Oxygen lowers intraocular pressure

Pamela F. Gallin-Cohen, Steven M. Podos, and Michael E. Yablonski

A significant decrease in intraocular pressure was demonstrated in 14 patients as atmospheric pressure was increased at intervals of 0.5 atmospheric pressure up to 3 atmospheres within a hyperbaric chamber. Nine of these patients had the identical protocol repeated in room air at atmospheric pressure without a significant change in intraocular pressure. Administration of 100% O₂ at 15 L/min by partial rebreathing face mask to these patients using the same protocol at atmospheric pressure resulted in a significant decrease in intraocular pressure. The results in the oxygen and hyperbaric groups were not statistically different. While in the hyperbaric chamber, scleral rigidity increased uniformly, outflow facility decreased significantly, and keratometry readings remained unchanged. A significant decrease in intraocular pressure occurred in 20 rabbits that received 100% oxygen by partial rebreathing face mask for 180 minutes. Arterial blood gases were obtained at 0, 90, and 180 min in seven rabbits. The pH and pCO₂ did not change significantly; however, pO₂ was markedly elevated. Increased oxygen concentration was felt to be responsible for the decrease in intraocular pressure and the changes in other parameters observed in patients and rabbits.

Key words: glaucoma, oxygen, intraocular pressure, hyperbaric chamber, keratometry, pseudofacility

At increased atmospheric pressure, Praetorius¹ found a decrease in the outflow facility of rabbits without an alteration of intraocular pressure (Schiotz). Kalthoff and John² did not find a change in the intraocular pressure of divers following 8m dives. However, a rapid rise in atmospheric pressure caused a decrease in intraocular pressure in a patient with chronic glaucoma simplex.³ Beehler and associates⁴ found that hypotony was the sequel to retinal detachments following 145 hr of oxygen administration.

The purpose of this experiment was to investigate the effect of increasing atmospheric pressure and oxygen on the intraocular pressure in humans and rabbits.

Materials and methods

Humans. Fourteen volunteers with normal ocular examinations had Goldmann applanation tonometry measured bilaterally at 1 atmosphere (atm) (room air). They were then placed in the Union Carbide Hyperbaric Chamber at The Mount Sinai Medical Center, in which the pressure was progressively increased from 1.0 atm to 1.5, 2, 2.5, and 3 atm. At each interval, intraocular pressure was measured in only one eye, while at 1 and 3 atm it was measured bilaterally. The minimum time interval between successive applanation measurements was 5 min. The mean time (±SD) from onset of increased atmospheric pressure to intraocular pressure measurement at 3 atm was 38.3 ± 10.0 min. At 3 atm, tonography and keratometry were performed.

Each patient went into the hyperbaric chamber on only one occasion. All other room air measurements were obtained on other days. Nine of the above patients had the applanation protocol
Fig. 1. The administration of oxygen to rabbits by pediatric partial rebreathing face mask.

On another day, 14 of the patients had tonography (Alcon), and in 12 patients keratometry was performed on the same eye as within the chamber but at 1 atm (room air).

Analysis was carried out on the same nine patients within three distinct environments.

1. **Hyperbaric group.** These patients were placed within a hyperbaric chamber in which atmospheric pressure was increased from 1 to 3 atm at 0.5 atm increments (3 atm pressure, 520 mm Hg, partial pressure oxygen).

2. **Control group.** Intraocular pressure was obtained at room air within an office (1 atm pressure, 22.8% oxygen, 173 mm Hg, partial pressure oxygen).

3. **Oxygen group.** Face mask oxygen was administered to patients within an office (1 atm pressure, 100% oxygen administration with 90% to 95% delivery, 722 mm Hg, partial pressure oxygen). Times were standardized with respect to the applanations within the chamber. Time 1 represents the time within the control or oxygen groups equivalent to the applanation at 1 atm within the hyperbaric chamber. Similarly, time 3 is the time equivalent to the applanation at 3 atm pressure within the chamber.

The mean time until the "3 atm" reading of intraocular pressure in these three groups was 38.5 ± 8.8 min.
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Table I. Effect of atmospheric pressure and oxygen on intraocular pressure (mm Hg) in humans

<table>
<thead>
<tr>
<th>Time</th>
<th>1 Atm</th>
<th>1½ Atm</th>
<th>2 Atm</th>
<th>2½ Atm</th>
<th>3 Atm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperbaric chamber (14 subjects)</td>
<td>15.3 ± 2.1</td>
<td>13.9 ± 2.2</td>
<td>13.1 ± 1.8</td>
<td>13.0 ± 1.7</td>
<td>12.3 ± 1.7*</td>
</tr>
<tr>
<td>Room air (9 subjects)</td>
<td>Time 1†</td>
<td>Time 1½</td>
<td>Time 2</td>
<td>Time 2½</td>
<td>Time 3</td>
</tr>
<tr>
<td>Control</td>
<td>15.2 ± 1.6</td>
<td>14.3 ± 1.4</td>
<td>14.6 ± 1.6</td>
<td>14.8 ± 1.6</td>
<td>15.0 ± 1.7†</td>
</tr>
<tr>
<td>100% O2</td>
<td>14.8 ± 2.8</td>
<td>13.4 ± 3.2</td>
<td>13.4 ± 3.1</td>
<td>12.8 ± 3.4</td>
<td>12.7 ± 3.0*</td>
</tr>
</tbody>
</table>

*Significant difference between IOP at last measurement and first measurement (paired t test; p < 0.001).
†Time is that of IOP measurement corresponding to similar time while in hyperbaric chamber at various atmospheres.
Significant difference between (a) control IOP at time 3 and 3 atm. (p < 0.001); (b) control IOP at time 3 and 100% oxygen at time 3 (p < 0.025).

Table II. Effect of atmospheric pressure on ocular parameters in humans

<table>
<thead>
<tr>
<th></th>
<th>No. patients</th>
<th>1 Atm</th>
<th>3 Atm</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IOP Applanation (mm Hg)</td>
<td>12</td>
<td>14.8 ± 2.3</td>
<td>11.9 ± 1.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Other eye*</td>
<td>14</td>
<td>14.0 ± 1.9</td>
<td>11.3 ± 1.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>IOP Schiötz (mm Hg)†</td>
<td>14</td>
<td>0.34 ± 0.15</td>
<td>0.24 ± 0.10</td>
<td>&lt;0.020</td>
</tr>
<tr>
<td>Outflow facility (ml/mm/mm Hg)‡</td>
<td>14</td>
<td>0.019 ± 0.005</td>
<td>0.023 ± 0.005</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ocular rigidity (µl−1)</td>
<td>14</td>
<td>43.7 ± 1.5</td>
<td>43.9 ± 1.7</td>
<td>&gt;0.050</td>
</tr>
</tbody>
</table>

Values at 1 and 3 Atm are mean ± S.D.
*Eye receiving applanation tonometry only at 1 Atm and 3 Atm.
†Corrected for scleral rigidity.
‡Significant difference of values at 1 and 3 Atm, by paired t test.

Rabbits. Face mask oxygen was administered to 20 rabbits. Intraocular pressure was measured at the baseline (−15, −10, −5, and 0 min) and during oxygen administration at 30 min intervals for 180 min using a calibrated pneumotonograph. One hundred percent oxygen was delivered at 15 L/min through 6 ft connection tubing (¼ inch diameter) using a Puritan humidifier and the pediatric size of the partial rebreathing face mask used previously (Fig. 1). The above sequence of intraocular pressure measurement was also followed for a "control group" of six rabbits which did not receive oxygen.

During this study, arterial blood gas composition was determined by the withdrawal of 4 ml of arterial blood into a heparinized syringe at 0, 90, and 180 min from the ear artery. The blood was placed on ice and blood gas determination made within 15 min using an ABL-2 machine. Despite 20 attempts, only seven complete sets of gases were obtained due to severe peripheral vasoconstriction during oxygen administration.

Results

Humans. When the intraocular pressure was repetitively measured at 0.5 atmospheric pressure intervals in 14 patients within the hyperbaric chamber, it showed a significant decrease from 15.3 ± 2.1 mm Hg at 1 atm to 12.3 ± 1.7 mm Hg at 3 atm (Table I, Fig. 2). The intraocular pressure of the fellow eye was measured at 1 and 3 atm. It decreased from 14.8 ± 2.3 mm Hg (1 atm) to 11.9 ± 1.7 mm Hg (3 atm). There was no significant difference between the decrease in the eye subjected to repetitive pressure measurements and the fellow eye receiving baseline and final pressure measurements.

Comparisons between the baseline intraocular pressure in the control, oxygen, and hyperbaric groups (see Methods) were not statistically different. There was no statistically significant change of intraocular pres-
Table IV. Effect of face mask oxygen on arterial blood gas in seven rabbits

<table>
<thead>
<tr>
<th>Minutes of oxygen</th>
<th>pH (mean ± SD)</th>
<th>pO2 (mean ± SD)</th>
<th>pCO2 (mean ± SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7.44 ± 0.02</td>
<td>91.3 ± 22.1</td>
<td>37.6 ± 5.5</td>
</tr>
<tr>
<td>90</td>
<td>7.42 ± 0.05</td>
<td>426.3 ± 99.4*</td>
<td>38.6 ± 4.9</td>
</tr>
<tr>
<td>180</td>
<td>7.40 ± 0.05</td>
<td>427.8 ± 97.1*</td>
<td>37.4 ± 5.8</td>
</tr>
</tbody>
</table>

*Significant difference between 0 min and 90 or 180 min mean readings (paired t test, p < 0.001).

sure in the control group, 15.2 ± 1.6 mm Hg at time 1 and 15.0 ± 1.7 at time 3. However, the intraocular pressure of the control group at time 3 was significantly (p < 0.001) higher than that of the hyperbaric group at 3 atm (Table I).

There was a significant (p < 0.001) decrease in intraocular pressure from time 1 to time 3 within the oxygen group. The control group and oxygen group intraocular pressures differed significantly at time 3 (p < 0.025). There was no statistically significant difference between the intraocular pressure of the patients within the hyperbaric chamber at 3 atm and the oxygen group at time 3.

Ocular rigidity was calculated for each eye at 1 and 3 atm by the method of Friedenwald, as described in Becker and Shaffer. Scleral rigidity increased significantly (p < 0.001) from 0.019 ± 0.005 at 1 atm to 0.023 ± 0.005 at 3 atm (Table II). Mean outflow facility corrected for scleral rigidity, as above, decreased significantly (p < 0.02) from 0.34 ± 0.15 ml/min/mm Hg at room air to 0.24 ± 0.10 ml/min/mm Hg at 3 atm (Table II). The change in keratometry readings from 1 atm to 3 atm was not statistically significant. At 1 atm the mean was 43.73 ± 1.46 diopters, in comparison to 43.92 ± 1.70 diopters at 3 atm. The keratometry readings of a steel ball were the same at 1 atm and 3 atm.

Rabbits. The intraocular pressure of 40 rabbit eyes (20 rabbits) showed a significant decrease (p < 0.001), from 24.3 ± 2.3 mm Hg at the baseline to 21.9 ± 2.9 mm Hg at 180 min of oxygen administration (Table III). The intraocular pressure in 12 control rabbit eyes did not change significantly at 90 or 180 min.

Blood gases were obtained at 0, 90, and 180 min in seven rabbits (Table IV). No statistically significant change in pH was seen. The pO2 increased significantly (p < 0.001) from 91.3 ± 22.1 at the baseline to 426.3 ± 99.4 at 90 min and 427.8 ± 97.1 at 180 min. The pCO2 remained unchanged with mean values of 37.6 ± 5.5 at the baseline, 38.6 ± 4.9 at 90 min, and 37.4 ± 5.8 at 180 min.

Discussion

An increase of atmospheric pressure from 1 to 3 atm within the hyperbaric chamber caused a significant decrease in human applanation intraocular pressure. This was in contrast to the findings of Praetorius, who did not note a change in the Schiötz pressures of rabbits at 3 and 4 atm.

Moses, Bynke and associates, and Wilke reported decreases of 2 to 3 mm Hg in applanation tonometry values following five to six repetitive applanation readings at 1 min intervals. In our study, the minimum time interval between applanations was 5 min. No significant differences between the decreases in intraocular pressure were demonstrable between the eye receiving repetitive pressures and the eye receiving only baseline and final measurements. Therefore, the effect of repeated applanation tonometry cannot account for the observed effect of the decrease in intraocular pressure.

Welsh and associates have reported increases of 0.75 to 1.0 diopter in the keratometry readings of Navy divers (and a steel ball) within a hyperbaric chamber at 4 and 5 atm. In contrast, our keratometry readings did not change. Welsh and associates attributed the keratometry changes to a change in the refractive index of the air. Structural changes within the keratometer were ruled out by Bausch and Lomb engineers (personal communication). However, Welsh and associates did not consider the effect of tem-
perature, which reached 130° F within the chamber. The Mount Sinai hyperbaric chamber was continuously air-conditioned. The lack of change in cornea curvature is consistent with the concept that slowly increasing atmospheric pressure rapidly equilibrates throughout the entire body, causing little demonstrable change in the contour of the globe.

The significant decrease in intraocular pressure demonstrated in 40 rabbit eyes receiving face mask oxygen at room air confirms the results in humans. The change in IOP was significant at 90 and 180 min. As in the patient control group, there was no significant decrease in the intraocular pressure of the control rabbits.

Although oxygen is probably responsible for the decrease in intraocular pressure demonstrated within the hyperbaric chamber and with face mask oxygen at room air, the effects of arterial pH and carbon dioxide are not known. Intracerebral vasoconstriction occurs within the hyperbaric chamber9-11; however, the individual effect of increasing oxygen or decreasing carbon dioxide is debated. Marcus and associates12 demonstrated a decrease in intraocular pressure associated with a pH change secondary to increasing partial pressure of carbon dioxide. It is possible that our patient data might have been produced by increasing oxygen or a change in carbon dioxide.

While the question of the effect of CO₂ and pH on intraocular pressure in the patients within the chamber and with face mask O₂ was unanswered in the patient population, it was clearly elucidated in the rabbit group. Although the pH decreased approximately 0.04, this was not a statistically significant decrease. The oxygen increased to a pO₂ of 427 mm Hg, consistent with the oxygen administration. It is important to note that the pCO₂ did not change significantly. Thus the factor responsible for the change in intraocular pressure in rabbits is probably the oxygen.

Scleral rigidity recalculated according to the formula of Friedenwald5 increased uniformly from 1 atm to 3 atm. The total outflow facility decreased significantly at 3 atm in comparison to 1 atm. The decrease in outflow facility was consistent with the data of Praetorius. He did not measure scleral rigidity.

Bárány13 and Goldmann14, 15 indicated that an apparent increase in scleral rigidity and decrease in total outflow facility is possible due to a relative decrease in choroidal blood volume. The effects of oxygen on retinal vessels have been observed in man. Fundus photos showed retinal vasoconstriction due to increased oxygen and no change following hypocarbia.16 Similar results (constriction due to hyperoxgenation) have been reported,17-19 although Duke-Elder20 did not note any change after 5 min. Only Beehler and associates21 directly described oxygen and intraocular pressure. Following 145 hr of constant oxygen administration in dogs at room air, retinal detachments were followed by hypotony. Therefore a decrease in choroidal volume, secondary to an oxygen-induced vasoconstriction, could yield the above observation of increased scleral rigidity and decreased total facility of outflow.

We conclude that the increased oxygen concentration is responsible for the changes in tonography parameters and the decrease in intraocular pressure observed in human subjects and rabbits. The exact mechanism of the decrease in pressure is not clear. A contraction of the choroidal volume at a rate of about 40% of the normal secretory rate would yield the observed decrease in intraocular pressure; however, it seems unlikely that such a contraction of the choroid would still be occurring after 38 min in the human experiments and after 180 min in the rabbit experiments. Either a 40% decrease in the rate of aqueous humor formation or an approximately 3 mm Hg fall in episcleral venous pressure would account for the observed fall in intraocular pressure. Direct measurements of aqueous flow and episcleral venous pressure are necessary to evaluate these two possible mechanisms.

We thank Doctor J. Jacobson, Chief of Vascular Surgery, for his suggestions and use of the hyperbaric chamber; D. Mandell, R.N., Director of Ophthalmology Clinics; and Colette Severin and Maria Perez.
REFERENCES


