Clinical Evaluation of the Aqueous Outflow System in Primary Open-Angle Glaucoma for Canaloplasty

Matthias C. Grieshaber,1,2 Ané Pienaar,1 Jan Olivier,1 and Robert Stegmann1

PURPOSE. To assess the aqueous outflow pathway in primary open-angle glaucoma (POAG) through provocative gonioscopy and channelography with a flexible microcatheter and fluorescein tracer during canaloplasty.

METHODS. One eye each was randomly selected from 28 consecutive black African POAG patients undergoing canaloplasty. Provocative gonioscopy was performed at the beginning of surgery, and blood reflux from collector channels into Schlemm’s canal (SC) was semiquantitatively evaluated. During canaloplasty, a flexible microcatheter injected fluorescein tracer stepwise into SC. The outflow pathway parameters of interest were blood reflux, transtрабecular passage of fluorescein, and episcleral vein filling.

RESULTS. Mean age, intraocular pressure (IOP), and cup-to-disc ratio were 45.9 years (SD ± 13.3), 41.0 mm Hg (SD ± 11.9), and 0.78 (SD ± 0.22), respectively. Mean IOP (P < 0.001) and episcleral venous egress (P = 0.01) correlated significantly with blood reflux, but cup-to-disc ratio (P = 0.71), age (P = 0.70), and fluorescein diffusion (P = 0.90) did not. A multivariable regression model showed that higher IOP (P < 0.001, OR, 1.687; 95% CI, 1.151–2.472) was strongly associated with poor blood reflux, independent of the patient’s age (P = 0.383, OR, 0.942; 95% CI, 0.823–1.078). No correlation was found between preoperative IOP, transtрабecular passage, episcleral venous egress, and cup-to-disc ratio. The mean IOP was 17.5 mm Hg (SD ± 3.7) 6 months after surgery. The level of IOP after surgery correlated with the grade of blood reflux and episcleral venous egress (P < 0.001).

CONCLUSIONS. High mean IOP may be associated with poor blood reflux and filling of SC. A collapsed canal, probably secondary to high IOP, may be an underestimated sign in black African patients with POAG. The quality of blood reflux and episcleral venous egress may both be predictive of the level of IOP after surgery. Provocative gonioscopy and channelography may reflect the function of the outflow pathway and may be helpful in assessing the surgical outcome of canaloplasty. (Invest Ophthalmol Vis Sci. 2010;51:1498–1504) DOI:10.1167/iovs.09-4327

Intraocular pressure (IOP) is caused by the flow of aqueous humor against resistance in the outflow system. In primary open-angle glaucoma (POAG), this resistance is often unusually high, resulting in elevated IOP, one of the major risk factors in the development and progression of glaucoma.1,2 It is understood that increased resistance in POAG is located mainly in the juxtaocular region.3–5 So far, no mechanism has been conclusively identified as being responsible for the increase in outflow resistance in POAG, although changes in the extracellular matrix in the trabecular meshwork (TM) have been suggested to be crucial.6–8 Even less is known about the structural alterations of the outflow system distal to TM in POAG and their relevance to outflow. It is assumed that Schlemm’s canal (SC) and the collector channel (CC)–aqueous vein system, if they are unconstricted, do not play a major role in the outflow resistance in POAG (Poiseuille’s law).9–11 In addition, experimental studies showed that in eyes with normal IOP, only 50% of outflow resistance (75% in eyes with IOP of 25 mm Hg) was eliminated after circumferential trabeculotomy, indicating that up to half of the outflow resistance is downstream of the TM.12–14

Although gonioscopy is widely used to visualize the structures of the chamber angle, poor contrast renders the SC hardly visible by this method. Blood reflux from the episcleral venous system into SC; however, is a well-known method of visualizing the SC.15–17 Commonly, blood regurgitation is induced by compression of the episcleral veins by means of the gonioscopic lens,16–23 with the disadvantage of forcibly expanding the lumen of SC under pressure. Another way to visualize the aqueous outflow system is by using a dye. Wessely24 and other investigators25–27 depicted the aqueous pathway by injecting fluorescein directly into the anterior chamber (AC). Most studies were performed in normal eyes and a few in glaucomatous eyes undergoing trabeculotomy28–29 or trabeculectomy.30 Clinical assessment of the natural outflow system has been of little importance since the introduction of trabeculotomy,31 in which aqueous is directed into the subconjunctival space, thus bypassing the physiological outflow pathway.32 However, there is increasing interest in studying the natural outflow system,33 with the advent of nonpenetrating glaucoma surgery,34–36 as various pathways of aqueous outflow have been postulated.37–39 Deep sclerectomy relies to some extent on the presence of a filtering bleb,38–39 whereas viscocanalostomy and its further development, canaloplasty, were conceived to be truly blebless procedures.40,41 Canaloplasty targets the pathophysiological site of aqueous outflow resistance by distending the SC and adjacent TM with a 360° tensioning suture; trans trabecular aqueous egress is reportedly increased and IOP reduced.41 In addition, inadvertent microruptures created by viscodilation may facilitate outflow, as has been demonstrated for viscocanalostomy (Smit BA, et al. IOVS 2000;41:ARVO Ab stract 3072).42,43 Nevertheless, the physiological outflow system distal to TM must be intact for canaloplasty to work. Recently, we have described a method (channelography) of visualizing the natural outflow system by using a flexible microcatheter and fluorescein.44

The purpose of the present study was to assess the outflow system by means of provocative gonioscopy (blood reflux) and...
channelography in patients with POAG who were undergoing canaloplasty.

METHODS

Setting
This study was performed at the Department of Ophthalmology, Medical University of Southern Africa, Medunsa, South Africa. Informed consent was obtained from each patient. The study was approved by the institutional ethics committees. The research adhered to the tenets of the Declaration of Helsinki.

Study Population
Thirty patients with POAG scheduled for canaloplasty were prospectively enrolled in the study. Because a lack of studies on channelography precluded a proper sample size calculation during the planning of the study, the number of recruited subjects was determined arbitrarily. Excluded were patients with narrow or closed iridocorneal angle; evidence of any secondary glaucoma, pigmentedary dispersion, or pseudoxefoliation; a history of trauma to the eye or of chronic or recurrent inflammatory eye disease (e.g., scleritis or uveitis); or any type of preceding refractive surgery or corneal disease. One eye was randomly selected in each subject for further investigation. Diurnal IOP curves were obtained from all patients the day before surgery and the mean IOP was used for statistical analysis. For both examinations (provocative gonioscopy and channelography) the patients were supine on the operating table after a 10-minute resting period. Both examinations were videotaped in each patient. The data were analyzed based on video sequences, and the observer was blinded to the patients’ data.

Provocative Gonioscopy
The IOP was lowered below episcleral venous pressure (EVP) by aspiration of aqueous from the AC to provoke blood reflux from the anterior ciliary veins via the CCs into the SC. After temporal paracentesis (at 3 o’clock in right eyes and 9 o’clock in left eyes) with a fine diamond knife (Mastel Precision, Rapid City, SD), a viscocannula with an inner lumen diameter of 165 μm (Alcon-Grieshaber, Schaffhausen, Switzerland) was inserted into the AC. The IOP was measured with Perkins applanation tonometry to ensure that IOP was below EVP (i.e., below 10 mm Hg) in all eyes. After a 1-minute waiting period, a goniolens (CGA-1; Haag-Streit, Bern, Switzerland) was placed on the globe, and blood reflux was observed and classified (pursuant to previous studies22,45) into three filling patterns: no filling (no blood present; group 1; Fig. 1A); incomplete filling (patchy or irregular pattern; group 2; Fig. 1B); and complete filling (continuous red band, uniform and regular pattern; group 3; Fig. 1C).

Microcatheter
The microcatheter (iTrack 250A; iScience Interventional, Menlo Park, CA) had a 200-μm diameter shaft with a blunt distal tip approximately 250 μm in diameter. The catheter incorporated an optical fiber that provided an illuminated beacon tip to assist in guidance. The illuminated tip was observed through the sclera during the catheterization of SC to identify the location of the distal tip of the catheter. The device had a lumen with a proximal Luer lock connector through which the fluorescein sodium could be delivered. A screw-driven syringe was connected to the proximal end of the microcatheter and delivered a precise volume of fluorescein sodium. One eighth of a turn on the injector knob equaled 150 μL of fluid injected.44

Fluorescein Tracer
The preparation of the fluorescein tracer was performed under sterile conditions. Three drops of fluorescein sodium (10%; Alcon Laborato-ries, Bryanston, South Africa) was mixed with 15 mL balanced salt solution (BSS; Alcon Laboratories) as previously described.44 The mixed fluorescein solution was transferred to the cartridge of the viscoinjector, which was attached to the microcatheter.

Microcatheter-Assisted Channelography
Schlemm’s canal was unroofed, its ostia were dissected by a standard nonpenetrating technique, and viscoelastics were injected to dilate the ostia.36 Thereafter, the microcatheter was introduced into the ostia and advanced stepwise. During the catheterization of the SC, the location of the blinking beacon tip was observed through the sclera and 150 μL diluted fluorescein sodium was injected through the microcatheter.

Figure 1. (A) Chamber angle with iris processes. Lack of refluxed blood is a sign of a completely collapsed canal and probably atrophied collector channels. (B) Patchy or irregular filling pattern of SC with blood may indicate a partially collapsed canal. Blood is only detectable at and around the ostia of intact collector channels. (C) Gonioscopic view of SC uniformly filled with blood represents healthy patent canal and collector channels.
once at the superior–temporal quadrant and once at nasal–inferior quadrant to take the anatomic variations of the outflow between these quadrants within individual eyes into account. One eighth of a turn on the injector knob equaled 150 μL fluid injected. Based on previous experience, episcleral venous egress was arbitrarily graded as the number of vessels filled with dye per quadrant and were classified into three groups: absence of filling (group A), moderate filling (less than 5 episcleral vessels filled; group B), and good filling (more than five episcleral vessels filled; group C; Fig. 2). The diffusion of fluorescein dye into the AC was graded semiquantitatively 10 seconds after the injection of 150 μL of diluted fluorescein by comparing its distance of spread to the diameter of the cornea. Poor fluorescein diffusion was shorter than one eighth of the corneal diameter (group 1; Fig. 3A); moderate diffusion (group 2; Fig. 3B) was longer than one eighth but shorter than one fourth of the corneal diameter; and extensive diffusion (group 3; Fig. 3C) was longer than one fourth of the corneal diameter. The transtrabecular passage of fluorescein into the AC and the filling properties of the episcleral veins were evaluated 10 seconds after injection. The duration of 10 seconds was adequate in our experience to distinguish between the filling and diffusion patterns.

Statistical Analysis

Frequency tables were used to describe categorical variables and descriptive statistics, to determine continuous variables (demographic data). The Fisher exact test was used to evaluate the associations between preoperative IOP, cup-disc ratio, and categorical variables (e.g., degree of retrograde filling of the SC with blood, filling of the episcleral veins, and degree of tracer diffusion into the AC). The Spearman rank correlation analysis (coefficient ρ) was used to evaluate the relationship between ordinal variables. Subsequently, a multinomial regression analysis was used to determine whether IOP and age are predictive of the quality of blood reflux. The reference category was set for complete (uniform) filling of the SC (group 3). Odds ratio (OR) for IOP and age was expressed as the ratio of the odds increasing by 1 mm Hg and year, respectively. Corresponding 95% confidence intervals (CIs) were also estimated comparing group 1 and group 2 to reference group 3. Furthermore, in a post hoc analysis, blood reflux and episcleral venous egress were evaluated as to whether they are predictive of IOP after surgery. In the statistical analyses, P < 0.05 was considered statistically significant (SPSS software ver. 13.0; SPSS Inc., Chicago, IL).

RESULTS

Twenty-eight subjects (15 women and 13 men) were included in the analysis. The mean age, IOP, and cup-to-disc ratio were 45.9 years (SD ± 13.3), 41.0 mm Hg (SD ± 11.9), and 0.78 (SD ± 0.22), respectively. In provocative gonioscopy, 10 eyes had no blood reflux, 10 had patchy blood reflux, and 8 had complete blood reflux. For the different reflux patterns, the mean IOP was 57.7 mm Hg (SD ± 6.1) in group 1, 40.4 mm Hg (SD ± 4.6) in group 2, and 30.1 mm Hg (SD ± 4.2) in group 3. Eight eyes had no episcleral venous egress of fluorescein, 6 had moderate filling, and 14 had good episcleral filling with fluorescein dye after intracanalicular injection. The transtrabecular diffusion was poor in 10 eyes, moderate in 11, and extensive in 7. Mean IOP (P < 0.001) and episcleral venous egress (P = 0.01) strongly correlated with blood reflux, whereas cup-to-
Table 1. Correlations between Patient’s Data and Outflow Parameters

<table>
<thead>
<tr>
<th></th>
<th>Age</th>
<th>Mean IOP</th>
<th>C/D Ratio</th>
<th>Blood Reflux</th>
<th>Episcleral Venous Egress</th>
<th>Diffusion into AC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>1</td>
<td>0.04</td>
<td>−0.018</td>
<td>0.076</td>
<td>0.056</td>
<td>−0.018</td>
</tr>
<tr>
<td>Significance (two-tailed)</td>
<td>—</td>
<td>0.844</td>
<td>0.929</td>
<td>0.701</td>
<td>0.777</td>
<td>0.934</td>
</tr>
<tr>
<td>Mean IOP</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.04</td>
<td>1</td>
<td>0.059</td>
<td>−0.774</td>
<td>−0.151</td>
<td>0.242</td>
</tr>
<tr>
<td>Significance (two-tailed)</td>
<td>0.844</td>
<td>—</td>
<td>0.776</td>
<td>0.000</td>
<td>0.453</td>
<td>0.277</td>
</tr>
<tr>
<td>Cup-to-disc ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>−0.018</td>
<td>0.059</td>
<td>1</td>
<td>−0.073</td>
<td>−0.015</td>
<td>0.278</td>
</tr>
<tr>
<td>Significance (two-tailed)</td>
<td>0.929</td>
<td>0.776</td>
<td>—</td>
<td>0.717</td>
<td>0.94</td>
<td>0.199</td>
</tr>
<tr>
<td>Blood reflux</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.076</td>
<td>−0.774</td>
<td>−0.073</td>
<td>1</td>
<td>0.444</td>
<td>−0.026</td>
</tr>
<tr>
<td>Significance (two-tailed)</td>
<td>0.701</td>
<td>0.000</td>
<td>0.717</td>
<td>—</td>
<td>0.018</td>
<td>0.906</td>
</tr>
<tr>
<td>Episcleral venous egress</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.056</td>
<td>−0.151</td>
<td>−0.015</td>
<td>0.444</td>
<td>1</td>
<td>−0.014</td>
</tr>
<tr>
<td>Significance (two-tailed)</td>
<td>0.777</td>
<td>0.453</td>
<td>0.94</td>
<td>0.018</td>
<td>—</td>
<td>0.95</td>
</tr>
<tr>
<td>Diffusion into the AC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>−0.018</td>
<td>0.242</td>
<td>0.278</td>
<td>−0.026</td>
<td>−0.014</td>
<td>1</td>
</tr>
<tr>
<td>Significance (two-tailed)</td>
<td>0.934</td>
<td>0.277</td>
<td>0.199</td>
<td>0.906</td>
<td>—</td>
<td></td>
</tr>
</tbody>
</table>

Correlations determined by Spearman’s $r$. Bold values are statistically significant.

disc ratio ($P = 0.71$), age ($P = 0.70$), and fluorescein diffusion ($P = 0.90$) did not (Table 1). In a multinomial regression model, higher IOP ($P < 0.001$, OR, 1.687; 95% CI, 1.151–2.472) correlated with poor blood reflux independent of age ($P = 0.583$, OR, 0.942; 95% CI, 0.823–1.078). No significant correlations were found between the following parameters: fluorescein diffusion, episcleral venous egress, age, IOP, and cup-to-disc ratio (Table 1). The mean IOP at 6 months after surgery was 17.5 mm Hg (SD ± 3.7). In a subgroup analysis for blood reflux, the mean IOP in eyes with good reflux was 14.7 mm Hg; in those with patchy reflux, 16.7 mm Hg; and in those with no reflux, 20.5 mm Hg. Likewise, the IOP after surgery in eyes with moderate reflux was 17.5 mm Hg, with poor reflux, 22.6 mm Hg. Furthermore, blood reflux and episcleral venous egress were both found to be predictive of the postoperative level of IOP ($P < 0.001$; Table 2).

Discussion

The results of this study suggest that blood reflux into SC may be perturbed in patients with POAG. Blood reflux correlated inversely with IOP before surgery, independent of the patient’s age. The distribution of refluxed blood was homogenous in eyes with slightly elevated IOP, patchy in eyes with high IOP, and absent in eyes with very high IOP. There was a significant correlation between blood reflux and episcleral venous egress; however, there was no correlation between blood reflux and age, transtrabecular diffusion, or morphologic glaucomatous damage.

The relationship found in this study between poor blood reflux and high IOP in POAG could be interpreted as indicative of the morphologic status of the SC, especially the status of the lumen. The mean IOP was ~50 mm Hg in eyes with regular filling, 40 mm Hg in eyes with patchy filling, and >50 mm Hg in eyes without filling, which could suggest a pathophysiological relationship between IOP and the status of SC. Our results are in line with those in previous clinical studies indicating an inverse relationship between IOP and blood reflux.17,21,23 Experimental studies further showed that the canal becomes much narrower as the TM expands into the lumen of the canal with increasing IOP,46,47,51,52 risking collapse at high IOP levels.48 It has been suggested that at an IOP of 40 mm Hg, the canal may be largely collapsed,49 except at the site of the CC ostia, where bridging septae may assist in the prevention of such a collapse.46,50 In our study, reflux limited to the ostia in the case of a collapsed canal was observed on gonioscopy as the appearance of single red spots in the area of the SC.

From a pathophysiologic perspective, it makes perfect sense that attenuation or even collapse of the SC would not only result from elevated IOP, but may itself contribute to a further marked reduction of aqueous outflow and hence to a further marked increase in IOP.49 A decrease in the porosity of the TM and inner wall, as in OHT and POAG,3,51,52 leads to increased outflow pressure to expel the aqueous flow. This increased IOP compresses the inner wall against the outer wall of the canal; over a prolonged period, this may even result in adherence between these structures,22,53 demonstrated gonioscopically as patchy blood-filling defects. However, weakness in reinforcing structures, such as the scleral spur, with a tendency toward the collapse of the inner wall, cannot be excluded as a primary cause,46 but rather could explain the high IOP levels and the early onset and rapid progression of glaucoma in the black African population.40,54–56 With regard to the pathomechanism of increased IOP, the present results are not conclusive in distinguishing between cause and effect in collapsed canals, which may play an important but hitherto underestimated role in the pathogenesis of POAG in this population. Furthermore, our findings confirm those of Smith55 and Suson and Schultz22 that greater age does not by itself account for a
higher incidence of SC filling defects in POAG, indicating that canal narrowing or collapse may not be a primarily age-related physiologic process.

The easiest means of visualizing the SC is to reflux blood into the canal, but this must alter the aqueous dynamics. Principally, the reversal pressure gradient can be produced either by lowering IOP or by raising EVP. The latter is achieved by manipulation of the gonioscopic lens so that the lens rests eccentrically on the episclera or by use of a suction cup. These methods have been applied in most studies on blood reflux. However, compression of the episcleral veins during gonioscopy increases EVP unduly, and it may reopen CCs and the SC in case of collapse. This certainly camouflages the genuine status of the CC and SC, and the reliability of this approach may be limited. Also, the patency of the SC based on the blood reflux produced by softening the eye with a Baiillard ophthalmodynamometer needs to be interpreted in this regard with caution. In the present study, blood reflux was produced by ocular hypotony with inherent reversal of the pressure gradient between EVP and IOP (e.g., without increasing EVP); aqueous humor was removed from the AC with a microsyringe that was connected to a visocannula with a small inner-lumen diameter of 165 μm. This setting allowed us to invert the pressure gradient in a controlled way, applying virtually no external force to the globe and avoiding deformation; thus, we believe it may provide a more accurate visualization of true patency in the distal outflow system. Furthermore, in this clinical setting it was necessary to avoid forcibly expanding the lumen or even separating the adherent wall before channelography.

Fluorescein’s egress through the episcleral veins differed among the patients studied. In half of the patients, episcleral egress after injection of the dye into the SC was immediate, which may represent patency of the distal outflow pathway in these patients. No detectable filling suggests the collapse of SC with occlusion of the CC ostia, as observed during exposure of the canal. This is also supported by the significant positive correlation between blood reflux and episcleral filling. So far, clinical evidence is scarce, but experimental studies have shown that, with narrowing of the SC, progressive herniations of the inner wall into the CC ostia occur after IOP elevation, accompanied by occlusion of these ostia.

The facility of transtrabecular diffusion determined by fluorescein dye varied strongly. The majority of the patients had either no diffusion or delayed diffusion. This low diffusion may be related to low permeability in the diseased TM, the postulated site of major resistance to outflow in POAG. The level of IOP by itself was not conclusive in regard to fluorescein diffusion and episcleral egress. As elevated IOP is only a surrogate for increased resistance of the outflow system in POAG, it does not indicate the location of the outflow impairment. In the individual case, however, poor trabecular passage and good episcleral fluorescein egress would indicate patent distal outflow pathways, poor trabecular passage and poor episcleral fluorescein egress would indicate obstructed TM and closed CC, and good trabecular passage together with poor episcleral fluorescein egress would suggest that the site of outflow impairment is mainly in the distal outflow system.

Imaging of the aqueous outflow with fluorescein was first described by Wessely in 1922. Since then, many investigators have visualized aqueous outflow pathways by injecting fluorescein directly into the AC. The outflow of fluorescein injected into the AC travels entirely along the natural route of aqueous outflow; however, such an injection requires a large volume of highly concentrated fluorescein, since the dye dilutes immediately with aqueous in the AC. Furthermore, the trabecular passage into SC delays the filling of the episcleral venous network. The significance of such visualizations may therefore be limited. Grote first recognized the advantage of intracanalicular injection of fluorescein dye in visualizing the outflow system downstream of the TM. During trabeculotomy, he used the surgical site for injecting fluorescein for the entire canal, again with the disadvantage of needing large volumes and high concentrations of fluorescein. Intracanalicular application of fluorescein by our method incorporates several advantages. SC was visualized, not only at the site of surgical exposure, but through 360°, by means of a flexible microcatheter with a beacon-illuminated tip. The beacon tip of the flexible microcannula enabled controlled and stepwise injection of fluorescein. Furthermore, direct injection of the dye into SC immediately visualized the collector channels and the subsequent episcleral veins, in contrast to the slower process of intracameral injection.

This study has several limitations. Blood reflux after paracentesis reveals the definite dependence of the reflux pattern on acute IOP reduction. Also, although blood reflux in the SC reflects the filling of the SC and is an indirect sign of the status of the lumen, the present results showed only the varying quality of blood reflux, since the canal volume was not measured. Nor could the diffusion volume be measured for channelography, although the injector knob of the microcatheter delivered a fixed volume per one eighth of a turn. Furthermore, fluorescein passed the TM in the direction opposite that of the physiologic pathway, thus possibly not reflecting true permeability. In addition, the number of episcleral vessels filled with fluorescein dye varied and may not represent the actual number of vessels carrying aqueous humor, since the beacon tip of the catheter may not have been adjacent to the CC ostia studied at the time of injection. Hypothetically, a falsely low filling rate may have also contributed to the poor correlation to IOP, transtrabecular diffusion, and glaucomatous cupping. To compensate for this shortcoming, a higher volume of fluorescein could have been injected into the SC to increase the chance of reaching more CC ostia. However, greater volume may also overexpand the canal, creating the chance that fluid dynamics would overcome the resistance of pathologic TM and lead to overestimation of the permeability of the TM. Another limitation of this study is that intrascleral (deep) networks and uveoscleral pathways could not be visualized. It is also important to emphasize that all the patients in this study were of black African origin. Thus, these findings may not be applicable to POAG patients of other ethnic groups.

Canaloplasty is performed with the intent of increasing the natural flow of aqueous humor from the AC, through the TM into SC, and out through the CCs. From a practical point of view, the combination of provocative gonioscopy and channelography may be helpful in determining the overall status of the individual case before surgical intervention. In our opinion, prompt reflux of blood into the canal and good episcleral filling automatically suggests that the canal is patent, that the CCs are healthy, and that the primary problem of outflow resistance is in the TM alone, especially if it is possible to demonstrate circumferential flow of mixed blood and aqueous in the canal. This notion is undermined by the fact that the mean IOP was lowest in these patients after surgery. Patchy filling of SC on gonioscopy and poor fluorescein diffusion suggest partial collapse of the SC, along with the potential of re-establishing canalicular patency and, therefore, CC function. It is reasonable to conclude that this surgical intervention also offers a favorable prognosis for partial collapse of the canal alone, as the inner wall is dilated circumferentially and a tensioning suture is placed to keep the lumen open. In contrast, absence of both blood reflux into the canal and episcleral filling suggests collapse of the canal and closure of the ostia of the CC. Canaloplasty was least successful in these cases, as the IOP after surgery was highest. Of interest, there was still some IOP...
reduction, which may be explained by a pilocarpin-like effect of the tensioning suture (suprachoroidal mechanism), as has been recently postulated for canaloplasty. A prospective study is planned to validate the significance of this approach in routine canaloplasty in regard to prediction of the surgical outcome.

In conclusion, blood reflux was reduced in a subgroup of patients with POAG and correlated inversely with IOP before surgery. A collapsed canal, whether primary or secondary, may be an underestimated sign in black African patients with POAG. Furthermore, blood reflux and episcleral venous egress are significant predictors of the success of canaloplasty. Blood reflux, transtрабecular diffusion, and episcleral venous egress of fluorescein may provide valuable information about the functional condition of the conventional outflow pathway in the patient before surgery. For these reasons provocative gonioscopy and channelography may become diagnostic tools in routine canaloplasty, as the outcome depends on the integrity of the distal outflow system.

References


43. Grieshaber MC, Pienaar A, Olivier J, Stegmann R. Channelography: imaging of the aqueous outflow pathway with flexible microcath-


