

The Effect of Continuous Strenuous Exercise on Intraocular Pressure

Isaac Ashkenazi, Shlomo Melamed, and Michael Blumenthal

The effect of a continuous 110-km march with a 20-kg backpack load on intraocular pressure (IOP), plasma osmolarity, blood lactate, pH, and other related laboratory parameters was studied in 22 healthy young volunteers. Intraocular pressure decreased significantly at all marching intervals and returned to baseline level 3 hr after the completion of marching. The maximal average reduction during marching was 4.1 mmHg, 26.5% below the baseline level. The IOP decreased again 48 hr after the march and returned to baseline level 48 hr later. There were two peaks of increased plasma osmolarity (one during the march and the other 48 hr after the march). There was no correlation between IOP changes and levels of pH, blood lactate, serum proteins, and electrolytes or hematologic parameters. These findings suggest that IOP reduction is related inversely to plasma osmolarity during and after strenuous exercise. Invest Ophthalmol Vis Sci 33:2874-2877, 1992

The effect of physical exercise on the intraocular pressure (IOP) of trained and untrained men has been investigated by various methods and protocols.¹⁻¹¹ All these reports described a transient reduction in IOP after exercise. The degree of IOP reduction differed from study to study in relation to the intensity and duration of the exercise,^{3,4,10,12} timing of IOP measurement,³ diurnal variation,^{3,13} preexercise conditioning,² and baseline IOP.^{10,12} Numerous systemic physiologic changes that occur during exercise were proposed as possible mechanisms for this ocular hypotensive response. Increases in plasma osmolarity and blood lactate levels and decreased pH levels have been associated with IOP reductions,^{4,7} although no significant difference was seen between the IOP after aerobic exercise compared with anaerobic exercise.⁴ Weight lifting was apparently the only known exercise that caused IOP elevation.¹⁴

Neither the duration of the IOP change nor the correlation between the pressure change and various laboratory parameters during exercise was reported.¹⁻¹¹ These studies used relatively few IOP measurements, tonometers with artifactual pressure lowering, various types and magnitudes of work loads, different age and physical condition of volunteers, and short periods of exercise.

However it is unclear why IOP is reduced after exercise and what the effect of long-term strenuous exercise on IOP is. We conducted a prospective study to

determine IOP response to prolonged endurance exercise in 22 well-conditioned young healthy subjects. An attempt was made to correlate determinants of strenuous exercise, such as plasma osmolarity and levels of blood lactate and pH with changes in IOP. This study was part of a research protocol conducted by the Israel Defense Forces Medical Corps to determine the influence of continuous strenuous exercise on renal function and other physiologic and laboratory parameters.

Materials and Methods

Twenty-two healthy men (age range, 19-20 yr; mean, 19.4 yr), who were conditioned physically to continuous strenuous exercise, volunteered to participate in the study (Table 1). These subjects were not receiving any medication and did not have a history of any medical or ocular disease. Informed consent was obtained after the nature of the procedures had been explained fully. The subjects were pretested for maximal oxygen consumption (VO_{2max}) as an indicator of aerobic capacity. The VO_{2max} was measured during a progressive treadmill running test, at a constant speed of 3.3-3.6 m/sec and stepwise grade increment of 2% every 2 min until exhaustion. The highest oxygen consumption (VO_2) value achieved was selected as the VO_{2max} . All aerobic parameters were monitored and recorded by an automated metabolic measurement system. The mean (\pm standard deviation) of VO_{2max} was 59.1 ± 7.9 ml/kg/min.

A complete ocular examination was done before and after the march. This included measurement of visual acuity and IOP and slit-lamp and funduscopy examinations. The pattern of the diurnal curve of IOP

From the Goldschleger Eye Institute, Tel-Hashomer, Israel.

Submitted for publication: April 26, 1991; accepted March 5, 1992.

Reprint requests: Isaac Ashkenazi, MD, Goldschleger Eye Institute, Tel-Hashomer 52621, Israel.

Table 1. Demographic and clinical characteristics of the study group

Characteristics	Mean	SD	Range
Age (yr)	19.4	0.3	19–20
Height (cm)	173.5	6.5	158–182
Body mass (kg)	68.3	6.4	54.5–80.2
$V_{O_{2max}}$ (ml/kg/min)	59.1	7.9	46.4–75.7

was determined 1 wk before the exercise in each volunteer. The IOP was measured every 4 hr for 48 hr.

Exercise Protocol

The exercise consisted of a continuous 110-km march on plain level dirt roads with a 20-kg backpack load at a constant speed of 4.5–5.5 km/hr. The time frame for completion of the march was 24 hr. The average calculated oxygen consumption during most the march was more than 30% of the VO_{2max} .¹⁵ Six rest periods of 20 min each were taken during the march. Water and food intake, urine-volume output, and body-weight changes were recorded at intervals during the march. Venous blood samples were obtained before; during (at hr 9 and 15 of the march); immediately after the march; and after 4, 24, 48, and 96 hr of recovery. Serum was separated immediately and stored with other blood samples at 4°C. Blood samples were transferred within 1 hr to the laboratory where they were examined on arrival.

The IOP was measured bilaterally using the American Optical noncontact tonometer. This instrument was chosen after inconsistent IOP measurements were found using the Goldmann applanation tonometer in an earlier pilot study. The main reasons for these inaccuracies were excessive sweating and the restlessness of the volunteers during the intervals. In addition, it was believed that the noncontact tonometer depended less on operator error and was associated with less artifactual pressure lowering.¹⁶ The IOP was measured before march, during the six rest periods during the march, every 30 min for the first 6 hr after the march, and from then on, every 8 hr. The last IOP measurement was made 96 hr after the march. During the march, IOP measurements were made immediately when the subject arrived at the rest point. All IOP readings were taken in the erect position. The IOP was calculated as an average of three repeated measurements. Pulse rates and blood pressures were determined in conjunction with the IOP measurements.

The marching was done under ambient conditions of 17–32°C dry temperature and 45–85% relative humidity. No limitations were placed on eating or drinking, and the subjects were urged to drink water during the march and rest periods.

Blood samples were analyzed for complete blood count; levels of proteins, electrolytes, glucose, myoglobin, lipids, blood lactate, and pH; plasma osmolarity; and renal function. Urine samples were analyzed for renal function, electrolyte levels, and osmolarity.

A two-tailed paired student t-test was used for statistical analysis. The significance level was $P < 0.01$. Multiple linear-regression analysis was used to assess correlations between IOP and other laboratory parameters. No statistical difference was found between fellow eyes of each volunteer; therefore, the data were pooled for statistical analysis.

Results

All 22 subjects completed the march. Intraocular pressures and plasma osmolarities before and during the march are presented in Figures 1–3. The mean fall in IOP was significant ($P < 0.01$) at all time intervals during the march. The mean IOP before the beginning of the exercise was 15.2 ± 1.6 mmHg; immediately after the march, it was 12.4 ± 2.3 mmHg (a mean IOP reduction of 18.1%). The IOP remained significantly below baseline level at 2 hr postmarch and returned to pre-march levels by 3 hr. The maximal IOP reduction during the march (25.6%) was detected 15 hr into the exercise. The IOP again was reduced significantly 48 hr after marching (mean reduction, 4.9%).

In two subjects, the IOP decreased during the first and second intervals of the exercise, but during the third interval, the IOP rose by 6 mmHg (22.3% of baseline pressure). Although no anterior chamber pigment dispersion or Krukenberg's spindle was evident before exercise in any subject, pigment dispersion was noticed during the third interval only in these two volunteers.

Subjects with higher initial IOP tended to have greater pressure reductions during and after marching. For example, those with initial pressures ≥ 15.5

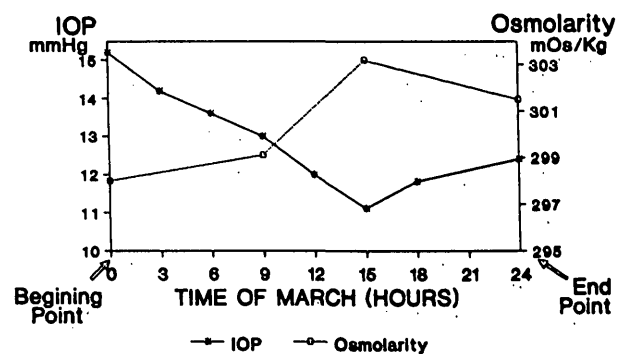


Fig. 1. Average changes in IOP and serum osmolarity during a 110-km march with a 20-kg backpack load.

mmHg had an average pressure reduction of 3.8 ± 0.4 mmHg compared with 2.9 ± 0.6 mmHg in the subjects with initial pressures < 15.5 mmHg. This difference was statistically significant ($P < 0.01$).

Subjects with lower VO_{2max} tended to have greater pressure reductions and greater osmolarity levels during and after marching. There was no correlation between VO_{2max} and the initial IOP.

There was a significant ($P < 0.001$) increase in plasma osmolarity during the march, with a peak rise at the second and third time intervals and a return to baseline values 4–24 hr after the march. Plasma osmolarity was elevated again 48 hr postmarch ($P < 0.01$) and returned to the baseline level 48 hr later.

The plasma osmolarity during the exercise was changed in association with blood urea, uric acid, and creatinine levels. However, during the recovery period, the plasma osmolarity could be correlated only with the blood urea level. The serum urea concentration demonstrated two peak rises, the first was during the march and the second was 48 hr after the march. During the exercise, the increase in serum urea concentration appeared to be mainly a result of reduced urinary excretion, although a lesser effect could be attributed to increased urea production. After the march, the laboratory data showed increased protein catabolism and urea production.^{17,18}

There was increased blood lactate concentrations and a minimal decrease in pH during the march. However, none of these changes were statistically significant or associated with IOP changes.

Only the plasma osmolarity had a strong correlation with IOP changes. This was an inversely proportional relationship, with the lowest IOP coinciding with the highest osmolarity level and vice versa. This correlation was most evident when compared 15 hr into the march ($R = -0.6793$, $P < 0.001$) and 48 hr postmarch ($R = -0.6496$, $P < 0.001$).

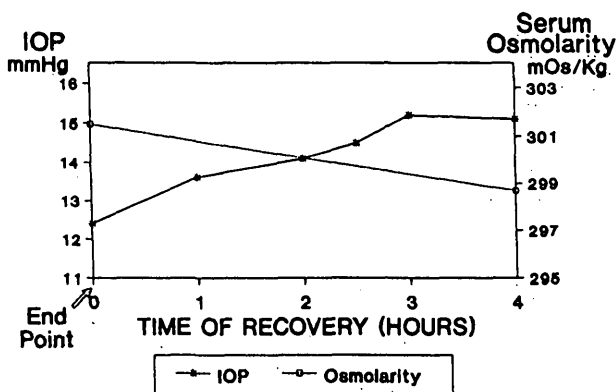


Fig. 2. Average changes in IOP and serum osmolarity during the first 4 h of recovery from a 110-km march with a 20-kg backpack load.

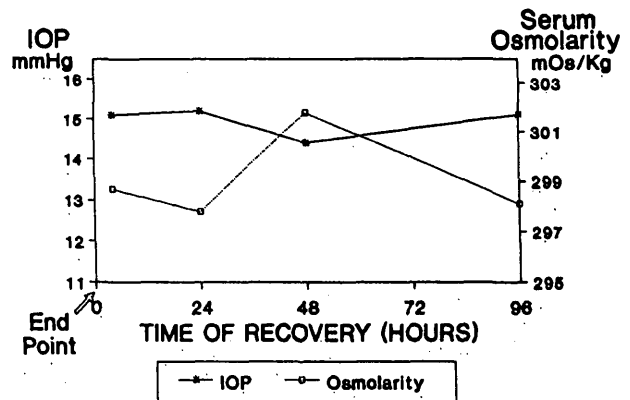


Fig. 3. Average changes in IOP and serum osmolarity during 96 h of recovery from a 110-km march with a 20-kg backpack load.

There was no correlation between IOP changes and levels of blood pH, blood lactate, serum proteins, and electrolytes; hematologic parameters; or renal function. The heart rate and the diastolic and systolic blood pressure were not correlated with the IOP.

When comparing diurnal curve measurements of IOP before the study with those during the study in the individual subject, no significant variations of IOP were found in the former. (This suggests that the significant ocular hypotensive response was related to the exercise and not to diurnal variation.)

Discussion

Numerous studies show a transient reduction in IOP in rabbits,¹⁹ normal volunteers,^{2-7,10-12} and glaucomatous patients^{3,8,9,20} after various forms of short-term exercise. The degree of ocular-hypotensive response may vary from study to study as a result of different experimental methods (such as the type and degree of stress), prestudy physical conditioning, baseline IOP, timing of pressure measurement, and diurnal variation.

Many physiologic and metabolic changes occur in the body during exercise, and the factors relevant to IOP cannot be differentiated easily from unrelated events. Although it is tempting to associate decreased IOP with intra- and postexercise systemic hemodynamic factors (such as heart rate or elevated diastolic or systolic blood pressure), we observed no such association in our study, despite the exposure of our subjects to an exceptionally strenuous exercise.

The outflow channels of the eye contain fibrinolytic activity. Such fibrinolysis may assist in preventing obstruction of the aqueous outflow pathways and participate in the regulation of IOP. Because exercise increases systemic fibrinolytic activity,²¹ we can specu-

late that exercise may increase the facility of outflow. However, others⁶ did not find significant changes in facility of outflow or episcleral venous pressure after exercise.

Some studies attempted to associate the ocular hypotensive response to exercise with increased plasma osmolarity, increased blood lactate level, and decreased pH level.^{4,7,19} However, no significant difference was found in IOP reduction when comparing aerobic and anaerobic exercise, despite significant differences in blood pH and lactate measurements.⁴

In our study, the subjects were well conditioned to tolerate such strenuous exercise. Despite this conditioning, IOP was reduced significantly during and after exercise. This was associated with an increased serum osmolarity, which could be related to dehydration and increased concentration of urea and other osmotic components. Subsequently, there would be an osmotic disequilibrium between the serum and aqueous humor. This would shift water from the aqueous humor and vitreous into the serum, causing ocular "dehydration" that would be manifested by an IOP reduction.

In two subjects, the IOP decreased during the first and second intervals of the march, but during the third interval, the IOP rose by 6 mmHg (22.3%) above baseline pressure. They both had exercise-induced pigment dispersion, and the release of pigment during the march mechanically obstructed the trabecular meshwork, decreased the outflow facility, and increased the IOP. Consequently, the pigment dispersion overrode the usual pressure-lowering effect of exercise and increased serum osmolarity seen in most normal volunteers.

However, the hyperosmolarity per se is not the only factor to be considered when interpreting the effect of exercise on IOP. Other factors not measured in our study might play a role in IOP reduction. For example, hormones like vasopressin²² or epinephrine^{6,19} may be involved in a regulatory mechanism that adjusts aqueous humor production during exercise.

Also, if the IOP decrease during the march correlated with body hydration and osmolarity, then by detecting an abnormal reduction of IOP, we could determine (in a simple and noninvasive way) physiologic status during a continuous strenuous exercise.

Key words: intraocular pressure, osmolarity, exercise, marching, pigment dispersion

References

1. Smith DL, Kao SF, Rabbani R, and Musch DC: The effect of exercise on intraocular pressure in pigmentary glaucoma patients. *Ophthalmic Surg* 20:561, 1989.
2. Passo MS, Goldberg L, Fliot DL, and Van Buskirk EM: Exercise conditioning and intraocular pressure. *Am J Ophthalmol* 103:754, 1987.
3. Lempert P, Cooper KH, Culver JF, and Tredici TJ: The effect of exercise on intraocular pressure. *Am J Ophthalmol* 63:1673, 1967.
4. Keilar RA, Teraslinna P, Row DG, and Jackson J: Standardized aerobic and anaerobic exercise: Differential effect on intraocular tension, blood pH and lactate. *Invest Ophthalmol* 14:782, 1975.
5. Shapiro A, Shoenfeld Y, and Shapiro Y: The effect of standardized submaximal work load on the intraocular pressure. *Br J Ophthalmol* 62:679, 1978.
6. Stewart RH, LeBlanc R, and Becker B: Effect of exercise on aqueous dynamics. *Am J Ophthalmol* 69:245, 1970.
7. Marcus DF, Krupin T, Podos SM, and Becker B: The effect of exercise on intraocular pressure: I. Human beings. *Invest Ophthalmol* 9:749, 1970.
8. Leighton DA: Effect of walking on the ocular tension in open-angle glaucoma. *Br J Ophthalmol* 56:126, 1972.
9. Shapiro A, Wolf E, Ferber I, and Merin S: The effect of physical activity on the intraocular pressure of glaucomatous patients. *Eur J Appl Physiol* 52:136, 1983.
10. Leighton DA, and Phillips CI: Effect of moderate exercise on the ocular pressure. *Invest Ophthalmol* 9:749, 1970.
11. Leighton DA and Phillips CI: Effect of moderate exercise on the ocular tension. *Br J Ophthalmol* 54:599, 1970.
12. Myers KJ. The effect of aerobic exercise on intraocular pressure. *Invest Ophthalmol* 13:74, 1974.
13. Henkid P, Leitman M, and Weitzman E. The diurnal curve in man: New observations. *Invest Ophthalmol* 12:705, 1973.
14. Biro I and Botar F: Ueber das Verhalten den Augendrucks Bei Verschiedenen Sportsleistugen. *Klin Monatsbl Augenheilkd* 140:123, 1962.
15. Pandolf KB, Givoni B, and Goldman RF. Predicting energy expenditure with loads while standing or walking very slowly. *J Appl Physiol* 43:577, 1977.
16. Moses RA, Lin CH: Repeated applanation tonometry. *Ophthalmologica* 142:663, 1961.
17. Booth FW and Watson PA: Control of adaptations in protein levels in response to exercise. *Federation Proceedings* 44:2293, 1985.
18. Refsum HE and Stromme SB: Urea and creatinine production and excretion in urine during and after prolonged heavy exercise. *Scand J Clin Lab Invest* 33:247, 1974.
19. Marcus DF, Krupin T, Podos SM, and Becker B: The effect of exercise on intraocular pressure: II. Rabbits. *Invest Ophthalmol* 9:753, 1970.
20. Kypke W and Hermannspann U: Glaukom, korperliche arbeit und sport. *Klin Monatsbl Augenheilkd* 164:321, 1974.
21. Biggs R, Macfarlane RG, and Pilling J: Observations on fibrinolysis. *Lancet* 1:402, 1947.
22. Cole DF and Nagasubramanian S: The effect of natural and synthetic vasopressins and other substances on active transport in ciliary epithelium of the rabbit. *Exp Eye Res* 13:45, 1972.