

Canaloplasty: Three-year results of circumferential viscodilation and tensioning of Schlemm canal using a microcatheter to treat open-angle glaucoma

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PURPOSE: To report 3-year results of the safety and efficacy of canaloplasty, a procedure involving circumferential viscodilation and tensioning of the inner wall of Schlemm canal to treat open-angle glaucoma.

SETTING: Multicenter surgical sites.

DESIGN: Nonrandomized multicenter clinical trial.

METHODS: This study comprised adult open-angle glaucoma patients having canaloplasty or combined cataract–canaloplasty surgery. Qualifying preoperative intraocular pressures (IOPs) were at least 16 mm Hg with historical IOPs of at least 21 mm Hg. A flexible microcatheter was used to viscodilate the full circumference of the canal and to place a trabecular tensioning suture. Primary outcome measures included IOP, glaucoma medication use, and adverse events.

RESULTS: Three years postoperatively, all study eyes ($n = 157$) had a mean IOP of $15.2 \text{ mm Hg} \pm 3.5$ (SD) and mean glaucoma medication use of 0.8 ± 0.9 compared with a baseline IOP of $23.8 \pm 5.0 \text{ mm Hg}$ on 1.8 ± 0.9 medications. Eyes with combined cataract–canaloplasty surgery had a mean IOP of $13.6 \pm 3.6 \text{ mm Hg}$ on 0.3 ± 0.5 medications compared with a baseline IOP of $23.5 \pm 5.2 \text{ mm Hg}$ on 1.5 ± 1.0 medications. Intraocular pressure and medication use results in all eyes were significantly decreased from baseline at every time point ($P < .001$). Late postoperative complications included cataract (12.7%), transient IOP elevation (6.4%), and partial suture extrusion through the trabecular meshwork (0.6%).

CONCLUSION: Canaloplasty led to a significant and sustained IOP reduction in adult patients with open-angle glaucoma and had an excellent short- and long-term postoperative safety profile.

Financial Disclosure: No author has a financial or proprietary interest in any material or method mentioned. Additional disclosures are found in the footnotes.

J Cataract Refract Surg 2011; 37:682–690 © 2011 ASCRS and ESCRS

 Supplemental material available at www.jcrsjournal.org.

Underlying the growing interest in Schlemm canal surgery is the desire to achieve a beneficial reduction in intraocular pressure (IOP) without the complications associated with trabeculectomy.^{1,2} Trabeculectomy is the standard against which all other forms of glaucoma surgery are compared due to its long-standing proven ability to lower IOP.^{3–5} Trabeculectomy involves the creation of a fistula in the anterior chamber, allowing aqueous humor to drain through a subconjunctival filtering bleb. Of concern is that penetration of the

intraocular space is associated with well-established immediate and long-term risks, including intraoperative and postoperative bleeding, shallow anterior chamber, hypotony, choroidal detachment, cataract formation, suprachoroidal hemorrhage, and bleb-related endophthalmitis.^{6–10}

Nonfiltering techniques obviate the need for a subconjunctival filtering bleb, which shunts aqueous to nonphysiologic routes. Canaloplasty intends to restore the natural trabeculocanalicular outflow system by

circumferentially catheterizing and viscodilating Schlemm canal along its entire length with the use of a flexible microcatheter.¹¹ The placement of an intracanalicular tension suture within Schlemm canal distends the trabecular meshwork inward, stenting the canal open.

Previously, Lewis et al.^{12,13} reported 1-year and 2-year interim results in this multicenter prospective clinical study of canaloplasty in adults with open-angle glaucoma. In those papers, canaloplasty yielded a significant reduction in IOP and antiglaucoma medication use with few surgical complications. This 3-year analysis addresses the longevity of treatment safety and efficacy, a key consideration in the treatment of any chronic disease.

PATIENTS AND METHODS

Study Design

This is the 3-year report of an international multicenter prospective open-label interventional study of canaloplasty at 15 clinical sites in the United States and Germany involving 18 surgeon investigators. This research was performed in accordance with the principles set forth in the Declaration of Helsinki, the Regulations and Guidelines of the U.S. Food and Drug Administration, International Organization for Standardization 14155-1, and the International Conference on Harmonization Good Clinical Practices. This study was designed to show the safety and efficacy of the canaloplasty procedure in reducing IOP in nonfiltering surgery for the treatment of open-angle glaucoma. The protocol was

approved for each study site by the appropriate institutional review board (IRB) or ethics committee (EC), and all patients provided informed consent before having any study-related procedure. Due to the encouraging results in the initial study with 1-year follow-up, all enrollees were asked to complete an additional IRB/EC-approved patient consent for extended follow-up at 6-month intervals for an additional 2 years. Details of the study methods have been described in the interim papers.^{12,13}

All enrollees had a complete baseline ophthalmic examination that included the ocular history, ophthalmic and systemic medication use, corrected distance visual acuity (CDVA), IOP by Goldmann applanation tonometry, slitlamp evaluation, central corneal thickness, gonioscopy, and a fundus examination. Snellen CDVA values were converted to logMAR equivalents for data analysis. Follow-up examinations were performed at 1 day, 1 week, and 1, 3, 6, 12, 18, 24, 30, and 36 months, and all relevant information was recorded, including ophthalmic medications, CDVA, IOP, slitlamp examination, gonioscopy, funduscopy, and adverse event and secondary procedure reporting. High-resolution ultrasound biomicroscopy (UBM) images (iUltrasound, iScience Interventional Corp.) of the anterior angle and Schlemm canal were captured preoperatively, intraoperatively, and postoperatively to assess viscodilation of Schlemm canal (Figure 1), distension of the trabecular meshwork due to the tensioning suture, and the size of the surgically created Descemet window. Anterior segment imaging relating postsurgical anterior segment morphology with IOP-lowering efficacy will be addressed in a future report.

Patient Selection

The study protocol allowed flexibility in patient selection and treatment options to reflect each investigator's current practice of glaucoma surgery. Specifically, the protocol allowed phacoemulsification with posterior chamber intraocular lens implantation in combination with canaloplasty and previous surgeries that would not interfere with complete circumferential catheterization of Schlemm canal. All patient enrollment and examination case report forms were verified against the original medical records by study monitors. Data that received 100% source data verification included all baseline data including inclusion and exclusion criteria; key efficacy and safety variables, such as IOP, number of glaucoma medications, secondary procedures, and adverse events; and all patients who had early termination from study participation. All treated eyes were enrolled in the study, and no roll-in or practice eyes were excluded. Eyes that did not meet enrollment criteria were excluded from this analysis, but the patients were followed for complications.

All patients were at minimum 18 years of age at the time of enrollment, able to understand and provide informed consent, and were scheduled for glaucoma surgery or combined cataract and glaucoma surgery. Inclusion criteria for this study included a diagnosis of primary open-angle glaucoma (POAG), pigmentary glaucoma, exfoliative glaucoma, or POAG mixed with another included mechanism and a baseline IOP of 16 mm Hg or higher taken, at most, 60 days before surgery, and a historical IOP of 21 mm Hg or higher. With many patients on maximally tolerated medical therapy, the protocol was designed to allow patients to withdraw from medications due to intolerance or poor compliance provided they had a historical IOP of 21 mm Hg or higher. Exclusion

Submitted: July 1, 2010.

Final revision submitted: October 11, 2010.

Accepted: October 28, 2010.

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Additional financial disclosure: Drs. Lewis, Tetz, Kearney, Shingleton, and Samuelson have consulting agreements with iScience Interventional Corp.

iScience Interventional Corp., Menlo Park, California, USA, sponsored the study and participated in the design of the study, data monitoring, and data management.

Presented in part at the American Glaucoma Society meeting, Naples, Florida, USA, March 2010, and the ASCRS Symposium on Cataract, IOL and Refractive Surgery, Boston, Massachusetts, USA, April 2010.

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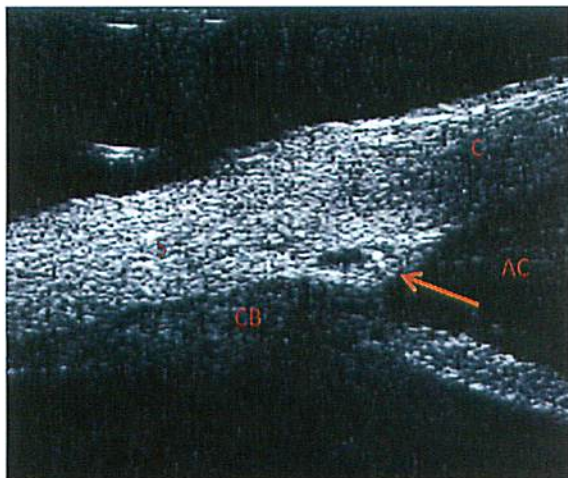


Figure 1. A UBM image of the anterior angle captured at the conclusion of the canaloplasty procedure. The arrow points to the 2 suture knots located in the anterior aspect of the viscodilated Schlemm canal (AC = anterior chamber; C = cornea; CB = ciliary body; I = iris; S = sclera).

criteria included neovascular disease, uveitis, peripheral anterior synechiae, angle recession, developmental or secondary glaucoma with the exception of pigmentary and exfoliative glaucoma, and patients with more than 2 laser trabeculoplasty procedures. Only 1 eye per patient was eligible.

Surgical Technique

A detailed description of the surgical procedure was published in the 1-year interim clinical report.¹² After a nonpenetrating 2-flap dissection technique to expose Schlemm canal, a flexible microcatheter (iTrack 250A, iScience Interventional Corp.) was used to dilate the full circumference of the canal by injecting sodium hyaluronate 1.4% (Healon GV) during catheterization. The microcatheter has a 200 μm diameter shaft with an atraumatic distal tip approximately 250 μm in diameter, a lumen through which the ophthalmic viscosurgical device is delivered, and an illuminated tip so the surgeon can guide the microcatheter by observing the beacon tip transsclerally. A Descemet window was formed just before or immediately after catheterization of the canal. After circumferential catheterization, a 10-0 polypropylene (Prolene) suture was tied to the microcatheter tip and the device was withdrawn, pulling the suture into the canal. The suture was cut from the microcatheter and then tied in a loop encircling the inner wall of the canal. The suture loop was tightened to distend the trabecular meshwork inward, placing the tissues in tension, and then locking knots were added. The deep flap was excised and the superficial flap sutured watertight to prevent bleb formation.

Statistical Analysis

The efficacy analysis was stratified by the treatment received, and the results of different subgroups of patients were evaluated. Group 1 included all patients meeting the inclusion and exclusion criteria, Group 2 included all patients with successful suture implantation during

canaloplasty alone, and Group 3 included all patients with successful suture implantation during canaloplasty combined with cataract surgery. The primary endpoints included mean IOP and mean number of glaucoma medications at each follow-up visit. Combination glaucoma medications were enumerated as individual medications in this study. The secondary endpoints included surgical and postsurgical complications and secondary interventions.

Baseline characteristics between surgical groups were compared using the Pearson chi-square test for categorical variables, such as sex, race, right and left eyes, previous surgery, and diagnosis and analysis of variance (ANOVA) for IOP, visual acuity (logMAR units), and number of glaucoma medications.¹⁴ In each of the 3 groups, repeated-measures ANOVA using a mixed-model approach for longitudinal data was applied to assess changes from baseline in IOP, acuity, and medications with Bonferroni adjusted *P* values for assessing group differences.¹⁵ When comparing Group 2 and Group 3, age, baseline IOP, and medications were included as covariates to control for possible confounding with the group-by-time interaction. The *F*-test for comparing slopes between groups from baseline through 36 months and differences in IOP, medications, and visual acuity was performed at specific time points. A compound symmetry covariance structure was used to handle the repeated measurements for the same patients at different time points. Two-tailed values of *P* less than or equal to 0.05 were considered statistically significant with adjustment for multiple comparisons as appropriate. The SPSS statistical package (version 18.0, SPSS Inc./IBM) was used for analysis of the data.

RESULTS

Demographics

The study cohort consisted of patients who met inclusion and exclusion criteria, provided consent for long-term follow-up, and completed baseline visits. Group 1 (all included patients) consisted of 157 eyes of 157 patients at baseline, with 134 eyes (84.7%) completing the 36-month visit. Of the remaining 23 patients, 9 (5.7%) were lost to follow-up, 7 (4.5%) had additional glaucoma surgery, 3 (1.9%) were terminated due to study site closure, 3 withdrew from the study for personal reasons, and 1 (0.6%) died after 24 months for reasons not related to the study.

Table 1 shows the patients' demographics. Patients were predominantly white and female, with the majority of the cohort diagnosed with POAG. Twenty-five eyes (15.9%) were pseudophakic at baseline. The successful placement of a tensioning suture into Schlemm canal was achieved in 133 eyes (84.7%). The primary reason successful suture placement was not achieved was surgery related, such as the microcatheter tip entering a collector channel ostium, deviating from the intended 360-degree circular Schlemm canal. However, no significant adverse events were recorded as a result of the failure to fully catheterize the canal. Eyes that were not completely catheterized to allow placement of a tensioning suture

Table 1. Study group demographics.

Parameter	Value
Patients/eyes, n	157
Age in years	
Mean \pm SD	67.6 \pm 11.6
Range	37.4 to 88.4
Sex, n (%)	
Female	84 (53.5)
Male	73 (46.5)
Race, n (%)	
White	144 (91.7)
Black	8 (5.1)
Hispanic	4 (2.5)
Asian	1 (0.6)
Glaucoma diagnosis, n (%)	
Primary open angle glaucoma	140 (89.2)
Pseudoexfoliative glaucoma	11 (7.0)
Mixed mechanism	3 (1.9)
Pigmentary dispersion glaucoma	3 (1.9)
Previous ocular surgery, n (%)	
Cataract	25 (15.9)
Laser trabeculoplasty	24 (15.3)
Viscocanalostomy	12 (7.6)
Laser peripheral iridotomy	9 (5.7)
Nd:YAG capsulotomy	2 (1.3)
Cyclophotocoagulation	1 (0.6)

n = sample size

Nd:YAG = neodymium YAG

were viscodilated to the extent possible by catheterizing the canal from both ostia. One hundred twenty-one eyes (77.1%) had canaloplasty only with or without tensioning suture placement, and 36 eyes (22.9%) with visually significant cataract had canaloplasty with or without suture placement combined with cataract extraction (phacocanaloplasty).

Change in Intraocular Pressure and Antiglaucoma Medication Use

Table 2 and Figure 2 show the efficacy results by group. In Group 1 (all included eyes), the decrease in IOP from baseline to 36 months was 36.1%. Twelve (7.6%) of 157 eyes were on no antiglaucoma medications and 33 eyes (21.0%) were on 3 or more antiglaucoma medications at baseline compared with 66 of 134 eyes (49.3%) and 4 eyes (3.0%), respectively, at 36 months. The IOP and medication use were significantly decreased from baseline at all time points ($P < .001$).

In Group 2 (canaloplasty alone with successful suture implantation), the decrease in IOP from baseline to 36 months was 34.0%. Four (3.9%) of 103 eyes were on no antiglaucoma medications and 21 eyes (20.4%) were on 3 or more medications at baseline compared with 37 (41.6%) of 89 eyes and 4 eyes (4.5%), respectively, at 36 months. The IOP and medication use were significantly decreased from baseline at all time points ($P < .001$). In 18 eyes that had canaloplasty alone, a tensioning suture was not placed because Schlemm canal could not be completely catheterized. This subgroup had a mean baseline IOP of 25.2 ± 6.4 mm Hg and a mean medication use of 2.1 ± 1.0 medications per eye, decreasing to 16.2 ± 3.3 mm Hg on 1.1 ± 0.8 medications, respectively, at 36 months. The reduction in IOP from baseline to 36 months was 35.7%. The sample size in this subgroup was too small for a meaningful statistical comparison with Group 2.

In Group 3 (canaloplasty with successful suture placement combined with phacoemulsification), the decrease in IOP from baseline to 36 months was 42.1%. The IOP and medication use were significantly decreased from baseline at all time points ($P < .001$). Baseline IOP was not significantly different between

Table 2. Outcomes.

Exam	Group 1: All Eyes			Group 2: Canaloplasty Alone with Suture Placement			Group 3: Phacocanaloplasty with Suture Placement		
	n	Mean IOP (mm Hg) \pm SD	Mean Meds (n) \pm SD	n	Mean IOP (mm Hg) \pm SD	Mean Meds (n) \pm SD	n	Mean IOP (mm Hg) \pm SD	Mean Meds (n) \pm SD
Baseline	157	23.8 \pm 5.0	1.8 \pm 0.9	103	23.5 \pm 4.5	1.9 \pm 0.8	30	23.5 \pm 5.2	1.5 \pm 1.0
Postop(mo)									
3	136	15.7 \pm 4.2	0.3 \pm 0.6	91	15.9 \pm 3.8	0.3 \pm 0.7	25	14.0 \pm 3.9	0.1 \pm 0.3
6	132	15.4 \pm 3.7	0.3 \pm 0.6	86	16.1 \pm 3.4	0.4 \pm 0.7	25	12.8 \pm 2.9	0.1 \pm 0.3
12	136	15.6 \pm 4.2	0.5 \pm 0.8	91	16.1 \pm 3.9	0.6 \pm 0.8	27	13.6 \pm 4.1	0.1 \pm 0.4
18	128	15.9 \pm 4.1	0.5 \pm 0.8	87	16.2 \pm 4.1	0.6 \pm 0.8	20	14.5 \pm 3.6	0.2 \pm 0.4
24	132	15.8 \pm 4.2	0.6 \pm 0.8	89	16.1 \pm 4.0	0.6 \pm 0.8	25	13.4 \pm 3.2	0.2 \pm 0.4
30	122	15.6 \pm 4.2	0.6 \pm 0.8	82	16.3 \pm 4.5	0.8 \pm 0.8	25	13.8 \pm 3.2	0.2 \pm 0.5
36	134	15.2 \pm 3.5	0.8 \pm 0.9	89	15.5 \pm 3.5	0.9 \pm 0.9	27	13.6 \pm 3.6	0.3 \pm 0.5

IOP = intraocular pressure; Meds = medications; n = sample size

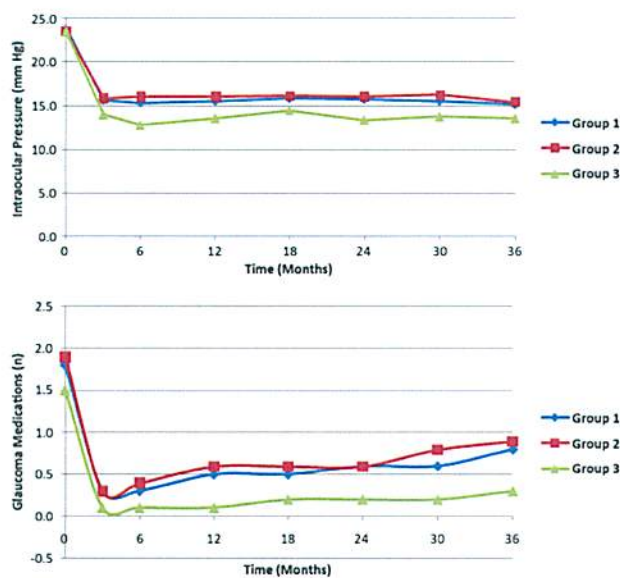


Figure 2. Graph comparing efficacy outcomes through 36 months in the 3 groups.

Group 2 and Group 3 ($P = .68$); however, postoperative IOP was lower in Group 3 at all time points ($P = .095$ at 36 months). Figure 3 shows a scatterplot graph of the baseline and 36-month postoperative IOP in all eyes in Group 2 and Group 3.

Visual Acuity

At 36 months, 13 (8.3%) of 157 eyes in Group 1 lost 2 or more lines (0.2 logMAR) of CDVA. The loss of visual acuity was attributed to glaucoma progression in 6 eyes (3.8%), cataract in 3 eyes (1.9%), age-related macular degeneration in 2 eyes (1.3%), and previously existing Fuchs' corneal dystrophy in 1 eye (0.6%); the reason for the visual acuity decrease in 1 eye was not reported. Group 2, which had a mean baseline CDVA of 0.22 ± 0.36 logMAR and a mean CDVA of 0.20 ± 0.25 logMAR at 36 months, had no significant change from baseline values ($P = 1.00$).

Success

Table 3 shows the success results stratified by the absolute IOP readings in Group 2 and Group 3. Complete success was defined as reaching the specified IOP without antiglaucoma medication and a qualified success, as including the use of 1 or 2 medications. At 36 months, 36.0% of Group 2 eyes attained an IOP of 18 mm Hg or lower with no medications and 77.5% achieved a qualified success. In Group 3, 70.4% of eyes achieved an IOP of 18 mm Hg or lower with no medications and 88.9% achieved a qualified success. Table 3 also shows the success results stratified by absolute IOP readings and a 25% reduction in IOP from the maximum baseline IOP. Figure 4 shows

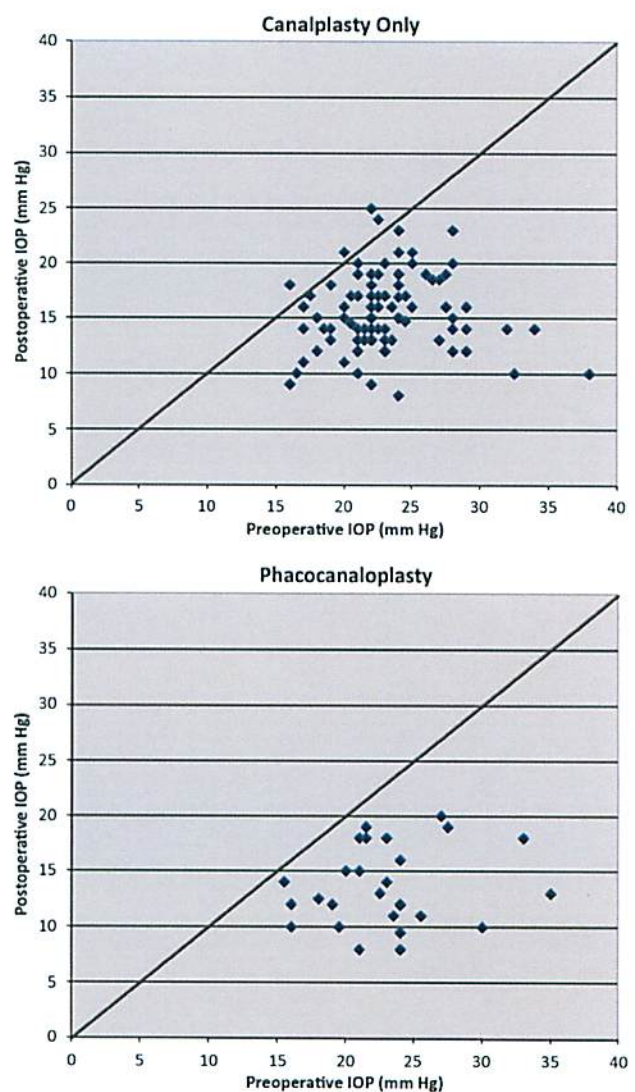


Figure 3. Scatterplot of preoperative IOP after 36 months in Group 2 (top) and Group 3 (bottom). Each point represents 1 eye. Points falling below the oblique line, which represents no change, are lower than the preoperative readings (IOP = intraocular pressure).

Kaplan-Meier survival plots for cumulative failure rates in Group 2 and Group 3 using the failure criterion of an IOP over 18 mm Hg on 2 consecutive visits. The chi-square approximations for log-rank and Wilcoxon tests comparing the failure proportions in Group 2 and Group 3 show a significant difference in the cumulative failure rate ($P < .03$).

Surgical and Postsurgical Complications

Overall, the frequency of surgical and postsurgical complications was low, with 16 adverse events in 12 eyes. Table 4 shows all ocular-related surgical and postoperative complications reported regardless of severity. Most complications occurred intraoperatively and in the early postoperative phase (≤ 90

Table 3. Success results at 12, 24, and 36 months in Group 2 and Group 3.

	Success Rate (%)					
	Group 2			Group 3		
	12 Months	24 Months	36 Months	12 Months	24 Months	36 Months
Complete success						
≤21 mm Hg	57.1	48.9	40.4	85.2	79.2	77.8
≤21 mm Hg and ≥25% IOP reduction*	50.5	42.7	34.8	81.5	76.0	70.4
≤18 mm Hg	48.4	40.9	36.0	77.8	75.0	70.4
≤18 mm Hg and ≥25% IOP reduction*	47.3	38.2	33.7	74.1	72.0	63.0
≤15 mm Hg	34.1	23.9	21.3	66.7	62.5	51.9
≤15 mm Hg and ≥25% IOP reduction*	34.1	23.6	21.3	66.7	60.0	51.9
Qualified success						
≤21 mm Hg	93.4	93.3	95.5	96.3	100.0	100.0
≤21 mm Hg and ≥25% IOP reduction*	79.1	80.9	85.4	88.9	100.0	92.6
≤18 mm Hg	70.3	74.2	77.5	85.2	92.0	88.9
≤18 mm Hg and ≥25% IOP reduction*	68.1	70.8	76.4	77.8	92.0	81.5
≤15 mm Hg	46.2	46.1	55.1	70.4	76.0	70.4
≤15 mm Hg and ≥25% IOP reduction*	46.2	46.1	55.1	70.4	76.0	70.4

IOP = intraocular pressure

*Reduction from maximum baseline IOP

days postoperatively). Intraoperative complications included partial suture extrusion through the trabecular meshwork, Descemet's detachment without involvement of the visual axis in 1 eye that resolved by 6 months postoperatively, and microhyphema, defined as circulating red blood cells without layered blood in the anterior chamber.

During the early postoperative period, the most common complications were microhyphema, hyphema, and elevated IOP (≥ 30 mm Hg). The hyphema resolved by the 1-week visit except in 3 eyes (1.9%), in which it resolved by 1 month postoperatively. The IOP rises were transient and resolved by the next scheduled follow-up except in 3 eyes (1.9%), 1 of

which was treated with neodymium:YAG (Nd:YAG) goniopuncture for scarring of the trabeculo-Descemet window and 2 of which were ultimately converted to trabeculectomies. All Descemet's membrane detachments had no visual axis involvement and resolved by the next scheduled visit except in 1 eye, in which the detachment resolved by 6 months postoperatively. The case of hypotony (IOP ≤ 5 mm Hg with shallow anterior chamber) was observed 1 day postoperatively and resolved by the next scheduled visit.

During the late postoperative period, the most common complications were cataract and elevated IOP (≥ 30 mm Hg). Three instances of elevated IOP in 2 eyes were successfully treated with glaucoma medical therapy. One eye with an IOP of 40 mm Hg at 869 days was believed to be a steroid responder after cataract surgery and was effectively treated with glaucoma medical therapy. An IOP rise of 30 mm Hg in 1 eye was attributed to a medication side effect and resolved after discontinuation of the drug. The remaining 5 eyes required further intervention or a combination of interventions including Nd:YAG goniopuncture, iridoplasty, cyclophotocoagulation, and trabeculectomy. In general, blebs were infrequent, and the 4 (2.5%) blebs reported were described as flat and diffuse.

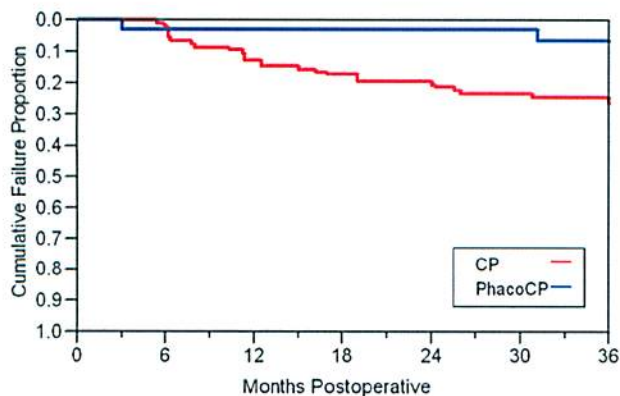


Figure 4. Kaplan-Meier plots of the cumulative probability of failure in Group 2 and Group 3. Failure was defined as an IOP higher than 18 mm Hg on 2 consecutive visits (CP = canaloplasty).

Postoperative Interventions

Table 5 shows all interventions, defined as any procedure or process performed after surgery with

Table 4. Ocular-related surgical and postsurgical complications.

Complication	Number (%)
Surgical/early postoperative (≤ 90 days)	
Microhyphema (< 1.0 mm layered blood)	19 (12.1)
Hyphema (≥ 1.0 mm layered blood)	16 (10.2)
Elevated intraocular pressure	10 (6.4)
Descemet's membrane detachment	5 (3.2)
Wound hemorrhage (corneal incision, conjunctiva, TDW)	4 (2.5)
Suture extrusion through trabecular meshwork	2 (1.3)
Hypotony (IOP ≤ 5 mm Hg with shallow anterior chamber)	1 (0.6)
Late postoperative (> 90 days)	
Cataract	20 (12.7)
Elevated intraocular pressure	10 (6.4)
Blebs at 36 months	4 (2.5)
Suture extrusion through trabecular meshwork	1 (0.6)

TDW = trabeculo-Descemet window

Table 5. Postoperative Interventions.

Type	Number (%)
Surgical	
Cataract surgery	20 (12.7)
Trabeculectomy	4 (2.5)
Canaloplasty	1 (0.6)
Laser	
Nd:YAG goniopuncture	14 (8.9)
Nd:YAG capsulotomy	12 (7.6)
Cyclophotocoagulation	3 (1.9)
Peripheral laser iridotomy	2 (1.3)
Iridoplasty	2 (1.3)
Synechialysis	2 (1.3)
Selective laser trabeculoplasty	1 (0.6)
Other	
Conjunctival suture replacement	8 (5.1)
Wound revision	1 (0.6)
Paracentesis	1 (0.6)
Pars plana steroid injection (for CRVO)	1 (0.6)

CRVO = central retinal vein occlusion; Nd:YAG = neodymium:YAG

the goal of enhancing the success of the surgical outcomes. The most commonly performed procedures included cataract extraction, Nd:YAG goniopuncture, Nd:YAG capsulotomy, and conjunctival suture replacement. Patients who received additional glaucoma surgery, including trabeculectomy, cyclophotocoagulation, and repeat canaloplasty, were censored from further analysis after the reoperations and were categorized as failures in the Kaplan-Meier curve and log-rank test.

DISCUSSION

When incisional glaucoma surgery is required, a trabeculectomy has traditionally been performed.¹⁶ However, the quest for superior glaucoma surgical procedures has been motivated by the need to achieve long-term IOP control in the safest possible manner. The 3-year results reported here show sustained pressure lowering accompanied by a low incidence of late postoperative complications.

Although it is difficult to compare results in studies with different patient populations and study designs, canaloplasty efficacy results are comparable to published reports of trabeculectomy 3 years postoperatively. Comparative studies of trabeculectomy show a mean IOP in the range of 12.5 to 17.7 mm Hg after 3 years with mean medication use in the range of 0.34 to 0.93.¹⁷⁻²⁰ In the Tube Versus Trabeculectomy Study,²⁰ the authors point out that the hypotonous eyes that were categorized as failures due to persistent low IOP had the effect of reducing the reported mean IOP.

In the study reported here, early complications included a 12.1% incidence of microhyphema, a 0.6% incidence of hypotony, and no instances of flat/shallow anterior chambers or choroidal detachment. With canaloplasty, it is not uncommon to observe a small amount of blood in the anterior chamber, which likely occurs when the IOP decreases to less than the episcleral venous pressure. In comparison, the incidence of hyphema after trabeculectomy is reported to be in the range of 3% to 43%.^{10,21-25} The incidence of hypotony as a postoperative complication of trabeculectomy is reported as between 10% and 42%.²¹⁻²⁵ Choroidal detachment subsequent to a trabeculectomy has been reported to range from 1% to 29%.^{21,23,25}

Late complications after canaloplasty were infrequent. Only 4 (2.5%) blebs were observed at 36 months and there were no long-term bleb-related complications. In contrast, the late postoperative complications subsequent to trabeculectomy have been well described.²⁰ Bindlish et al.²⁶ report a 42.3% incidence of delayed hypotony occurring at a mean of 26.1 months subsequent to mitomycin-C (MMC)-augmented trabeculectomy. In addition, the authors report that bleb leak occurred in 18 eyes (14.6%) a mean of 27.9 months after trabeculectomy and that up to 8% of new cases of hypotony occurred 4 to 5 years postoperatively.

In the 3-year follow-up period in our canaloplasty study, 12.7% of patients had cataract progression that was potentially related to the procedure or age-related progression; 3.8% of these eyes had significant preexisting cataracts. For patients who did not have

significant preexisting cataract, the mean length of time to postoperative cataract extraction was 24.0 months. In comparison, a study of patients with a mean age of 43.7 years by Adelman et al.²⁷ reports a cataract extraction rate of 24% after initial trabeculectomy, with a mean time to postoperative cataract extraction of 26 months.

An indicator of surgical success could include the number of repeated surgical interventions required to maintain the target IOP. For the postoperative management of the Descemet window and distended trabecular meshwork created during canaloplasty, secondary procedures were infrequent and included Nd:YAG goniopuncture, iridoplasty, and synechialysis. Because canaloplasty is not dependent on bleb formation, immediate postoperative care does not entail bleb massage or suture release to enhance flow. In comparison, Taube et al.²⁸ report that the mean number of visits to an ophthalmologist during the first postoperative year was 14.1 ± 3.1 per patient, with 93% of patients requiring bleb manipulations. King et al.²⁹ examined the type and frequency of postoperative bleb manipulations after trabeculectomy with intraoperative MMC and found that 93 (78.2%) of 119 trabeculectomies were followed by some form of bleb manipulation. Procedures requiring fewer follow-up visits and postoperative interventions could speak to a procedure being more cost effective with less resource utilization and greater convenience for the patient and surgeon.

The subset of eyes having primary cataract surgery in conjunction with canaloplasty surgery had a lower IOP than eyes having canaloplasty alone 3 years postoperatively, which suggests a combined beneficial effect. It may be surmised that removal of the natural lens improves outflow by further increasing trabecular meshwork tensioning in conjunction with canaloplasty. This potential advantage is supported by other studies of nonpenetrating glaucoma surgery in combination with phacoemulsification cataract surgery.³⁰⁻³² In contrast, some studies³³⁻³⁶ found that phacotrabeculectomy was not as effective as trabeculectomy in reducing IOP.

The results in this multicenter prospective clinical trial provide further evidence that canaloplasty safely and effectively lowers IOP with persistent control of IOP through a 3-year postoperative period. The use of a flexible microcatheter to circumferentially viscodilate and suture tension Schlemm canal facilitates restoration of aqueous outflow in open-angle glaucoma. Canaloplasty did not demand the close postoperative management that is often required after trabeculectomy. Late postoperative complications were infrequent compared with the well-documented long-term risks associated with trabeculectomy.

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