the postoperative case of filtration. At this stage of the surgery, a cannula-harpoon is introduced alternately through both ostia of Schlemm's canal, between the less permeable (corneoscleral TM, juxtacanalicular TM and the inner wall of SC) trabecular layers above and the well-permeable (uveal TM) trabecular layer below (Figs. 6, 7) to a depth of 3.5-4 mm

The cannula-harpoon represents a modification of the classical cannula for the viscocanalostomy procedure which provides the delivery of viscoelastic through the SC ostia (Fig. 6, *top panel*). There is a hook attached on the tip of the cannula, which looks like a crochet hook. The narrow end of the hook provides its easy insertion between trabecular layers and its movement inside Schlemm's canal through SC ostium away from the scleral lake, whereas the distant part of the hook allows its backwards manoeuvre with the dissection (a kind of husking) of less permeable

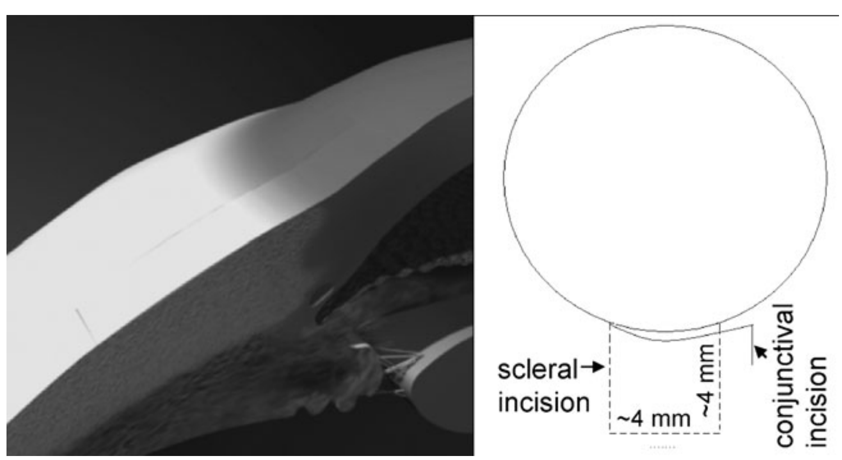

Fig. 2 Beginning of the surgery. Dissection of the conjunctiva and preparation of fornix-based conjunctival flap, followed by the dissection of the outer corneoscleral flap of 4 mm×4 mm in dimension

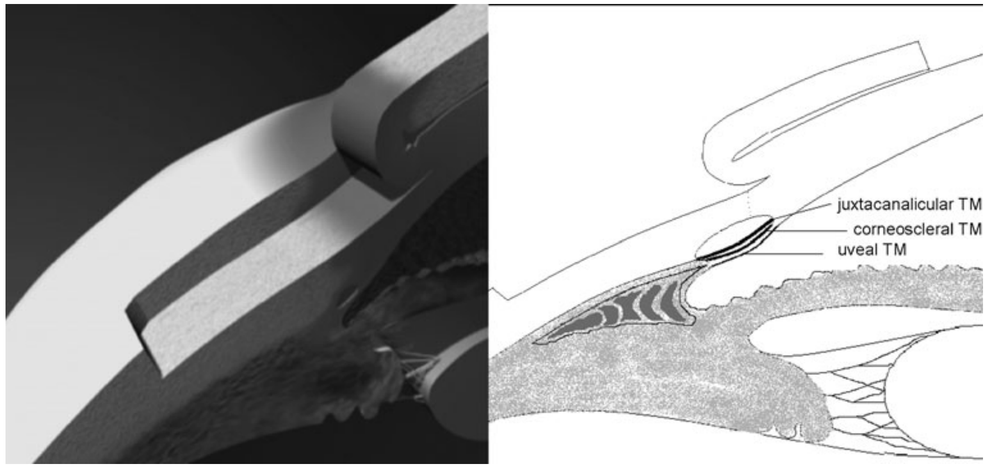

Fig. 3 Dissection of the scleral flap of 1/3 of scleral thickness (270-300 μm) 1 mm through the limbus towards the cornea. *TM* — trabecular meshwork

trabecular layers inside Schlemm's canal and their subsequent extraction trough SC ostium (Fig. 7).

It is not difficult to distinguish different TM layers on the visible ostia. The fragments of already removed superficial layers of the TM in the site of the scleral flap are clearly seen at each ostium. In the beginning, the cannula is sliding within the opening on the surface of the already prepared more permeable trabecula, aiming its peak towards an ostium under these fragments (Fig. 7a).

Thereby, the cannula-harpoon exits SC through its ostium, remaining on the surface of the more permeable trabecular layer and separating it from cuts of less permeable layers (Fig. 7). Viscoelastic is injected through the cannula-harpoon during its introduction through the SC ostium ***between trabecular layers*** in the present procedure. In this way, a permeable trabecular layer is separated from other less permeable layers within Schlemm's canal. Once inside SC, the cannula-harpoon is moved up and then backwards. Due to its harpoon orientation, the superficial less penetrated trabecular layers within SC are removed (Fig. 7), which is not the case in viscocanalostomy. Thus, the postoperative filtration zone becomes extended into Schlemm's canal through its ostia.

As the extended filtration membrane is created, the last step of the surgery is performed in the classical way. An absorbable collagen implant (STAAR Surgical Company, Monrovia, CA, USA) is inserted into the scleral lake in order to create a postoperative intrascleral space, preventing its scarring. Neither Mitomycin C nor other chemical agents are needed additionally. The scleral lake is closed with the superficial scleral flap. The latter is sutured in its two distal corners. Then, the conjunctival incision is closed with two separate sutures at the limbus and an additional paralimbal suture.

Data evaluation and statistical methods

A table with corresponding macros in MS Excel 2000 was created for data analysis. The normal distribution of measurement data was proved with Kolmogoroff–Smirnoff test. The parametric Student's test for two dependent samples (glaucoma patients before and after the treatment) and Bonferroni post-hoc test for multiple comparisons (glaucoma patients before, 1 month and 2 years after the treatment) were used in order to assess statistical differences of the evaluated characteristics. Since in some patients (four

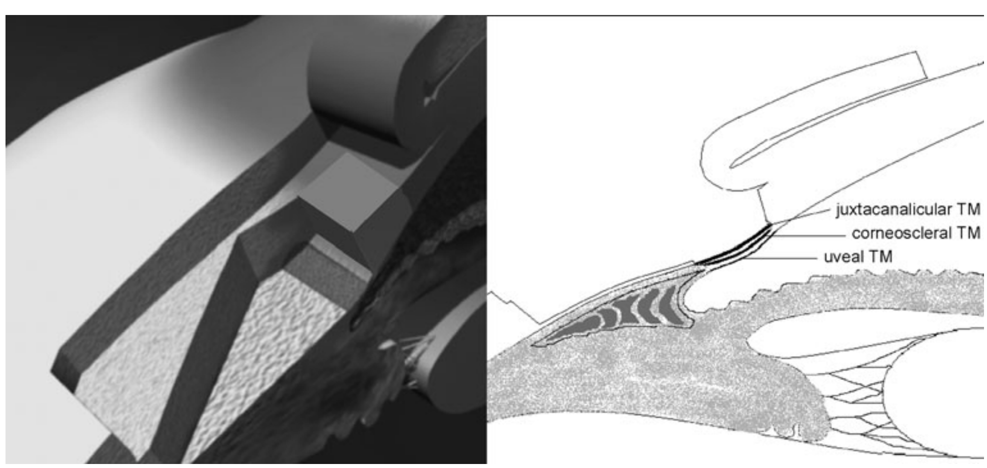

Fig. 4 Excision of a deep pentagonal scleral flap including the outer wall of Schlemm's canal in NPIT. *TM* - trabecular meshwork

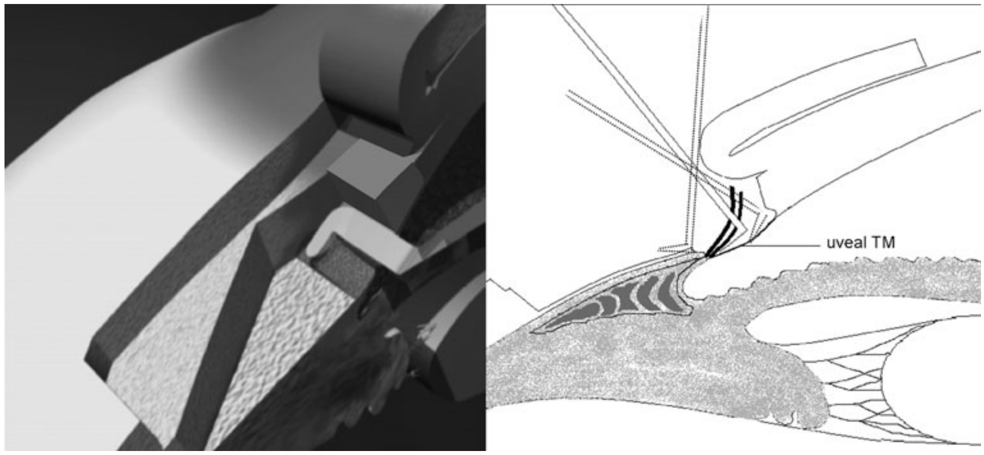

Fig. 5 Removal of less permeable (corneoscleral TM, juxtacanalicular TM and the inner wall of SC) trabecular layers with the atraumatic trabecular spatula by Dashevsky in the site of the scleral flap. Initial and final positions of the spatula are shown with *dashed lines*. *TM* — trabecular meshwork

patients) the surgery was performed in two eyes, single-eye IOP observations for each subject were averaged and then analyses for one-eye designs were performed on the averages [19]. Because of the small number of subjects, all the tests were applied on the level of significance of $P=0.05$ for each evaluated parameter. Statistical evaluation was performed with MS Excel 2000 for Windows and SPSS 11.0.

Results

As a result of the surgery, the filtration zone is extended, improving the natural outflow pathways towards SC without the disturbing principles of non-penetrating surgery.

Short-term postoperative IOP 1 month after the surgery amounted to 12.8±3.2 mmHg (range 8.0–16.0 mmHg), and was significantly lower than the preoperative IOP ($P<0.001$; *t*-test with Bonferroni correction, Fig. 8). In all the patients, gonioscopy 1 month after the surgery does not show any macrodisruptions of the TM anywhere in the operative zone of the Schlemm's canal. Compared to the intact part of SC, trabecular meshwork in this zone was usually less pigmented.

Postoperative IOP of 13.4±2.3 mmHg (range 9.0–18.0 mmHg) at 2 years of follow-up was measured in the evaluated group of glaucoma patients (Fig. 8). IOP reduction of 18.0±7.0 mmHg (range 9.0–31.0 mmHg) due to the surgery was significant ($P<0.001$; *t*-test with Bonferroni correction). In all 21 eyes, the hypotensive effect was absolute (without medications).

In seven cases (33%), a hyphema appeared during the surgery, which dissolved uneventfullly in all the cases at 2–3 days postoperatively. No other of the complications which are usual for penetrating glaucoma surgery, such as hypotony, choroidal detachment, formation of the cystic filtering bleb, shallow anterior chamber, inflammation in the anterior chamber, etc., were observed.

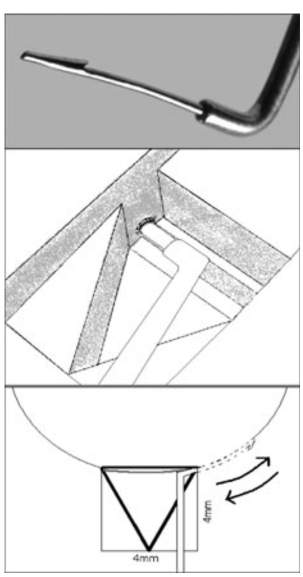

Fig. 6 Introduction of the cannula-harpoon by Dashevsky through the ostia of Schlemm's canal

Discussion

The reported results demonstrate a pronounced and sustained effect of the modified non-penetrating glaucoma surgery (NPIT), and show that this surgery can be successfully applied in patients with open-angle glaucoma as a valuable drug-sparing alternative to medical therapy and other types of glaucoma surgery including laser surgery.

For the reported 2-year follow-up period, a sufficient hypotensive effect was maintained in all eyes without any medications. Additionally, the usual postoperative "fine-tuning" of the IOP in NPDS using YAG-laser goniopuncture at the site of the dissected filtering membrane [17] has not been necessary in any of the eyes that underwent NPIT. However, the authors cannot exclude the possibility that it might be necessary occasionally.

In order to show the advantage of the new modification of non-penetrating glaucoma surgery, 2-year follow-up results of NPIT and our previously reported follow-up results of the classic non-penetrating deep sclerectomy in

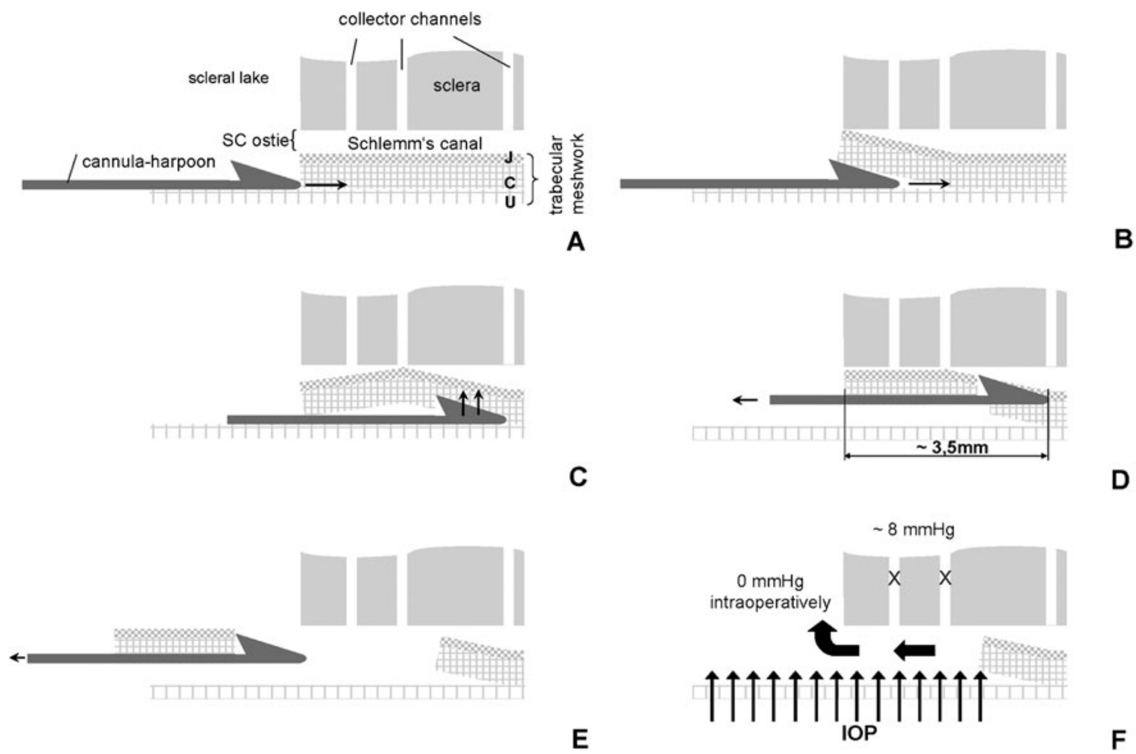

Fig. 7 Schematic drawing of intraoperative application of the cannula-harpoon. It is introduced with injected viscoelastic alternately in each ostium of SC between less permeable (corneoscleral TM, juxtacanalicular TM and the inner wall of SC) trabecular layers above and the well-permeable (uveal TM) trabecular layers below (**a**). In this way, a permeable trabecular layer is separated from two other less permeable layers within SC. Through SC ostium the cannula is moved up (**c**) and then backwards (**d**) inside of SC. Due to its harpoon orientation, two superficial less penetrated trabecular layers within the ostia are removed (**e**). Aqueous filtration trough the extended area of the permeable membrane is provided into the scleral lake (**f**). *SC* — Schlemm's canal; *J* — juxtacanalicular, *C* — corneoscleral, *U* — uveoscleral layers of the trabecular meshwork

the group of 28 patients (age: 72.7±9.2 years, range 55.0–89.0 years, 33 eyes) with therapy-resistant open-angle glaucoma [4] were compared. The technique of NPIT is made efficient by using the cannula-harpoon instrument. Since both surgeries were performed by one surgeon (AD), surgical skills did not play a role in the comparison.

One month and 1 year after the surgery, the difference in IOP between the two techniques was highly significant:

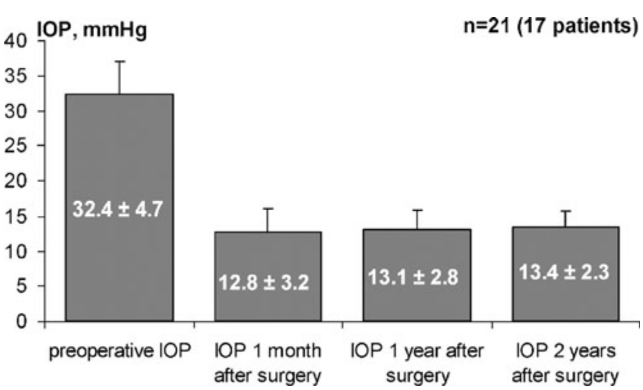

Fig. 8 IOP-lowering during the follow-up of NPIT: *n*=21 (17 patients). *Error bars* show standard deviations

13.4±2.3 mmHg after NPIT vs 16.6±4.4 mmHg after classic NPDS ($P<0.01$) (Fig. 9, *upper panel*). The scatter-plot diagram of pre- and postoperative IOP showed a better outcome of NPIT surgery technique as well (Fig. 9, *bottom panel*). A hypotensive effect of the modified non-penetrating surgery technique is well-comparable to that of trabeculectomy after 2 years of follow-up, while the hypotensive effect of the classic NPDS technique is rather insufficient and less pronounced compared to trabeculectomy.

The removal of less permeable layers of the trabecular meshwork represents the necessary condition for the NPDS surgery, since these layers cause the main resistance to the aqueous outflow from the anterior chamber into Schlemm's canal [6, 13]. The extension of the filtration membrane into SC through its ostia in the proposed NPIT technique amounts to approximately 175% of the initial membrane within the scleral lake: in NPIT, 3.5 mm left and right into SC are added to approximally 4 mm of the membrane inside of the scleral lake:

$$(3.5\text{mm} + 3.5\text{mm} + 4\text{mm}) \cdot 100\%/4\text{mm} = 175\%.$$

Considering the filtration rate of the dissected Descemet's membrane to be less than the filtration rate of the dissected

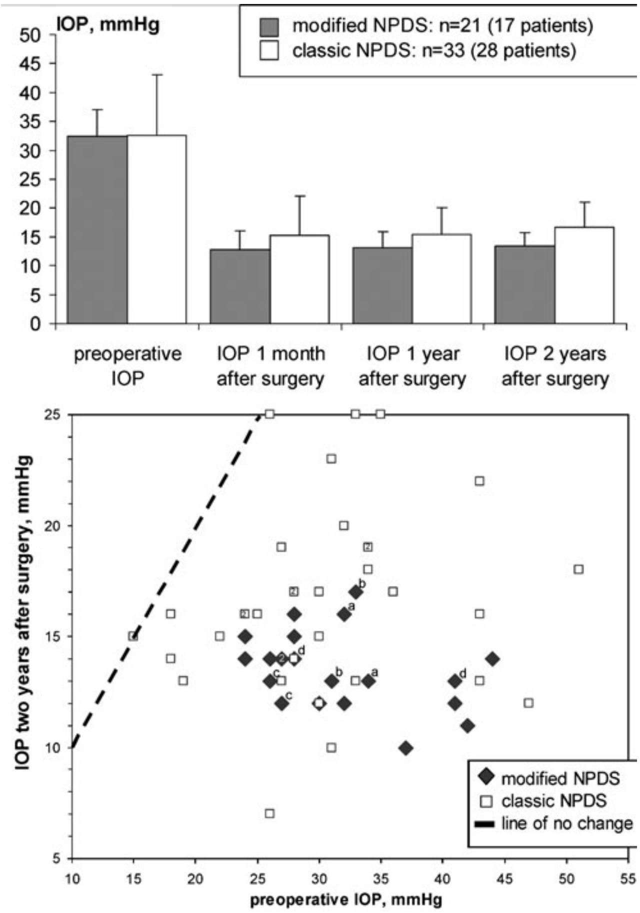

Fig. 9 Comparison of the results of NPIT (n=21, 17 patients) with the follow-up results for the classic NPDS technique (n=33, 28 patients) [4]. *Upper panel:* comparison of IOP-lowering after 2 years of follow-up. At 1 month, 1 year and 2 years after the surgery, the difference in IOP between the two groups was statistically significant (P<0.01). *Error bars* show standard deviations. *Bottom panel:* diagram of individual IOPs in 21 (NPIT) and 33 (NPDS) eyes pre- and 2 years after the surgery. Eight eyes of the four patients who had undergone bilateral NPIT surgery (*black rhombs*) are marked pair-wise with corresponding letters right above the data points. Points with equal pre- and postoperative values in two different patients are indicated with "*2*"

trabecula inside of the scleral lake [10], one would need to involve a relatively large part of Descemet's membrane in the classic NPGS, going to more than two Schlemm's canal widths central to the cornea from the scleral lake, in order to gain similar filtration rates.

The authors assume that the postoperative outflow inside of SC occurs both into collector channels and through the SC ostia into the scleral lake. Even if the scleral lake is scarred postoperatively, the outflow through the extended filtration membrane inside of SC into collector channels would remain, thus providing a major part of the aqueous outflow.

The filtering bleb after NPIT is diffuse and flat short-term postoperatively. It almost disappears in most cases long-term postoperatively. Formation of a filtering bleb is not the aim of the surgeon in NPIT any more, hence we did not see any postoperative cystic blebs in the present study. After NPIT, a major part of aqueous flows out not through the intrascleral lake over the superficial scleral flap under the conjunctiva, but through the natural outflow pathways including SC and collector channels into the intrascleral venous system. We assume that a flat, almost invisible postoperative flap represents a sign of successful postoperative filtration through the natural outflow pathways. However, we cannot exclude a certain incidence of postoperative cystic blebs after NPIT as a usual complication of filtration glaucoma surgery. After a classic NPDS, this incidence is reported by Mermoud as 15% [16] and is apparently lower after NPIT. Hence, more cases of NPIT need to be reported in order to reveal it.

No cytostatic drugs such as mitomycin C or 5 fluorouracil were used intra- and postoperatively in order to prevent postoperative scarring. For this purpose, we chose the STAAR sponge as a part of the procedure. Comparing our results with classical NPDS technique, with the same sponge used to prevent scarring [4], we did not observe any microcysts or cystic blebs 1 and 2 years postoperatively in either technique. In both procedures, the scleral flap was not tightly closed.

An attempt to increase the postoperative aqueous filtration through the ostia of Schlemm's canal was first made by viscocanalostomy as described by Stegmann [23], and later on in his modern glaucoma surgery named canaloplasty [11, 22]. In the opinion of the authors, not enough attention is paid to the dissection of the filtering membrane in viscocanalostomy, both within the scleral lake and in the parts of SC adjacent to its ostia. In viscocanalostomy, Schlemm's canal is opened and dilated using viscoelastic injected into its ostia, with the goal of increasing the permeability of the trabecula inside SC. According to Johnson and Johnson [8], the dilation of SC with viscoelastic substance most probably causes a micro-rupturing of the canal, and converts the procedure into a microtrabeculotomy in SC adjacent to the ostia. In NPIT, we cannot exclude the presence of microperforations of SC in the operative zone. However, NPIT can provide the outflow thorough the large part of TM outside the scleral lake, even if those microdisruptions do not occur.

The procedure of canaloplasty causes a mechanical stretching of the whole trabecular tissue along the canal. This might lead to an unnatural remodelling of this tissue, with possible scarring of the whole trabecular tissue and diminishing success of any re-operation. In the proposed NPIT, only approximately 29% of SC is involved. This might allow for a possible re-operation in the future in the remaining part of the canal.

$$(4\mathrm{mm} + 2 \cdot 3.5\mathrm{mm})/(\pi \cdot 12\mathrm{mm}) \cdot 100\% = 29\%.$$

Here, the length of the postoperative filtration membrane in NPIT as estimated above is divided by the whole SC length, calculated with a limbus diameter of 12 mm.

Only one type of intra- and postoperative complication was observed in NPIT, namely hyphema. This might be due to the unavoidable damage of the outer SC wall during backwards cannula-harpoon motion. Another explanation of this finding could be the changed pressure relationship in the operated eye with some blood from collector channels (pressure ~8–10 mmHg) entering SC after its opening and further progression into the scleral lake (pressure ~0 mmHg, Fig. 7f). Already at the stage of removal of less permeable trabecular layers inside the scleral lake, intraoperative hypotony might occur. After the removal of less permeable trabecular layers inside SC through its ostia, the pressure inside SC can be higher than the decreased IOP. Hence, blood from collector channels might penetrate through the residual more permeable trabecular layers inside SC into the anterior chamber, causing hyphema. This may occur at the initial postoperative time, as a steady-state pressure distribution has not yet been established. In the classic NPDS version, all trabecular layers inside SC are intact, and blood from collector channels flows directly intraoperatively to the scleral lake with a pressure of ~0 mmHg, which is less than the IOP. Therefore blood remains in the scleral lake intraoperatively. Consequently, hyphema does not normally represent a postoperative complication after classic NPDS.

Lately, a tendency has been observed that most eye surgeries are performed on an outpatient basis. This demands high-quality surgery technique, minimal operative trauma, as well as reduction of intra- and postoperative complications. The conversion towards outpatient operations has already happened in cataract surgery, and is now observed in vitreo-retinal surgery. Moreover, outpatient surgery is already a standard for trabeculectomy in many places. In the opinion of the authors, refined surgical technique without any perforation of the filtering membrane makes it possible to perform NPIT as an outpatient procedure.

Some limitations to the study need to be mentioned. The relatively small number of patients included in the study does not allow for generalized conclusions for a large population. Moreover, a multicenter approach and additional inclusion of two control groups, including glaucoma patients undergoing classic trabeculectomy and glaucoma patients undergoing classic NPDS, would permit better conclusions concerning the safety and long-term effects of the surgery.

Doubtless the present modification of NPGS needs to be evaluated in larger groups of patients and in further follow-ups of 3, 5 and 10 years to control the persistence of the hypotensive effect of the surgery.

Conclusions

The reported results demonstrate a pronounced and sustained effect of the NPIT glaucoma surgery, and show that this surgery can be successfully applied in patients with therapy-resistant open-angle glaucoma as a valuable drug-sparing and almost complication-free alternative to medical therapy and other types of glaucoma surgery including laser surgery.

The NPIT technique possesses the advantages of both trabeculectomy (well-established hypotensive effect during the follow-up) and classic NPDS by Kozlov (low rates of intra- and postoperative complications) without the main disadvantages of both techniques.

The refined surgical technique of NPIT without any perforation of the filtering membrane makes it possible to perform this surgery as an outpatient procedure.

Two new instruments were introduced for the proposed NPIT. The use of the **atraumatic spatula** assures well-controlled removal of less permeable layers of the trabecula in the surgical zone, providing sufficient postoperative aqueous outflow and a persistent hypotensive effect after 2 years of follow-up in the present study, and improves the learning curve of NPDS. The introduction of the **cannula-harpoon** makes it possible to extend the filtration membrane and to improve the hypotensive effect of NPDS, making the hypotensive effect of NPIT persistent, sufficient and almost complication-free during at least 2 years of follow-up.

References

1. Chen TC, Wilensky JT, Viana MA (1997) Long-term follow-up of initially successful trabeculectomy. Ophthalmology 104:1120–1125
2. Chiou AG, Mermoud A, Hediguer SE, Schnyder CC, Faggioni R (1996) Ultrasound biomicroscopy of eyes undergoing deep sclerectomy with collagen implant. Br J Ophthalmol 80:541–544
3. Dashevsky A, Kotliar K (2006) Trabekulektomie schichtweise in Ostien des Schlemm'schen Kanals — die neue nicht-penetrierende Glaukom-Chirurgie-Technik. Klin Monatsbl Augenheilkd 223 (suppl 2):11
4. Dashevsky A, Steinmetz B (2004) Atraumatische Technik zur Öffnung des Schlemm'schen Kanals. 18. Kongress der Deutschsprachigen Gesellschaft für Intraokularlinsen-Implantation und Refraktive Chirurgie. Heidelberg: 27–28.02.2004
5. Dietlein TS, Luke C, Jacobi PC, Konen W, Krieglstein GK (2000) Variability of dissection depth in deep sclerectomy: morphological analysis of the deep scleral flap. Graefes Arch Clin Exp Ophthalmol 238:405–409
6. Ethier CR, Kamm RD, Palaszewski BA, Johnson MC, Richardson TM (1986) Calculations of flow resistance in the juxtacanalicular meshwork. Invest Ophthalmol Vis Sci 27:1741–1750
7. Fyodorov SN, Kozlov VI, Timoshkina NT (1989) Non-penetrating deep sclerectomy in open-angle glaucoma. IRTC Eye Microsurgery 3:52–55
8. Johnson DH, Johnson M (2001) How does non-penetrating glaucoma surgery work? Aqueous outflow resistance and glaucoma surgery. J Glaucoma 10:55–67
9. Kohlhaas M, Boehm AG, Spoerl E, Pursten A, Grein HJ, Pillunat LE (2006) Effect of central corneal thickness, corneal curvature, and axial length on applanation tonometry. Arch Ophthalmol 124:471–476
10. Kozlov VI, Bagrov SN, Anisimova SY (1990) Non-penetrating deep sclerectomy with collagen. IRTC Eye Microsurgery 1:44–46

11. Lewis RA, von Wolff K, Tetz M, Korber N, Kearney JR, Shingleton B, Samuelson TW (2007) Canaloplasty: circumferential viscodilation and tensioning of Schlemm's canal using a flexible microcatheter for the treatment of open-angle glaucoma in adults: interim clinical study analysis. J Cataract Refract Surg 33:1217–1226
12. Luke C, Dietlein TS, Jacobi PC, Konen W, Krieglstein GK (2003) A prospective randomised trial of viscocanalostomy with and without implantation of a reticulated hyaluronic acid implant (SKGEL) in open angle glaucoma. Br J Ophthalmol 87:599–603
13. Mc.Ewen WK (1958) Application of Poiseuille's law to aqueous outflow. AMA Arch Ophthalmol 60:290–294
14. Mendrinos E, Mermoud A, Shaarawy T (2008) Nonpenetrating glaucoma surgery. Surv Ophthalmol 53:592–630
15. Mermoud A (2000) Sinusotomy and deep sclerectomy. Eye 14(Pt 3B):531–535
16. Mermoud A (2001) Evaluation of non-penetrating glaucoma surgery. In: Mermoud A,Shaarawy T (eds) Non-penetrating glaucoma surgery. Martin Dunitz, London, pp 13-20
17. Mermoud A, Karlen ME, Schnyder CC, Sickenberg M, Chiou AG, Hediguer SE, Sanchez E (1999) Nd:Yag goniopuncture after deep sclerectomy with collagen implant. Ophthalmic Surg Lasers 30:120–125
18. Nesterov AP (1995) Glaucoma. Medicina, Moscow, p 271
19. Ray WA, O'Day DM (1985) Statistical analysis of multi-eye data in ophthalmic research. Invest Ophthalmol Vis Sci 26:1186–1188
20. Shaarawy T, Flammer J (2003) Pro: non-penetrating glaucoma surgery—a fair chance. Graefes Arch Clin Exp Ophthalmol 241:699–702
21. Shaarawy T, Nguyen C, Schnyder C, Mermoud A (2003) Five year results of viscocanalostomy. Br J Ophthalmol 87:441–445
22. Shingleton B, Tetz M, Korber N (2008) Circumferential viscodilation and tensioning of Schlemm canal (canaloplasty) with temporal clear corneal phacoemulsification cataract surgery for open-angle glaucoma and visually significant cataract: one-year results. J Cataract Refract Surg 34:433–440
23. Stegmann R, Pienaar A, Miller D (1999) Viscocanalostomy for open-angle glaucoma in black African patients. J Cataract Refract Surg 25:316–322
24. Watson PG, Jakeman C, Ozturk M, Barnett MF, Barnett F, Khaw KT (1990) The complications of trabeculectomy (a 20-year follow-up). Eye 4(Pt 3):425–438
25. Weder W, Lissel U, Stoltzing M (1987) Complications and results after trabeculotomy. Dev Ophthalmol 13:78–84
26. Zimmerman TJ, Kooner KS, Ford VJ (1984) Effectiviness of nonpenetrating trabeculotomy in aphakic patients with glaucoma. Ophthalmic Surg 15:44–50
27. Zimmerman TJ, Kooner KS, Ford VJ, Olander KW, Mandlekorn RM, Rawlings EF, Leader BJ, Koskan AJ (1984) Trabeculectomy vs. non-penetrating trabeculectomy: a retrospective study of two procedures in phakic patients with glaucoma. Ophthalmic Surg 15:734–740