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Influence of exercise on the structure of the anterior chamber of the eye

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ABSTRACT.

Purpose: **To measure changes in anterior chamber structure before and after exercise in healthy individuals using anterior segment optical coherence tomography (ASOCT).**

Methods: **Thirty-two healthy young individuals performed jogging for 20 min. Eye blinking rate was recorded during rest and exercise. The anterior chamber angle (ACA), angle opening distance at 500 μm from the scleral spur (AOD500), trabecular-iris space area at 500 μm from the scleral spur (TISA500), iris concavity (IC), iris concavity ratio (CR), iris thickness at 750 μm from the scleral spur (IT750), anterior chamber depth (ACD), anterior chamber width (ACW), pupil diameter (PD), intraocular pressure (IOP), blood pressure (BP) and heart rate (HR) were recorded before and after exercise. Anterior chamber angle (ACA), AOD500, TISA500, IC, IT750, ACD, ACW and PD were measured with ASOCT.**

Results: **Compared with rest, the blinking rate during exercise did not change significantly (13.04 $\pm$ 5.80 versus 13.52 $\pm$ 5.87 blinks/min, p = 0.645). The average IOP (15.4 $\pm$ 2.4 versus 12.4 $\pm$ 2.1 mmHg), ACA (35.96 $\pm$ 11.35 versus 40.25 $\pm$ 12.64 degrees), AOD500 (0.800 $\pm$ 0.348 versus 0.942 $\pm$ 0.387 mm), TISA500 (0.308 $\pm$ 0.155 versus 0.374 $\pm$ 0.193 mm^2), IC ($-$0.078 $\pm$ 0.148 versus $-$0.153 $\pm$ 0.159 mm) and CR ($-$0.027 $\pm$ 0.050 versus $-$0.054 $\pm$ 0.056) changed significantly (all p < 0.001), while the average IT750 (0.463 $\pm$ 0.084 versus 0.465 $\pm$ 0.086 mm; p = 0.492), ACD (3.171 $\pm$ 0.229 versus 3.175 $\pm$ 0.238 mm; p = 0.543) and ACW (11.768 $\pm$ 0.377 versus 11.755 $\pm$ 0.378 mm; p = 0.122) showed no significant change after exercise.**

Conclusion: **The blinking rate did not change significantly during exercise, while ACA, AOD500 and TISA500 increased after exercise. Exercise also induced or increased IC. These changes in anterior chamber structure were only associated with exercise, but not with the postexercise change in PD or IOP.**

Key words: anterior chamber structure – exercise – iris concavity – reverse pupillary block

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Introduction

In 1963, Janiszewska first reported an interesting phenomenon that exercise could decrease IOP (Janiszewska 1963). Thereafter, some researchers focused on the relationship between exercise and IOP and found that IOP also decreases in primary open angle glaucoma (POAG) following exercise and the extent of the decrease is greater than that in normal individuals (Risner et al. 2009). Meanwhile, other researchers observed a different phenomenon that exercise could induce anterior chamber pigment dispersion with elevated IOP in patients with pigment dispersion syndrome (PDS) and therefore suggested an evaluation for patients with PDS or pigmentary glaucoma (PG) who exercise regularly to determine whether they develop marked anterior chamber pigment dispersion and/or IOP elevation after exercise (Schenker et al. 1980; Haynes et al. 1992). The most widely accepted mechanism for PDS/PG is reverse pupillary block. The iris drapes over the lens and acts as a flap valve that prevents aqueous humour in the anterior chamber from returning to the posterior chamber and reverse pupillary block could increase IC and finally induce depigmentation of the iris (Jensen et al. 1995; Mardin et al. 2000; Kanadani et al. 2006). The exercise study of Jensen showed that the iris bowed posteriorly with the ACA and peripheral area increasing after exercise in patients with PG (Jensen et al. 1995). Therefore, changes in the configuration of the iris caused by reverse pupillary block after exercise may explain the phenomenon of increased IOP in patients with PG. Besides in the patients with PG, Haargaard et al. (2001) used 50-MHz ultrasound biomicroscopy (UBM) and reported that after exercise, the same changes in the configuration of the iris and ACA could also be observed in normal individuals.

However, the 50-MHz UBM examination requires the use of an eyecup and prevents eye blinking during the examination. According to the study of Amini et al., pressurization of the corneoscleral surface during eye blinking could rotate the iris root posteriorly via whole-globe deformation, increasing the apparent iris-lens contact, inducing reverse pupillary block, and finally maintaining the iris in a state of posterior bowing (Amini & Barocas 2009, 2010; Amini et al. 2012). Any changes in the eye blinking rate may have an impact on the configuration of iris (Liebmann et al. 1995; Schuster et al. 2017). Thus, the use of an eyecup would have an iris forward drifting effect (Liebmann et al. 1995; Amini et al. 2012). In addition, 50-MHz UBM could only be used to observe the ACA, but not the entire anterior chamber, including the PD, ACD and ACW. Therefore, we cannot analyse the potential association between the changes in the anterior chamber structure and the changes in PD, ACD or ACW. And it is also difficult to control for accommodation during UBM imaging (Cheung et al. 2010).

Anterior segment optical coherence tomography (ASOCT) is a non-contact, non-invasive, real-time method with high resolution, allowing the participants to have normal blinking during examination and minimizing the influence of accommodation by adjusting the focus of internal fixation to the appropriate refractive error for the subjects. Furthermore, it could scan the anterior chamber more comprehensively, allowing measurements of PD, ACD and ACW.

Accordingly, we aimed to observe the changes in the anterior chamber structure before and after exercise in healthy individuals by ASOCT and hoped to investigate the potential causes of these changes.

Materials and Methods

This observational study was approved by the ethics committee of Tongji Hospital and adhered to the tenets of the Declaration of Helsinki. All subjects provided written informed consent prior to study participation.

Subjects

Sixty-four eyes from 32 healthy individuals (16 male, 16 female) were included. All subjects received a comprehensive ophthalmic examination, including measurement of best-corrected visual acuity (BCVA) based on Snellen chart, spherical equivalent (SE; RT-2100, NIDEK CO.LTD, Gamagori, Japan), central corneal thickness (CCT; pachymetry map, Visante OCT; Carl Zeiss Meditec, Dublin, USA), axial length (AL; IOL-Master; Carl Zeiss Meditec), slit-lamp examination (Haag-streit, Bern, Switzerland), gonioscopy and fundus photography. Subjects were included only when they met the following criteria: (i) age ≥18 years; (ii) IOP between 10 and 21 mmHg (based on Goldmann tonometry; model AT900; Haag-Streit); (iii) normal ACD, with an open angle; and (iv) no use of any drugs that could have an effect on the circulatory system within the last month. Subjects were excluded if they had (i) a family history of glaucoma; (ii) history of ophthalmic disease or surgery; (iii) history of systemic disease or (iv) poor ASOCT imaging quality (evaluated on the basis of corneal reflection, visibility of scleral spurs, continuity of anterior segment structures and motion artefacts) (Lee et al. 2013). Both the right and left eyes, which showed no significant interocular biometric difference (Pärssinen et al. 2016), were selected for the analysis of IOP, ACA, angle opening distance at 500 μm from the scleral spur (AOD500), trabecular-iris space area at 500 μm from the scleral spur (TISA500), IC, CR, iris thickness at 750 μm from the scleral spur (IT750), ACD, ACW and PD. All participants were requested to abstain from alcohol and caffeine for 3 days and from any food or beverage for at least 30 min before the experiment.

Measurement of IOP, BP, HR and OS, and control of exercise intensity

Each participant rested for 20 min and then exercised by jogging on the treadmill (mean speed of 6.89 ± 0.43 km/hr) for 20 min. Intraocular pressure (IOP) was measured before and immediately after the exercise using a non-contact tonometer device (NIDEK RT-2100; NIDEK, CO., LTD). In total, three measurements were obtained and the average IOP was recorded. Systolic blood pressure (SBP) and diastolic blood pressure (DBP) were also recorded before and immediately after exercise using an automatic sphygmomanometer (OmronHEM-7201; Omron, Dalian, Liaoning, China). Heart rate (HR) and oxygen saturation (OS) were monitored throughout exercise. Exercise intensity was maintained by calculating the percentage of HR reserve (%HR_{max}) according to the following equation: %HR_{max} = 100 × ($HR_{during\ exercise}$ − $HR_{at\ rest}$)/($HR_{maximum}$ − $HR_{at\ rest}$), and $HR_{maximum}$ = 220 − age (years) (Kiuchi et al. 1994). To calculate mean ocular perfusion pressure (MOPP), mean arterial pressure (MAP) was calculated as: MAP = DBP + [1/3 × (SBP − DBP)] and MOPP = 2/3 × MAP − IOP (Gherghel et al. 2000).

Eye blinking recording

All the subjects agreed to be videotaped unaware of the aim of this study. They were instructed to adapt to the indoor environment of the examination room for 5 min. The indoor temperature (range from 18 to 21 °C) and humidity (range from 31 to 40%) were controlled. During rest, the subjects were asked to sit comfortably and look at the infinite straightly, and they were not required to maintain any specific position of the eyes, head or body. A camera (FDR-AX40; Sony Co., LTD, Shanghai, China, with Vario-Sonnar lens) was positioned on a tripod, in front of the subjects but off at a slight angle and ensure both eyes of the subjects were satisfactorily in full and clear screen view (Bentivoglio et al. 1997; Acosta et al. 1999; Doughty 2013). The rest with eye blinking recording lasted 20 min, and then, the subjects underwent BP, IOP and ASOCT examinations. After that, the subjects performed jogging on the treadmill for 20 min. During the exercise, the subjects were instructed to look at the infinite straightly and the camera was also positioned on a tripod in front of the subjects with a slight angle off to record the eye blinking during exercise. After exercise, the subjects immediately underwent BP, IOP and ASOCT examinations again.

All video recordings were assessed using the camera built-in software. The recordings were replayed, and the number of eye blinks was manually counted. Any uncertainty required to replay sections of the recoding (Doughty 2013). Only obvious eyelid movements were noted, that is, those that produced more than one-half coverage and extending over part of the pupil or completely occluding the pupil, but a note was made if an obvious incomplete eye blinking occurred. Any minor eyelid twitches or tremors were ignored (Doughty 2014).

Anterior segment optical coherence tomography

All recruited subjects were imaged in the dark with ASOCT (Visante OCT; Carl Zeiss Meditec, Inc.), which has a high resolution and captures cross-sectional images of the anterior chamber with light at a wavelength of 1310 nm. The examination was performed just before and immediately after exercise. The scan angle was horizontal (nasal-temporal angles at 0–180°) across the centre of the pupil in one single image, while the subject was staring at the internal fixation point. The operator adjusted the noise and optimized the polarization during the examination to ensure image quality. Three images were obtained for each recruited eye, and the image with best quality was chosen for further analysis. Image quality was evaluated on the basis of a steady central fixation as judged by a clear corneal reflection, good visibility of the scleral spurs, the presence of continuity in anterior segment structures and the absence of motion artefacts (Lee et al. 2013).

Image processing

Anterior chamber angle (ACA), AOD500, TISA500, IC, IT750, ACD, ACW and PD were measured by the built-in version 3.0 software of the Visante OCT. For the measurement of IC, the iris root was manually determined by an experienced operator (ML) who was masked to the subject information, and for the measurements of AOD500, TISA500, IT750, ACD and ACW, the two scleral spurs were manually determined by the same operator.

The ACA was defined as the arms of the posterior cornea and the opposite peripheral iris, with its apex in the angle recess (Müller et al. 2006; Vossmerbaeumer et al. 2013). AOD500 was defined as the length of the line extending from the anterior iris to the corneal endothelium, perpendicular to the line drawn along the trabecular meshwork at 500 μm anterior to the scleral spur. TISA500 was defined as the trapezoidal area with the following boundaries: anteriorly, a perpendicular line between the inner corneoscleral wall and the iris surface at 500 μm anterior to the scleral spur; posteriorly, a line perpendicular to the inner corneoscleral wall extending from the scleral spur to the iris surface; superiorly, the inner corneoscleral wall; and inferiorly, the iris surface. IT750 was defined as the thickness of the iris 750 μm away from the scleral spur. Anterior chamber depth (ACD) was defined as the length of the central perpendicular line between the anterior surface of the lens and the posterior surface of the cornea. Anterior chamber width (ACW) was defined as the length between the scleral spurs on the two opposite sides (Zheng et al. 2013). Pupil diameter (PD) was measured as the distance from one side to the opposite side of the pupillary tip of the iris on the images by ASOCT. Iris concavity (IC) was defined as the maximum distance between the posterior surface of iris and the chord from the iris root to the most peripheral point of contact between the iris and lens (Liebmann et al. 1995) (Fig. 1). In addition, according to the study of Amini et al., the iris CR (the ratio of the IC to iris chord length) was also calculated because IC could better quantify the displacement of the iris, while CR could better quantify the deformation of the iris and take the change in PD into account (Amini et al. (2010); Schuster et al. 2017).

Statistical analyses

All analyses were performed using the SPSS software 19.0 (IBM Corp., Armonk, NY, USA). Data are presented as mean ± standard deviation. The general estimate equations (GEEs), which take into account the correlation between the measurements from two eyes of one subject, were used

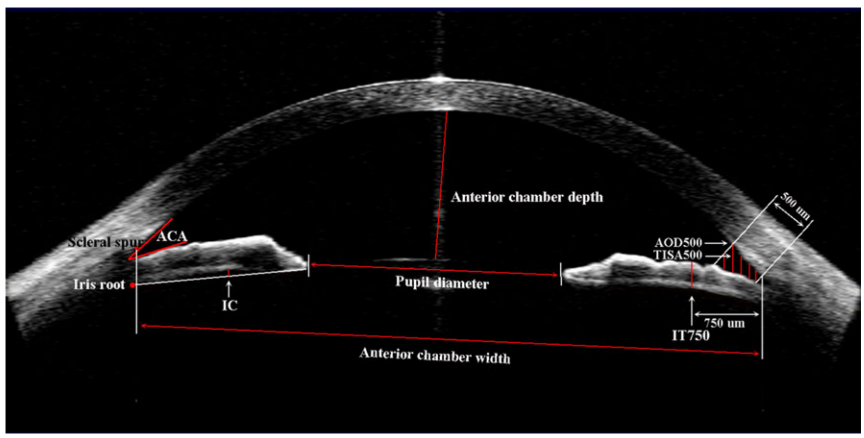

Fig. 1. Anterior segment optical coherence tomography image showing the measurements of anterior chamber angle (ACA), angle opening distance at 500 μm from the scleral spur (AOD500), trabecular-iris space area at 500 μm from the scleral spur (TISA500), iris concavity (IC), iris thickness at 750 μm from the scleral spur (IT750), anterior chamber depth (ACD), anterior chamber width (ACW) and pupil diameter (PD).

Table 1. Heart rate, BP, IOP, MOPP and eye blinking rate change after exercise.

Parameters (Mean ± SD)	Rest	Exercise	p-value
HR (bpm)	69.5 ± 5.5	157.8 ± 5.7	**< 0.001***
SBP (mmHg)	110.6 ± 9.0	141.2 ± 7.70	**< 0.001***
DBP (mmHg)	70.4 ± 7.4	78.4 ± 7.2	**< 0.001***
MAP (mmHg)	83.8 ± 6.9	99.4 ± 6.3	**< 0.001***
IOP (mmHg)	15.4 ± 2.4	12.4 ± 2.1	**< 0.001†**
MOPP (mmHg)	40.5 ± 5.0	53.8 ± 4.6	**< 0.001†**
Eye blinking rate (bpm)	13.04 ± 5.80	13.52 ± 5.87	0.645*

DBP = diastolic blood pressure, HR = heart rate, IOP = intraocular pressure, MAP = mean arterial pressure, MOPP = mean ocular perfusion pressure, SBP = systolic blood pressure. Bold values indicate statistical significance.
* Paired *t*-test.
† General estimate equations.

to compare the pre- and postexercise ACA, AOD500, TISA500, IC, CR, IT750, ACD, ACW, PD, IOP, MOPP;

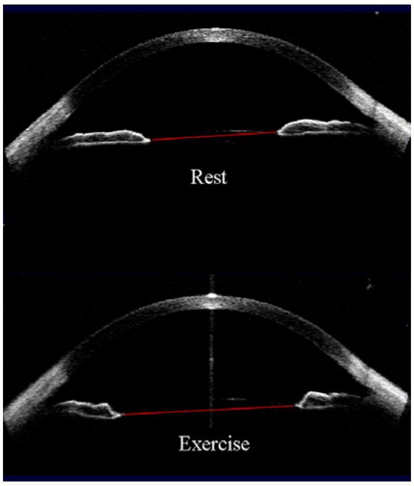

Fig. 2. Pupil diameter at resting state and during exercise.

and the paired sample *t*-test was used to compare HR and BP before and after exercise and the eye blinking rate during rest and exercise. Multivariate linear regression was used to determine the association between the changes in ACA, AOD500, TISA500, IC, CR and age, sex, AL, SE, CCT, the change in PD, the change in IOP, exercise. Multivariable-adjusted β coefficients, with 95% confidence intervals (CIs), for the associations between independent and dependent variables were assessed using GEEs. To evaluate intra-observer variance, 15 eyes were randomly selected and the anterior segment parameters were remeasured by the same observer at a separate session. The intra-observer reproducibility was assessed with the intraclass correlation coefficient [ICC (2,1)]. All tests were two-tailed, and statistical significance was defined as a p value of <0.05.

Table 2. Anterior chamber angle, AOD500, TISA500, IC, CR, IT750, ACD and ACW at rest and following exercise.

Parameters (Mean±SD)	Rest	Exercise	β [95% CI]	p-value
ACA (degree)	35.96 ± 11.35	40.25 ± 12.64	4.282 [3.134, 5.431]	**< 0.001***
AOD500 (mm)	0.800 ± 0.348	0.942 ± 0.387	0.142 [0.100, 0.184]	**< 0.001***
TISA500 (mm^2)	0.308 ± 0.155	0.374 ± 0.193	0.065 [0.047, 0.084]	**< 0.001***
IC (mm)	−0.078 ± 0.148	−0.153 ± 0.159	−0.075 [−0.099, −0.051]	**< 0.001***
CR	−0.027 ± 0.050	−0.054 ± 0.056	−0.027 [−0.036, −0.018]	**< 0.001***
IT750 (mm)	0.463 ± 0.084	0.465 ± 0.086	0.002 [−0.004, 0.009]	0.492*
ACD (mm)	3.171 ± 0.229	3.175 ± 0.238	0.004 [−0.008, 0.016]	0.543*
ACW (mm)	11.768 ± 0.377	11.755 ± 0.378	−0.014 [−0.031, 0.004]	0.122*

ACA = anterior chamber angle, ACD = anterior chamber depth, ACW = anterior chamber width, AOD500 = angle opening distance at 500 μm from the scleral spur, CI = confidence interval, CR = iris concavity ratio, IC = iris concavity, IT750 = iris thickness at 750 μm from the scleral spur, TISA500 = trabecular-iris space area at 500 μm from the scleral spur. Bold values indicate statistical significance.
* General estimate equations.

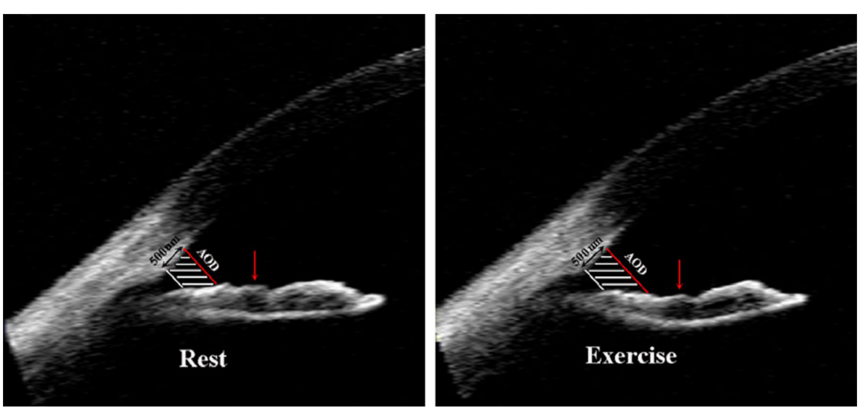

Fig. 3. Comparison images of exhibiting AOD500, TISA500 and iris concavity in a normal eye before exercise and after exercise (AOD500 is indicated by red line, TISA500 is indicated by trapezoidal area, and iris concavity is indicated by red arrow).

Results

Subject characteristics

Sixty-four eyes from 32 healthy volunteers (16 male, 16 female) were included in the study. The mean age was 26.9 ± 2.2 years, the mean body mass index (BMI) was 21.03 ± 1.96, and the mean per cent maximal HR (% HR_{max}) was 71.5 ± 4.1%. Mean decimal BCVA was 1.04 ± 0.14, mean CCT was 543.5 ± 36.2 μm, mean AL was 25.25 ± 1.00 mm, and mean refraction error was −3.77 ± 2.03 D for the enrolled eyes.

When compared with rest, there was a significant increase in HR (69.5 ± 5.5 versus 157.8 ± 5.7 bpm; p < 0.001), SBP, DBP and MAP (110.6 ± 9.0 versus 141.2 ± 7.70 mmHg, 70.4 ± 7.4 versus 78.4 ± 7.2 mmHg and 83.8 ± 6.9 mmHg versus 99.4 ± 6.3 mmHg, respectively; all p < 0.001) following exercise. We also observed a significant IOP decrease after exercise (15.4 ± 2.4 versus 12.4 ± 2.1 mmHg, p < 0.001). And as a result of the higher MAP and lower IOP, the MOPP was significantly higher after exercise (40.5 ± 5.0 versus 53.8 ± 4.6 mmHg, p < 0.001). The eye blinking rate did not change significantly during rest and exercise (13.04 ± 5.80 versus 13.52 ± 5.87 blinks/min, p = 0.645; Table 1).

Comparison of PD, ACA, AOD500, TISA500, IC, CR, IT750, ACD and ACW at rest and following exercise

Following exercise, there was also a significant increase in mean PD of 5.2% of the eyes (p < 0.001, Fig. 2). Moreover, after exercise, there were significant changes in the following parameters: ACA (35.96 ± 11.35 versus 40.25 ± 12.64 degrees; p < 0.001), AOD500 (0.800 ± 0.348 versus 0.942 ± 0.387 mm; p < 0.001), TISA500 (0.308 ± 0.155 versus 0.374 ± 0.193 mm^2; p < 0.001), IC (−0.078 ± 0.148 versus −0.153 ± 0.159 mm; p < 0.001) and CR (−0.027 ± 0.050 versus −0.054 ± 0.056; p < 0.001). In the meantime, the IT750 (0.463 ± 0.084 versus 0.465 ± 0.086 mm; p = 0.492), ACD (3.171 ± 0.229 versus 3.175 ± 0.238 mm; p = 0.543) and ACW (11.768 ± 0.377 versus 11.755 ± 0.378 mm; p = 0.122) showed no significant variation after exercise (Table 2 and Fig. 3).

Multivariate linear regression between the change in ACA, AOD500, TISA500, IC, CR and age, sex, AL, SE, CCT, the change in PD, the change in IOP, exercise

As summarized in Table 3, after adjusting for age, sex, AL, SE, CCT, pre-exercise PD and pre-exercise eye blinking rate, the changes in ACA, AOD500, TISA500, IC and CR were only associated with exercise (β = 5.540, 0.171, 0.075 −0.072 and −0.025, respectively; p = 0.009, 0.033, 0.043, 0.022 and 0.021, respectively) but were not associated with age, sex, AL, SE, CCT and the change in PD, IOP.

Intra-observer reproducibility of anterior segment parameters measurements

To evaluate intra-observer variance, the intra-observer reproducibility of anterior segment parameters measurements was assessed in a randomly selected subset of 15 eyes with the ICC (2,1). The result showed an excellent reproducibility (Table 4).

Discussion

Our study findings demonstrated that exercise could induce a change in the anterior chamber biometrics in normal individuals. The previous study has reported an association of ACA width with iris configuration (wider angle with concave iris and narrower angle with convex iris) (Schuster et al. 2017). In this study, we observed that ACA, AOD500 and TISA500 increased and that IC and CR decreased significantly after exercise. The changes in those parameters indicated that both the position and the configuration of the iris altered after exercise and exercise could induce or increase concavity of the iris in normal individuals. Using mydriatics or the alteration between light and dark, some researchers have suggested that a change in PD could induce changes in iris configuration and anterior chamber structure (Liu 2009; Aptel et al. 2012; Dastiridou et al. 2015; Guo et al. 2015), but in terms of exercise, according to the results of the multivariate linear regression in our study, we could observe that not only the changes in ACA, AOD500, TISA500 and IC, but also the change in CR, which takes the change in PD into account, were only associated with exercise, but not with

Table 3. Multivariate linear regression between the change in ACA, AOD500, TISA500, IC, concavity ratio and age, sex, AL, SE, CCT, the change in PD, the change in IOP, exercise.

	ΔACA (degree)		ΔAOD500 (mm)		ΔTISA500 (mm^2)		ΔIC (mm)		ΔCR	
Parameter	β [95% CI]	p	β [95% CI]	p	β [95% CI]	p	β [95% CI]	p	β [95% CI]	p
Age (years)	−1.033 [−2.207, 0.141]	0.086	0.010 [−0.031, 0.052]	0.625	0.004 [−0.017, 0.025]	0.718	−0.006 [−0.024, 0.012]	0.494	−0.002 [−0.008, 0.004]	0.573
Sex	1.590 [−4.309, 7.489]	0.597	−0.012 [−0.227, 0.202]	0.910	−0.009 [−0.116, 0.098]	0.871	−0.050 [−0.135, 0.034]	0.242	−0.012 [−0.041, 0.017]	0.409
AL (mm)	1.552 [−4.354, 7.458]	0.607	0.143 [−0.037, 0.323]	0.118	0.058 [−0.029, 0.145]	0.191	−0.060 [−0.134, 0.014]	0.113	−0.018 [−0.044, 0.008]	0.167
SE (D)	−0.050 [−2.518, 2.418]	0.968	0.018 [−0.050, 0.086]	0.600	0.006 [−0.026, 0.038]	0.713	−0.020 [−0.053, 0.013]	0.239	−0.005 [−0.016, 0.006]	0.343
CCT (μm)	−0.028 [−0.127, 0.071]	0.577	−0.001 [−0.005, 0.002]	0.409	−0.001 [−0.002, 0.001]	0.541	0.001 [0.000, 0.002]	0.136	0.000 [0.000, 0.001]	0.255
ΔPD (mm)	−3.452 [−7.705, 0.800]	0.112	−0.092 [−0.237, 0.054]	0.217	−0.039 [−0.107, 0.029]	0.259	0.057 [−0.001, 0.115]	0.056	0.015 [−0.003, 0.034]	0.107
ΔIOP (mmHg)	0.087 [−1.202, 1.375]	0.895	0.001 [−0.041, 0.043]	0.974	−0.001 [−0.021, 0.020]	0.949	0.007 [−0.009, 0.023]	0.406	0.002 [−0.003, 0.008]	0.409
Exercise	5.540 [1.388, 9.693]	**0.009**	0.171 [0.013, 0.328]	**0.033**	0.075 [0.002, 0.148]	**0.043**	−0.072 [−0.134, −0.011]	**0.022**	−0.025 [−0.046, −0.004]	**0.021**

ACA = anterior chamber angle, AL = axial length, CCT = central corneal thickness, IOP = intraocular pressure, PD = pupil diameter, SE = spherical equivalent. Bold values indicate statistical significance.
Δ, the change of the variables after exercise. The variables without Δ were baseline data.
β/p value: regression coefficient and p values of the independent variables in the generalized estimating equations. The influence factors as age, sex, AL, SE, CCT, pre-exercise PD and pre-exercise eye blinking rate have been adjusted.

Table 4. Reproducibility of anterior segment parameters measurements in a randomly selected subset of 15 eyes.

Parameters	ICC	Mean	Difference	95% CI
PD	0.990	5.975	0.022	0.980, 0.995
ACD	0.941	3.098	0.005	0.877, 0.972
ACW	0.937	11.744	0.015	0.868, 0.970
ACA	0.939	37.55	0.663	0.897, 0.963
AOD500	0.966	0.833	0.074	0.943, 0.980
TISA500	0.968	0.301	0.001	0.947, 0.981
IC	0.955	−0.124	0.006	0.925, 0.973
CR	0.958	−0.045	0.007	0.930, 0.975
IT750	0.922	0.472	0.005	0.870, 0.954

ACA = anterior chamber angle, ACD = anterior chamber depth, ACW = anterior chamber width, CR = concavity ratio, IC = iris concavity, ICC = intraclass correlation coefficient, PD = Pupil diameter.

the change in PD. Thus, during exercise, displacement and deformation of the iris occurred, but neither of these changes was caused by changes in PD. Moreover, we could also observe a significant postexercise reduction in IOP along with the change in anterior chamber structure. Previous studies have also reported the reduction in IOP after body or ocular exercise (Janiszewska 1963; Yan et al. 2016; Dimitrova & Trenceva 2017). However, as the change in PD, the change in IOP was also not associated with the change in anterior chamber structure based on the multivariate linear regression result, indicating that the causative factor for the postexercise change in anterior chamber structure might not be the postexercise reduction in IOP and the study of Schuster et al. (2017) has also suggested no association between iris configuration and IOP. In addition, using optical coherence tomography (OCT) measurements (Leng et al. 2014; Zhong et al. 2014; Zhu et al. 2016) or computational evaluation (Heys & Barocas 2002), previous studies have also reported that a change in lens could also induce concavity of the iris, but usually in association with decreases in ACD and PD, which are not consistent with our present exercise study results (unchanged ACD and increased PD), indicating that the concavity of the iris during exercise might not result from the change in lens. Furthermore, as mentioned above, eye blinking could maintain the iris in a state of posterior bowing and any change in the eye blinking rate might have an influence on the configuration of the iris (Liebmann et al. 1995; Amini & Barocas 2010; Amini et al. 2012; Schuster et al. 2017). However, our results showed that the eye blinking rate did not change significantly during rest and exercise and this result was consistent with previous studies (O'Connor & Petruzzello 1992; Tantillo et al. 2002) that showed no significant change in the eye blinking rate between rest and exercise in normal individuals. Thus, we speculated that changes in the anterior chamber structure after exercise were not caused by a change in the eye blinking rate. Therefore, after exercise, the lens and the eye blinking rate did not change significantly and might not contribute to the changes in anterior chamber structure. The PD and IOP had a significant change but was also not associated with the changes in the anterior chamber structure. The changes in anterior chamber structure were only associated with exercise, but the underlying mechanism still requires further research.

Haargaard et al. (2001) reported that, because of the reverse pupillary block, iris would bow posteriorly during exercise in normal individuals and Jensen et al. (1995) also observed that exercise could induce or increase IC in eyes with PG. Although healthy individual and PDS/PG patients both exhibited postexercise iris bowing due to reverse pupillary block, postexercise IOP decreased significantly in healthy individuals, while increased significantly in PDS/PG patients (Schenker et al. 1980; Risner et al. 2009). Furthermore, the postexercise iris bowing is temporary in normal individuals, but permanent for many eyes with PDS/PG (Jensen et al. 1995). The abnormal anatomical structure of the eye with PDS/PG (e.g. increased iridolenticular contact; more posterior insertion of the iris into the ciliary body) might be the reason for the different postexercise IOP change and iris bowing duration (Liebmann et al. 1995; Sokol et al. 1996). Therefore, given the abnormal anterior chamber configuration and distinct postexercise IOP change in patients with PDS/PG compared with healthy individuals, Haargaard et al. (2001) speculated that reverse pupillary block in healthy individual is a physiological phenomenon during exercise, while that in PDS/PG patients is a pathological status.

Compared with normal individual, patient with myopia has deeper and larger anterior chamber, which is a significant predictor of a larger iridolenticular contact and could result in the reverse papillary block (Liebmann et al. 1995; Aptel et al. 2011). Moreover, myopia is associated with a concave iris configuration (Schuster et al. 2017) and the postexercise changes in the peripheral anterior chamber areas in myopic eyes are significantly greater than that in emmetropic and hypermetropic eyes (Haargaard et al. 2001). Therefore, the likelihood of the iris pigment epithelium rubbing against zonular bundles during exercise is greater in myopic patients than normal individuals. Besides the abnormal structure and motion in myopic patients, full PDS may occur in normal (usually myopic) human eyes (Epstein et al. 1978) and myopia is a risk factor for the development and severity of glaucoma in PDS (Farrar et al. 1989). With regard to this, a screening of PDS/PG is advisable for the myopic patients who exercise regularly.

The present study has certain limitations. First, the sample size was relatively small. Second, all participants in the present study were young adults and it is unclear whether the same effects of exercise would be observed in elderly subjects. Thus, our results might have bias and our conclusion might be limited. Third, this study only involved normal individuals but no patients with PDS/PG, we would like to recruit patients with PDS/PG in this exercise study for further research. Fourth, this current study only observed the effect of high-intensity aerobic exercise on the change in anterior chamber structure, and it would also be interesting to investigate the effect of different exercise type or intensity of the change in anterior chamber structure in the future.

In conclusion, during exercise, the blinking rate did not change significantly, while IOP reduced significantly. Moreover, ACA, AOD500 and TISA500 increased following exercise. Exercise also induced or increased IC. These changes in anterior chamber structure were only associated with exercise, but not with the change in PD or IOP after exercise.

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