



Effect of repeated endurance exercise on intraocular pressure in healthy subjects: a prospective pilot study based on a 500-km swim relay

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ABSTRACT

Aim of the study: To investigate exercise-related changes in the intraocular pressure (IOP) in healthy participants of a 500-km swim relay.

Material and methods: A group of 12 well-trained amateur swimmers aged 13-67 years participated in a 500-km swim relay in the Warta River, Poland. Each participant underwent detailed clinical examinations, including IOP and central corneal thickness measurements, 2-3 weeks before the relay (baseline) and at peak effort (10 min after the last shift). A baseline maximal treadmill exercise test was also conducted for measurement of the maximal oxygen consumption (VO₂) and metabolic equivalent of task (MET) values.

Results: None of the athletes (12 eyes) exhibited significant changes in IOP at peak effort (mean change from 14.3 to 15.4 mmHg,

$p > 0.05$). Six male subjects exhibited an exercise-induced mean increase in IOP at peak effort, from 15.6 to 18.5 mmHg (6 eyes, $p < 0.05$). In six female subjects, the peak effort was not associated with significant IOP changes; IOP mean declined slightly from 13.0 to 12.3 mmHg (6 eyes, $p > 0.05$). IOP parameters, including the pressure at rest, pressure at peak effort, and pressure change, showed no significant correlations with cardiorespiratory aerobic fitness determined by VO₂ and MET.

Conclusions: This pilot study did not reveal changes in IOP among well-trained amateur athletes in response to prolonged vigorous swimming. These results, as well as sex-specific differences, in IOP changes at peak effort due to the small sample size must be confirmed by examinations in a larger group.

KEY WORDS: endurance swim, exhaustive exercise, intraocular pressure, glaucoma, men, women.

INTRODUCTION

Glaucoma is the leading cause of blindness worldwide. Importantly, it is an avoidable visual impairment; therefore, potential prevention strategies are crucial [1-3]. The primary risk factor for glaucoma development is an elevated intraocular pressure and associated fluctuations that lead to gradual dysfunction of the optic nerve [1-3].

Of late, interest in participation in intense endurance exercise has been increasing globally. The popularity of sports events such as running marathons, ultramarathons, and triathlons is systematically rising, with thousands of participants gathering for every event. As opposed to regular moderate physical activity (PA), which has well-known beneficial effects, exhaustive prolonged exercise may have a negative impact on

health, particularly in susceptible individuals. Muscle damage, electrolyte fluctuations, hemostatic disorders, and even sudden cardiac death are among the most common detrimental effects of intensive PA [4, 5]. Several studies have also investigated the potential relationship between exercise and intraocular pressure (IOP), although the obtained results are inconsistent. The majority of studies show that PA may reduce IOP, although the decrease is transient and the pressure shortly returns to its baseline value [6, 7]. In contrast, some studies have shown that exercise induces a transient increase in IOP [8]. Interestingly, IOP fluctuations may be associated with the habitual PA level and physical fitness. Dane *et al.* obtained different responses to submaximal exercise in athletes and sedentary subjects [9]. However, most previous studies examined the effects of short

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PA sessions, and data regarding the relationship between long-term intensive exercise and IOP are scarce. Moreover, to our knowledge, no study has investigated the relationship between exhaustive endurance swimming and IOP.

AIM OF THE STUDY

The aim of this study was to investigate the relationship between intensive prolonged endurance exercise and IOP by evaluating IOP changes in individuals participating in a 500-km swim relay.

MATERIAL AND METHODS

All athletes provided written consent to participate in the swimming marathon and study as well as publication of their data. Parents provided consent on behalf of the teenage swimmers. The study protocol was approved by the Bioethics Committee of the Medical University of Lodz.

From July 12 to 17, 2016, a team of well-trained amateur athletes participated in a 500-km swim relay in the Warta River, Poland. Mr. Roman Bartkowiak, the main organizer as well as a participant, is a well-known athlete and swimming guard who completed a 120-km, non-stop, open-water ultramarathon swim in 2010 [10]. He created the team of amateur swimmers who trained under his supervision. The main goal of the event was to collect funds for the Pediatric Oncology and Hematology Clinic in Poznan, Poland.

The present study included 12 participants of the relay (six female participants aged 16-43 years and six male participants aged 13-67 years; mean age, 29.4 ± 15.4 years). Two to three weeks before the relay, each participant underwent detailed clinical examinations in the Department of Preventive Medicine and Centre of Sports Medicine, Medical University of Lodz, Poland.

The components of the baseline evaluations were as follows: IOP and central corneal thickness (CCT) measurements, a questionnaire interview, physical examination, blood pressure measurements, analysis of the body composition, spirometry, a maximal treadmill exercise test, echocardiography, endothelial function measurements, and blood sample collection. Metabolic equivalent of task values (MET) and the maximal oxygen consumption (VO_2) were recorded as measures of cardiorespiratory aerobic fitness during the maximal treadmill exercise test. The examinations revealed favorable health conditions, with no history of any chronic diseases or treatments in all participants. Detailed medical history was obtained from all participants, with emphasis on the eye condition. There was no history of high refractive error (including high astigmatism), dry eye, glaucoma, ocular hypertension, or other systemic diseases (diabetes, hypertension, etc.). The athletes denied any history of eye surgery (including refractive surgery). At the time of measurements, all participants had non-inflamed eyes.

During the event, the body temperature and heart rate (HR) were continuously monitored using the Polar V800 HR monitors (POLAR Electro, Kempele, Finland), which has been proven useful for measuring HR [11]. IOP was mea-

sured at rest during the baseline clinical examination and at peak effort, i.e., 10 min after the last swim relay, using a handheld applanation tonometer (Tono-Pen AVIA; Reichert Technologies, Buffalo, NY, USA). Prior to these measurements, all eyes were anesthetized using 0.5% proparacaine hydrochloride (Alcaine). Three consecutive readings were taken to obtain a difference of < 2 mmHg. If the difference was > 2 mmHg, a fourth or fifth reading was taken and the average was calculated. CCT was also measured at rest during the baseline clinical examination using a handheld pachymeter (iPac; Reichert Technologies, Buffalo, NY, USA). A single experienced investigator performed all measurements using the same equipment with the participant in a sitting position. All measurements were obtained for the right eye and corrected for CCT. Similar methodology and devices have been used by other authors [9]. All swimmers used the same model of swimming goggles: Speedo Futura Biofuse Flexiseal during the day and Speedo Futura Biofuse during the night. The face area of both models is the same (vertical width: 46 mm, horizontal width: 63 mm, face area: 2898 mm^2).

Protocol of the 500-km swim relay

The event was set to start on July 12, 2016 at 9:00 p.m., between the 297th and 292nd kilometer of the Warta River. The distance was repeated 90.5 times (5 km per stage), and the last 48 km ended in Poznan, in the 244th kilometer of the Warta River, at 4.00 p.m. on July 17. The total covered distance was approximately 500 km. The athletes took turns swimming during the relay; each time they started, they jumped into the water from the boat after the previous swimmer completed a 5-km shift. The competitors swam each shift within 44:46 to 60:02 min, depending on the time of day, water temperature, and atmospheric conditions (i.e., strong wind, rain, etc.). The air temperature ranged between 8°C (9.00 p.m.) and 22°C (9.00 a.m.). The mean temperature of the water ranged between 18.8°C (9.00 p.m.) and 17.2°C (9.00 a.m.). All participants were accommodated in tents during rough conditions.

Statistical analysis

All statistical analyses were performed using Statistica version 13.3 (TIBCO Software Inc., Statistica, Tulsa, Oklahoma, USA). The results for the quantitative variables are presented as mean \pm standard deviation. Data were verified for normality of distribution by the Shapiro-Wilk test. For the assessment of sex-specific differences in the mean values of the analyzed indices, Student's *t*-test for two means from small samples was used after controlling for the equality of variances in the Fisher-Snedecor test. Spearman's correlation analysis was used to evaluate the association between IOP and PA parameters. A *p*-value of < 0.05 was considered statistically significant in all analyses.

RESULTS

Table I presents the IOP characteristics (corrected for CCT) as well as cardiorespiratory aerobic fitness (VO_2 max and MET) values for each participant.

Table I. Intraocular pressure (corrected for central corneal thickness) measured in the right eye and baseline cardiorespiratory aerobic fitness characteristics for all participants in a 500-km swim relay

Volunteer	Age (years)	IOP at rest (mmHg)	IOP at peak effort (mmHg)	ΔIOP (mmHg)	MET (3.5 ml/kg/min)	VO ₂ max (ml/kg/min)
Male participants						
1	13	15.75	16.40	+0.6	10.5	36.7
2	16	19.25	24.10	+4.9	14.9	52.2
3	29	20.00	25.50	+5.5	15.1	52.8
4	29	12.47	17.07	+4.6	15.2	54.0
5	37	13.33	14.58	+1.3	10.4	37.5
6	67	13.00	13.25	+0.3	12.0	42.2
Female participants						
1	16	12.33	9.33	-3.0	11.5	39.8
2	17	15.00	13.75	-1.3	12.3	43.1
3	22	18.00	15.13	-2.9	11.6	42.4
4	24	7.00	11.60	+4.6	13.3	46.5
5	39	13.00	13.00	0.0	14.3	50.2
6	43	12.50	11.25	-1.3	11.1	38.9

IOP – intraocular pressure, ΔIOP – change in intraocular pressure (IOP at peak effort – IOP at rest), MET – metabolic equivalent, VO₂ max – maximal oxygen consumption

Table II. Exercise-induced changes in the mean intraocular pressure (corrected for central corneal thickness) in the right eye of male and female participants in a 500-km swim relay

	Intraocular pressure (mmHg)					
	Male		Female		All	
	Mean	SD	Mean	SD	Mean	SD
At rest	15.63	3.3	12.97	3.6	14.30	3.6
Peak effort	18.48	5.1	12.34	2.1	15.41	4.9
Change	+2.85*	1.8	-0.63	1.6	+1.11	1.3
<i>p</i>	0.032*		0.606		0.236	

Student's *t*-test, *p* – probability value, **p* < 0.05

In the male subjects (6 eyes), intensive repeated exercise was associated with an increase in IOP (*p* < 0.05). On the other hand, no significant association was observed for the female subjects (6 eyes, *p* > 0.05). The mean exercise-induced changes in IOP (corrected for CCT) in the entire group of participants are shown in Table II.

The observed changes in IOP at the peak of effort were not dependent on age. Finally, there was no significant correlation between the IOP parameters, including IOP at rest, IOP at peak effort, and change in IOP, and cardiorespiratory aerobic fitness determined by VO₂ max and MET values obtained during the baseline maximal exercise test (Table III).

DISCUSSION

The purpose of the present study was to investigate changes in IOP in response to repeated prolonged intensive swimming. Our paper presents unique data concerning tonometry measurements for individuals participating in an open-water

swim relay. To our knowledge, this is the first study investigating changes in IOP during long-distance swimming. Most previously published reports involved rather short-term dynamic exercises, sometimes without relevant IOP measurements.

In the present study, we attempted to determine whether participation in such an exhaustive exercise influenced IOP values and explored the potential factors contributing to the observed changes. The most consistent results were observed for male subjects, who exhibited an IOP increase (*p* = 0.032). Contrary to male subjects, female subjects showed no change in IOP in response to the exercise. All twelve athletes (12 eyes) exhibited no changes in intraocular pressure at peak effort (Table II). However, all the results, as well as some observed differences in both sexes in intraocular pressure changes at the peak of effort, due to the small size of the sample, should be confirmed in further longitudinal studies and do not allow for any general statements and conclusions to be made in this pilot study.

The effects of PA on the risk of glaucoma are poorly understood. There is no consistency in results regarding the relationship between the dose and intensity of exercise and IOP and glaucoma development [9, 12, 13]. Some previous studies have shown that regular long-term dynamic exercise (mostly running) might lower IOP. Williams provided evidence that regular vigorous physical activity may reduce glaucoma risk. In a prospective epidemiological study involving a cohort of 29,854 male runners followed for 7.7 years, there was a 54% decline in the risk of incident-reported glaucoma for subjects who ran, relative to the risk for the unfit men [13]. Several explanations for a dynamic exercise-related IOP decrease have been reported, including changes in plasma lactate lev-

els, plasma osmolarity, episcleral venous pressure, blood pH, and hormones [14]. Moreover, some studies reported that exercise-related improvements in the metabolic status, particularly insulin resistance and blood pressure, may decrease IOP [15].

In contrast to the above findings, a study of 11,246 South Korean adults found that daily vigorous exercise was associated with a higher glaucoma prevalence. In addition, the intensity of exercise was positively associated with glaucoma diagnosis in men [12]. An exercise-related increase in IOP has also been reported in other studies, with a transient IOP elevation and even glaucomatous damage observed in individuals practicing anaerobic activities such as yoga, weightlifting, bodybuilding, etc. [8, 16, 17].

Little is known about the potential effects of swimming on IOP and the risk of glaucoma. A study performed in an animal model revealed that daily swimming by middle-aged mice was beneficial in terms of protection of the retinal ganglion cells against age-related functional loss and signs of stress [18].

The results obtained in our study are, to some extent, similar to those reported by Dane *et al.*, who examined 25 sedentary subjects and 24 athletes aged 17-22 years. Acute exercise elevated IOP in male athletes and had no influence on IOP in female athletes [9]. Sex-specific differences were also presented in the latest report of Lin *et al.* Among male subjects, the authors found that high-intensity exercise resulted in a higher glaucoma prevalence than did moderate intensity exercise [12]. Interestingly, this relationship was not found in women. It is difficult to explain the reason for these sex-specific discrepancies, and further studies in large cohorts are warranted.

A few other studies involving swimmers primarily considered the relationship between the use of goggles and IOP [19, 20]. According to Morgan *et al.*, the use of goggles increased IOP by 4.5 mmHg; however, the pressure increase persisted only for the duration of goggle use [19]. Moreover, a greater IOP increase was associated with a smaller face area of the swimming goggles. In our study, we assumed that the use of swimming goggles would have no significant influence on IOP values, because the face area of the goggles was 317 mm² larger than that of the biggest goggles used in the study of Morgan *et al.*, which resulted in a mean IOP increase of 0.4 mmHg. The IOP value obtained 5 min after removal of the goggles was lower than the value obtained before goggle application by a mean of 1.75 mmHg ($p < 0.001$, $df = 19$) [19]. According to Ma *et al.*, the average IOP values before, during (5-20 min), and after swimming goggle wear were 11.88 ± 2.82, 14.20 ± 2.81, and 11.78 ± 2.89 mmHg, respectively. The pressure increased immediately after goggle wear ($p < 0.05$) and returned to normal values immediately after removal ($p > 0.05$) [20]. In the present study, however, there was no control group, and the above data partially justify our preclusion of the impact of goggles on IOP in the study group.

Hyponatremia is another important factor influencing health outcomes during intensive prolonged exercise [21].

Table III. Relationship of the intraocular pressure at rest, intraocular pressure at peak effort, and change in intraocular pressure with the maximal oxygen consumption and metabolic equivalent values obtained during a baseline maximal treadmill exercise test for participants in a 500-km swim relay

	<i>n</i>	Spearman's correlation between IOP and PA parameters	<i>p</i>
Male participants			
IOP at rest vs.			
MET	6	-0.028571	0.957155
VO ₂ max	6	-0.085714	0.871743
IOP peak effort vs.			
MET	6	0.657143	0.156175
VO ₂ max	6	0.600000	0.208000
ΔIOP vs.			
MET	6	0.600000	0.208000
VO ₂ max	6	0.657143	0.156175
Female participants			
IOP at rest vs.			
MET	6	0.028571	0.957155
VO ₂ max	6	0.028571	0.957155
IOP peak effort vs.			
MET	6	0.428571	0.396501
VO ₂ max	6	0.428571	0.396501
ΔIOP vs.			
MET	6	0.695725	0.124789
VO ₂ max	6	0.695725	0.124789
All participants			
IOP at rest vs.			
MET	12	0.087566	0.786694
VO ₂ max	12	0.105079	0.745177
IOP peak effort vs.			
MET	12	0.433566	0.159106
VO ₂ max	12	0.440559	0.151735
ΔIOP vs.			
MET	12	0.540354	0.069717
VO ₂ max	12	0.519301	0.083589

n – number of participants, IOP – intraocular pressure, PA – physical activity, *p* – probability value, ΔIOP – change in intraocular pressure (IOP peak effort – IOP at rest), MET – metabolic equivalent, VO₂ max – maximal oxygen consumption

Wagner *et al.* observed two cases of asymptomatic hyponatremia among 25 male open-water ultramarathon swimmers participating in a marathon swim in Lake Zurich [20]. However, such changes did not develop during the swim marathon that we described in our previous report [10]. In the present swim relay, we also monitored the electrolyte status. Only slight electrolyte fluctuations were noted in both male

and female subjects. The complete results will be presented in another article.

The main strength of our study is the unique exercise protocol involving repeated exhaustive outdoor swimming in difficult environmental conditions. We have not found similar data in the available scientific literature. Apart from IOP, we monitored several important vital functions, including cardiological, biochemical, and hemostatic changes, during the event; those results have been published elsewhere [22].

A major shortcoming of this study is the small number of participants, which may have influenced the statistical significance of the obtained results. However, it should be noted that only a few amateur swimmers are physically and mentally prepared to perform similar strenuous, repeated endurance efforts in very difficult environmental conditions. We used a unique opportunity to monitor several important physiological and biochemical parameters in female and male participants of this unusual charitable 500-km swim relay [22].

Moreover, although IOP was measured at baseline (2-3 weeks before the relay) and at peak effort (10 min after the last shift), its recovery over time after the event (e.g., at 48 h) was not measured. Evaluation of its recovery can provide relevant information regarding possible prolonged or even permanent IOP changes in response to repetitive endurance swimming. In addition, IOP was not measured during the event (after every shift or every few shifts); these data could also improve our findings.

Another limitation is the resting time between sessions. We analyzed a heterogeneous group of swimmers that included male and female adolescents (13- to 16-year-old participants) and adults. The exercise was performed during seven 45- to 60-min sessions, and the rest period between sessions may have allowed partial or full recovery of IOP to the initial values. Factors that may have had an additional impact on IOP include the lack of sleep, cold weather, and stress related to responsibility for success of the enterprise, which was be-

yond individual commitment (group responsibility for success).

The lack of a control group is yet another limitation; however, it is justified. A control group would include individuals who would wear and remove goggles just like the swimmers, spend their free time between shifts in swimming in the same manner and in the same conditions, and enter the water without swimming for the same period of time in their shifts during the relay. However, this seems very difficult and even unethical, considering the reports about the impact of goggles on IOP without additional activity in the form of swimming. In our study, IOP was measured 10 min after the swimmers left the water and removed their goggles. Therefore, it seems reasonable that IOP changes at peak effort relative to the baseline pressure should simply be considered a result of long-term repetitive swimming.

Despite the above limitations, the present study seems to be the first to present changes in IOP in response to long-term repetitive exhaustive swimming. Considering the popularity of participation in endurance sports, further large studies are required to address our findings.

Observation of the relationship between IOP and regular exercise among the participants of this study is ongoing. The results of the follow-up measurements will be presented in future manuscripts.

CONCLUSIONS

This pilot study did not reveal changes in intraocular pressure among well-trained amateur athletes in response to prolonged vigorous swimming. All results, as well as some sex-specific differences, in intraocular pressure changes at the peak of effort due to the small size of the sample should be confirmed in further longitudinal studies.

DISCLOSURE

The authors declare no conflict of interest.

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