Measurement of Ophthalmodynamometric Pressure with the Vented-Gas Forced-Infusion System during Pars Plana Vitrectomy

Fumiki Okamoto, Yoshimi Sugiura, Yoshifumi Okamoto, Yumi Hasegawa, Takahiro Hiraoka, and Tetsuro Oshika

PURPOSE. To measure ophthalmodynamometric pressure (ODP) with the vented-gas forced-infusion (VGFI) system during vitrectomy in patients with various vitreoretinal disorders and to investigate factors related to ODP.

METHODS. This study included 169 eyes of 169 patients undergoing pars plana vitrectomy. After core vitrectomy, the intracranial pressure was gradually raised by using the VGFI system. When the central retinal artery or its branches on the optic nerve head showed pulsations, the pressure was recorded as ODP. Diastolic blood pressure (DBP) and systolic blood pressure (SBP) were measured simultaneously with ODP. Multiple regression analysis was performed to investigate the relationship between ODP and various explanatory variables: DBP, SBP, age, presence of diabetic mellitus (DM) and hypertension (HT), body mass index, and serum total cholesterol. Results in studies have demonstrated that ODP is low in patients with ischemic ophthalmopathy and giant-cell arteritis-induced anterior ischemic optic neuropathy.5,10 Several methods of ophthalmodynamometry have been used to raise and measure IOP, such as external calibrated compression and direct cannulation.11–18 The external calibrated compression method, however, may not measure precise ODP, because IOP is added to the external pressure applied to the eye. Moreover, repeated pressure application to the eye can change IOP. In contrast, the direct cannulation method measures ODP more precisely by directly monitoring IOP, but this method cannot be easily used in living human eyes.5

We developed a new method of measuring ODP during vitrectomy: vented-gas forced-infusion (VGFI; Accurus vitrectomy system; Alcon Ltd., Fort Worth, TX). This technique directly applies pressure into the vitreous cavity. As our new method is comparable with the direct cannulation technique in principle, it seems that precise and reproducible measurements of ODP are possible. The purpose of this study was to measure ODP using the VGFI system during vitrectomy in patients with various vitreoretinal disorders and to investigate factors related to ODP.

RESULTS. ODP was 66.9 ± 12.5 mm Hg (range, 15.5–103.7), and it correlated significantly with DBP (r = 0.60, P < 0.0001) but not with SBP (r = 0.12, P = 0.12). ODP in DM patients who had proliferative diabetic retinopathy and diabetic macular edema was lower than that in non-DM patients, whereas DBP was not significantly different between the two groups. Similar results were obtained in HT patients. Multiple regression analysis revealed that ODP had a significant correlation with DBP (P < 0.0001), presence of DM (P = 0.02), and presence of HT (P = 0.03).

CONCLUSIONS. VGFI is a new method of determining ODP. ODP was significantly associated with DBP and was lower in patients with DM and HT. (Invest Ophthalmol Vis Sci. 2010;51:4195–4199) DOI:10.1167/iovs.10-5165

Ophthalmodynamometry is a method used to determine the pressure in the central retinal artery. It is measured by increasing the intracranial pressure (IOP) by exerting a standardized pressure on the globe while observing the optic nerve head. Ophthalmodynamometric pressure (ODP) is the minimum IOP at which the central retinal artery intermittently collapses, that is, pulsates. Measurement of ODP is important in the assessment of ocular, orbital, and neurologic diseases.1–8 Findings in studies have demonstrated that ODP is low in patients with ischemic ophthalmopathy and giant-cell arteritis-induced anterior ischemic optic neuropathy.5,10

SUBJECTS AND METHODS

IOP and VGFI Setting in Porcine Eyes

To assess the relation between the VGFI setting and actual IOP, we conducted an experiment in porcine eyes. The eyes were obtained within 1 day after slaughter. After conjunctival excision, three scleromies were placed, and a standard three-port pars plana vitrectomy was performed. After core vitrectomy, the vitreous gel around the tip of the irrigation cannula was removed with a vitrectomy cutter. A 20-gauge cannula was inserted into the vitreous cavity through another sclerotomy site, which was connected to a pressure transducer (MLT0670; ADInstruments, Colorado Springs, CO). The pressure transducer was connected via conditioning modules to a chart recorder (PowerLab; ADInstruments), and IOP was continuously recorded. The transducer was held and calibrated at the level of the porcine eye.

The VGFI system controls the perfusion pressure by delivering the pressurized air (0–120 mm Hg) into the bottle of balanced saline solution, instead of changing the height of an irrigation bottle. First, we preset the VGFI pressure at 10 mm Hg and recorded IOP for 5 seconds. Next, the VGFI pressure was raised to 20, 30, 40, 50, 60, 70, 80, 90 and 100 mm Hg, and IOP was recorded. The experiment was repeated 10 times, and the coefficient of variation (CV) of the mean values was calculated.

Patients

We included 169 eyes of 169 patients with vitreoretinal disorders who were undergoing standard 20-gauge pars plana vitrectomy or 25-gauge transconjunctival sutureless vitrectomy from May 15, 2007, through December 14, 2008. There were 104 men and 65 women, and their...
ages averaged 60.7 ± 11.0 years (mean ± SD). The study was conducted in accordance with the tenets of the Declaration of Helsinki, and the protocol was approved by the institutional review committees. Before enrollment, the nature of the study was explained to all the patients, and their written informed consent was obtained. Exclusion criteria included preoperative IOP above 22 mm Hg or previously diagnosed glaucoma, age under 18 years, and a history of vitreous surgery. Indications for vitrectomy were proliferative diabetic retinopathy (PDR) in 78 patients, diabetic macular edema (DME) in 29, rhegmatogenous retinal detachment (RD) in 25, macular hole (MH) 17, epiretinal membrane (ERM) 12, branch retinal vein occlusion (BRVO) in 4, central retinal vein occlusion (CRVO) in 3, and retinal arteriolar macroaneurysm in 1. The following information was collected for each patient: age, sex, presence of diabetic mellitus (DM), presence of hypertension (HT), body mass index, and serum total cholesterol. Data on the patients' characteristics are presented in Table 1. All surgeries were performed by two vitreoretinal surgeons (FO or YO) with the subjects under sub-Tenon local anesthesia (0.5% bupivacaine hydrochloride 3.0–4.0 mL). When required, the crystalline lens was removed by phacoemulsification and intraocular lens implantation before vitrectomy.

Measurement of ODP

We measured ODP during vitrectomy by using the VGFI system. The liquid level of balanced saline solution was held and calibrated at the level of the patients’ eyes. After core vitrectomy, we confirmed that the balanced saline solution was not leaking from the sclerotomies. IOP was gradually raised by VGFI, and the optic nerve head was continuously monitored through a planoconvex contact lens on the cornea. When the central retinal artery or its branches on the optic nerve head showed pulsations, the pressure was recorded as ODP. The measurements were repeated three times, and the mean was calculated.

Systemic blood pressure was measured simultaneously with ODP. Systolic blood pressure (SBP) and DBP were recorded with an oscillometric measurement.

Statistical Analysis

The mean and standard deviation was calculated for each variable. The relationship between actual IOP and VGFI setting pressure was examined with Pearson’s correlation coefficient. The relationship between ODP and systemic blood pressure was also examined with Pearson’s correlation coefficient. Fisher’s protected least significant difference (Fisher’s PLSD) was used to compare ODP among different vitreoretinal disorders. The Mann-Whitney U test was performed to compare numerical values between groups. Multiple regression analysis was performed to investigate the relationship between various explanatory variables and ODP. Variables tested were DBP, SBP, age, body mass index, presence of HT, presence of DM, and serum total cholesterol. All tests of association were considered statistically significant if \( P < 0.05 \) (StatView, ver. 5.0; SAS Inc., Cary, NC).

RESULTS

IOP and VGFI Setting in Porcine Eyes

Table 2 summarizes the relation between the VGFI setting (10–100 mm Hg) and the actual IOP measured in porcine eyes.

Table 1. Clinical Characteristics of Patients

<table>
<thead>
<tr>
<th>Eyes, n</th>
<th>169</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>60.7 ± 11.0</td>
</tr>
<tr>
<td>Men/women</td>
<td>104/65</td>
</tr>
<tr>
<td>Diabetes mellitus, +/-</td>
<td>104/65</td>
</tr>
<tr>
<td>Hypertension, +/-</td>
<td>79/90</td>
</tr>
<tr>
<td>Body mass index</td>
<td>23.5 ± 3.4</td>
</tr>
<tr>
<td>Serum total cholesterol, mg/dL</td>
<td>200.3 ± 45.8</td>
</tr>
</tbody>
</table>

Values are presented as mean ± SD.

Values are presented as the mean ± SD.

Table 2. Settings of the VGFI System and IOP in Porcine Eye

<table>
<thead>
<tr>
<th>VGFI Setting (mm Hg)</th>
<th>Actual IOP (mm Hg)</th>
<th>Coefficient of Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>10.5 ± 0.11</td>
<td>0.0102</td>
</tr>
<tr>
<td>20</td>
<td>20.7 ± 0.13</td>
<td>0.0064</td>
</tr>
<tr>
<td>30</td>
<td>31.6 ± 0.12</td>
<td>0.0038</td>
</tr>
<tr>
<td>40</td>
<td>42.0 ± 0.07</td>
<td>0.0018</td>
</tr>
<tr>
<td>50</td>
<td>53.2 ± 0.08</td>
<td>0.0015</td>
</tr>
<tr>
<td>60</td>
<td>65.2 ± 0.06</td>
<td>0.0009</td>
</tr>
<tr>
<td>70</td>
<td>74.3 ± 0.07</td>
<td>0.0009</td>
</tr>
<tr>
<td>80</td>
<td>84.5 ± 0.07</td>
<td>0.0008</td>
</tr>
<tr>
<td>90</td>
<td>94.9 ± 0.05</td>
<td>0.0006</td>
</tr>
<tr>
<td>100</td>
<td>106.0 ± 0.06</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

CV in 10 measurements is also shown. The actual IOP tended to be slightly higher than the VGFI setting, and there was a significant positive correlation between the actual IOP and VGFI setting (\( r = 0.99, P < 0.0001 \)). The relation between the VGFI setting and actual IOP was expressed as follows:

\[
\text{(Actual IOP)} = 1.062 \times (\text{VGFI setting}) - 0.338
\]

This equation was used to convert the VGFI setting to the actual IOP in the measurements in human eyes.

Measurements of ODP

ODP measured during vitrectomy was 66.9 ± 12.5 mm Hg (range, 15.5–103.7). DBP and SBP measured at the same time were 75.9 ± 11.5 mm Hg (range, 42–110) and 148.5 ± 19.2 mm Hg (range, 102–187), respectively (Fig. 1). ODP was found to be 88.1% of DBP and correlated significantly with DBP (\( r = 0.60, P < 0.0001 \), Fig. 2A), but there was no significant correlation between ODP and SBP (\( r = 0.12, P = 0.12 \), Fig. 2B). ODP varied depending on the type of vitreoretinal disorder (Fig. 3). ODP in patients with PDR, DME, and CRVO tended to be lower than in patients with MH, ERM, and RD, but a significant difference was not observed among diseases. ODP was significantly lower in patients with DM than in non-DM patients (\( P < 0.0001 \)), although DBP was not significantly different between the two groups (Fig. 4). Similar results were obtained in patients with HT (Fig. 5). Multiple regression analysis revealed...
that DBP ($P < 0.0001$), presence of DM ($P = 0.02$), and presence of HT ($P = 0.05$) exhibited a significant correlation with ODP, whereas other explanatory variables showed no relationship with it (Table 3).

**DISCUSSION**

Ophthalmodynamometry has been used to measure ODP. The IOP is raised by exerting a standardized pressure on the globe while the optic nerve head is directly observed with an ophthalmoscope. It is a simple and well-designed device for measuring ODP. Ophthalmodynamometry has been used to measure ODP in various ocular disorders including retinal vein occlusion, retinal arterial occlusion, glaucoma, and ischemic ophthalmopathy. Jonas demonstrated that ODP in patients with CRVO was lower than that in normal control subjects. ODP in patients with giant-cell arteritis-induced anterior ischemic optic neuropathy was reduced compared with patients with nonarteritic anterior ischemic optic neuropathy. Another study demonstrated that ODP in patients with ischemic central retinal vein occlusion was significantly lower than that of patients with nonischemic central retinal vein occlusion. However, due to the pressure exerted on the globe by the ophthalmodynamometric contact lens, repeated measurements will change IOP. Furthermore, since the target pressure is the sum of IOP and externally applied pressure, the precise determination of IOP is difficult. In addition, ODP measurement is not possible in cases with hazy media which hinder observation of the optic disc head or pulsation of the retinal vessels. In contrast, the direct cannulation method can measure ODP more precisely, because it monitors the true pressure in the eye. This method, however, is not easily applicable to living human eyes due to its invasiveness. We developed a new method of determining ODP by using VGFI during vitrectomy.

To verify the accuracy and reliability of the VGFI setting, we conducted an experiment to measure the actual IOP in porcine eyes by changing the VGFI settings from 10 to 100 mm Hg. We found that the actual IOP tended to be slightly higher than the pressure level set by VGFI, but there was no significant difference between them. From these data, an equation was derived to convert the VGFI setting to the actual IOP. This conversion equation was used in the subsequent ODP measurements in human eyes. We also confirmed the reproducibility of IOP level settings by repeating the measurements 10 times in porcine eyes, where the coefficient of variation was sufficiently small.

As mentioned in the Results section, the ODP in human eyes was found to be 88.1% of DBP. This result agrees well with the findings of Duke-Elder, who reported that mean ODP was 92% of the mean aortic pressure when using the direct cannulation method.

In the present study, ODP showed a significant correlation with DBP. This result is explained by the fact that ODP represents the diastolic phase of the central retinal artery collapse pressure. These findings are in good agreement with the previous reports of ODP evaluation with an ophthalmodynamometer and direct cannulation. On the other hand, ODP was not associated with SBP. Jonas used an ophthalmodynamometer to measure ODP in patients with various eye diseases, and reported that ODP in normal control subjects showed a signif-
ificant association with both DBP and SBP, whereas ODP in patients with retinal vascular occlusive disease did not show a significant association with SBP. Disturbance of retinal blood flow seems to be the reason for lack of correlation between SBP and ODP in those patients. In fact, many of the subjects in the present study had retinal ischemic diseases such as PDR, DME, BRVO, and CRVO.

When compared among diseases, ODPs in PDR, DME, and CRVO were lower than those in MH, ERM, and RD, although a significant difference was not observed among the diseases. Such tendency may be attributable to the fact that retinal circulation disturbance is not involved in MH, ERM, and RD, whereas PDR, DME, and CRVO are retinal ischemic diseases.

Multiple regression analysis revealed that ODP had a significant negative correlation with the presence of DM and HT. No studies have reported that ODP is reduced in patients with DM or HT. Of interest, ODP in DM patients was lower than that in non-DM patients, but DBP was not significantly different between the two groups. Decreases in retinal blood flow and retinal artery velocities are detected even in the very early stage of diabetic retinopathy. Mendivil measured blood flow velocity of the central retinal artery in PDR patients by using color Doppler imaging, showing that the blood flow velocity in the patients was lower than that of normal control subjects. In our study, PDR and DME were included in DM patients. It may be that DM retinopathy causes retinal perfusion disturbances, resulting in reduced ODP in DM patients even though DBP is not compromised. Conversely, the reduction in ODP may be partly responsible for the development or progression of retinopathy in patients with DM. Elucidation of such mechanisms awaits further studies.

ODP in HT group was lower than that in the non-HT group, whereas DBP was not significantly different between the two groups in this study. Although Doppler ultrasonography of the ophthalmic and carotid arteries was not performed in the patients in this study, it appears that circulatory disturbance in the ophthalmic artery or carotid artery due to arteriosclerosis should be lower when sitting and standing than when supine. The position of the patient’s eye and the brachium/heart, ODP and systemic blood flow were measured with the subjects supine. In daily lives, however, patients spend longer hours in the sitting and standing positions. Considering the relative position of the patient’s eye and the brachium/heart, ODP should be lower when sitting and standing than when supine. Third, ODP may be influenced by surgical anesthesia. Retrobulbar anesthesia induces a reduction of velocity in the retrobulbar vessels in contrast with subconjunctival anesthesia. All patients underwent sub-Tenon local anesthesia in this study. Although sub-Tenon local anesthesia is a less invasive technique than is retrobulbar anesthesia, ODP may decrease due to a reduction in velocity in the central retinal artery. Fourth, the systemic blood pressure of patients tends to rise during surgery due to operative stress. As a result, the patient’s ODP can be elevated to some extent. Measurements of ODP and blood pressure under more physiological conditions awaits further refinement of technology and methodology.

In conclusion, we developed a new method to measure ODP with a VGFI system. ODP was significantly associated with DBP and was lower in patients with DM and HT.

### References


### Table 3. Correlations with Ophthalmodynamometric Pressure (the Objective Variable) in Multiple Regression Analysis

<table>
<thead>
<tr>
<th>Explanatory Variables</th>
<th>β</th>
<th>SE</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diastolic blood pressure</td>
<td>0.56</td>
<td>0.11</td>
<td>&lt;0.0001*</td>
</tr>
<tr>
<td>Systolic blood pressure</td>
<td>0.17</td>
<td>0.06</td>
<td>0.09</td>
</tr>
<tr>
<td>Age</td>
<td>–0.03</td>
<td>0.10</td>
<td>0.75</td>
</tr>
<tr>
<td>Presence of diabetes mellitus</td>
<td>–0.22</td>
<td>2.23</td>
<td>0.02*</td>
</tr>
<tr>
<td>Presence of hypertension</td>
<td>–0.18</td>
<td>1.96</td>
<td>0.03*</td>
</tr>
<tr>
<td>Body mass index</td>
<td>–0.09</td>
<td>0.29</td>
<td>0.26</td>
</tr>
<tr>
<td>Serum total cholesterol</td>
<td>0.03</td>
<td>0.02</td>
<td>0.69</td>
</tr>
</tbody>
</table>

* β: Standard regression coefficient, *: Significant at P < 0.05.