Glaucoma Filtration Surgery and Retinal Oxygen Saturation

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PURPOSE. Glaucoma may involve disturbances in retinal oxygenation and blood flow. The purpose of this study was to measure the effect of glaucoma filtration surgery on retinal vessel oxygen saturation.

METHODS. A noninvasive spectrophotometric retinal oximeter was used to measure hemoglobin oxygen saturation in retinal arterioles and venules before and after glaucoma filtration surgery. Twenty-five consecutive patients were recruited, and 19 had adequate image quality. Fourteen underwent trabeculectomy and five glaucoma tube surgery. Twelve had primary open-angle glaucoma and seven had exfoliative glaucoma. IOP decreased from 23 ± 7 to 10 ± 4 mm Hg (mean ± SD, P = 0.0001).

RESULTS. Oxygen saturation increased in retinal arterioles from 97% ± 4% to 99% ± 6% (n = 19; P = 0.046) after surgery and was unchanged in venules (63% ± 5% before surgery and 64% ± 6% after, P = 0.76). There were no significant changes in saturation in the fellow eyes (P > 0.60). The arteriovenous difference was 34% before and 36% after surgery (P = 0.35).

CONCLUSIONS. Glaucoma filtration surgery had almost no effect on retinal vessel oxygen saturation. (Invest Ophthalmol Vis Sci. 2009;50:5247–5250) DOI: 10.1167/iovs.08-3117

The exact pathogenesis of glaucoma is not known. The role of hypoxia is supported by increased staining of hypoxia-induced factor (HIF-1α) in the retina and optic nerve of patients with glaucoma compared with that present in healthy individuals.1 Animal studies have demonstrated that optic nerve oxygen tension decreases if intraocular pressure (IOP) rises to high levels and increases if IOP is lowered again.2,3 Decreased or poorly controlled ocular blood flow has been shown in patients with glaucoma in many studies (for review, see Refs. 4, 5).

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METHODS

The automatic retinal oximeter has been described previously.15 It is based on a fundus camera (Canon CR-6-45NM, Canon Inc., Tokyo, Japan), which is coupled with a beam splitter (MultiSpec Patho-Imager; Optical Insights, Tucson, AZ) and a digital camera (SBIG ST-7E; Santa Barbara Instrument Group, Santa Barbara, CA). It yields fundus images with four wavelengths of light simultaneously. Specialized software automatically selects measurement points on the oximetry images and calculates the optical density (absorbance) of retinal vessels at two wavelengths: 605 and 586 nm. Optical density is sensitive to oxygen saturation at 605 nm but not at the reference wavelength, 586 nm. The ratio of these optical densities is approximately linearly related to hemoglobin oxygen saturation,14,15 and the oximeter yields relative oxygen saturation levels. Although the saturation data are not absolute, the oximeter has been shown to give reproducible results and to be sensitive to changes in oxygen saturation.15 The comparison of data in the same eye before and after surgery is therefore valid.

Pupils were dilated with 1% tropicamide (Mydriacyl; Alcon-Convreur NV, Puurs, Belgium), which was in some cases supplemented with 10% phenylephrine hydrochloride (AK-Dilate; Akorn Inc., Lake Forest, IL). Oximetry was performed in first- and second-degree retinal arterioles and venules. Oximetry was performed before glaucoma surgery and again approximately 1 month after surgery (Fig. 1). Infrared light was used to align the fundus camera (oximeter), and the images were taken in a dark room. The time between images (flashes) of the same eye was on average 1 to 2 minutes. An average was taken of measurable arterioles and venules in each eye and the same vessels’ segments were averaged before and after surgery.
All consecutive patients with open-angle glaucoma, with and without pseudoexfoliation syndrome, undergoing glaucoma surgery in Iceland in a 6-month period were invited to participate in the study. All patients were using topical glaucoma drugs before their surgery, and one was also taking oral acetazolamide (Table 1). None of the patients used glaucoma drugs at the time of postoperative oximetry. Twenty-five patients were measured before and after surgery. Six patients were excluded from analysis because of poor optical quality of the eye.

Fourteen patients underwent trabeculectomy with mitomycin C and five patients underwent glaucoma drainage device surgery with the Ahmed tube. All surgeries were performed by the same surgeon.

Statistical analysis was performed with R ver. 2.6.1 (provided in the public domain by the R Foundation for Statistical Computing, Vienna, Austria, available at http://www.r-project.org/). Paired \( t \)-tests were used for comparing the means. Post hoc power analyses were performed separately for arterioles, venules, and arteriovenous differences. An effect size of five percentage points and standard deviations of differences between measurements before and after surgery (surgical eye) were used to calculate the power. The study was approved by the National Bioethics Committee of Iceland and The Icelandic Data Protection Authority and adhered to the tenets of the Declaration of Helsinki.

### RESULTS
A statistically significant increase from 97\% ± 4\% to 99\% ± 6\% \((n = 19; P = 0.046, \text{ paired } t\text{-test, Table 2; Fig. 2})\) was found in arteriolar oxygen saturation after glaucoma filtration surgery. No change \((P = 0.76)\) was seen in oxygen saturation in the venules, and the oxygen saturation in the fellow eyes remained stable \((P > 0.60)\). The arteriovenous difference in oxygen saturation was 34\% before surgery and 36\% after surgery \((P = 0.35)\). Assuming an effect size of 5 percentage points, post hoc power analysis yields a power of 99\% for arterioles, 87\% for venules, and 70\% for arteriovenous difference.

### DISCUSSION
Our results show almost no change in oxygen saturation with glaucoma filtration surgery. We found a statistically significant 2\% increase in arteriolar oxygen saturation and no change in venules after dramatic lowering of IOP with surgery. Changes in arteriovenous difference did not reach statistical significance. Although the sample size is small, a post hoc power analysis demonstrates that it is unlikely that a difference of 5 percentage points or larger was missed in retinal venules (or in arteriovenous difference). It can therefore be concluded that the surgery had almost no effect on oxygen saturation.
where OAP is the ophthalmic artery pressure and \( R \) is the resistance to flow. Therefore, if IOP is decreased after surgery and if other factors are constant, the flow should increase. Whether the other factors are constant, however, is not certain. Autoregulation of blood flow may, for example, increase the resistance, \( R \), and limit the change in flow, \( F \). Some studies have found an increase in blood flow after glaucoma filtration surgery, whereas others have found no change (see the introduction). Whether the retinal blood flow changed in the present study is uncertain. It should be noted, however, that the small increase found in arteriolar saturation is consistent with an increase in retinal blood flow (i.e., less oxygen is lost per unit volume of blood through the arteriolar walls when the flow increases).

Oxygen delivery by the retinal vasculature mostly reflects oxygen consumption by the inner retina, whereas the choroid mostly supplies the outer retina, although these boundaries shift a little depending on light conditions.\(^{21-25}\) Choroidal blood flow increases with dramatic increases in perfusion pressure,\(^{24-29}\) and some studies have indicated an increase after glaucoma surgery.\(^{11,12}\) However, oxygen was not measured in the choroid in this study and it is uncertain whether the decrease in IOP in this study has an effect on oxygenation. If there is any effect of the surgery on oxygen delivery from the choroid, an increase is more likely than a decrease.

One limitation of the present study is that the patients received glaucoma drug treatment before but not after surgery and this may influence the oxygen saturation. However, despite the withdrawal of drugs, the IOP was dramatically decreased between the pre- and postoperative measurements. Unfortunately, blood pressure data are not available to confirm that perfusion pressure was increased. Most of the patients (14/19; Table 1) were using ocular \( \beta \)-blockers before surgery and not after surgery, and the cessation of the medication may have increased blood pressure after surgery. The oxygen saturations are relative, although comparison between the same eye before and after surgery is valid (see the Methods section). Finally, although the retinal oximeter has been systematically defined and tested,\(^{13}\) clinical oximetry studies are limited so far.

We conclude that glaucoma filtration surgery, which lowers IOP, results in almost no change in retinal vessel oxygen saturation. Coupled with an increase in retinal blood flow, the sustained oxygenation saturation would result in increased oxygen delivery to the retina after surgery. Changes in retinal blood flow are uncertain, however, and further studies are needed. It should also be stressed that the present study only includes retinal measurements, with no evaluation of potential changes in optic nerve oxygenation.

**References**


