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PNEUMATIC MEASUREMENT OF INTRAOCULAR PRESSURE: INTERPRETATION OF HYPOBARIC AND HYPOXIC EFFECTS[1]

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Abstract. Using a non-contact tonometer, we previously demonstrated that intraocular pressure (IOP) was reduced after exposure to 446 mm Hg for two hours, as well as during 15 days of residence at Pikes Peak (4300 m, ~446 mm Hg). Although a definite acclimatization effect was shown during the latter exposure, the nature of the abrupt 20% reduction in IOP (15.8 ± 0.6 vs 12.9 ± 0.9 mm Hg, mean ± S.E., n=11) during the 2-h altitude simulation was of concern. We hypothesized that the reduction could be due either to the reduction in barometric pressure (P_B) and/or to the physiological effects of hypoxia. In two, 2-h series of experiments separated by one week, seven subjects were exposed to either normobaric hypoxia (P_B=760 mm Hg; 12.8% O_2) (NH) or hypobaric normoxia (P_B= 446 mmHg; 37.3% O_2)(HN). During NH, IOP gradually decreased, reaching statistical significance after two hours ($P<0.009$). During HN, IOPs were reduced at 0.5 hours ($P<0.0001$) and remained decreased for the entire two hours. Within two minutes of return to normobaria after HN, IOP returned to 17.1±1.0 mm Hg, demostrating an immediate pressure effect on the measurement of IOP. These results indicate that the reduction in IOP observed during altitude exposure is the result of the combination of hypobaria and a physiological hypoxic effect. The hypobaric effect is relatively immediate, and the hypoxic effect manifests itself after a minimum of two hours of exposure. The previously-observed IOP changes with altitude exposure remain valid.

Keywords: intraocular pressure, hypobaria, hypoxia, altitude

Resumen. Anteriormente, usando un tonómetro de no contacto, demostramos que la presión intra-ocular (PIO) estaba reducida después de una exposición a 446 mm de Hg durante dos horas, como también durante una estadía de 15 días en Pikes Peak (4300 m ~446 mm Hg). A pesar de que se observó una aclimatación durante los 15 días, el origen de la súbita reducción del 20% en la PIO (15.8±0.6 vs 12.9-±0.9 mm Hg, promedio±SE, n=11) durante la exposición de 2 horas es de preocupación. Hemos formulado la hipótesis que la reducción podría ser debida ya sea a la presión barométrica (PB) y/o a los efectos fisiológicos de la hipoxia. En 2 series de experimentos de 2 horas, separados por una semana, siete sujetos fueron expuestos a una hipoxia normobárica (PB=760 mm Hg; 12.8% O_2) (HN) o normoxia hipobárica (PB=446 mm Hg; 37.3% O_2)(NH). Durante la HN, la PIO gradualmente disminuyó, alcanzando significación estadística después de dos horas ($p<0.009$). Durante NH, las PIOs se redujeron a la 0.5 horas ($p<0.0001$) y permanecieron disminuídas por las 2 horas restantes. Dos minutos después de retornar a la mormobaria después de la NH, la PIO retornó a 17.1±1.0 mm Hg, demostrando un efecto inmediato de la presión en la medición de la PIO. Estos resultados indican que la reducción en la PIO observada durante la exposición a la altura es el resultado de la combinación de la hipobaria y un efecto fisiológico hipóxico. La influencia hipobárica es relativamente inmediata y los efectos hipóxicos se evidencian después de un mínimo de 2 horas de exposición. Los cambios de la PIO con la exposición a la altura previamente observados permanecen válidos.

Palabras Claves: Presión intraocular, hipobaria, hipoxia, altitud.

INTRODUCTION

Altitude effects on intraocular pressure have been examined on mountain expeditions and in mountain field laboratories with results that appear contradictory. No changes in IOP were found in four subjects who were members of a team of British and Sherpa climbers (Clarke and Duff, 1976). Using a Perkins contact tonometer which was very uncomfortable and unpopular, Clarke and Duff obtained measurements between 1800 and 2100 hours, a time when IOP is at a nadir in its diurnal cycle. Measurements performed in the morning when the IOPs can be 3-4 mm Hg higher are more likely to show observable changes. Reductions in IOP and retinal venous dilatation in Himalayan climbers two weeks after descent have also been obser-

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ved, but these decreases were associated with the climbers' increased physical activity (Brinchmann-Hansen and Myhre, 1989). However, the physical exertion effect on IOP usually lasts only minutes after exertion (McDaniel et al., 1983). It is difficult to believe that significant reductions of 1-5 mm Hg in 21 subjects would still be evident two weeks after altitude exposure.

Because of confounding problems that can affect IOP such as hyperventilation (hypocapnia) and increases in blood osmolality and blood pressure associated with climbing expeditions, we measured IOPs under more controlled, resting conditions. A series of field and chamber studies were conducted to determine whether IOP changes occurred under both normobaric hypoxic (hypoxia) and hypobaric normoxic (hypobaria) conditions and to correlate noncontact tonometer measurements with a contact tonometer under altitude conditions.

METHODS

Studies were conducted at the Pikes Peak Altitude Laboratory (4,300 m, Colorado Springs, CO) or the hypobaric chamber at U.S. Army Research Institute of Environmental Medicine, Natick, MA. Subjects remained quietly seated for at least 10 minutes before any measurements were taken. Only right eye IOPs were measured. Pneumatic tonometer measurements were always performed first to avoid any potential errors due to application of a short-acting local anesthetic used in conjunction with the Tono-Pen (See study 6).

Study 1: intraocular pressure measurements, using a non-contac pneumatic tonometer (CT-20 Tonometer, Topcon Corporation, Paramus, NJ), were obtained on 11 resting male volunteers (29$\pm$1 yr) on days 2, 12, and 15 of a 19-day residence at the summit of Pikes Peak, CO (4,300m) IOP at Pikes Peak.

Study 2: To determine whether hypobaria affects the measurement of IOP using a pneumatic tonometer, a calibrated "test eye" was obtained from the Topcon Corporation and attached to the CT-20 tonometer. IOPs were measured within 30 minutes at each 1,000 ft interval of simulated altitudes from sea level (760 torr) to 4,587 m (428 torr).

Study 3: To determine the acute effect of hypobaria per se on IOP, seven volunteers were exposed to a hypobaric, normoxic environment by reducing hypobaric chamber ambient pressure to 446 torr (4,300 m). To maintain sea-level inspiratory PO_2 values volunteers breathed a 37.3% oxygen-balance nitrogen gas mixture. A mean of three measurements was obtained every 0.5 hours for two hours with control measurements made at 760 torr before and immediately after exposure.

Study 4: To determine the effect of hypoxia per se on IOP, seven volunteers were exposed to a normobaric hypoxic environment by breathing a gas of 12.3% oxygen-balance nitrogen at sea- level barometric preassure (760 torr). A mean of three measurements was obtained every 0.5 hour for two hours with control measurements made at 760 torr breathing room air before and immediately after exposure. Blood oxygen saturation was monitored using a finger pulse oximeter (Oxyshuttle, Sensormetics Corp, Anaheim, CA).

Study 5: In order to determine whether hypobaria affected long term pneumatic IOP measurements, the Topcon CT-20 tonometer was maintained at 446 torr in the hypobaric chamber for four continuous days. Every morning IOPs were obtained from two volunteers immediately upon descompression to 446 torr.

Study 6: To determine whether pneumatic tonometry correlated with a more direct measurement of IOP, we compared measurements taken from a contact and pneumatic tonometer on the summit of Pikes Peak (4,300 m). Morning IOPs were obtained from 19 volunteers for the first three days using both the Topcon CT-20 pneumatic tonometer and a contact tonometer (Tono-Pen XL Tonometer, Mentor O&O, Norwell, MA). The Tono-Pen uses a micro strain gauge which is gently tapped four times over a 1.5 mm area of anesthetized cornea to obtain a mean and coefficient of variation.

RESULTS AND DISCUSSION

Figure 1A shows the IOP results from the 1992 Pikes Peak Field Study. The acute hypobaric chamber exposure resulted in a significant reduction in IOP after 2 hours of simulated

altitude exposure. After transport to Pikes Peak, CO (4300 m), a slightly greater reduction was observed after 2 days with a gradual increase toward pre-exposure values after 2 weeks residence. The reduction in IOP could be related to the reduction in barometric pressure and/or the partial pressure of oxygen and subsequent physiological consequences. In order to obtain further information of the cause of the reduction, a calibrated "test" eye was exposed to simulated altitude in a barometric chamber.

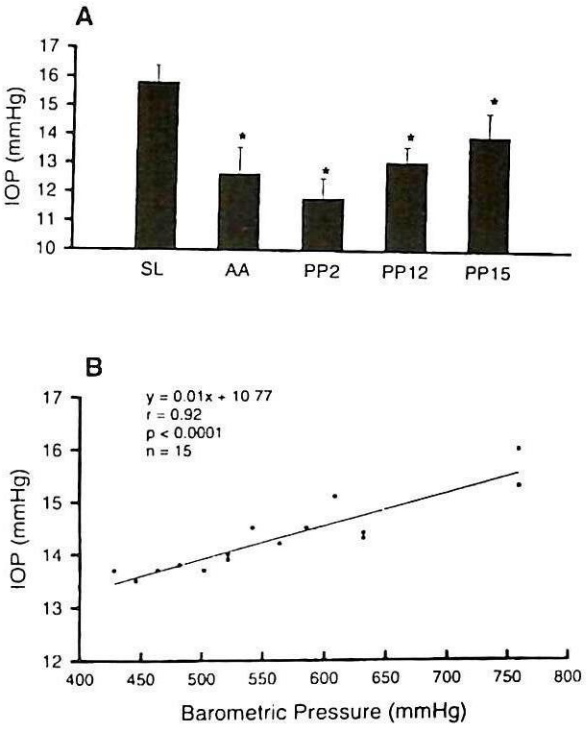

Figure 1. (A) Pneumatic intraocular pressure measurements from 11 resting male volunteers (29 ± 1 yr) at sea level (SL), 2 hours of exposure to simulated altitude in a hypobaric chamber (4,300 m, AA), and on days 2 (PP2), 12 (PP12), and 15 (PP15) of a 19-day exposure at the summit of Pikes Peak, CO (4,300m). *P<0.005. (B) Linear regression of a calibrated test eye exposed to ambient barometric pressure ranges from 425 to 760 torr. Measurements were made within 0.5 h at each barometric pressure.

Results indicated that there is a reduction in the pressure measured by the pneumatic tonometer that linearly correlated with the ambient pressure (Figure 1B). Therefore, some of the reduction observed acutely in the chamber and at Pikes Peak could be due to the direct effects of hypobaria on the tonometer, i.e., a lower barometric pressure would result in a less dense puff of air and a lower reading. However, direct barometric effects (which would be constant) could not explain the changes observed during acclimatization, i.e., the gradual increase with time at altitude.

The next two studies were designed to assess the independent effects of hypobaria and hypoxia in the two hour time frame that resulted in a reduction in IOP in the original study. Figure 2A shows the results of seven volunteers exposed to two hours of hypobaric normoxia. There was an immediate reduction in IOP with exposure of subjects and tonometer to hypobaria. The reduction lasted the entire two hours and then returned to normal with exposure to normobaria. While these results showed IOP decreases with HN, it could not be discerned whether the reduction was due to effects on the subject or the instrument. Therefore, one week later, the same seven subjects were exposed to normobaric conditions, but this time they breathed a mixed gas containing 12.8% O_2. Figure 2B shows no change in IOP until two hours of hypoxic breathing, indicating that the hypoxic effect on IOP takes at least two hours to manifest itself. Finger pulsed oximeter readings for the 2-hour period were 84.8±11.1% O_2 saturation. Therefore, there is an immediate, physical effect on IOP dependent solely on barometric effect after two hours.

The next question was whether continuous exposure of the tonometer to hypobaria caused any change in the instrument's ability to measure IOP. If changes with time under hypobaric conditions were found, then conclusions concernig IOP acclimatization effects could be in question. Figure 3A indicates no change in the IOP of subjects acutely exposed to hypobaric hypoxia using a machine that was kept under hypobaric conditions for four days.

A study recently conducted at Pikes Peak afforded the opportunity to compare IOP measurements taken with the same pneumatic tonometer as previously used with those obtained using a contact Tono-Pen. Measurements made with the Topcon pneumatic, non-contact tonome-

ter were found to signicantly correlate with the Tono-pen validating the changes observed in our initial study, at least for the first three days of altitude exposure (Figure 3B).

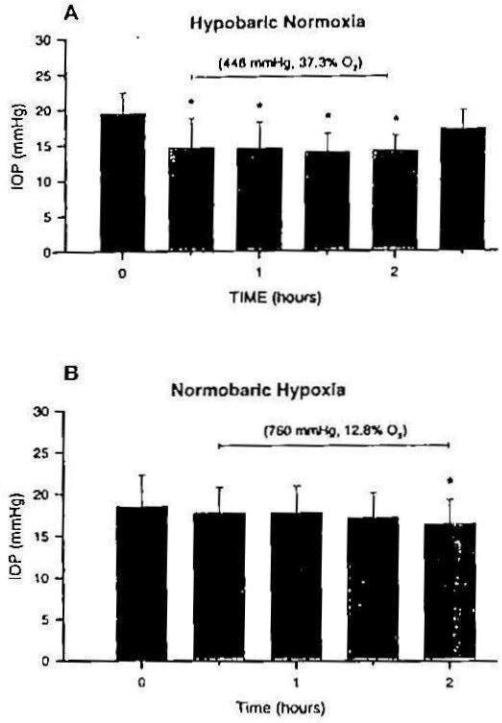

Figure 2. (A) The effects of exposure to a hypobaric (446 torr), normoxic (37.3% O_2) environment. A mean of three measurements were obtained from seven volunteers with measurements made every 0.5 hour for two hours. Control measurements were made at 760 torr before and immediately after exposure (black bars). (B) The effects of exposure to normobaric (760 torr), hypoxia (12.3% O_2). A mean of three measurements from seven volunteers was obtained every 0.5 hour for two hours with control measurements made at 760 torr breathing room air before exposure (black bar). *P-<0.05.

In summary, hypobaria causes a systematic reduction in the measurement of IOP using a pneumatic tonometer. However, a physiologic reduction in IOP is also caused by hypoxia *per se* that is evident after two hours. The reduction in IOP and the possible acclimatization effect that was observed at Pikes Peak receives further validity based on the direct correlation of pneumatic and direct contact tonometer measurements. Direct contact tonometer measurements were found to be in support of the pneumatic tonometer data which indicated a reduction in IOP with short term high altitude exposure and an acclimatization effect after two weeks.

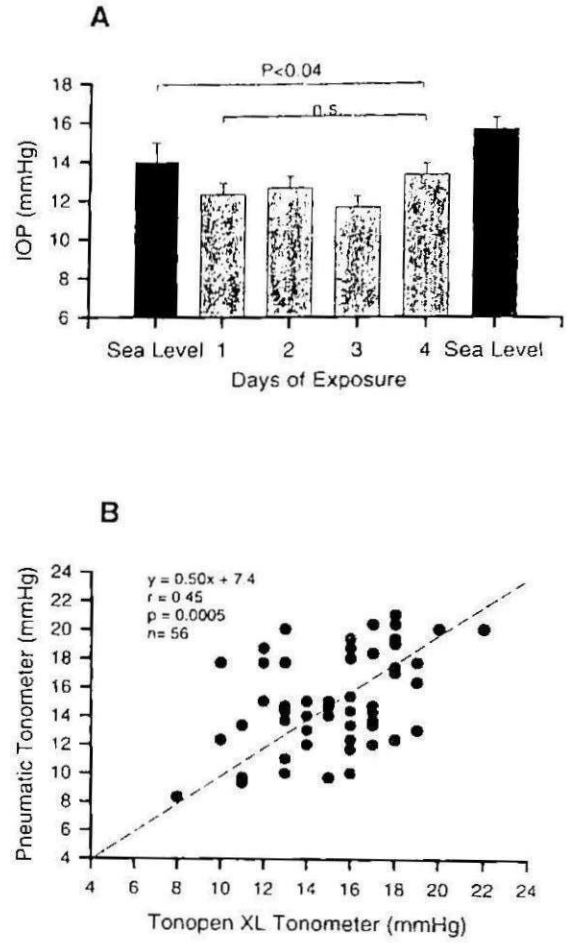

Figure 3. (A) The Topcon CT-20 tonometer was maintained at 446 torr in the hypobaric chamber for four continuos days. Every morning IOPs were obtained from two volunteers immediately upon decompression to 446 torr. (B) 19 volunteers were acutely exposed to hypobaric hypoxia on the summit of Pikes Peak. Measurements were obtained using both the pneumatic tonometer and the Tono-Pen each of three successive mornings.

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