Results of CO_2 Laser-assisted Deep Sclerectomy as Compared With Conventional Deep Sclerectomy

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Purpose: To evaluate the efficacy of CO_2 laser-assisted sclerectomy surgery (CLASS) compared with classic nonpenetrating deep sclerectomy (NPDS) with implant in medically uncontrolled glaucoma patients.

Materials and Methods: Patients who underwent primary filtration surgery with CO_2 laser system at the time interval between July 2010 and April 2011 were identified, their medical files were reviewed, and their results were compared with matched control group who underwent classic NPDS with intrascleral implant at the same time period. Intraocular pressure (IOP) was measured at baseline, 1 week, and 3, 6, 12, 18, and 24 months, respectively. Main outcome measures were: IOP, use of supplemental medical therapy, and failure (5 mm Hg > IOP > 18 mm Hg, reoperation for glaucoma, or loss of light perception).

Results: A total of 58 patients were reviewed, including 27 in the CLASS group and 31 in the NPDS group. For the CLASS group the follow-up (mean ± SD) was 20.7 ± 6.8 months, the mean preoperative IOP was 23.3 ± 8.2 mm Hg (range, 10 to 38 mm Hg), and the mean number of antiglaucoma medication before surgery was 3.0 ± 1.0 (range, 1 to 4). At final follow-up visits, the mean IOP was 11.7 ± 3.1 mm Hg (range, 6 to 19 mm Hg), and the mean number of antiglaucoma medication was reduced to 1.0 ± 1.6 ($P < 0.0003$). The complete success rate (IOP ≤ 18 mm Hg without antiglaucoma medication) was 73% and the qualified success rate (IOP ≤ 18 mm Hg with/without antiglaucoma medication) was 96%. For the control group the mean follow-up was 17.6 ± 6.7 months, the mean preoperative IOP was 23.1 ± 7.3 mm Hg (range, 14 to 44 mm Hg), and the mean number of antiglaucoma medication before surgery was 3.0 ± 0.8 (range, 1 to 4). At final follow-up visits, the IOP was 13.3 ± 3.6 mm Hg (range, 8 to 20 mm Hg), and the mean number of antiglaucoma medication was reduced to 0.7 ± 1.1 ($P < 0.0004$). The complete success rate and the qualified success rate were 71% and 89%, respectively.

Conclusions: A new technique using a CO_2-laser ablation system allows precise and easy creation of the scleral space and ablation of Schlemm canal. This technique has been shown to be as efficient as the standard NPDS surgery in terms of IOP-lowering effect. This would render the deep sclerectomy an easier glaucoma surgery.

Key Words: glaucoma surgery, deep sclerectomy, CO_2 laser, laser surgery

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Conventional trabeculectomy has so far remained the gold standard for glaucoma surgery, despite its potential vision-threatening complications, including shallow or flat anterior chamber, hypotony, infection, choroidal hemorrhage, and malignant glaucoma.[1] Nonpenetrating deep sclerectomy (NPDS) is known to have a higher safety profile compared with trabeculectomy.[2] The major advantage of NPDS is that it precludes the sudden hypotony that occurs following trabeculectomy by creating progressive filtration of aqueous humor from the anterior chamber to the surgically created intrascleral space through an intact trabeculo-Descemet membrane (TDM).[3] In addition, the advantage of deep sclerectomy lies in its unique pattern of aqueous resorption pathways. In complement to the standard subconjunctival pathway as in trabeculectomy, the additional mechanisms that were described in deep sclerectomy are the intrascleral and suprachoroidal pathways, through the rejuvenated Schlemm canal and episcleral veins.[4,5]

One of the main drawbacks of the procedure remains its technical difficulty. The procedure requires dissection of 2 scleral flaps, the superficial and deep ones. The anterior sclerocorneal dissection is performed to remove the sclerocorneal tissue superficial to the anterior trabeculum and the Descemet membrane, thus creating an intact TDM through which an effective fluid percolation occurs.[6] The most common intraoperative complication of this surgery is perforation of the thin TDM during the deep sclerectomy dissection. This was common in the learning phase of deep sclerectomy, occurring in 30% to 50% of the cases during the early stages of the learning curve,[7,8] dropping dramatically to < 3% in experienced hands.[9] Conversely if the sclerocorneal tissue is not dissected deep enough, effective filtration may not be achieved. This technical difficulty has never permitted this technique to gain popularity among glaucoma surgeons.

CO_2 laser-assisted sclerectomy surgery (CLASS) procedure[10] offers a potential alternative to the most difficult parts in the classic NPDS, which are the manual dissection of the deep sclera, the anterior sclerocorneal dissection, and the creation of the TDM. The CO_2 laser energy ablates the tissue and its effect ceases once aqueous humor starts to percolate, preventing further unneeded ablation, and probably avoiding the inadvertent perforation that can occur during manual dissection.[11] By using this new technique surgeons can still benefit from the advantages of NPDS and still avoid its drawbacks.

In this pilot study, we evaluated the safety and efficacy of the CLASS technique compared with the classic NPDS technique in a population of medically uncontrolled glaucoma patients.

MATERIALS AND METHODS

This retrospective, comparative, monocentric clinical pilot study was approved by the Ethics Committee of the

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University of Lausanne, Switzerland. All patients who underwent a primary filtration surgery with CO_2 laser system (OT-134-IOPtiMate; IOPtima Ltd, Ramat Gan, Israel) at Montchoisi Clinique, Lausanne, Switzerland were identified, their files were reviewed, and their results were compared with an age-matched and sex-matched group that was operated in the classic NPDS technique at the same time period. All surgeries were performed by a single experienced surgeon (A.M.) at the same center, at the time period between July 2010 and April 2011.

Inclusion criteria for the study were: adult patients (aged 18 y or above) of both sexes with medically uncontrolled glaucoma of any type that underwent filtration surgery either by CLASS procedure or classic NPDS. There was no randomization in this pilot study to assign patients to either group. Selection for each procedure was based on patient willingness to participate in this initial study and clinical indications. Medically uncontrolled glaucoma was defined as well-documented progression of visual field defects and glaucomatous optic nerve morphology, including thinning or notching of the neuroretinal rim accompanied by localized or diffuse retinal nerve fiber layer loss, and accompanied by correlated typical glaucomatous visual field loss. Patients who underwent combined cataract and glaucoma surgery at that time period or have had any other eye surgery within 6 months before the present surgery were excluded from the study. Patients who underwent a previous eye surgery including glaucoma surgery >6 months prior the present surgery were included.

All patient files were reviewed and data from the patient baseline examination within 2 weeks before surgery, 1 day, 1 week, and 3, 6, 12, 18, and 24 months or last follow-up visit after surgery were recorded. The data included distance best-corrected visual acuity measured with a Snellen chart, comprehensive biomicroscopy, intraocular pressure (IOP) assessment with a calibrated Goldman applanation tonometer, and fundus examination including optic disc evaluation. Number of antiglaucomatous medication at each visit was recorded. The visual field testing using the Octopus 101 program G1 (Interzeag AG, Schlieren, Switzerland) before surgery was recorded.

Main outcome measures were: IOP, use of supplemental medical therapy, and failure (IOP $>$ 18 mm Hg, IOP $\leq$ 5 mm Hg, reoperation for glaucoma, or loss of light perception vision). "Complete success" was defined as IOP values measured at 24-month visit or at last follow-up visit, ranging between 5 and 18 mm Hg without glaucoma medication and "qualified success" when this IOP was achieved with glaucoma medication.

All complications, both intraoperative and postoperative, were recorded (Table 1).

TABLE 1. List of Complications and Definition of CLASS Versus NPDS Study Patients

Complications	Definition
Microperforation	Microholes in the TDM without iris prolapse
Macroperforation	Perforations accompanied by iris prolapse
Hyphema	Erythrocytes in the anterior chamber
Hypotony	Postoperative IOP $<$ 4 mm Hg for $>$ 2 wk
Shallow anterior chamber	Iridocorneal touch in the periphery
Flat anterior chamber	Corneal lenticular touch
Choroidal detachment	Visible in the peripheral retina
Wound leak	Postoperative leakage that necessitated suturing
Macular edema	Visually significant, documented by OCT

CLASS indicates CO_2 laser-assisted sclerectomy surgery; IOP, intraocular pressure; NPDS, nonpenetrating deep sclerectomy; OCT, optical coherence tomography; TDM, trabeculo-Descemet membrane.

Surgical Technique

All the operations were performed under retrobulbar anesthesia (3:1 of bupivacaine 0.5% and lidocaine 2%, with hylase) without epinephrine.

NPDS With Implant

Deep sclerectomy was performed in the superior quadrant using the surgical technique described previously.[12–14] In details, a limbal-based conjunctival flap was created and the sclera was exposed. A one-third scleral thickness limbal-based scleral flap measuring 5×5 mm was delineated using a diamond knife, dissected using a crescent ruby knife, and extended anteriorly 1 mm into clear cornea. Mitomycin C [(MMC) 0.2 mg/mL] was then applied under the conjunctiva and under the scleral flap for 2 minutes. The site was irrigated with 20 mL of BSS. A square of deep sclera was then removed, leaving a thin layer of deep sclera over the choroid posteriorly and ciliary body anteriorly. The cornea was dissected down to the Descemet membrane and the residual inner wall of Schlemm canal was peeled off. At this stage of the procedure, aqueous humor was seen to percolate through the TDM. At this point either a collagen implant (STAAR; Surgical AG Nidau, Switzerland) was placed radially and secured with a single 10-0 nylon suture, or a cross-linked sodium hyaluronate (NaHA) injectable implant (HEALAflow; Anteis, Switzerland) was injected to the deep scleral bed, in those cases where overflow of aqueous humor through the intact TDM was suspected. The superficial scleral flap was repositioned and secured with ≥ 2 single 10-0 nylon sutures depending on the amount of aqueous humor percolation through the TDM. The Tenon capsule and the conjunctiva were closed with a running 8-0 polyglactin suture (Fig. 1).

CLASS Procedure

The CLASS procedure was also performed in the superior quadrant using the surgical technique described previously.[10] The conjunctival flap, the superficial scleral flap, and the MMC application was identical to the NPDS procedure mentioned above. The desired scanning area and the shape were set, the laser beam was focused, and the area to be treated was verified with a red laser (HeNe)-aiming beam. First, the CO_2 laser beam was applied over an area that is parallel to the square of deep sclera that was removed in the classic procedure. A few ablations were performed, thinning the sclera above the choroid posteriorly and the ciliary body anteriorly (the deep sclerectomy component), and then the CO_2 laser beam was applied over an area that included the Schlemm canal until the outer wall of the canal was ablated and a scleral bed was formed. The energy settings were kept similar for all patients. The residual charred tissue was wiped away with a BSS damp Weck-Cel sponge and ablation was continued until sufficient percolation was achieved along a region of at least 3 mm in length. A high–molecular weight ophthalmic viscosurgical device (Healon 5; Abbott Medical Optics, Santa

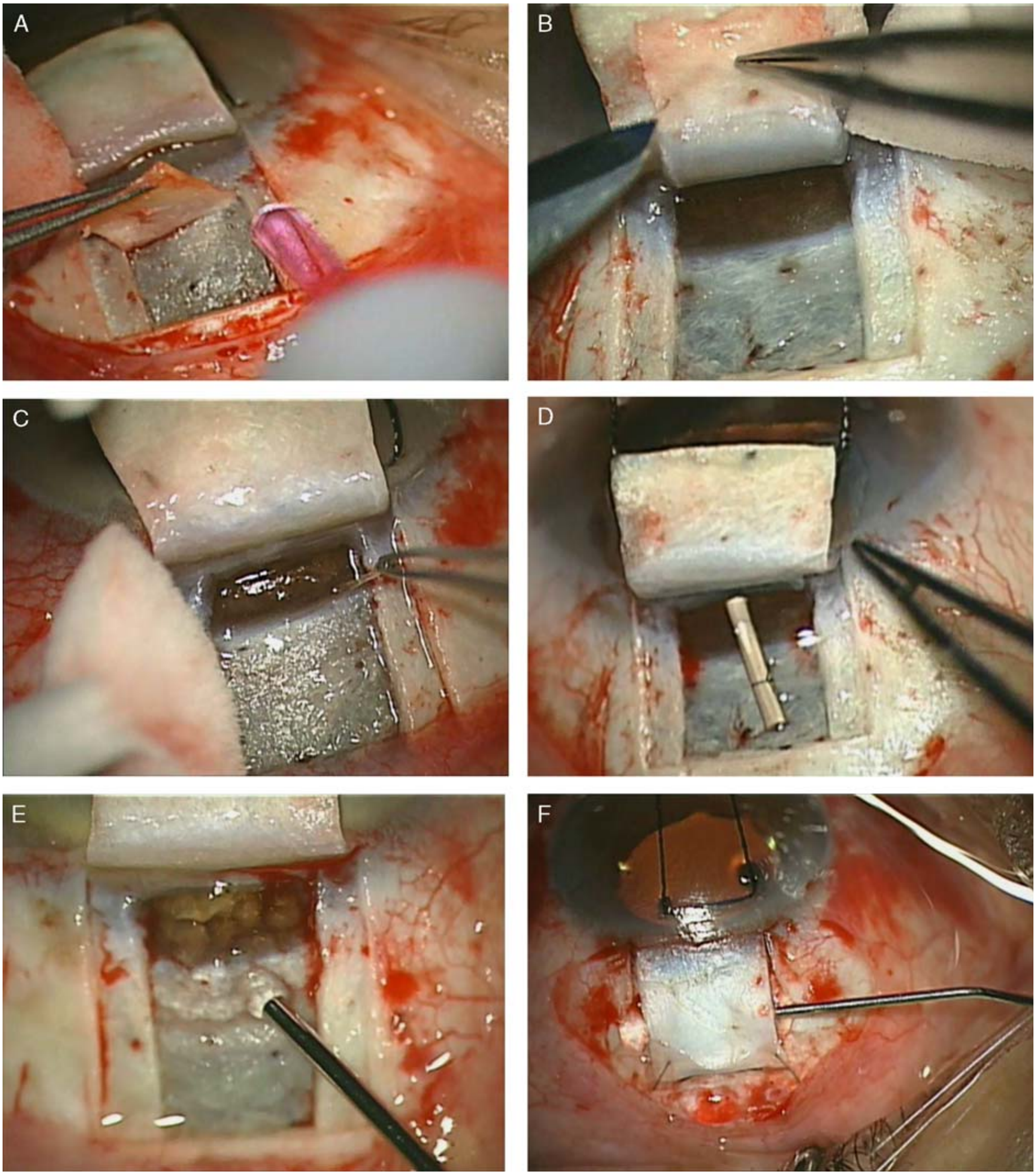

FIGURE 1. A, Dissection of the deep scleral flap using a ruby crescent blade. B, Section of the deep scleral flap using conventional blade and scissors. C, Peeling of the inner wall of Schlemm canal using fine forceps. D, The cylindrical collagen implant is sutured onto the scleral bed. E, Alternatively, viscoelastics can be used as space maintainer to fill the scleral space. F, After closing and suturing the superficial flap, some viscoelastics is injected under the flap to act as space maintainer and to prevent fibrosis.

Ana, CA) or cross-linked sodium hyaluronic acid glaucoma injectable implant (HEALAflow; Anteis) was applied in the deep scleral bed, and the scleral flap was repositioned and secured in the same manner described in the classic NPDS group (Fig. 2).

In these series, 1 of 3 intrascleral space–maintaining materials were used. The first to be used was the collagen Aquaflow implant (STAAR; Surgical AG Nidau), a highly purified porcine collagen dehydrated into a cylinder (4 × 1 mm). It swells rapidly once exposed to the aqueous humor and is resorbed within 6 to 9 months after surgery.[5]

The second to be used was a cross-linked sodium hyaluronate injected implant ((HEALAflow; Anteis) that has been shown recently that by filling up the intrascleral space, it may prevent postoperative scarring and fibrosis of

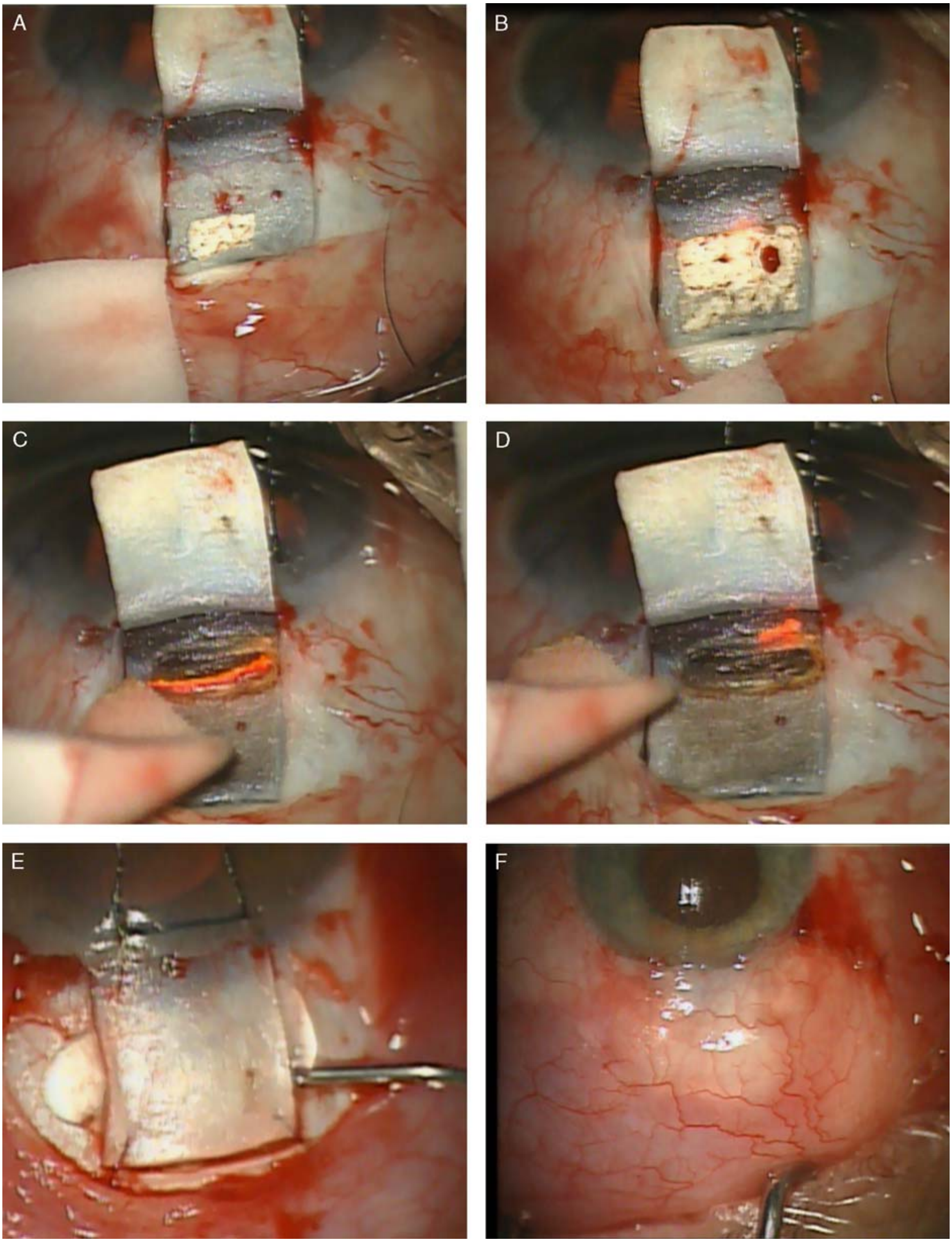

FIGURE 2. A, Initial CO_2 laser dissection of the deep sclera. Prior that step the superficial scleral flap was dissected using conventional blade. B, Further dissection of the scleral bed. C, Dissection of Schlemm canal toward the trabeculo-Descemet membrane. D, Dissection of the trabeculo-Descemet window. E, The superficial flap is closed and viscoelastics is injected under the flap. F, The conjunctival flap is sutured showing a nice filtering bleb.

TABLE 2. Baseline Demographic Characteristic of CLASS Versus NPDS Study Patients

	CLASS Group	NPDS Group	*P*
No. patients (n)	27	31	
Age [mean ± SD (range)] (y)	68.4 ± 8.0 (54-84)	69.2 ± 10.5 (54-90)	0.37
Sex			
Female/male	12/15	12/19	
Diagnosis			
POAG	18	20	
PACG	3	4	
PXFG	5	5	
Fuchs uveitic glaucoma	0	2	
NTG	1	0	
Distance best-corrected visual acuity (logMar) (mean ± SD)	0.8 ± 0.3	0.7 ± 0.3	0.3
IOP [mean ± SD (range)] (mm Hg)	23.3 ± 8.2 (10-38)	23.1 ± 7.3 (14-44)	0.48
Glaucoma medication [mean ± SD (range)]	3.0 ± 1.0 (1-4)	3.0 ± 0.8 (1-5)	0.34
Lens status			
Phakia	11	12	
Pseudophakia	16	19	
No. patients who underwent previous glaucoma surgery	3	1	

CLASS indicates CO_2 laser-assisted sclerectomy surgery; IOP, intraocular pressure; NPDS, nonpenetrating deep sclerectomy; NTG, normal-tension glaucoma; PACG, primary angle-closure glaucoma; POAG, primary open-angle glaucoma; PXFG, pseudoexfoliation glaucoma.

the filtering site and helping to maintain a functional filtration after NPDS.[15]

The third to be used is a high–molecular weight ophthalmic viscosurgical device (Healon5 OVD; Abbott Medical Optics). Basically, this material is intended for use in anterior segment ophthalmic surgical procedures, but can also be used to efficiently separate ocular tissues, and can be injected under the superficial scleral flap.

In the NPDS group, the default space-maintaining materials implant that has been used was the collagen Aquaflow implant (STAAR; Surgical AG Nidau). Whenever an overfiltration through the intact TDM was suspected during surgery, the tendency was to use the cross-linked sodium hyaluronate injected implant ((HEALAflow; Anteis) instead.

In the CLASS group, all cases that have been operated until March 2011 were treated with a high–molecular weight ophthalmic viscosurgical device (Healon5 OVD; Abbott Medical Optics) as a space-maintaining element under the scleral flap. All cases following this date were treated with the cross-linked sodium hyaluronate injected implant ((HEALAflow; Anteis) instead. No other clinical aspect influenced the decision of which material type to use.

One drop of dexamethasone sodium phosphate 0.1% and chloramphenicol 0.5% (SPERSADEX COMP; Novartis, Basel, Switzerland) was applied at the end of the surgery, and the eye was patched until the next day in both groups.

Postoperative Management

The patients were treated postoperatively with dexamethasone sodium phosphate 0.1% and chloramphenicol 0.5% (SPERSADEX COMP; Novartis) 4 times daily for 4 weeks, followed by ketorolac tromethamine ophthalmic solution 0.4% (ACULAR; Allergan, Irvine, CA) 3 times daily for the following next 2 months.

When the filtering bleb at any postoperative visit was encysted or showed signs of fibrosis, a needling with a subconjunctival injection of 0.1 to 0.2 mL of MMC (0.2 mg/mL) was considered. The needlings were repeated several times as necessary to resolve the failed filtering bleb.

Goniopuncture (GPT) with a Nd:YAG laser (Tango; Ellex Designs) was performed when the target IOP range for each patient was not achieved because of insufficient filtration through the TDM. The procedure for GPT has been previously reported.[16]

GPT and needling were not considered to be failures or adverse events, as both are commonly used as normal postoperative interventions that are required to maintain or augment the operative results of glaucoma surgeries.[5,14,17,18] The number and the timing of the GPT or needling in each group were also recorded and compared.

Statistical Methods

Data are expressed as the mean ± SD and minimum and maximum values. Results were analyzed using the paired Student *t* test and Kaplan-Meier survival curves. Differences were considered significant when $P < 0.05$. The data were analyzed using the S-PLUS 8.1 software (Tibco, CA).

RESULTS

Baseline and Characteristics

Baseline demographic characteristics are detailed in Table 2. The mean follow-up for the CLASS versus the control groups was 20.7 ± 6.8 and 17.6 ± 6.7 months, respectively ($P = 0.04$). Two patients (3.4%) in the latter group died at 6 and 12 months and were lost to follow-up for the statistics.

No significant differences in any of the demographic or clinical features were observed between both groups. Similar mean IOP and glaucoma mediations were seen among patients in both treatment groups.

IOP Reduction

Both surgical procedures produced a significant and sustained reduction in the IOP (Fig. 3). At final follow-up visits, the mean IOP was 11.7 ± 3.1 mm Hg (range, 6 to 19 mm Hg) in the CLASS group and 13.3 ± 3.6 mm Hg

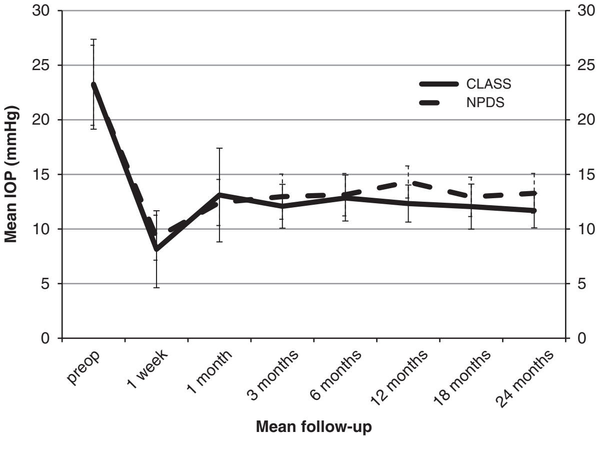

FIGURE 3. Mean IOP (mm Hg) over time for the CLASS (continuous line, n = 27) and the NPDS (dashed line, n = 31). Bars = SD. CLASS indicates CO_2 laser-assisted sclerectomy surgery; IOP, intraocular pressure; NPDS, nonpenetrating deep sclerectomy.

(range, 8 to 20 mm Hg) in the control group ($P = 0.14$). The IOP reduction from base line was 49% in the CLASS group and 42% in the control group. Patients who underwent additional interventions such as needling or GPT were included in the calculation.

Visual Acuity

The visual acuity went from 0.8 ± 0.3 (range, 0.3 to 1.1) preoperatively to 0.7 ± 0.3 (range, 0.05 to 1.0) at last follow-up in the CLASS group, whereas visual acuity went from 0.7 ± 0.3 (range, 0.05 to 1.1) to 0.6 ± 0.3 (range, 0.05 to 1.1) in the control group. No significant difference was found at last visit between both groups ($P = 0.3$).

Medical Therapy

A significant reduction in the use of medical therapy was seen in both treatment groups. The number of antiglaucoma medication went down to 1.0 ± 1.6 in the CLASS group ($P < 0.0003$) and to 0.7 ± 1.1 ($P < 0.0004$) in the control group, respectively. No significant difference was seen between both groups at last follow-up visit ($P = 0.44$).

Treatment Outcomes

The complete success rate ($5 \leq \text{IOP} \leq 18$ mm Hg without antiglaucoma medication) was 73% in the CLASS group and 71% in the control group, respectively, whereas the qualified success rate ($5 \leq \text{IOP} \leq 18$ mm Hg with/without medication) was 96% in the CLASS group and 89% in the control.

Kaplan-Meier survival curves were also used to compare failure rates between the 2 treatment groups (Fig. 4). The cumulative failure rate was 48% in the CLASS group and 35% in the control group at 2 years ($P > 0.8$). There were 7 patients (26%) in the CLASS group and 8 patients (28%) in the control group who have a failed procedure because of inadequate IOP reduction. None of them underwent reoperation for IOP reduction during the first

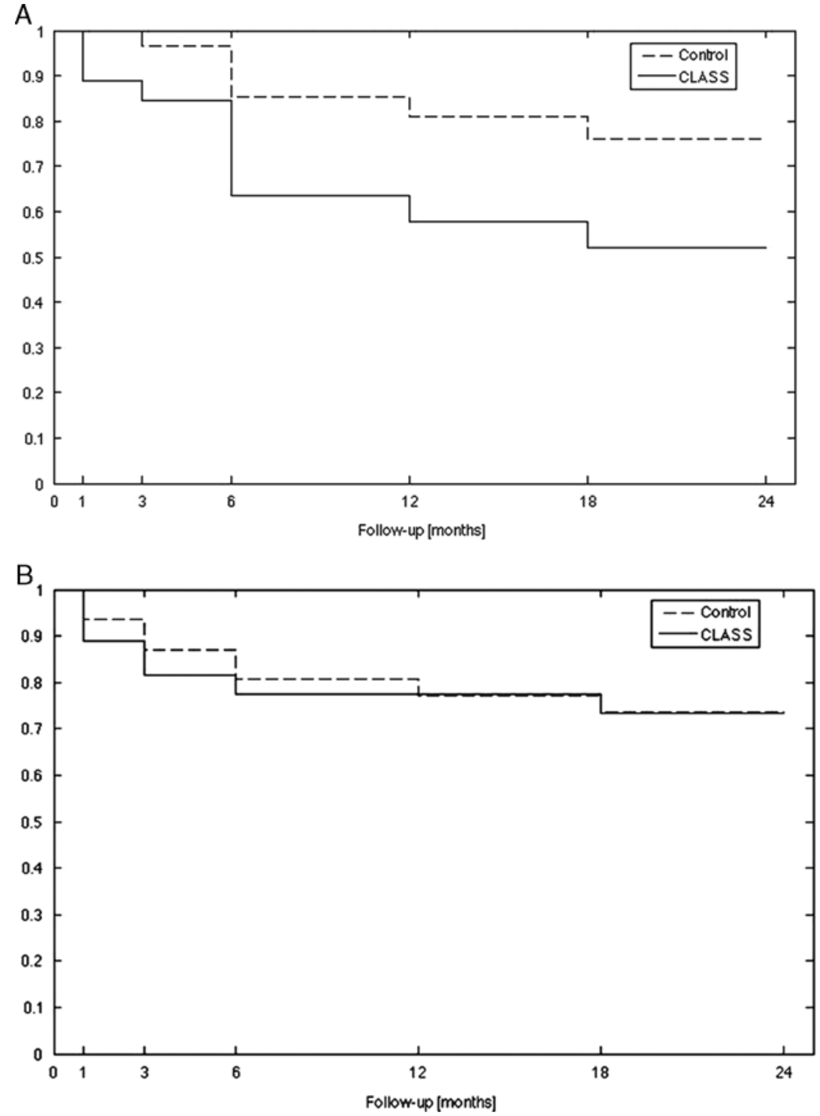

FIGURE 4. A, Kaplan-Meier cumulative survival curves for CLASS group and control groups, showing complete success rates. B, Kaplan-Meier cumulative survival curves for CLASS group and control groups, showing qualified success rates. CLASS indicates CO_2 laser-assisted sclerectomy surgery.

TABLE 3. Reasons of Treatment Failure in CLASS Versus NPDS Study: 2 Years Follow-up

	n (%)	
	CLASS Group	**NPDS Group**
Inadequate IOP reduction*	7 (26)	8 (28)
Persistent hypotony†	2 (7)	1 (3)
Reoperation	5 (19)	2 (6)
Loss of light perception	0	0

*IOP > 18 mm Hg at 2-year follow-up or at last visit.

†IOP < 5 mm Hg for > 2 weeks.

CLASS indicates CO_2 laser-assisted sclerectomy surgery; IOP, intraocular pressure; NPDS, nonpenetrating deep sclerectomy

2 years of follow-up. Table 3 lists the reasons for classification as a treatment failure in both groups.

In the CLASS group 5 patients (19%) required further surgery: 1 patient needed surgical revision for persistent iris incarceration resistant to Nd:YAG laser treatment; 1 patient required pars plana vitrectomy for malignant glaucoma; and 3 patients had bleb revision because of persistent hypotony. In the control group 2 patients (7%) were reoperated: 1 patient had a bleb revision because of persistent Seidel secondary to late needling with MMC, and 1 patient underwent revision because of persistent hypotony followed by GPT.

Postoperative Management

GPT was performed on 23 patients (85%) in the CLASS group on a mean time of 82.5 ± 107 days (range, 1 to 365 d) after surgery. The IOP went from a mean of 23.2 ± 10.7 mm Hg (range, 16 to 60 mm Hg) down to 10.6 ± 4.0 mm Hg (range, 4 to 19 mm Hg) after GPT. Of these 23 patients, 12 had concomitant bleb needlings with MMC injection that further reduced the IOP to 9.8 ± 7.3 mm Hg (range, 3 to 23 mm Hg). This procedure was performed on 20 patients (65%) in the control group on a mean time of 103.6 ± 112.3 days (range, 6 to 425 d) after surgery. The IOP went from a mean of 20.4 ± 5.9 mm Hg (range, 13 to 36 mm Hg) down to 11.4 ± 4.3 mm Hg (range, 4 to 22 mm Hg) after the procedure ($P = 0.27$). Of these 20 patients, 10 had concomitant bleb needlings with MMC injection that further reduced the IOP to 7.5 ± 3.6 mm Hg (range, 3 to 12 mm Hg).

Complications

The list of complications is described in Table 4, and detailed as follows:

CLASS Group

Two macroperforations with iris prolapse that necessitated iridectomy during procedure, 1 followed by hypotony of 21 days that resolved spontaneously, and 1 followed by short episode of choroidal detachment and eventually needed revision and resuturing the flap, 1 microperforation with no iris prolapse followed by hypotony of 15 days that resolved spontaneously, 1 macular edema, 1 malignant glaucoma that necessitated pars plana vitrectomy, 1 choroidal detachment that persisted 30 days with spontaneous resolution, 5 Seidel suturing, 13 iris incarceration among which 7 occurred spontaneously after surgery and 6 occurred after performing GPT with Nd:YAG laser. All incarcerations were treated successfully by pilocarpin followed by Nd:YAG laser but 1 case, that necessitated manual deincarceration in the operating room.

TABLE 4. List of Complications in CLASS Versus NPDS Groups: 2 Years Follow-up

	n (%)		
Complication	**CLASS (n = 27)**	**NPDS (n = 31)**	***P***
Microperforation	1 (3)	5 (16)	0.008
Macroperforation	2 (7)	0	NS
Hyphema	2 (7)	0	NS
Hypotony	2 (7)	1 (3)	NS
Shallow AC	1 (3)	0	NS
Flat AC	0	0	—
Choroidal detachment	2 (7)	0	NS
Seidel	5 (18)	5 (16)	—
Iris incarceration	13 (48)	0	0.00004
Macular edema	1 (3)	0	NS
Malignant glaucoma	1 (3)	0	NS
Total no. patients with complications*	17 (62)	7 (23)	

*Patients can have > 1 complication.

AC indicates anterior chamber, CLASS, CO_2 laser-assisted sclerectomy surgery; NPDS, nonpenetrating deep sclerectomy; NS, nonsignificant.

Control Group

No macroperforations, 5 microperforation with no iris prolapse, 1 patient necessitated revision and flap resuturing because of persistent hypotony followed by early GPT, and 1 patient underwent a bleb revision because of persistent Seidel secondary to late needling with MMC. There were 5 Seidel suturing. No choroidal detachment and no iris incarceration were reported.

DISCUSSION

Safety Profile and Efficacy Compared With Trabeculectomy and Glaucoma Drainage Device

In terms of efficacy, the IOP that was achieved in both study groups at 24 months (11.7 ± 3.1 mm Hg in the CLASS group and 13.3 ± 3.6 mm Hg in the control group) was similar to the IOP achieved in standard glaucoma surgeries (13.0 ± 4.9 mm Hg in Baerveldt tube group and 13.3 ± 6.8 mm Hg in trabeculectomy group), with a significant and equivalent decrease of the antiglaucoma medical treatment.[19]

The most significant postoperative complications typical to classic penetrating glaucoma surgeries include persistent hypotony, choroidal effusion, and shallow or flat anterior chamber. These complications were found in about 27% in tube surgeries and 42% in classic trabeculectomy.[20] In this study, this complication rate was around 19% in the CLASS group compared with 3% in the NPDS group. As expected from a nonpenetrating surgery that consists of maintaining a natural tissue barrier that prevents the early postoperative hypotony, these types of complications are lower.

CLASS Versus NPDS

Nonpenetrating filtration surgery is a promising surgical procedure for open-angle glaucoma treatment, with an excellent safety profile and low complication rate.[2] A review of the literature shows contradictory findings, however, with some studies describing NPDS as superior[16,21,22] and others as similar or inferior to standard trabeculectomy in terms of IOP reduction on a medium-term and long-term basis.[23,24] The major advantage of NPDS is that it precludes the sudden hypotony that occurs following trabeculectomy by creating progressive filtration of aqueous humor from the anterior chamber to the surgically created intrascleral space through the TDM.[3]

Preservation of the thin TDM, however, is technically challenging, particularly before the surgeon gains experience with this procedure, and therefore despite its possible advantages, many surgeons are reluctant to use this procedure. The use of laser technology to improve surgical accuracy and to shorten the learning curve period is therefore a highly appealing option.

It has been shown recently that scleral dissection for NPDS surgery can be accurately achieved using a femtosecond laser technique.[25] Although this laser is very precise and delicate, its use in the future is not so promising as the sclerocorneal plane of ablation is curved and cannot be straightened by a vacuum ring like in refractive surgery, and a perforation of the TDM might still happen if the dissection is very deep.

The CO_2 laser has certain qualities that confer significant advantages when it is used specifically to facilitate deep sclerectomy filtration surgeries. These include photoablation of dry tissues, coagulation of bleeding vessels, and almost complete absorption of the laser energy by even minute amount of water. As the emitted radiation is readily absorbed by the percolating aqueous humor, the trabecular meshwork is effectively protected from the laser energy when percolation takes place. Thus, perforation of the thin TDM during deep sclerectomy, which is the most frequent intraoperative complication of manual NPDS, is substantially minimized.[6,8]

As shown in this study, the CLASS procedure achieved a significant IOP-lowering effect with a significant decrease in the supplemental medical therapy in the 2-year follow-up period. The decrease in IOP and medication was found to be equal in both groups, and demonstrates that in terms of efficacy the CLASS procedure can be considered to be at least as good as the conventional manual deep sclerectomy performed by an experienced surgeon.

In that aspect, the CLASS procedure by its simplicity of performance is an appealing advantage, as it obviates the prolonged learning curve characteristic of manual NPDS, and thus can be confidently performed by surgeons with a wide range of experience in filtration surgery. The surgeon does not need to manually dissect layers of sclera or locate the orifice of the Schlemm canal, as in manual NPDS techniques. Instead, the surgeon gradually ablates an area, which is easily identified by the use of simple landmarks (aiming dots of the scan pattern positioned on the surgical limbus). Once fluid is seen percolating, the natural drainage apparatus is clearly visible and the emerging fluid prevents further damage and perforation of the remaining thinned tissue.

CLASS-related Complications

No malfunctions of the laser device were recorded in this pilot study. Microperforations were suspected in some cases, but this did not interfere with the safety or efficacy of the surgical outcome and might even have improved filtration.

Two intraoperative complications occurred, involving macroperforation with iris prolapse. These cases can be compared with classic NPDS in which the TDM was perforated during the manual dissection. Theoretically, the emerging fluid that percolates from the trabeculum was supposed to prevent the further ablation by the laser, avoiding perforation. One explanation that can be given is that the working energy of the CO_2 laser was too high, performing too steep ablation steps, and once fluid percolated in these cases it was too late as the perforation was already done. To avoid that, the surgeon should decrease the amount of CO_2 energy while approaching the deep levels ablation in proximity to Schlemm canal, continuing the deep ablation more safely. For this pilot study, we have kept the CO_2 level of energy similar throughout the entire conduction of the study, and this could explain the occurrence of such complications in these patients, for whom the energy should have been lower.

One case of malignant glaucoma was treated by pars plana vitrectomy. This complication can occur after any ocular surgery: cataract, trabeculectomy, or NPDS. However, one should remember that by using this unique technique of CLASS, by applying laser energy on the scleral bed, especially the first applications that are aimed posteriorly to create an intrascleral space, this energy can irritate the ciliary body, and increase the risk of malignant glaucoma in susceptible patients.

Iris Incarceration

Almost half of the patients developed iris incarcerations, which means that part or all the filtrating zone was blocked by iris prolapse, causing an elevation of the IOP. In some cases this phenomenon followed a regular GPT that was performed to augment the filtration and to decrease the IOP, but in $>50\%$ of cases this phenomenon happened spontaneously without any previous intervention.

As mentioned before, GPT is considered a routine procedure in NPDS, and used as normal postoperative interventions to maintain or augment the operative results of glaucoma surgeries.[5,14,17,18] Incarceration can occur but are quite rare in routine GPT after classic NPDS. The high rate of incarceration after GPT in CLASS procedure can be related to the fact that the zone to be treated in GPT is a bit different in CLASS compared with classic NPDS. In classic NPDS, the TDM or "window" is much wider and located anteriorly, resulting from the manual anterior dissection that is performed during surgery, getting far from the iris root. Therefore, the aperture that is made in GPT is not in close proximity to the iris, decreasing the risk of incarceration. This anterior dissection does not exist in CLASS. In contrast, in CLASS procedure, the aiming beam of the CO_2 laser is focused on the area of the Schlemm canal and the pigmented trabeculum under it. The ablation progresses to deeper layers, until a very thin residual trabeculum persists, allowing the fluid to percolate. In CLASS there is no "window" that was dissected anteriorly to the clear cornea but this thin residual membrane that separates the anterior chamber from the intrascleral space. This membrane is located at the pigmented trabeculum, in a close proximity to the iris root. Perforating this membrane in GPT carries a risk of iris incarceration in those cases where the angle is not widely opened.

In those cases of spontaneous incarceration without GPT, probably, this membrane was so thin, permitting high-flow filtration that ended in incarceration. In a subanalysis of all cases with spontaneous incarceration, in 4 of 7 cases, overfiltration was suspected during the surgery itself, and the scleral flap was repositioned and sutured using >2 single nylon sutures to increase the resistance to outflow. In 2 other cases a viscoelastic material was even injected into the anterior chamber at the end of surgery to prevent a potential hypotony in the early postoperative days. In such a case when overfiltration is suspected during surgery, a preventive treatment with pilocarpin given in the first postoperative days could be considered. Alternatively a preventive iridotomy next to the filtering zone, in situation when the angle is not widely opened, can also be proposed.

We would like to emphasize, however, that no matter which type or at what stage the incarceration occurred, all cases but 1 were successfully treated by Nd:YAG laser. Only 1 case was refractory to laser treatment that needed reoperation and eventually manual deincarceration.

Study Limitations and Future Thoughts

To the best of our knowledge, this is the first pilot study that was conducted comparing CLASS procedure to standard NPDS. The 2 groups of patients in this study were matched in terms of age, sex, preoperative IOP, and preoperative medication; the procedures were performed by the same surgeon at the same time period, but this is still a retrospective pilot study with a limited follow-up (24 mo). A randomized prospective study with longer follow-up is required to further evaluate and substantiate the safety and long-term efficacy of the CLASS procedure and to compare the outcomes to standard NPDS.

The use of the CO_2 laser ablation is aimed to replace and simplify the manual dissection of the deep sclerectomy in NPDS. Deep ablation achieves good percolation and low IOP but at the risk of perforation of the TDM with an increased risk of spontaneous iris incarceration. This step in the CLASS procedure is critical and still lacks standardization. A uniform "small step" deep ablation is required, with consistent and controlled percolation, allowing sufficient outflow in one hand but minimizing the risk of perforation and iris incarceration on the other hand.

The concept of using a space-occupying substance in the intrascleral space has been proved to improve success rates in NPDS. In this study there was no subgroup analysis that investigated and compared the efficacy of the various types of implants that were being used. In the future this aspect should be further investigated and analyzed, to conclude which type of implant shows superiority in combination with CLASS if at all needed.

CONCLUSIONS

In this pilot study, the CLASS procedure was found to be as efficient as classic NPDS in terms of IOP-lowering effect in the intermediate term (24 mo). There was a higher rate of complications due to iris incarceration that can be attributed to the level of laser energy given. Mastering the procedure and refining the energy parameters are necessary to enhance the safety levels. The ease of use promotes confidence even to surgeons showing limited experience in filtering surgery. Further studies are needed to evaluate and bolster the safety and long-term efficacy of the CLASS procedure compared with other filtrating glaucoma surgeries.

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