Ocular Biometry in the Subtypes of Angle Closure: An Anterior Segment Optical Coherence Tomography Study

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• PURPOSE: **To evaluate ocular biometric parameters in different subtypes of angle-closure disease in the Iranian population and compare them with normal eyes.**
• DESIGN: **Prospective, cross-sectional.**
• METHODS: **In this clinic-based study, 189 eyes of 154 patients consisting of 40 acute angle-closure glaucoma (AACG) eyes, 40 fellow eyes of AACG, 42 chronic angle-closure glaucoma (CACG) eyes, 40 primary angle-closure suspect (PACS) eyes, and 27 normal eyes underwent complete examination including gonioscopy, A-scan biometry, and anterior segment optical coherence tomography. Only 1 eye of CACG, PACS, and control subjects were selected. Main outcome measures included angle opening distance and trabeculo-iris space area at 500 μm from the scleral spur (AOD500, TISA-500), anterior chamber angle, lens vault, lens thickness, anterior chamber depth (ACD), and lens position.**
• RESULTS: **Anterior chamber angle, AOD500, TISA500, ACD, and lens position were less and lens thickness and lens vault were greater in angle-closure than open-angle eyes. ACD was less in AACG than CACG and PACS ($P < .001$). It was also less in fellow eyes than PACS eyes ($P = .04$). Lens vault was highest in AACG eyes, followed by fellow eyes, PACS, and CACG. It was significantly more in AACG eyes than CACG and PACS eyes ($P < .001$ and $P = .007$, respectively). No difference was observed between AACG and fellow eyes.**
• CONCLUSIONS: **The anterior segment was crowded in closed-angle compared to open-angle eyes. Higher lens vault may play a role in the development of an acute attack of angle closure.** **(Am J Ophthalmol 2013;155: 664–673. © 2013 by Elsevier Inc. All rights reserved.)**

ANGLE-CLOSURE DISEASE IS AN ANATOMIC disorder in which iris- trabecular contact impedes aqueous drainage through the trabecular meshwork.[1] Although pupillary block and angle crowding have been proposed as the 2 main mechanisms in the pathogenesis of angle-closure disease, other factors related to the lens and ciliary body have been shown to play an important role.[1,2] When aqueous humor cannot flow easily through the iris-lens channel from the posterior to anterior chamber, pupillary block is present. Therefore, the iris, lens, their positions, and their relationship to each other have important roles in angle-closure pathogenesis.[1]

Study of biometric parameters associated with this condition helps us understand the underlying mechanisms and guides us toward more effective diagnosis and treatment. Several ocular risk factors have been identified for angle-closure disease, such as short axial length, shallow anterior chamber, and a thick and anteriorly positioned lens.[1,3–6] This condition is more prevalent in those of Chinese ethnicity and female sex; however, these racial and sex differences cannot be explained by axial length or anterior chamber depth variations alone.[4]

With the advent of anterior segment optical coherence tomography (AS-OCT), researchers can capture the entire anterior segment in a single image and assess angle, iris, and lens parameters more precisely. Nongpiur and associates have recently evaluated anterior chamber width, defined as the horizontal scleral spur-to-scleral spur distance in AS-OCT images, in a large sample of subjects.[7] They found that angle-closure patients had smaller anterior chamber width than open-angle subjects.

Lens vault is an additional novel parameter that can be measured with AS-OCT and has been associated with angle closure.[8] It is defined as the perpendicular distance between the anterior lens pole and the horizontal line joining the temporal and nasal scleral spurs. In a recent study, Nongpiur and associates measured lens vault in angle-closure and open-angle eyes, and found that lens vault and lens thickness are greater in closed-angle eyes and lens vault is significantly associated with angle-closure disease regardless of lens thickness or lens position.[8]

Angle-closure disease is classified into different subtypes including primary angle-closure suspect (PACS), acute angle-closure glaucoma (AACG), and chronic angle-closure glaucoma (CACG).[9] Although some ocular biometric parameters such as anterior chamber depth, lens thickness, lens position, axial length, and angle parameters have been shown to differ in various subtypes of angle-closure disease,[10–12] the difference between these subtypes has not been fully elucidated. Understanding this

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difference may be helpful in explaining the pathogenesis of angle closure.

In this study, eyes of different subtypes of angle-closure patients including AACG, their fellow eyes, CACG, and PACS, as well as normal eyes, were evaluated. We used AS-OCT and A-scan biometry to measure ocular biometric parameters, including the lens characteristics and the new parameter lens vault.

METHODS

THE PROTOCOL OF THE STUDY WAS APPROVED BY THE INSTITUTIONAL review board of Farabi Eye Hospital, Tehran, Iran. This was a prospective study in which all patients gave informed consent to participate in this research protocol.

In this cross-sectional study, 239 eyes of 154 patients were included. Study participants were consecutively recruited from the glaucoma clinic of the Farabi Eye Hospital, Tehran, Iran—a tertiary care center—as part of the Farabi Angle Closure Study. Twenty-eight eyes with poor AS-OCT image quality were excluded. Only the right eye of CACG, PACS, and control patients were selected for analysis. If the left eye was the only affected one, the left eye was chosen. A total of 189 eyes were classified into 1 of the following 5 groups: (1) acute angle-closure glaucoma (AACG; 40 eyes); (2) fellow eye of AACG (40 eyes); (3) chronic angle-closure glaucoma (CACG, 42 eyes); (4) primary angle-closure suspect (PACS, 40 eyes); and (5) control (27 eyes).

AACG was defined by the presence of the following: (1) at least 2 of the symptoms of an acute episode of intraocular pressure (IOP) rise, which are ocular pain or headache, nausea and/or vomiting, decreased vision, and rainbow-colored halos around lights; (2) IOP at presentation of at least 30 mm Hg with Goldmann applanation tonometry; (3) examination findings such as conjunctival injection, corneal epithelial edema, fixed mid-dilated pupil, and shallow anterior chamber; and (4) shallow anterior chamber and narrow angle in the other eye, defined as our second group (fellow eye). AACG attacks were broken with intravenous mannitol or oral glycerin, oral acetazolamide, and topical timolol. The AACG attack was defined as broken when IOP was less than 21 mm Hg with or without medication, and symptoms and signs of acute IOP rise had subsided. Eyes whose attack could not be broken with these medications were excluded from the study and treated with further therapy.

CACG eyes had chronically elevated IOP above 21 mm Hg (prior to treatment) along with glaucomatous optic neuropathy (such as diffuse or localized rim thinning, disc hemorrhage, a notch in the rim, or a vertical cup-to-disc ratio higher than the other eye by ≥0.2) or visual field defects typical of glaucoma (defined as pattern standard deviation with $P < .05$, glaucoma hemifield test result [$P < .01$] outside normal limits, and 4 abnormal points with $P < .05$ on pattern deviation plot), shallow anterior chamber, and iridotrabecular contact in at least 3 quadrants on gonioscopy, along with variable amount of peripheral anterior synechiae (PAS). There were no history or signs of previous acute glaucoma attack in this group.

PACS eyes were classified based on the posterior trabecular meshwork not being visible in at least 3 quadrants without PAS or any evidence of glaucomatous optic nerve or visual field damage. These patients did not have any history or signs of previous AACG attack, and IOP was ≤21 mm Hg in this group without medication.

The normal controls were recruited from the comprehensive ophthalmology service. The control subjects were included if they did not have any other pathology such as open-angle glaucoma, retinal disease, corneal opacity, or high myopia. They had open angles, healthy optic nerves, normal visual fields, and IOP ≤21 mm Hg.

Individuals with history of trauma, uveitis, surgery, or any kind of laser therapy (eg, laser peripheral iridotomy [LPI]) were excluded. Also, eyes with iris or angle neovascularization, pseudoexfoliation (PEX), any kind of secondary angle closure, or any iris or corneal abnormalities were excluded. Miotic or mydriatic medications had not been used for any of the patients.

Slit-lamp examination of the anterior segment, Goldmann applanation tonometry, and gonioscopy in dark conditions (with and without indentation) was conducted for all the patients. A glaucoma specialist (S.M.) performed gonioscopy using a Zeiss-style 4-mirror goniolens (Model G-4; Volk Optical, Mentor, Ohio, USA) with a narrow 1-mm beam of light. A vertical beam was used to evaluate the superior and inferior angles, whereas a horizontal beam was used for the nasal and temporal angles. Gonioscopic grading of the angle was done according to the following system: 0 = none of the angle structures is visible; 1 = only the Schwalbe line and nonpigmented anterior trabecular meshwork are visible; 2 = posterior trabecular meshwork can also be seen; 3 = scleral spur can be detected; and 4 = all angle components including Schwalbe line, trabecular meshwork, scleral spur, and ciliary band are visible.

A-scan biometry (Echoscan, model U3300; Nidek, Tokyo, Japan) was used to measure axial length (AL), lens thickness, and anterior chamber depth (ACD). Five readings were taken for each eye. After omitting the highest and lowest values, the mean of the other 3 readings was used for analysis. The standard deviations for AL, lens thickness, and ACD were 0.04 mm, 0.03 mm, and 0.02 mm, respectively. These data were used to calculate lens position (lens position = ACD + 1/2 lens thickness), relative lens position (relative lens position = lens position / AL), and lens axial factor (lens axial factor = lens thickness / AL). Anterior segment optical coherence tomography was performed as well for anterior segment parameters.

All subjects underwent static automated white-on-white threshold perimetry (program 24-2, Swedish Interactive

Threshold Algorithm standard, model 750, Humphrey Field Analyzer; Humphrey Instruments, Dublin, California, USA). Visual fields were read by a glaucoma specialist who was masked to the clinical data. A reliable field had to meet 3 criteria: false-positive rate 15% or less, false-negative rate 25% or less, and fixation loss less than 25%. If the visual field was deemed unreliable by the grader, then it was repeated.

• **ANTERIOR SEGMENT OPTICAL COHERENCE TOMOGRAPHY:** LPI was not performed for any of the patients until after the anterior segment optical coherence tomography (AS-OCT) was done. AS-OCT (Visante OCT; Carl Zeiss Meditec, Dublin, California, USA) was performed for all the patients in dark ambient lighting. Scans were centered on the pupil, and were obtained along the horizontal and vertical axes using the enhanced anterior segment single protocol. Two images were captured for each axis, and the one with higher quality was chosen for analysis. The brightness and contrast of each image were adjusted so that the scleral spurs could be detected as clearly as possible. Two experienced ophthalmologists (S.M., Z.V.) determined scleral spur location in each image. The principal investigator (S.M.) validated all the images for quality and scleral spur location.

Because the superior and inferior angle images usually do not have the optimal quality and are not reproducible,[13] only the temporal and nasal angle parameters were used for analysis.

The following parameters were measured using the tools provided be the machine (software version 2.0.1.88). This application has been used previously in other studies to measure anterior segment and angle parameters.[14–16] This semiautomatic software has algorithms defining borders and curvatures of the anterior chamber structures. However, the observer identifies the scleral spurs and anterior lens border in order for the automated software program to measure the parameters (Figure 1).

(1) Angle opening distance at 500 μm from scleral spur (the distance between the posterior corneal surface and the anterior iris surface on a line perpendicular to the trabecular meshwork, 500 μm from the scleral spur).[5,17–19]
(2) Trabeculo-iris space area at 500 μm from scleral spur (the surface area of a trapezoid with the following boundaries: anteriorly, the angle opening distance at 500 μm from scleral spur; posteriorly, a line drawn from the scleral spur perpendicular to the plane of the inner scleral wall to the iris; superiorly, the inner corneoscleral wall; and inferiorly, the iris surface).[17]
(3) Anterior chamber angle (the trabecular–iris angle measured with the apex in the iris recess and the arms of the angle passing through a point on the trabecular meshwork at 500 μm from the scleral spur and the point on the iris perpendicularly opposite).[5]

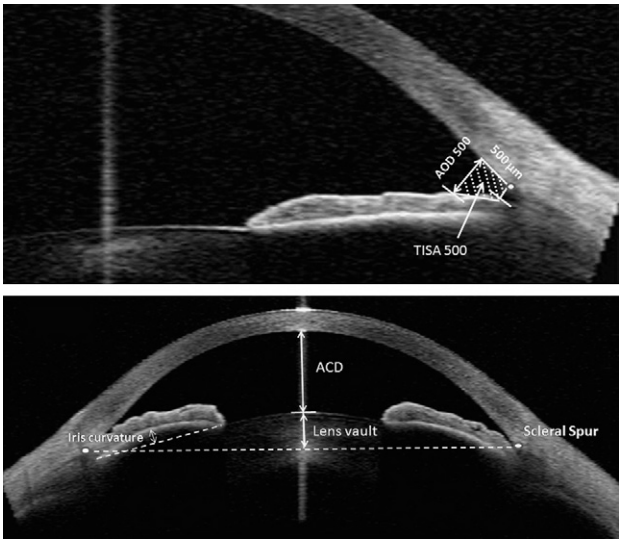

FIGURE 1. Anterior segment optical coherence tomography images illustrate the different parameters that were measured in this study for all subtypes of angle-closure and normal control eyes. (Top) Angle opening distance at 500 μm from scleral spur (AOD 500) is the distance between the posterior corneal surface and the anterior iris surface on a line perpendicular to the trabecular meshwork, 500 μm from the scleral spur. Trabeculo-iris space area at 500 μm from scleral spur (TISA 500) is the surface area of a trapezoid with the following boundaries: anteriorly, the angle opening distance at 500 μm from scleral spur; posteriorly, a line drawn from the scleral spur perpendicular to the plane of the inner scleral wall to the iris; superiorly, the inner corneoscleral wall; and inferiorly, the iris surface. (Bottom) Lens vault, which is the perpendicular distance from the anterior lens surface to the horizontal line connecting the 2 scleral spurs. Iris curvature is measured by drawing a line between the most peripheral and most central points of the iris pigment epithelium, and then measuring the largest perpendicular distance from this line to the iris pigment epithelium. ACD = anterior chamber depth.

(4) Lens vault, which is the perpendicular distance from the anterior lens surface to the horizontal line connecting the 2 scleral spurs, measured by the chamber tool of the Visante OCT. When the anterior pole of the lens was located anterior to the scleral spur line, lens vault was positive; and when it was posterior to the line, lens vault was reported as negative.[8]
(5) Iris curvature, measured by drawing a line between the most peripheral and most central points of the iris pigment epithelium and then measuring the largest perpendicular distance from this line to the iris pigment epithelium.[20]

Angle opening distance and trabeculo-iris space area at 500 μm from the sclera spur, anterior chamber angle, and lens vault were generated by the software and recorded. Iris curvature was measured manually with the caliper built into the software. The mean of the nasal and temporal

TABLE 1. Comparison of Demographic and Clinical Examination Data in Angle-closure Subtypes and Normal Controls

	AACG	Fellow Eye	CACG	PACS	Control	*P* Value
No. eyes	40	40	42	40	27	-
Age (y)	61.6 ± 9.3	59.4 ± 9.2	61.1 ± 8.7	60.2 ± 8.1	62.4 ± 10.6	.69
Sex (F/M)	31/9	31/9	22/20	29/11	19/8	.08
IOP (mm Hg)	13.6 ± 6.8	12.7 ± 3.2	20.8 ± 7.3	15.8 ± 2.6	15.4 ± 3.3	<.001
Medication number	1.9 ± 0.4	1.0 ± 0.7	1.7 ± 1.3	0.0 ± 0.0	0.0 ± 0.0	<.001
C/D ratio	0.30 ± 0.13	0.30 ± 0.11	0.68 ± 0.21	0.29 ± 0.09	0.29 ± 0.07	<.001
Gonioscopy average	0.27 ± 0.34	0.44 ± 0.55	0.53 ± 0.58	0.64 ± 0.57	3.66 ± 0.50	<.001
PAS (degrees)	45.8 ± 79.6	13.1 ± 32.6	174.1 ± 150.1	0.0 ± 0.0	0.0 ± 0.0	<.001
Lens nucleus opacity (per LOCS III)	2.8 ± 0.8	2.5 ± 0.7	2.8 ± 0.9	2.6 ± 0.9	3.2 ± 1.1	.01

AACG = acute angle-closure glaucoma; CACG = chronic angle-closure glaucoma; C/D = cup-to-disc; IOP = intraocular pressure; LOCS III = Lens Opacities Classification System III; PACS = primary angle-closure suspect; PAS = peripheral anterior synechiae.

angle opening distance at 500 μm from scleral spur, trabeculo-iris space area at 500 μm from scleral spur, anterior chamber angle, and iris curvature are labeled as AOD 500, TISA 500, ACA, and iris curvature, respectively.

• **LASER PERIPHERAL IRIDOTOMY:** To eliminate the effect of LPI on anterior segment and angle parameters, we performed gonioscopy, AS-OCT, and A-scan before LPI. However, all the angle-closure patients underwent LPI as standard medical care. Patients with prior LPI were excluded. For all angle-closure cases, the pupil was constricted with pilocarpine 2%, and LPI was performed using the ophthalmic neodymium–yttrium-aluminum-garnet (Nd:YAG) laser (Laserex Tango Nd:YAG; Ellex Medical, Adelaide, Australia) and an Abraham iridotomy contact lens.

• **GRADING NUCLEAR DENSITY:** After pupillary dilation, crystalline lens nucleus density was graded according to the Lens Opacities Classification System III (LOCS III).[21] The examiners were not masked for crystalline lens opacification grading. This grading was performed for both angle-closure and control patients. All eyes underwent dilated fundus examination including stereoscopic examination of the optic nerve head.

• **STATISTICAL ANALYSIS:** Statistical analysis was performed using SPSS software version 17 (SPSS Inc, Chicago, Illinois, USA). Parametric variables were analyzed using analysis of variance (ANOVA) and post hoc Tukey tests. Adjusted lens vault for age, sex, lens thickness, and lens nucleus density was calculated and compared using analysis of covariance (ANCOVA). Analysis of nonparametric variables was done by the Kruskal-Wallis test. χ^2 testing was used for analysis of qualitative variables. Pearson and Spearman correlation coefficients were calculated between lens vault and parametric and nonparametric variables, respectively. *P* value of less than .05 was considered statistically significant. Assuming standard deviation (SD) = 250 μm, we needed 25 patients in each group in order to achieve an 80% power to detect a difference of 200 μm in lens vault in different subtypes of angle closure with a *P* value of .05.

Our sample size has an 83% power to detect a 0.3-mm difference in lens thickness (SD = 0.4 mm) between angle-closure and control eyes, and 0.2-mm difference in lens thickness (SD = 0.4 mm) between the different subtypes of angle-closure disease, using a type I error level of 0.05. Our study also had an 86% power to differentiate a 0.21-mm difference in ACD (SD = 0.24 mm) between all groups.

RESULTS

THE DEMOGRAPHIC AND CLINICAL EXAMINATION DATA OF the 5 groups are summarized in Table 1. There was no difference in age and sex among these groups. As would be expected, IOP was significantly greater in CACG eyes than in the other groups, even with medication usage ($P < .001$). These eyes also had a larger cup-to-disc ratio ($P < .001$) (Table 1).

Intraclass correlation coefficient of variables generated by the AS-OCT software ranged from 93.5% to 99.1% for intravisit and 94.8% to 99.1% for intervisit measurements.

• **ANGLE STATUS:** CACG eyes had 174.1 ± 150.1 degrees of PAS, which was significantly more than the other 4 groups ($P < .001$). Gonioscopically, the anterior chamber angle was narrowest in the AACG eyes, followed by fellow eyes, CACG, PACS, and control; the only significant difference among the angle-closure diagnoses was between AACG and PACS eyes ($P = .01$). The same pattern was also observed for ACA, AOD 500, and TISA 500. ACA and TISA 500 were significantly less in the AACG, fellow eye, and CACG groups than the PACS group (Table 2). AOD 500 was less in AACG and fellow eyes than in PACS eyes ($P = .002$ and $P = .021$, respectively)

TABLE 2. Angle, Anterior Chamber, and Lens Parameters of Subtypes of Angle-Closure and Normal Control Eyes Measured by Anterior Segment Optical Coherence Tomography or A-scan Ultrasound

	AACG	Fellow Eye	CACG	PACS	Control	*P* Value
N_AOD 500 (mm)	0.027 ± 0.039	0.044 ± 0.042	0.065 ± 0.065	0.111 ± 0.073	0.398 ± 0.200	<.001
N_TISA 500 (mm^2)	0.015 ± 0.022	0.022 ± 0.020	0.025 ± 0.025	0.048 ± 0.029	0.148 ± 0.075	<.001
N_ACA (degree)	1.82 ± 3.32	3.19 ± 3.64	4.80 ± 5.43	9.28 ± 6.33	29.52 ± 11.38	<.001
T_AOD 500 (mm)	0.028 ± 0.038	0.043 ± 0.041	0.067 ± 0.061	0.105 ± 0.075	0.410 ± 0.262	<.001
T_TISA 500 (mm^2)	0.014 ± 0.020	0.023 ± 0.022	0.029 ± 0.025	0.054 ± 0.033	0.159 ± 0.107	<.001
T_ACA (degree)	2.01 ± 3.14	3.19 ± 3.74	5.08 ± 5.11	8.64 ± 6.24	29.54 ± 12.11	<.001
AOD 500 (mm)	0.028 ± 0.032	0.044 ± 0.030	0.066 ± 0.054	0.108 ± 0.059	0.404 ± 0.221	<.001
TISA 500 (mm^2)	0.014 ± 0.018	0.022 ± 0.016	0.027 ± 0.021	0.051 ± 0.025	0.154 ± 0.087	<.001
ACA (degree)	1.92 ± 2.67	3.19 ± 2.73	4.94 ± 4.74	8.96 ± 5.08	29.53 ± 11.15	<.001
Lens thickness (mm)	5.06 ± 0.46	4.96 ± 0.32	4.85 ± 0.39	4.92 ± 0.30	4.16 ± 0.49	<.001
Anterior chamber depth (mm)	2.26 ± 0.22	2.36 ± 0.21	2.50 ± 0.24	2.53 ± 0.28	3.15 ± 0.33	<.001
Axial length (mm)	21.84 ± 1.17	21.69 ± 1.13	22.24 ± 0.80	21.97 ± 0.73	22.46 ± 4.35	.26
Lens vault (μm)	1067.95 ± 252.54	977.00 ± 192.32	847.14 ± 189.74	890.25 ± 221.30	266.67 ± 308.38	<.001
Lens position (mm)	4.80 ± 0.23	4.85 ± 0.23	4.93 ± 0.23	4.99 ± 0.27	5.23 ± 0.34	<.001
Relative lens position	0.22 ± 0.02	0.22 ± 0.02	0.22 ± 0.01	0.23 ± 0.01	0.32 ± 0.47	.13
Lens axial factor	0.23 ± 0.02	0.23 ± 0.02	0.22 ± 0.02	0.22 ± 0.01	0.25 ± 0.34	.87

AACG = acute angle-closure glaucoma; ACA = average of nasal and temporal anterior chamber angle; AOD 500 = average of nasal and temporal angle opening distance at 500 μm from scleral spur; CACG = chronic angle-closure glaucoma; N_ACA = nasal anterior chamber angle; N_AOD 500 = nasal angle opening distance at 500 μm from scleral spur; N_TISA 500 = nasal trabeculo-iris space area at 500 μm from scleral spur; PACS = primary angle-closure suspect; T_ACA = temporal anterior chamber angle; T_AOD 500 = temporal angle opening distance at 500 μm from scleral spur; TISA 500 = average of nasal and temporal trabeculo-iris space area at 500 μm from scleral spur; T_TISA 500 = temporal trabeculo-iris space area at 500 μm from scleral spur.

(Table 2). Compared with the control eyes, all angle-closure groups had less AOD 500, TISA 500, and ACA ($P < .001$) (Table 2).

• **ANTERIOR CHAMBER DEPTH:** The eyes with a history of AACG attack had similar ACD as their fellow eyes ($P = .46$), but had shallower anterior chambers than CACG and PACS eyes ($P < .001$ for both) (Table 3). ACD was less in fellow eyes than in PACS eyes ($P = .04$). As expected, the anterior chamber was deeper in control eyes than all angle-closure types ($P < .001$). The result was the same after adjustment for age, sex, lens thickness, AL, and lens vault ($P = .02$ and $P = .002$ for AACG vs CACG and PACS, respectively; $P = .01$ for fellow eyes vs PACS; and $P < .001$ for control vs all angle-closure groups) (Table 4).

• **LENS VARIABLES:** Lens position was less in AACG eyes than in PACS eyes ($P = .01$) (Table 3). Control eyes had higher lens position values than all angle-closure types ($P < .001$ for AACG, fellow, and CACG, respectively; $P = .004$ for PACS).

Lens nucleus opacification was similar among the 4 angle-closure groups (Table 3). Although the lens was thinner in the control patients than in all angle-closure groups ($P < .001$), control eyes had greater nuclear opacity than fellow eyes and PACS eyes ($P = .01$ and $P = .03$, respectively). There was no significant difference in lens thickness among the angle-closure groups (Table 3). This was also true when we adjusted lens thickness for age, sex, AL, lens vault, and ACD (Table 5).

Lens vault, which is a measure of lens protuberance into the anterior chamber, was less in control eyes than in all angle-closure eyes ($P < .001$) (Table 3). Among the angle-closure groups it was highest in the AACG eyes, followed by fellow eyes, PACS, and CACG, but the difference between AACG and their fellow eyes was not statistically significant ($P = .40$). Lens vault was significantly greater in AACG eyes than in CACG and PACS eyes ($P < .001$ and $P = .007$, respectively). After adjusting for age, sex, lens thickness, and nucleus opacity, lens vault was significantly less in control than in angle-closure groups ($P < .001$) (Table 6). It was significantly greater in AACG eyes than in CACG and PACS eyes ($P = .001$ and $P = .005$, respectively).

Iris curvature was significantly less in control patients (0.15 ± 0.09 mm) than in all angle-closure ones (0.26 ± 0.10 mm) ($P < .001$).

Among all the patients collectively, lens vault was strongly negatively correlated with ACD and AOD 500 ($r = -0.75$ and $r = -0.71$, respectively; $P < .001$). It had a moderately positive correlation with iris curvature (Figure 2) and lens thickness ($r = 0.52$ and $r = 0.63$, respectively; $P < .001$) and a negative correlation with lens

TABLE 3. Pairwise Comparison of Anterior Chamber and Lens Parameters in Subtypes of Angle-closure and Normal Control Eyes

	AACG	Fellow Eye	CACG	PACS
Lens vault (*P* value)				
Fellow	.40	-	-	-
CACG	<.001	.11	-	-
PACS	.007	.45	.94	-
Control	<.001	<.001	<.001	<.001
Lens thickness (*P* value)				
Fellow	.79	-	-	-
CACG	.16	.79	-	-
PACS	.51	.99	.95	-
Control	<.001	<.001	<.001	<.001
Lens nucleus opacity (LOCS III) (*P* value)				
Fellow	.46	-	-	-
CACG	.95	.89	-	-
PACS	.73	.99	.99	-
Control	.36	.01	.10	.03
Anterior chamber depth (*P* value)				
Fellow	.41	-	-	-
CACG	<.001	.11	-	-
PACS	<.001	.04	.95	-
Control	<.001	<.001	<.001	<.001
Lens position (*P* value)				
Fellow	.90	-	-	-
CACG	.13	.59	-	-
PACS	.01	.15	.90	-
Control	<.001	<.001	<.001	.004

AACG = acute angle-closure glaucoma; CACG = chronic angle-closure glaucoma; LOCS III = Lens Opacities Classification System III; PACS = primary angle-closure suspect.

position ($r = -0.44$, $P < .001$). Its correlation with AL was weak ($r = -0.15$, $P = .05$). However, it was not correlated with age or lens nucleus opacity (Table 7).

For patients without PAS (PACS group and controls), lens vault had a strong correlation with lens thickness, ACD, and AOD 500 ($r = 0.71$, $r = -0.82$, $r = -0.78$, respectively; $P < .001$ for all) (Figure 3) and moderate negative correlation with lens position ($r = -0.50$, $P < .001$) (Table 7). Age, lens nucleus opacity, and AL were not found to have correlation with lens vault.

The AL, relative lens position, and lens axial factor showed no statistically significant difference between the groups ($P \geq .14$ for all comparisons) (Table 2).

DISCUSSION

THE BIOMETRIC CHARACTERISTICS OF EYES WITH NARROW angles have been studied extensively, particularly in the Asian populations. These eyes usually have shorter axial length, shallower anterior chamber, smaller corneal diameter, and thicker and more anteriorly positioned lens than open-angle eyes.[3,5,6,12,22–24] In this study, lens vault was highest in AACG eyes. ACA, AOD 500, and TISA 500 were less in all categories of angle closure as compared with controls. Furthermore, lens thickness was greater and ACD and lens position were less in all subtypes of angle-closure disease than in normal eyes. Consistent with previous studies in other ethnicities,[5,19] these findings show more crowded anterior segments in narrow-angle eyes among Iranians.

A shallow anterior chamber is the most important and consistent biometric feature predisposing to AACG in different races. Eyes with AACG had a much shallower anterior chamber than normal eyes in our study (2.26 ± 0.22 mm vs 3.15 ± 0.33 mm). The eyes with AACG had the shallowest anterior chamber, followed by the uninvolved fellow eyes, CAGG, PACS, and normal controls. It has been shown that up to 50% of the fellow eyes of AACG patients will have an attack of angle closure within 5 years if left untreated[25–27] and are considered to be in pre-attack stage.[10,28] Although Lan and associates and Lim and associates—in 2 separate study populations—reported shallower anterior chamber and more anterior lens position in AACG than their fellow eyes,[10,29] the 2 eyes had many anatomic similarities as well. We did not find any significant difference in lens vault, lens thickness, ACD, lens position, relative lens position, ACA, AOD 500, and TISA 500 between these 2 subtypes of angle-closure disease.

In our patients, fellow eyes of AACG had shallower anterior chamber than normal eyes. Freidman and associates also reported that the fellow eyes of patients with AACG have a mean ACD that was 0.63 mm shallower than in normal controls.[28] Moreover, we found that in these eyes, mean ACD was 0.17 mm less than in PACS eyes. The significant difference between this group and PACS supports the importance of the ACD in the development of acute angle-closure glaucoma. For this reason, some investigators proposed that the shallower the ACD, the higher the risk of an acute attack.[10,28]

Although previous investigators have confirmed the role of ACD in PACG, not all of them found a significant difference in lens thickness between normal eyes and eyes with PACG.[30] In our study, angle-closure eyes had significantly thicker lenses than open-angle eyes, and lens thickness progressively decreased from AACG to fellow eyes to PACS and to CACG. However, the difference in lens thickness between subtypes of angle-closure disease was not significant. This result is in agreement with the study by Mimiwati and associates, in which they did not report any difference in lens thickness between acute, subacute, and chronic angle-closure glaucoma patients.[12] Other studies also did not find any difference in lens thickness between AACG eyes and their fellow eyes.[10,29] Lan and associates have demonstrated a thicker lens in AACG

TABLE 4. Pairwise Comparison of Adjusted Anterior Chamber Depth for Age, Sex, Lens Thickness, Axial Length, and Lens Vault in Subtypes of Angle-closure and Normal Control Eyes

	AACG	Fellow Eye	CACG	PACS	Control
Mean ± SE (mm)	2.38 ± 0.04	2.41 ± 0.04	2.50 ± 0.04	2.54 ± 0.03	2.86 ± 0.06
Pairwise comparison (*P* value)					
Fellow	.51	-	-	-	-
CACG	.02	.12	-	-	-
PACS	.002	.01	.37	-	-
Control	<.001	<.001	<.001	<.001	-

AACG = acute angle-closure glaucoma; CACG = chronic angle-closure glaucoma; PACS = primary angle-closure suspect; SE = standard error.

TABLE 5. Pairwise Comparison of Adjusted Lens Thickness for Age, Sex, Axial Length, Lens Vault, and Anterior Chamber Depth in Subtypes of Angle-closure and Normal Control Eyes

	AACG	Fellow Eye	CACG	PACS	Control
Mean ± SE (mm)	4.93 ± 0.06	4.92 ± 0.06	4.84 ± 0.06	4.91 ± 0.05	4.47 ± 0.09
Pairwise comparison (*P* value)					
Fellow	.95	-	-	-	-
CACG	.32	.34	-	-	-
PACS	.81	.86	.41	-	-
Control	<.001	<.001	<.001	<.001	-

AACG = acute angle-closure glaucoma; CACG = chronic angle-closure glaucoma; PACS = primary angle-closure suspect; SE = standard error.

TABLE 6. Pairwise Comparison of Adjusted Lens Vault for Age, Sex, Lens Thickness, and Lens Nucleus Opacity in Subtypes of Angle-closure and Normal Control Eyes

	AACG	Fellow Eye	CACG	PACS	Control
Mean ± SE (μm)	1011.45 ± 36.19	942.55 ± 35.97	840.77 ± 34.20	872.47 ± 33.95	482.17 ± 57.47
Pairwise comparison (*P* value)					
Fellow	.17	-	-	-	-
CACG	.001	.04	-	-	-
PACS	.005	.15	.49	-	-
Control	<.001	<.001	<.001	<.001	-

AACG = acute angle-closure glaucoma; CACG = chronic angle-closure glaucoma; PACS = primary angle-closure suspect; SE = standard error.

than in CACG eyes, but the difference was only 0.26 mm.[10] These findings may suggest different relative roles of lens thickness in the various presentations of angle-closure disease.

Lens vault is a newly introduced parameter that represents the height of the lens anterior to the scleral spur plane. In this study, we found that angle-closure eyes had significantly greater lens thickness and lens vault than eyes with open angles. Our finding is consistent with the findings of Nongpiur and associates in their recent study, in which they found that higher lens vault is a significant predictor of angle-closure disease.[8] The greater the lens vault, the more the iris is pushed anteriorly. This increases iridolenticular contact and lengthens and narrows the iris–lens channel, causing pupillary block. Also, the angle becomes more crowded.[8] Thus, higher lens vault predisposes the eye to angle closure through both mechanisms.[1] This is confirmed in our study by the significant negative correlation that was present between lens vault and AOD 500 and ACD regardless of the amount of PAS. Similar to the Nongpiur study, our results show that after adjustment for lens thickness, lens nucleus opacity, age, and

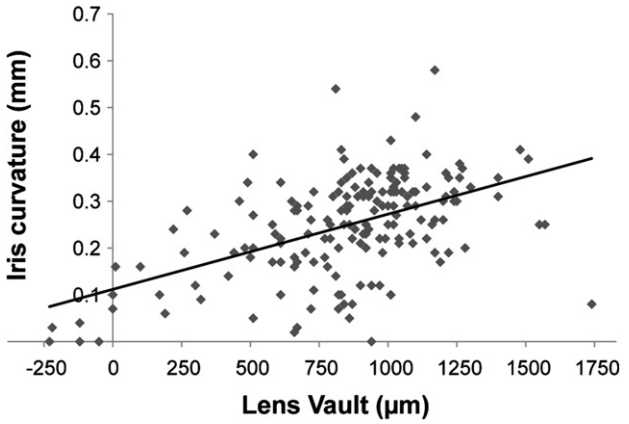

FIGURE 2. Correlation between lens vault and mean nasal and temporal iris curvature in combined eyes (all subtypes of angle closure and normal controls) ($r = 0.52$, $P < .001$).

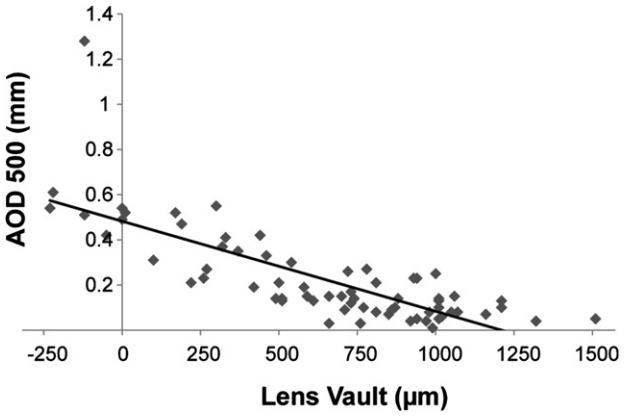

FIGURE 3. Correlation between lens vault and mean nasal and temporal angle opening distance at 500 μm from scleral spur (AOD 500) in primary angle-closure suspect (PACS) and normal control eyes ($r = -0.78$, $P < .001$).

TABLE 7. Correlation Between Lens Vault and Age, Lens Thickness, Anterior Chamber Depth, Average of Nasal and Temporal Angle Opening Distance at 500 μm From Scleral Spur, Axial Length, Lens Position, and Lens Nucleus Opacity in All Patients (All Subtypes of Angle Closure Plus Normal Controls) and in Primary Angle-closure Suspect + Normal Control Subjects

	All Patients		PACS + Control	
	r	*P* Value	r	*P* Value
Age	0.06	.43	−0.002	.98
Lens thickness	0.63	<.001	0.71	<.001
Anterior chamber depth	−0.75	<.001	−0.82	<.001
AOD 500	−0.71	<.001	−0.779	<.001
Axial length	−0.15	.05	−0.09	.49
Lens position	−0.44	<.001	−0.50	<.001
Lens nucleus opacity (LOCS III)	0.000	.99	−0.212	.09

AOD 500 = average of nasal and temporal angle opening distance at 500 μm from scleral spur; LOCS III = Lens Opacities Classification System III; PACS = primary angle-closure suspect; r = correlation coefficient.

sex, the angle-closure groups had greater lens vault than the control group. This might suggest that lens thickness alone is not an important pathogenic factor for angle closure; rather, the amount of its anterior protrusion is one of the major determinants of angle-closure disease.[31]

In the present study, lens vault was greatest in AACG eyes, followed by their fellow eye, and then PACS. The eyes with CACG had the least lens vault among angle-closure eyes. A similar sequence is also reported by Nongpiur and associates.[8] Our study revealed that AACG eyes had significantly higher lens vault than PACS eyes. Lens vault is one of the major determinants of angle width in angle-closure eyes.[31] Thus it is not surprising that ACA, AOD 500, and TISA 500 were shown to be significantly less in AACG than in PACS in our cases. The greater amount of the lens that is protruded anteriorly may lead to a narrower angle and predispose the eye to an acute attack of angle closure.

Iris curvature has been proposed to be an indicator of pupillary block.[32] Recent studies have also shown that this variable could be a predictor of LPI success in opening the angle in narrow-angle eyes.[33] We found a moderate positive correlation between iris curvature and lens vault. As pupillary block mechanism is more prominent in AACG, it is not surprising that we found the highest lens vault in this group compared with the other subtypes of angle closure. However, the large number of outliers in our samples infers that pupillary block is an important, albeit not the only, mechanism by which increased lens vault causes angle closure. Angle crowding attributable to exaggerated lens vault might also be responsible in the development of AACG attack.[2]

Relative lens position and lens position were not different between AACG and CACG eyes. Therefore, these 2 parameters cannot accurately explain the difference in clinical presentation of elevated IOP in acute and chronic angle-closure glaucomas, possibly because they are calculated from and dependent on other parameters (ACD, lens thickness, and AL).[8]

In the literature, there have been inconclusive and sometimes conflicting reports about the role of lens position, relative lens position, and lens axial factor in different subtypes of angle closure. Some investigators reported less relative lens position in patients with PACS or PACG than normal eyes.[5,12,34] Lowe, in his study on angle-closure and normal eyes, showed a considerable overlap in relative lens position measures between the 2 groups.[23] In a recent study on 278 patients, Nongpiur and associates have reported higher lens axial factor in subjects with angle

closures than in normal eyes, but they found no difference in lens position or relative lens position.[8] In our series of patients as well, AL, lens axial factor, and relative lens position were not significantly different between closed- and open-angle patients.

The results of our study should be interpreted with the study limitations in mind. Because the patients were of Iranian descent, the results of this study may not be applicable to other racial groups. The patients were recruited from the glaucoma clinic of Farabi Eye Hospital, which is a tertiary care center. Therefore, the observed results may not be generalizable to the larger population. Another limitation was the low AS-OCT image quality of the superior and inferior angles, which led us to use only the nasal and temporal angle parameters for analysis. For secondary outcomes, although we had enough cases in the angle-closure group for comparison with the normal eyes, the number of patients in each subgroup may not be sufficient to identify some differences between angle-closure subtypes. Lastly, some studies showed that cortical or nuclear cataract may be associated with angle closure.[35] Full dilation of pupil may not have been achieved because of iris changes resulting from prior medications or acute attack, making grading cortical cataract difficult. However pupils were dilated sufficiently to grade the nuclear density. This was the reason we focused only on the nuclear opacification.

In conclusion, in this study we found that ACA, AOD 500, TISA 500, ACD, and lens position were significantly less and lens thickness and lens vault were significantly greater in all subtypes of angle-closure than open-angle eyes. All the measured biometric parameters were similar in AACG and their fellow eyes. Eyes with a history of AACG had the least ACA, AOD 500, and TISA 500, followed by their fellow eyes, CACG eyes, and PACS eyes. ACD progressively increased, and lens thickness and lens vault decreased, from AACG to the uninvolved fellow eyes, to PACS, and to CACG. We suggest that higher lens vault may play a particularly strong role in the development of an acute attack of angle closure. Future studies with larger populations and different ethnic groups will help to determine if our findings are applicable to other populations, particularly those at increased risk for angle closure.

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Biosketch

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