Posture-Related Changes of Intraocular Pressure in Patients With Acute Primary Angle Closure

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Purpose. To evaluate the posture-related change in intraocular pressure (IOP) of eyes with angle-closure disease and the associated factors.

Methods. Eyes were prospectively enrolled and divided into three groups: eyes with acute primary angle-closure (APAC), fellow eyes of acute primary angle-closure (FAPAC), and eyes with nonacute primary angle-closure disease (PACD). All of them had been treated with laser peripheral iridotomy. IOP was measured in the sitting, supine, and lateral decubitus positions (LDP) five minutes after posture change. Anterior chamber angle parameters and angle-closure mechanism were evaluated by anterior segment optical coherence tomography.

Results. Forty-four eyes were enrolled into each group. APAC eyes showed more LDP-Sitting IOP increase than fellow eyes (5.7 ± 2.7 vs. 2.2 ± 1.4 mm Hg, $P < 0.001$) and nonacute PACD eyes (3.6 ± 2.0 mm Hg, $P < 0.001$). LDP-sitting IOP change was higher in eyes with exaggerated lens vault (having shallow anterior chamber and volcano-like iris-lens configuration) than in those without it (APAC: 6.3 ± 2.6 vs. 3.9 ± 2.1 mm Hg, $P = 0.011$). Linear regression revealed that LDP-sitting IOP change in the APAC group was negatively associated with angle opening distance (AOD), trabecular iris space area, scleral spur angle, and anterior chamber depth (ACD1000). With multivariable stepwise regression analysis, AOD750 remained statistically significant (beta-coefficient = −8.36, $P = 0.014$).

Conclusions. APAC eyes had significant posture-related IOP changes, associated with narrower angle structures and exaggerated lens vault.

Keywords: angle-closure disease, anterior segment, posture-related intraocular pressure change, acute angle-closure attack

Changing body position is known to cause intraocular pressure (IOP) fluctuations.[1–4] IOP increased significantly when changing from the sitting to the supine position.[5] Taking lateral decubitus positions (LDP) may further increase the IOP,[1] especially in the dependent eyes.[6] Compared to healthy subjects, the magnitude of posture-related IOP change was greater in glaucoma patients.[7] Furthermore, posture-related IOP change correlates with thinning of the retinal nerve fiber layer [8] and visual field progression in open-angle glaucoma eyes.[7]

Most studies regarding posture-related IOP change focused on healthy subjects or eyes with open-angle glaucoma. Only few studies investigated the angle-closure population,[3,9] reporting that posture-related IOP change was similar between open-angle glaucoma and angle-closure eyes without history of angle-closure attack and was comparable among primary angle-closure diseases (PACD).[3,9] Acute primary angle-closure (APAC) attack is a unique form of angle-closure disease. To our knowledge, previous studies did not focus on eyes with history of acute primary angle-closure (APAC) attack. We speculated that these eyes, with more extreme anatomic characteristics, might have more significant posture-related IOP changes. In addition, the different mechanisms of angle-closure may also affect the posture-related IOP change. We used anterior segment optical coherence tomography (AS-OCT) to analyze the correlation between anterior segment structures and posture-related IOP changes, which were not investigated in previous studies.

In summary, the current study aimed to evaluate the posture-related IOP change in eyes with unilateral APAC attack, compare with their fellow eyes and PACD eyes, and to identify the factors associated with posture-related IOP change in angle-closure eyes.

Material and Methods

Study Population

This prospective and observational study was conducted at the National Taiwan University Hospital, Taipei, Taiwan, from November 2018 to July 2019. Patients diagnosed with unilateral APAC were enrolled, using the following criteria[10]: (1) the presence of at least two of these symptoms: ocular pain, headache, nausea/vomiting, or blurred vision; (2) the presenting IOP > 30 mm Hg; (3) the presence of at least

three of these signs: injected conjunctiva, corneal epithelial edema, mid-dilated unreactive pupil, or shallow anterior chamber; (4) the presence of an occludable angle recorded by gonioscopy. Eyes fulfilling these criteria were classified as the APAC group, whereas their fellow eyes were classified as the FAPAC group. Besides, patients diagnosed with nonacute PACD, including primary angle-closure suspect, primary angle-closure, and primary angle-closure glaucoma, were enrolled as the nonacute PACD group. All enrolled eyes received prior laser peripheral iridotomy (LPI). In the nonacute PACD group, only the data from their right eye was used for the analysis. Patients with bilateral APAC attacks, or those who underwent a cataract surgery were excluded. Eyes with secondary causes of angle-closure identified by gonioscopy were also excluded. This study was approved by the Institutional Review Board of the National Taiwan University Hospital and adhered to the tenets of the Declaration of Helsinki. Informed consent was obtained.

Intraocular Pressure Measurement

IOP was measured using the Icare rebound tonometer (Icare Pro; Tiolat Oy, Helsinki, Finland) in different body positions without pillow use five minutes after adopting each posture, in the sequence of sitting position, supine position, and LDP.[1,3] The tip of the Icare was maintained perpendicular to the corneal surface. In the APAC group, the patient was asked to turn first to the affected eye-dependent LDP for five minutes and then turn to the fellow eye-dependent LDP. The IOP in the affected eyes was measured first at every position. In the nonacute PACD group, the patient was asked to turn to the right LDP for five minutes and then turn to the left LDP. The IOP in the right eyes was measured first at every position. Six repeated IOP measurements were performed to obtain an averaged IOP value, and two consecutives averaged IOP values were obtained for each eye. If the difference between the two values was greater than 2 mm Hg, the IOP was measured again, and the median of the three IOP values would be obtained.[2] The IOP in the LDP was designated as the average of the IOP values measured in the dependent position (dependent LDP) and IOP measured at nondependent position (nondependent LDP). The posture-related IOP change was calculated, including the IOP change between the sitting and the supine positions (the Supine-Sitting IOP), and between the sitting position and the LDP (the LDP-Sitting IOP).

Ophthalmic Examinations

All patients underwent detailed ophthalmic examinations, including best-corrected visual acuity, refractive status determination (auto kerato-refractometer KR-8800; Topcon Inc., Tokyo, Japan), slit-lamp biomicroscopy, gonioscopy, and ocular biometry (Lenstar LS 900; Haag-Streit, Koeniz, Switzerland). Gonioscopy was performed under dark conditions using the Shaffer grading system. Lens tilting or indentation was permitted. Axial length, anterior chamber depth (ACD), and lens thickness were measured. The number of anti-glaucoma medications was documented. Visual field tests (Humphrey VF analyzer, Carl Zeiss Meditec, Dublin, CA, USA) were performed with the 24-2 SITA-fast program. A reliable visual field test was defined as false positive $<$ 33%, false negative $<$ 33%, and fixation loss $<$ 20%. Mean deviation was recorded. Scanning of the optic nerve head and macula were performed by OCT (Cirrus HD-OCT 4000; Carl Zeiss Meditec Inc., Dublin, CA, USA). The average retinal nerve fiber layer thickness, average ganglion cell complex thickness, and vertical cup-disc ratio were documented.

Anterior segment OCT (AS-OCT, Cirrus HD-OCT 4000) was performed under dark conditions. Centered on the pupil, the horizontal scan was performed to evaluate the temporal and nasal angle parameters. Three images were captured, and the one with the best visualization of the scleral spur was chosen for analysis. Two glaucoma specialists (CCS & JYH) who were blinded to each other's measurement and the patient's data analyzed the images. The following parameters were measured by the manual caliper of the machine: lens vault, iris curvature (IC), angle opening distance (AOD), trabecular iris space area (TISA), scleral spur angle (SSA), anterior chamber width (ACW), anterior chamber area (ACA), ACD, and iris thickness (IT).[10–13] ACD was measured at three locations: central ACD, ACD1000 and ACD2000 (ACD at 1000 and 2000 µm from the scleral spur). AOD and TISA were measured at 500 and 750 µm from the scleral spur (AOD500, AOD750, TISA500, and TISA750). IT was measured at 750 and 2000 µm from the scleral spur (IT750 and IT2000). The average of the two measurements was obtained for each parameter. The main mechanism of angle-closure was identified by two glaucoma specialists (CCS & JYH), including exaggerated lens vault, pupillary block, plateau iris configuration, or thick peripheral iris roll and was further grouped into with or without exaggerated lens vault.[11,14] The definition of each mechanism was listed as below: (1) exaggerated lens vault: eyes with shallow anterior chamber and iris being pushed anteriorly by the lens and having a "volcano-like configuration"; (2) pupillary block: eyes with anteriorly convex-shaped iris, peripheral shallow anterior chamber depth, and central iridolenticular contact (iris bombe); (3) peripheral thick iris roll: eyes with thick peripheral circumferential iris fold, which blocked the angle structure; (4) plateau iris configuration: eyes with deep anterior chamber and flat iris plane, and their iris root rose steeply from the insertion and closely to the angle wall, and then turned directly toward the center. If the consensus could not be reached, the third glaucoma specialist (THW) would be consulted.

Statistical Analysis

All statistical analyses were performed using SPSS version 22 (IBM Corp. Released 2013. IBM SPSS Statistics for Windows; IBM, Armonk, NY, USA) and R statistical programming language (V.3.6.0). The sample size was calculated using G*Power software (version 3.1.9.3; Universität Kiel, Dusseldorf, Germany) with $\alpha = 0.05$ and $\beta = 0.2$. It was determined that 37 patients would be required in each group to determine a difference of posture-related IOP change $>$ 2.0 mm Hg at a standard deviation of 3.0 mm Hg. A 25% dropout rate was considered.

For the descriptive statistics, means and standard deviations were calculated for the parametric numerical data, and percentages were calculated for the categorical variables. Paired *t*-test was used to compare the IOP at different positions, ocular biometry, and angle parameters between the APAC eyes and their fellow eyes. In addition, independent sample *t*-test was used to compare the above-mentioned parameters between the APAC eyes and the right eyes of the nonacute PACD patients. The interobserver reproducibility of the anterior chamber angle measurements was assessed by intraclass correlation coefficients.

Table 1. Clinical Characteristics

	APAC (44)	FPAPC (44)	Nonacute PACD (44)	*P* Value*	*P* Value†
Sex (female)	31 (70.5)	31 (70.5)	36 (81.8)	Not available	0.317
Age (years)	66.1 ± 8.60	66.1 ± 8.60	68.8 ± 6.5	Not available	0.103
LogMAR visual acuity	0.20 ± 0.28	0.11 ± 0.16	0.14 ± 0.13	0.002§	0.236
Nuclear sclerotic cataract grading (1+:2+:3+:4+)‡	9:21:12:2	9:26:8:1	1:27:14:2	0.645	0.062
Central corneal thickness (μm)	556 ± 34	557 ± 32	538 ± 24	0.742	0.003§
Lens thickness (mm)	5.1 ± 0.40	5.02 ± 0.41	4.9 ± 0.54	0.167	0.061
Axial length (mm)	22.7 ± 0.9	22.7 ± 0.9	22.8 ± 0.3	0.778	0.481
Anterior chamber depth (mm)‖	2.24 ± 0.35	2.45 ± 0.5	2.58 ± 0.55	0.013	0.001§
Mean deviation (dB)	−8.23 ± 9.40	−2.34 ± 3.65	−4.06 ± 4.61	<0.001§	0.008
Average retinal nerve fiber layer (μm)	82.3 ± 16.3	95.0 ± 11.6	85.1 ± 13.7	<0.001§	0.375
Cup-disc ratio	0.62 ± 0.62	0.51 ± 0.17	0.67 ± 0.12	<0.001§	0.191
Number of anti-glaucomatous medication	2.4 ± 1.2	1.1 ± 1.2	0.8 ± 0.9	<0.001§	<0.001§

* APAC group vs. FPAPC group, paired *t*-test.
† APAC group vs. nonacute PACD group, independent *t*-test.
‡ WHO cataract grading system.
§ Statistically significant with the Bonferroni correction for multiple comparisons ($P < 0.004$).
‖ Measured with Lenstar LS 900.

Table 2. Anterior Segment Optical Coherence Tomography Parameters

	APAC (44)	FPAPC (44)	Nonacute PACD (44)	P Value*	P Value†
Lens vault (mm)	0.98 ± 0.34	0.84 ± 0.27	0.77 ± 0.26	0.006	0.002‡
Anterior chamber width (mm)	11.1 ± 0.4	11.2 ± 0.5	11.2 ± 0.4	0.022	0.202
AOD500 (mm)	0.15 ± 0.11	0.19 ± 0.08	0.23 ± 0.09	0.024	0.001‡
AOD750 (mm)	0.24 ± 0.12	0.27 ± 0.12	0.29 ± 0.09	0.146	0.045
TISA500 (mm^2)	0.05 ± 0.04	0.08 ± 0.03	0.08 ± 0.04	0.001‡	0.001‡
TISA750 (mm^2)	0.10 ± 0.07	0.17 ± 0.15	0.15 ± 0.06	0.007	0.002‡
SSA (degree)	16.1 ± 10.1	20.8 ± 8.8	23.7 ± 8.3	0.007	<0.001‡
Iris curvature (mm)	0.13 ± 0.08	0.16 ± 0.06	0.15 ± 0.03	0.052	0.197
IT750 (mm)	0.35 ± 0.07	0.36 ± 0.10	0.36 ± 0.07	0.300	0.393
IT2000 (mm)	0.39 ± 0.09	0.42 ± 0.10	0.42 ± 0.07	0.073	0.114
Anterior chamber area (mm^2)	12.94 ± 2.83	14.04 ± 2.78	14.20 ± 2.60	0.034	0.046
Anterior chamber depth (mm)	1.78 ± 0.32	1.99 ± 0.28	2.02 ± 0.31	<0.001‡	0.001‡
ACD1000 (mm)	0.50 ± 0.18	0.54 ± 0.21	0.58 ± 0.18	0.289	0.066
ACD2000 (mm)	1.06 ± 0.24	1.14 ± 0.21	1.18 ± 0.27	0.033	0.046

* APAC group vs. FPAPC group, paired *t*-test.
† APAC group vs. nonacute PACD group, independent *t*-test.
‡ Statistically significant with the Bonferroni correction for multiple comparisons ($P < 0.004$).

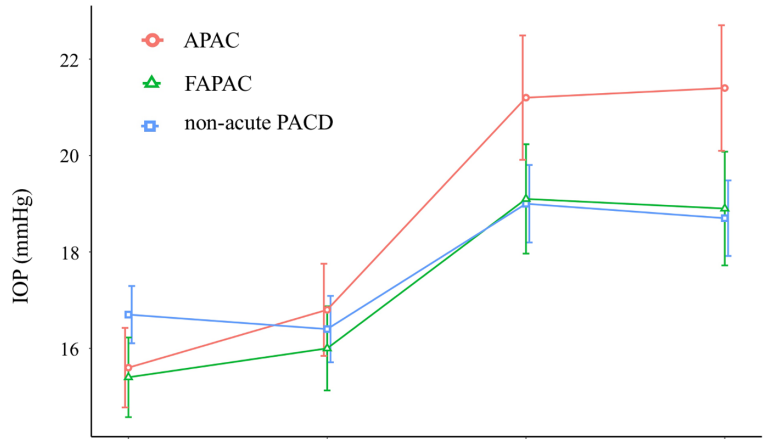
Univariate linear regression analysis was conducted to evaluate the predictive factors for the LDP-Sitting and the Supine-Sitting IOP changes. Variables with $P < 0.1$ were included in the stepwise backward multivariate linear regression analyses. A value of $P < 0.05$ was statistically significant.

Results

Forty-nine patients with unilateral APAC attacks and 48 right eyes with nonacute PACD were included. Nine patients (five patients in the APAC group and four patients in the nonacute PACD group) were excluded because of poor AS-OCT quality or unidentifiable scleral spur. Forty-four patients were considered for statistical analysis. The demographic data and results of the basic ophthalmic examinations are listed in Table 1. The demographic data, including sex, age, and axial length, was similar between the APAC and nonacute PACD groups. However, the APAC eyes had shallower ACD and worse mean deviation in the visual field tests than the FAPAC and nonacute PACD eyes. The APAC eyes were also treated with more antiglaucoma agents than the FAPAC and nonacute PACD eyes. Table 2 demonstrates the parameters of AS-OCT and shows that the APAC group has narrower angle structures than the FAPAC and nonacute PACD groups by AOD, TISA, SSA, ACA, and ACD. Exaggerated lens vault was categorized as the main angle-closure mechanism in 31 (70.5%) eyes, 28 (63.6%) eyes, and 28 (63.6%) eyes in the APAC, FAPAC, and nonacute PACD groups, respectively ($P = 0.738$, χ^2 test). The intraclass correlation coefficients of the angle parameters are listed in Table 3.

IOP Measurement in Different Positions

The Figure shows the IOP measured in different positions among the three groups, including sitting, supine, dependent LDP, and nondependent LDP. In the sitting position, the APAC group had lower IOP than the nonacute PACD group (15.6 ± 2.8 mm Hg vs. 16.7 ± 2.0 mm Hg, $P = 0.038$). There was no significant difference between the APAC and FAPAC groups (15.6 ± 2.8 mm Hg vs. 15.4 ± 2.8 mmHg, $P = 0.749$). In the supine position, the APAC group did not have different IOP compared to the other two groups. (APAC vs. FAPAC: 16.8 ± 3.2 mm Hg vs. 16.0 ± 3.0 mm Hg, $P = 0.283$; APAC vs. nonacute PACD: 16.8 ± 3.2 mm Hg vs.



	Sitting	Supine	LDP (dependent)	LDP (non-dependent)
Non-acute PACD	16.7 ± 2.0	16.4 ± 2.3	19.0 ± 2.7	18.7 ± 2.7
FAPAC	15.4 ± 2.8	16.0 ± 3.0	19.1 ± 3.8	18.9 ± 4.0
APAC	15.6 ± 2.8	16.8 ± 3.2	21.2 ± 4.4	21.4 ± 4.4
APAC vs. FAPAC	P = 0.749	P = 0.283	P = 0.016	P < 0.001
APAC vs. PACD	P = 0.038	P = 0.591	P = 0.006	P = 0.001

Figure. Intraocular pressure measured at different positions in the APAC group, FAPAC group, and nonacute PACD group. The APAC group had highest IOP at lateral decubitus position.

Table 3. ICC for the Anterior Segment Parameters of Anterior Segment Optical Coherence Tomography

Parameters	ICC (95% CI)
Lens vault	0.978 (0.966–0.985)
Anterior chamber width	0.988 (0.982–0.992)
AOD 500	0.961 (0.940–0.974)
AOD 750	0.959 (0.937–0.973)
TISA 500	0.935 (0.901–0.957)
TISA 750	0.975 (0.961–0.984)
Scleral spur angle	0.959 (0.937–0.973)
Iris curvature	0.910 (0.865–0.941)
Iris thickness 750	0.877 (0.822–0.918)
Iris thickness 2000	0.903 (0.855–0.936)
Anterior chamber depth 1000	0.964 (0.945–0.977)
Anterior chamber depth 2000	0.923 (0.883–0.949)

CI, confidence interval; ICC, intraclass correlation coefficients.

16.4 ± 2.3 mm Hg, $P = 0.591$). In the dependent LDP, the APAC group had higher IOP than the FAPAC group (21.2 ± 4.4 mm Hg vs. 19.1 ± 3.8 mm Hg, $P = 0.016$) and the nonacute PACD eyes (21.2 ± 4.4 mm Hg vs. 19.0 ± 2.7 mm Hg, $P = 0.006$). In the nondependent LDP, the APAC group also had higher IOP than the FAPAC group (21.4 ± 4.4 mm Hg vs. 18.9 ± 4.0 mm Hg, $P < 0.001$) and the nonacute PACD eyes (21.4 ± 4.4 mm Hg vs. 18.7 ± 2.7 mm Hg, $P = 0.001$). Because the IOP in the dependent and nondependent LDP were similar in each group, we designated the average value as the IOP in the LDP for further statistical analysis.

Posture-Related IOP Change

Table 4 shows the comparison of posture-related IOP change between the three groups. The change of supine-sitting IOP was higher in the APAC group than in the nonacute PACD group. The change of LDP-Sitting IOP was also higher in the APAC group than in the FAPAC and nonacute PACD groups. Table 5 represents the factors associated with IOP rise in the APAC eyes when adopting the LDP or supine position. Linear regression adjusted for age and sex revealed that the LDP-sitting IOP was negatively associated with several AS-OCT parameters including AOD500, AOD750, TISA500, TISA750, SSA, and ACD1000. Stepwise multivariable regression analysis revealed that AOD750 (β-coefficient = −8.356, $P = 0.014$) remained significantly associated with the LDP-Sitting IOP and accounted for 12.2% of the variance. The supine-sitting IOP was only negatively associated with ACD1000 (β-coefficient = −4.394, $P = 0.035$).

Table 6 shows the comparison of posture-related IOP changes in eyes with or without exaggerated lens vault. Among the three groups, eyes categorized as having exaggerated lens vault had higher lens vaults than those with other mechanisms. The LDP-sitting IOP was significantly higher in all eyes with exaggerated lens vault. The supine-sitting IOP was only significantly higher in the eyes with exaggerated lens vault in the nonacute PACD group.

Discussion

It is known that IOP increases when changing from the sitting position to the supine or LDP in all subjects.[1–6] Moreover, posture-related IOP change is a clinically relevant issue in glaucoma patients. The magnitude of posture-induced IOP change and the preferred sleeping positions were proved to be associated with glaucoma progression.[7,15,16] Most studies investigated the posture-related IOP change in healthy subjects and open-angle glaucoma patients. The present study showed that angle-closure eyes also had significant posture-related IOP change, which was highest in the LDP. Among different subgroups of PAC diagnosis, eyes with a history of APAC attack had much more significant posture-related IOP elevation compared to their fellow eyes and

Table 4. Posture-Related Intraocular Pressure Changes in Different Positions

	IOP Change (mm Hg)				
Position	**APAC**	**FAPAC**	**Nonacute PACD**	***P* Value***	***P* Value†**
Supine-Sitting	1.2 ± 2.4	0.7 ± 2.1	−0.3 ± 0.5	0.098	**0.001**
Dependent LDP-Sitting	5.7 ± 3.3	3.7 ± 2.3	2.4 ± 1.5	**0.026**	**<0.001**
Nondependent LDP-Sitting	5.8 ± 3.0	3.5 ± 2.4	2.1 ± 1.6	**<0.001**	**<0.001**

* APAC group vs. FPAPC group, paired *t*-test.
† APAC group vs. nonacute PACD group, independent *t*-test.

Table 5. Univariable Linear Regression Analysis for Factors Associated With Posture-Related Intraocular Pressure Change in the Acute Primary Angle-Closure Group Adjusted With Age and Sex

	LDP-Sitting IOP Change		Supine-Sitting IOP Change	
Factors	**Coefficient**	***P* Value**	**Coefficient**	***P* Value**
Age	−0.182	0.238	−0.056	0.191
Sex	0.136	0.377	0.668	0.408
Central corneal thickness	−0.008	0.514	0.002	0.877
Anterior chamber depth*	0.835	0.514	0.426	0.712
Lens thickness	−1.140	0.269	−0.013	0.989
Axial length	0.483	0.278	0.181	0.653
Lens vault	2.156	0.088	0.799	0.493
Anterior chamber width	0.453	0.696	−0.178	0.866
AOD 500	−8.630	0.024	−4.237	0.231
AOD 750	−6.840	0.038	−4.682	0.137
TISA 500	−8.839	0.009	−12.747	0.171
TISA 750	−14.407	0.023	−8.274	0.154
Scleral spur angle	−0.085	0.042	−0.052	0.170
Iris curvature	2.016	0.708	6.592	0.172
IT 750	−5.571	0.376	−8.792	0.120
IT 2000	−3.410	0.476	−5.289	0.220
Anterior chamber area	−0.179	0.251	−0.056	0.693
ACD 1000	−5.345	0.019	−4.394	0.035
ACD 2000	−1.367	0.416	−1.722	0.258

* Measured with Lenstar LS 900.
† If the Bonferroni correction was applied for multiple comparisons, *P* value was required to be less than 0.003 to achieve statistical significance.

nonacute PACD eyes. The narrow anterior segment parameters were associated with an increased LDP-Sitting IOP change. Eyes with exaggerated lens vault compared to those without it had greater elevation of the posture-related IOP.

In healthy subjects, when changing from the sitting to the supine position, the IOP rises by 0.3-5.1 mmHg,[1,5,17–20] which can be observed within five minutes of position alteration and could be offset by head elevation.[19] This IOP elevation may be induced by the increase of the episcleral venous pressure or by choroidal vascular engorgement.[5,20] The LDP further increases the IOP by 2 to 5.5 mm Hg,[1,3–5,21,22] often higher in the dependent eyes[6] but with variable intereye differences.[1,4,21,23] These posture-related IOP changes were also observed even with a higher magnitude in untreated or treated eyes with open-angle glaucoma.[2,3,6–8,23,24] Eyes with compromised trabecular outflow suffer from more significant posture-related IOP changes, which could be effectively reduced by trabeculectomy or deep scleretomy.[24–26] Sawada et al.[3] reported that posture-related IOP change was comparable among open-angle glaucoma, angle-closure, and control eyes. In their study, eyes with acute angle-closure attack or those treated with LPI were excluded. However, these eyes may have narrower anterior segment structures and potentially more significant changes in posture-related IOP. In the present study, we found that APAC eyes had much more significant IOP rise

Table 6. The Comparison of Posture-Related Intraocular Pressure Changes in Eyes With Different Angle Closure Mechanisms

	APAC Group			FAPAC Group			NonAcute PACD Group		
	LV (31)	**Non-LV(13)***	***P* Value**	**LV (28)**	**Non-LV (16)***	***P* Value**	**LV (28)**	**Non-LV (16) ***	***P* Value**
Lens vault (mm)	1.06 ± 0.31	0.70 ± 0.23	**0.002**	0.95 ± 0.21	0.61 ± 0.23	**<0.001**	0.85 ± 0.26	0.64 ± 0.20	**0.008**
LDP-Sitting IOP (mmHg)	6.3 ± 2.6	3.9 ± 2.1	**0.011**	4.1 ± 2.1	2.8 ± 1.7	**0.038**	2.5 ± 1.4	1.7 ± 1.2	**0.039**
Supine-Sitting IOP (mmHg)	1.5 ± 2.5	0.1 ± 2.1	0.122	0.8 ± 2.1	0.4 ± 2.0	0.569	0.1 ± 1.4	−0.9 ± 1.7	**0.046**

LV, with exaggerated lens vault; Non-LV, without exaggerated lens vault.
* Pupillary block: peripheral thick iris roll: plateau iris configuration was 5:7:1 in the APAC group, 7:6:3 in the FAPAC group, and 6:4:6 in the nonacute PACD group.

(5.7 ± 2.7 mm Hg) in the LDP compared with their fellow eyes and nonacute PACD eyes. Although the study protocol was highly variable among different studies, this IOP elevation was still very prominent compared to the eyes with open-angle glaucoma and healthy subjects. Previous studies adopted a fixed-order[1,9,27] or randomized[5,18,22] sequence of positional change. Because our study aimed to compare the posture-related IOP change of the APAC group and the other two groups at a certain position, instead of comparing the posture-related IOP change between different positions, we adopted the fixed-order sequence. However, the relatively low elevation of supine-sitting IOP (1.2 mm Hg) in our study group compared to other study groups (0.3–5.1 mm Hg)[1,5,17–20] may be related to taking the supine position prior to LDP. Besides, it is worth noticing that the APAC eyes had more antiglaucoma medications than the other two groups. However, one previous randomized control trial showed that ocular hypotensive agents did not affect posture-related IOP change and speculated that the pharmacologic IOP-lowering effect was different from the mechanism of posture-related IOP change.[28] Therefore the possible effect of taking more anti-glaucoma medications on the APAC group could be neglected.

The factors affecting posture-related IOP change were not well understood. Shorter axial length was reported to be associated with higher fluctuation in supine-sitting IOP,[5,20,29] because the choroidal vascular expansion may have a greater effect on the IOP in eyes of shorter axial lengths.[29] In the present study, the APAC group did not have a shorter axial length compared to the FAPAC and nonacute PACD groups. Therefore axial length was not the key factor causing this difference in posture-related IOP change in our cohort. We identified that smaller AOD750 was the only factor associated with increased LDP-sitting IOP change with multivariable regression analysis. Previous studies had confirmed the role of AOD750 in diagnosing occludable angles[30,31] and its association with the APAC attack.[30] Baseline smaller AOD750 could predict the development of angle-closure in the future.[32] AOD750 also had a good correlation with other angle parameters.[30] Moreover, AOD750 was negatively correlated with IOP in angle-closure eyes.[33,34] These observations emphasized that AOD750 was an important AS-OCT parameter in the management of angle-closure diseases. One previous study found that the anterior chamber angle changed between the supine and sitting positions in the elderly and inferred it related to lens tilting.[35] Another study observed that young adults also had changes in angle parameters when shifting from sitting to LDP, which may be explained by aqueous humor movement caused by gravity.[36] Therefore the positional effect on angle parameters and its underlying mechanism varied between young and old subjects. The positional change of angle parameters might be more significant in older and angle-closure patients than younger subjects with open angle. The posture-related changes in AOD750 might explain its association with posture-related IOP changes. However, more investigations are needed to clarify the actual effect of positioning on angle parameters in patients of different age and angle status and its association with posture-related IOP changes.

According to previous studies, PAC eyes can be classified into three subgroups: (1) those with higher lens vault and shallow ACD (exaggerated lens vault); (2) those with smaller lens vault, relatively deep ACD, larger iris area, and thicker iris (predominant iris component); and (3) those with intermediate features and high iris curvature representing the pupillary block mechanism.[37,38] Because all eyes enrolled were treated with LPI, the pupillary block mechanism was mostly eliminated. Eyes with higher lens vault were characteristics of smaller AOD and TISA.[37] In addition, lens vault contributed greatly to the occurrence of APAC attacks and exacerbated the effects of pupillary block.[39] Therefore we classified our patients into the "with exaggerated lens vault" and "without exaggerated lens vault" groups to inspect whether exaggerated lens vault also affects the posture-related IOP change. In our APAC group, eyes with smaller AOD, TISA, SSA, and ACD, typical of the "exaggerated lens vault" group, were associated with higher changes in posture-related IOP. Although lens vault only had borderline association ($P = 0.088$) with LDP-Sitting IOP change, when the eyes were being classified by AS-OCT morphology, those with exaggerated lens vault indeed had higher posture-induced IOP changes. Therefore we assumed that angle-closure eyes with higher lens vault tend to have more posture-related IOP changes compared to eyes with thick peripheral iris or plateau iris configuration. Kwon et al.[40] stated that a higher lens vault was associated with zonular instability in eyes with acute angle-closure attack. Changes in posture-related angle parameters were also observed in the elderly and were attributed to the zonular laxity.[35,36] Additionally, one case report showed that acute angle-closure attack was associated with prolonged LDP after microvascular decompression surgery for trigeminal neuralgia in a 79-year-old female.[41] Therefore the movement of lens because of zonular insufficiency during posture change might have contributed to the exaggerated lens vault and IOP elevation. The relatively low elevation of supine-sitting IOP in our study group might be explained by the backward movement of the lens and the slightly open of angle caused by gravity when in the supine position.[42]

This study has several limitations. We did not enroll normal subjects as controls. Under the consideration of possible effect of anterior segment configuration and LPI on posture-related IOP changes, we instead enrolled patients with nonacute angle-closure disease treated with LPI as control. They had more similar anatomic condition as the APAC patients. The diagnoses of nonacute PACD group were heterogeneous in the present study, including primary angle-closure suspect, primary angle-closure, and primary angle-closure glaucoma. But one previous study had shown that posture-induced IOP change were compatible among eyes with these three diagnoses.[9] We used the 840 nm SD-OCT for the anterior segment imaging, and the tissue penetration was lower than the 1310 nm Visante OCT. However, our study population consisted of eyes with angle-closure and crowded anterior segment structures. We also excluded cases with poor image quality or unidentifiable scleral spur. Therefore the image quality was acceptable for analysis. We measured IOP change only five minutes after posture change. A longer time interval may reveal different results of posture-related IOP change.[18] However, in most previous studies, obvious IOP changes could be detected five to ten minutes after posture change.[1,3,5,6] Besides, the effect of LPI on posture-related IOP change in angle-closure eyes needs further investigation. Because there was a risk of IOP fluctuation in untreated APAC eyes, we only measured posture-related IOP change in APAC eyes with LPI. Because of the uncertain effect of LPI on posture-related IOP changes, we enrolled their fellow eyes and nonacute PACD eyes treated with LPI as control. Therefore the findings in treated nonacute PACD eyes might not represent the condition in

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untreated eyes. However, we emphasized that APAC eyes still had elevated posture-related IOP changes even in resolved status. Because we would like to explore the correlation between the anterior segment structure and the posture-related IOP changes, we analyzed many angle parameters of AS-OCT. However, multiple comparisons had the risk of increasing type I error; therefore we listed the adjusted *P* value in the tables with multiple comparison for the reader's interpretation. We still discussed based on the results without Bonferroni correction, because it was conservative and may increase the type II error. Last, we speculated that the posture-related IOP change was associated with zonular instability; however, there was no reliable and quantifiable clinical examination that could prove the presence of zonular instability. Further study is needed to determine whether cataract surgery in these patients reduces the posture-related IOP change or whether eyes with higher posture-related IOP change have a higher prevalence of zonular instability and lens wavering intraoperatively.

Among angle-closure eyes, eyes with a history of acute angle-closure attack had the most significant increase in posture-related IOP, which was associated with exaggerated lens vault and smaller AOD750. Patients with significant IOP change may be advised to avoid certain sleeping positions at night. Further investigation is indicated to determine whether this significant IOP fluctuation is associated with long-term structural and functional deterioration.

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