EFFECTS of MODERATE EXERCISE on INTRAOCULAR PRESSURE & OCULAR BLOOD FLOW

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Abstract

The purpose of this pilot study was to evaluate the effect of moderate exercise over a short duration on intraocular pressure and pulsatile ocular blood flow. Thirty-one subjects (20 males and 11 females) ranging in age from 20-60 had measurements of intraocular pressure and pulsatile ocular blood flow before and after pedaling on a stationary bicycle for 10 minutes. Measurements were taken with an Ocular Blood Flow Analyzer™ Tonograph. Intraocular pressure was significantly reduced, and pulsatile ocular blood flow was significantly increased, following moderately intense exercise. There was a significant reduction in intraocular pressure for both the male and female subjects. However, only the male subjects showed a significant increase in pulsatile ocular blood flow. The subjects who did not exercise or who exercised 1-2 times a week showed both a significant reduction in intraocular pressure and increase in pulsatile ocular blood flow. Subjects who exercised 3-5 times a week showed a significant reduction in intraocular pressure, but they did not have a significant increase in pulsatile ocular blood flow. This study gives evidence that exercise can decrease intraocular pressure and increase pulsatile ocular blood flow.

Key Words

choroid, diabetes, exercise, glaucoma, intraocular pressure, neuroretina, pulsatile ocular blood flow

INTRODUCTION

There is significant understanding of how exercise affects physiological functions, and there have been extensive studies evaluating the effects of exercise on the cardiovascular and respiratory systems.[1,2] Exercise has been demonstrated to positively impact musculo-skeletal, endocrine, and immune functions.[1] Physical exercise can reduce the risk of coronary heart disease, stroke, high blood pressure, colon cancer and Type 2 Diabetes. Exercise can even provide a temporary reduction in intraocular pressure (IOP) from 2-5 mm Hg. Aerobic exercise programs of 3-6 months duration have been found to lower IOP in patients with glaucoma and with glaucoma suspects. However, within 3 weeks of quitting the exercise program, IOP returned to the levels present prior to starting the aerobic exercise program.[3]

ANATOMY OF OCULAR BLOOD FLOW

Two circulatory pathways with different characteristics supply the human retina.[4,5] These are the retinal vasculature pathway and choroidal vasculature pathway.

The retinal vasculature pathway

This pathway is a pulsatile component that varies with each heartbeat while the choroidal vasculature pathway is a more continuous component of the retinal circulation.[4,6] The retinal vasculature supplies the nutrients to the inner two-thirds of the neuroretina.[5] The retinal vasculature is relatively sparse and is nonexistent in the macula area.[7] This vasculature pathway consists of a few atypical large arteries, arterioles, venules and veins oriented parallel to the circumference of the neuroretina. Arterioles, capillaries and veins also may travel a course perpendicular to the retinal circumference. This anatomical structure prevents photoreceptors from being covered by a dense, circumferential vasculature. The sparse retinal vasculature has a corresponding disadvantage in that the outer neuroretina is relatively distant from the larger vessels that could be its source of nourishment. The development of any vascular defect in the retina will interfere with the retina's supply of nutrients or elimination of waste products.[7]

The choroidal vasculature pathway

The choroid is immediately posterior to the retina, and its vessels support the outer one-third of the retina.[5] This, in part, helps to make up for the sparsity and distribution of retinal vessels. The choroidal vasculature is composed of two distinct vascular layers, with the outer layer comprising the large choroidal arteries and veins.[4] The second layer is the choriocapillaris, an extensive network of large, capillary-like vessels bound to the basal lamina of the retinal pigmented epithelium by Bruch's membrane. The choroidal circulation plays an important role in maintaining adequate function of the outer retina, photoreceptors, and macular regions.[7,8] Fenestrations, or small pores, in the choriocapillaris aid in supplying metabolites to the retina. Two characteristics of the choroidal circulation that are of interest are: 1) the blood flow in the choroid is in excess of the metabolic demand of the retina 2) abnormalities of the choroidal circulation are hypothesized to be part of the mechanism leading to the development of retinal degenerative diseases.[4,7]

Studies show that with increased age, there is a decrease in pulsatile ocular blood flow (the ocular blood flow with each heartbeat measured in μL/sec).[8,9] Age-related structural changes that occur in the retina could impact choroidal blood flow.[8] These changes include a reduction in photoreceptor density and retinal pigment epithelial cell cytoplasm volume. Further, a decrease in the number of viable retinal and choroidal cells could reduce the metabolic demand and, therefore, lead to a reduction of both retinal and choroidal blood flows.

PULSATILE OCULAR BLOOD FLOW CHANGES WITH EXERCISE

Age-related maculopathy, glaucoma and diabetic retinopathy are diseases of the neuroretina that together account for most blindness.[10] If changes in pulsatile ocular blood flow (POBF) precede degeneration of the neuroretina, any disruption in this blood flow might be a variable risk factor for age-related maculopathy. Changes in POBF during exercise might affect people with glaucoma associated with an elevated intraocular pressure.[2] Glaucoma may also involve a decrease in effective blood supply to ganglion cell axons at the prelaminar and laminar area of the optic nerve. Diabetic retinopathy is another important blinding disease with vascular complications that could be affected by pulsatile changes during exercise. Areas of the retina with diabetic damage may undergo neovascular proliferation or ischemic atrophy because of problems with blood regulatory mechanisms.[2]

Retinal and choroidal circulations play an important role in maintaining the metabolic needs of the retina.[7] Surprisingly, there are few studies evaluating changes in pulsatile ocular blood flow during exercise.[2,6] Obtaining this knowledge could have implications for understanding the etiology and treatment of maculopathy in the elderly.[10]

INTRAOCULAR PRESSURE CHANGES WITH EXERCISE

When the outflow of aqueous humor is restricted, the intraocular pressure (IOP) tends to rise. Since glaucoma is a disease that is associated with increased IOP, the treatment of choice is to use topical or oral pharmaceutical agents that maintain a safe level of IOP.[3] If there is an elevation of IOP, the patient's risk for ocular damage, also increases. Any method that reduces IOP in a glaucomatous eye is of interest. Exercise is such a tool.

Exercise leads to stimulation of the alpha and beta adrenergic receptors in target cells.[11] Because of this, physical exercise can cause a significant drop in intraocular pressure when compared to a subject's baseline level due to a hypotensive effect. The hypotensive effect is related to the relative workload, which is based on the exertion required, relative to the subject's fitness level.[6] With a continuous exercise program, a person's IOP values can be sustained at a significantly lower level.[12] When the exercise is discontinued, the IOP ultimately tends to return to pre-exercise levels.[13] Factors considered in these studies include age,[3,11-18] an active versus a sedentary lifestyle,[3,11,13-15] abnormally high IOPs, and the presence of suspected or diagnosed glaucoma.[3,16,19]

Avunduk et al found a correlation between total energy consumption and a decrease in IOP for both isokinetic and isometric exercises.[17] Furthermore, isokinetic exercise caused a more significant drop in IOP than isometric exercise when each was done at the same intensity level. Harris, Malinosky and Martin[11] also discovered that dynamic exercise lowered IOP. The effect was dependent on the intensity of the exercise. Shapiro, Shoenfeld and Shapiro found no correlation between a further decrease in IOP with a stepwise increasing workload. They proposed that this finding is because of a negative feedback mechanism attempting to stabilize the changing IOP.[20]

The purpose of the present study was to investigate the effects of moderate exercise of short duration on IOP and POBF. Evaluating the effect exercise has on both IOP and POBF allows for statistical analysis of pre-exercise IOP and POBF measurements, and post-exercise IOP and POBF.

MATERIALS

Instrument Operation

The Ocular Blood Flow Analyzer™ Tonograph (BFA)[a] was used in the study. See Figure 1A. The BFA measures the IOP 200 times per second while automatically measuring POBF. The POBF is calculated by the computer through analysis of the increase of systolic and decrease of diastolic IOP due to the pulsatile ocular blood flow.[21]

Using the BFA with a slit lamp reduces movement of both the patient and the examiner. This allows for a more accurate measurement of the blood flow. When the BFA is operating, air flows through the contact probe. The surface of the probe contains four circles, one inside the other. Air flows from the innermost circle underneath a thin membrane to the second circle from the outside. When the contact probe is touching the surface of the eye (Figure 1B.), the BFA measures intraocular pressure by way of pressure from the eye distorting the thin membrane on the probe tip. A red focusing beam is incorporated in the innermost circle on the contact probe to provide stability of the patient's fixation and to give the operator assistance of where to place the probe on the eye.[22] Data collected included IOP, POBF, pulse amplitude (PA), maximum IOP-minimum IOP, pulse volume (PV), and pulse rate (PR).

POBF was measured in microliters per second (μl/sec). Repeated measurements of the POBF bring the pulsatile ocular blood flow analyzer to detect changes of 16% with 95% confidence. While 16% does not seem discrete, invasive probes would be needed to obtain more accurate measurements. The average POBF is approximately 12.96μl/sec for normal males, and 15.36μl/sec for normal females. A Low POBF is indicated if the values fall below 8.4μl/sec for males, and 9.35μl/sec for females. The BFA tonograph measures IOP in a manner comparable to the Goldmann tonometer. The pulse volume estimates the change in blood volume needed to cause a change in pressure. The pulse rate indicates the heart rate in beats per minute.[22]

SUBJECTS

The parameters of the study were approved by the Northeastern State University Human Experimentation Advisory Committee. Our sample comprised 21 male and 12 female participants. All subjects reported they were in good health, and were not presently taking medications. The subjects read and signed informed consent forms that described the activity of the study, possible risks related to exercise and the researchers' contact information. The subjects were free to with-

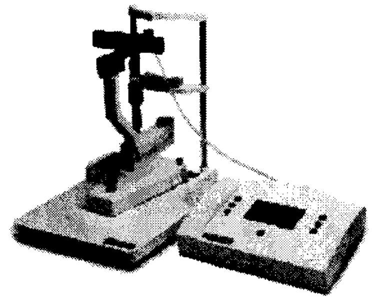

Figure 1A. Paradigm Ocular Blood Flow Analyzer™ Tonograph

Figure 1B. Model SE in contact with subject's cornea

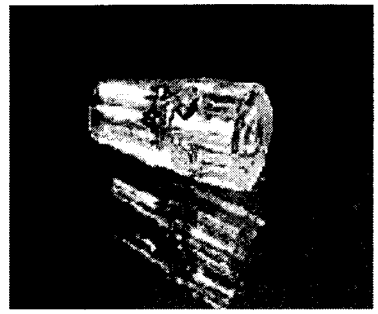

Figure 2. A photograph of the Ocular Blood Flow Analyzer probe tip.

draw from the study at any time for any reason. The age of the subjects ranged from 20 to 60. There were 25 subjects in the 20-29 year old category, two in the 30-39 year old category, three in the 40-49 year old category, one in the 50-59 year old category, and two in the 60-69 year old category. See Appendix A. The subjects were separated into two groups categorized by their stated routine exercise activity: 1) none/mild exercise (0 to 2 times per week); and 2) moderate/heavy exercise (3-5 times per week).

METHODS

Before any exercise began, blood pressure was measured to ensure cardiac stability. The subjects were then seated in an exam chair and one drop of 0.5 % proparacaine was instilled in each eye. Pre measurements of IOP, POBF, pulse rate, pulse volume and pulse amplitude were taken using the BFA mounted on a slit lamp. The subjects then exercised on a Schwinn AirDyne® stationary exercise bicycle[b] at low resistance for 10 minutes. The exercise bike was near the examination chair. The subjects were instructed to maintain a rate of 44 rpm on the bicycle speedometer, and were monitored for signs of distress that might require discontinuation of exercise. Each subject finished the 10 minute time limit and maintained 44 rpm successfully. Immediately following the exercise, the subjects walked to the exam chair, and another drop of 0.5 % proparacaine was instilled in each eye. The post exercise measurements of IOP, POBF, pulse rate, pulse volume and pulse amplitude were taken using the BFA. After sufficient pulses were recorded, all subjects' corneal health was evaluated by slit lamp evaluation before they left. Two of the subjects (one male, one female) were excluded due to a malfunction of the blood flow analyzer. This left 31 participants with useable data.

RESULTS

When comparing all subjects, mean intraocular pressure (IOP) significantly dropped from about 15.5 mm Hg to 11.1 mm Hg after 10 minutes of exercise (Table 1). This change was statistically significant ($p < 0.001$). At the same time there was a significant increase in pulsatile ocular blood flow (POBF) from 11.3 µL/sec to 14.1 µL/sec (Table 1). This also was statistically significant ($p=0.004$). Individual findings are shown in Appendix A.

Male vs. Females

When the 31 subjects were divided by gender, the females ($n= 11$) demonstrated a reduction in mean IOP from 16.1 to 11.4 mm Hg (Table 2), that was statistically significant ($p= 0.001$, Table 2). However, the increase in POBF was not significant ($p=0.17$). Males ($n= 20$) showed both a significant reduction in IOP (from 15.3 to 10.9 mm Hg, $p< 0.001$) and a significant increase in POBF (11.2 to 14.4 µL/sec, $p=0.015$, Table 2). Both males (65 to 100 bpm) and females (70 to 125 bpm), had significant increases in pulse rates (Table 2).

Exercise Level

When the subjects were categorized according to level of weekly exercise, the no exercise/mild exercise group ($n=14$) showed a mean reduction of more than 5 mm Hg in IOP ($p< 0.001$, Table 3). There was also a mean gain of 3.4 µL/sec in pulsatile ocular blood flow. This was marginally significant ($p=0.042$).

The second group ($n=17$), those with moderate/heavy weekly exercise regimen, showed a mean reduction in IOP of 3.8 mm Hg that also was statistically significant ($p< 0.001$, Table 3). This group also demonstrated a marginal increase in POBF (2.4 µL/sec). The significance of this result was comparable to the no exercise/mild exercise group ($p= 0.058$). Both groups showed significant increases in mean pulse rate; the low exercise group had a 47 beats per minute (bpm) increase and the heavy exercise group showed a 38 bpm increase.

DISCUSSION

Moderate exercise was found to immediately reduce IOP, even in those subjects who exercised frequently. There was an average reduction of 4.4 mm Hg, which was similar to the mean reduction of 5.5 mm Hg reported by Price et al.[3] There was a similar IOP reduction in the male subjects and female subjects (4.305 vs. 4.618 mm Hg). There was a greater mean reduction in IOP (5.20 mm Hg) for the subjects who had zero to mild routine weekly exercise regimen (0-3 times/week) as compared to those subjects who exercised moderately to heavily each week (3.771 mm Hg).

There was an average increase in POBF of 2.861 µL/sec for all subjects. Interestingly, the male subjects had a greater increase in POBF than did females (3.160 vs. 2.318 µL/sec), although male subjects outnumbered females by the ratio of 2:1. The subjects with zero to mild weekly exercise showed a greater increase in POBF than the subjects with moderate to heavy weekly exercise (3.364 vs. 2.447 µL/sec).

Our findings regarding the positive effects of exercise are potentially valuable for individuals with diseases such as glaucoma and retinal ischemic disorders. If moderate exercise decreases intraocular pressure by 4-5 mm Hg, practitioners could use exercise as an adjunct to topical medications to lower intraocular pressure on a sustained basis. This combination could help bring about a larger decrease in IOP than medications used alone, and could help reduce the need for additional treatments to reach or maintain the desired decrease in IOP. Additionally, patients with retinal ischemic disorders may benefit from increased blood flow to the retina and choroid. The increased blood

Table 1. Mean pre- and post-exercise measurements of all subjects.			
	Pre-exercise (mean +/- SD)	Post-exercise (mean +/- SD)	Significance of change (p Value)
IOP (mm Hg)	15.535 +/- 2.739	11.119 +/- 2.956	< 0.001
POBF (µL/sec)	11.284 +/- 3.523	14.145 +/- 5.558	0.004
Pulse Rate (bpm)	66.92 +/- 16.08	109.17 +/- 25.35	< 0.001

Table 2. Mean pre- and post-exercise measurements of male vs. female subjects.			
	Pre-exercise (mean +/- SD)	Post-exercise (mean +/- SD)	Significance of change (p Value)
IOP (mm Hg) Males	15.250 +/- 2.735	10.945 +/- 2.151	< 0.001
IOP (mm Hg) Females	16.055 +/- 2.798	11.436 +/- 4.157	0.001
POBF (µL/sec) Males	11.215 +/- 3.166	14.375 +/- 5.782	0.015
POBF (µL/sec) Females	11.409 +/- 3.436	13.727 +/- 5.373	0.172
Pulse Rate (bpm) Males	65.07 +/- 10.173	100.12 +/- 22.582	< 0.001
Pulse Rate (bpm) Females	70.30 +/- 23.656	125.64 +/- 22.281	< 0.001

Table 3.Mean pre- and post-exercise measurements of subjects divided into frequency of weekly exercise (none/mild and moderate/heavy).			
	Pre-exercise (mean +/- SD)	Post-exercise (mean +/- SD)	Significance of change (p Value)
IOP (mm Hg) zero/mild	16.114 +/- 2.723	10.914 +/- 3.019	< 0.001
IOP (mm Hg) moderate/heavy	15.059 +/- 2.740	11.288 +/- 2.988	< 0.001
POBF (µL/sec) zero/mild	10.543 +/- 2.992	13.907 +/- 5.985	0.042
POBF (µL/sec) moderate/heavy	11.894 +/- 3.889	14.341 +/- 5.360	0.058
Pulse Rate (bpm) zero/mild	74.34 +/- 13.814	120.93 +/- 24.008	< 0.001
Pulse Rate (bpm) moderate/heavy	60.82 +/- 15.558	99.49 +/- 22.713	< 0.001

flow may aid in more nutrients reaching the retinal cells.

CONCLUSION

This pilot study provides further evidence that there can be a significant reduction in IOP and increase in POBF following a short duration of moderately strenuous exercise.[6] There are implications for the treatment of glaucoma and ischemic retinal disorders, and the use of exercise as an adjunct to the pharmacological management of these conditions. Moreover, moderate exercise could be a valuable tool in managing many retinal ischemic disorders for which treatment options are presently limited.

More research is needed to determine precise exercise protocols for the various conditions. Longitudinal studies should be conducted to evaluate the effect of moderate exercise on glaucoma patients, patients with retinal disease and controls to further investigate how exercise affects IOP and retinal function (vision, fields, ERG, etc.). These studies should expand the size of the patient group and track patients over an extended period of time.

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Appendix A

Males (n=20)

Subject #	**2**	**6**	**7**	**9**	**11**	**13**	**14**	**16**	**17**	**18**	**19**	**20**
Age	29	25	47	24	25	32	60	26	25	25	24	38
Exercise amount	mild	none	heavy	mild	heavy	moderate	moderate	moderate	moderate	mild	mild	mild
Pre IOP	16.2	16.3	16.9	12.3	13.4	15.6	8.4	16.7	13.9	11.9	18.9	15.8
Post IOP	11.6	12.4	13.5	9.1	13.5	8.2	6.8	12.3	9.3	7.3	14	7.6
Pre OBF	7.1	13.1	7.6	13.6	13.2	9.4	14.7	12	19.8	11.2	5.6	9.3
Post OBF	6.2	18.3	11.4	13.4	12.4	19.1	16.9	13.4	27.4	9.2	6.2	21.4
Pre Pulse Rate	65	63	59	74	65	65	55	47.3	58	54	70	88
Post Pulse Rate	70	139	75	117	77	109	83	62	90	127	93	125
Pre Pulse Volume	3.1	5.9	4	5.3	5.2	4.4	8.3	7.9	10.5	6.1	2.4	2.7
Post Pulse Volum	2.6	3.6	4	2.9	4.5	4.8	5.8	6.4	8.9	2.1	1.8	4.3
Pre Pulse Amp	1.5	2.9	2	2.1	2.1	2.1	2.2	4	4.5	2.3	1.3	1.3
Post Pulse Amp	0.9	1.4	1.7	0.09	1.9	1.3	1.3	2.5	2.6	0.5	0.78	1

Males (n=20)

Subject #	**21**	**22**	**23**	**25**	**26**	**30**	**31**	**33**
Age	40	24	24	60	23	24	26	58
Exercise amount	none	moderate	heavy	heavy	moderate	moderate	moderate	none
Pre IOP	17.4	13.7	20.7	14	14	17.7	14.3	16.9
Post IOP	11	11.4	12.1	12	11.7	12.4	11.1	11.6
Pre OBF	8.4	19	11	10.6	9.9	9.2	11.7	7.9
Post OBF	24.1	16.2	11	14.3	7.8	9.7	11.2	17.9
Pre Pulse Rate	88	67	68	57	71	66	64	57
Post Pulse Rate	127	88	130	80	110	100	89.3	111
Pre Pulse Volume	2.5	8.7	5.1	5.4	4.2	4.1	6	4.4
Post Pulse Volum	4.7	5.6	2.2	5.9	1.8	2.7	3.3	4.1
Pre Pulse Amp	1.3	3.6	3	2.3	1.8	2.1	2.6	2.3
Post Pulse Amp	1.6	2	0.8	2.2	0.63	1	1.2	1.5

Females (n=11)

Subject #	**1**	**3**	**5**	**8**	**10**	**12**	**15**	**27**	**28**	**29**	**32**
Age	25	25	23	25	25	25	25	22	28	20	46
Exercise amount	none	none	moderate	mild	moderate	mild	moderate	heavy	none	none	moderate
Pre IOP	18.1	21.5	17.4	17.7	17.5	13.8	15.4	14.5	16.3	12.5	11.9
Post IOP	9.9	19.2	19.1	10.6	7	9.4	11.8	12.3	10.7	8.4	7.4
Pre OBF	10.9	10.9	7.6	9.7	17.1	10.1	6.2	12.8	17.3	12.5	10.4
Post OBF	11.3	11.6	14	11.9	11.6	8.4	8.5	13.8	22.8	12	25.1
Pre Pulse Rate	85	81	70	83	73	58	78	7.6	100	74.7	63
Post Pulse Rate	1717	136	105	120	153	98	117	103	139	120	120
Pre Pulse Volume	3.3	2.8	3.3	3.4	6.7	5.6	2.5	4.9	4.5	5.1	4.6
Post Pulse Volum	1.6	2.2	3	2.7	1.8	2.6	2	3.5	4.1	2.7	5.6
Pre Pulse Amp	1.8	1.8	1.7	1.8	3.5	2.4	1.2	2.2	2.2	2	1.7
Post Pulse Amp	0.5	1.3	1.7	0.9	0.4	0.8	0.8	1.4	1.4	0.7	1.3