Biometric Evaluation of Anterior Chamber Changes after Physiologic Pupil Dilation Using Pentacam and Anterior Segment Optical Coherence Tomography

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Purpose. We evaluated changes in anterior chamber (AC) morphology and iris volume induced by physiological mydriasis in fellow eyes of acute angle-closure patients, and age-, sex-, and central AC depth-matched primary angle-closure suspects (PACS).

Methods. In our study, 21 fellow eyes of patients with acute angle closure; 40 age-, sex-, and central AC depth-matched PACS eyes; and 40 age- and sex-matched normal open-angle eyes were imaged using a Pentacam and anterior segment optical coherence tomography (AS-OCT) under light conditions, and after 5 minutes of darkness using AS-OCT. Iris volume was estimated using AS-OCT and a customized image-processing software.

Results. Central AC depth, corneal curvature, axial length, and lens thickness did not differ significantly between the PACS and fellow eyes. When going from light to dark, angle opening distance at 500 μm decreased significantly more in fellow eyes than in PACS (–68% vs. –52%, $P < 0.001$). When going from light to dark, the mean iris volume increased significantly in the fellow eyes (from 45.34 ± 2.1 to 47.68 ± 3.2 mm^3, $P < 0.01$), whereas it decreased significantly in most PACS eyes (from 45.01 ± 2.2 to 42.11 ± 2.3 mm^3, $P < 0.01$), and in all open-angle eyes (from 44.68 ± 1.16 to 41.67 ± 1.20 mm^3, $P < 0.01$). Based on multivariate analysis, significant predictors of angle narrowing under darkness (relative change in angle-opening distance 500) were fellow eyes compared to PACS ($\beta = -2.98$, SE = 0.249, $P = 0.005$) and higher iris volume increase with pupil dilation ($\beta = -3.146$, SE = 0.432, $P = 0.015$).

Conclusions. Under dark conditions, angles of fellow eyes closed dramatically more than did those of PACS. Iris volume increase per millimeter of pupil dilation is an independent predictor of angle narrowing in darkness. (*Invest Ophthalmol Vis Sci.* 2012;53:4005–4010) DOI:10.1167/iovs.11-9387

Over the past decade, new anterior chamber (AC) imaging techniques, such as ultrasound biomicroscopy (UBM) and optical coherence tomography (OCT), have provided numerous valuable insights into the pathogenesis of angle-closure glaucoma, and demonstrated that the well-identified anatomic risk factors are not sufficient to produce angle closure.[1] Clearly, anatomic conditions, such as shallow AC, shorter axial length, larger lens thickness and volume, or greater lens vault, are statistically demonstrated risk factors of angle closure, angle-closure glaucoma, or acute angle closure.[2–7] However, the anatomic mechanisms taken alone do not explain that 80%–90% of the eyes with such predisposing characteristics never have angle closure, that Asians have a much higher prevalence of angle closure and angle-closure glaucoma than Caucasians despite often comparable biometric characteristics, and that the numerous available biometric measurements have a poor predictive power to identify eyes a priori that will have further development of angle closure and need iridotomy.[7–12] Recent studies have investigated the role of the dynamic response of some intraocular structures to physiologic conditions, particularly the response of the iris to pupil dilation, and have suggested that angle closure could be due to abnormal dynamic behavior of the iris occurring in anatomically predisposed eyes. First, Quigley et al., using anterior segment OCT (AS-OCT), found that the iris cross-sectional area is nearly two times smaller after physiologic or pharmacologic pupil dilation in healthy eyes, and that a lower reduction of the iris cross-sectional area after pupil dilation may be a potential risk factor for angle closure.[13] They hypothesized that the normal iris loses volume in the dark or after pharmacologic pupil dilation, and that eyes with angle closure lose less iris volume on dilation, contributing to iridotrabecular apposition. In addition, we demonstrated previously, using customized software allowing us to estimate the whole iris volume from AS-OCT data, that iris volume increases after pupil dilation in narrow-angle eyes predisposed to acute angle closure, whereas it decreases in healthy open-angle eyes.[14] We suggested that these changes could result from a change in vascular tonus leading to venous outflow decrease and intravascular volume increase. We compared the fellow eyes of patients with acute angle closure with healthy open-angle eyes. By extrapolation, we and others have hypothesized that the behavior of the iris may explain that a small proportion of narrow-angle eyes develop angle closure, whereas the majority of narrow-angle eyes with comparable biometric characteristics do not develop angle closure.[14–16]

The objective of our present study was to evaluate the changes in AC morphology after physiologic mydriasis in the fellow eyes of acute angle-closure patients compared to primary angle-closure suspects (PACS; i.e., asymptomatic narrow-angle eyes) and normal open-angle eyes. To evaluate the role of the dynamic response of the iris more precisely (i.e., risk factors not related to the static anatomy), we compared age-, sex-, and AC depth-matched PACS eyes. We assessed prospectively the anterior segment static anatomy using a Pentacam (Oculus, Wetzlar, Germany) and evaluated change in iris volume using AS-OCT.

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METHODS

Patients and Procedures

We conducted a prospective investigation in a French university-affiliated glaucoma center. The study followed the tenets of the declaration of Helsinki and was approved by the French Society of Ophthalmology Ethics Committee. All patients provided verbal and written informed consent. We studied 21 fellow eyes of 21 patients presenting at the center from September 2010 to March 2011 with a unilateral episode of primary acute angle closure, 40 PACS eyes of 40 patients recruited from the outpatient clinic, and 40 normal eyes of 40 healthy volunteers. All eyes with primary acute angle closure were treated successfully with topical and systemic medications, followed by laser peripheral iridotomy ($n = 21$), associated with trabeculectomy in some patients ($n = 2$). To be included, the fellow eye had to have a narrow angle with a grade 0–2 angle depth in Shaffer's classification without any patent prophylactic laser peripheral iridotomy.[17] We excluded patients who had ever experienced ocular pain, blurred vision, or halos in the study eye, as well as patients who had plateau iris configuration. PACS eyes were defined as eyes with an angle in which more than 270° of the posterior trabecular meshwork (the part that often is pigmented) cannot be seen, without features indicating that trabecular obstruction by the peripheral iris had occurred, such as peripheral anterior synechiae, elevated intraocular pressure, iris whorling (distortion of the radially orientated iris fibers), glaukomfleken lens opacities, or excessive pigment deposition on the trabecular surface. PACS had normal-appearing optic discs and a normal standard automated perimetry (after a minimum of two visual fields). Healthy volunteers were recruited from outpatient clinic patients seen for refraction tests. All control eyes had open angles with grade 3–4 angle depths in the Shaffer classification, and were not receiving any drops. PACS eyes were age-, sex-, and central AC depth-matched to the fellow eyes of acute angle-closure patients. Normal open-angle eyes were age- and sex-matched to the fellow eyes of acute angle-closure patients. We used a ratio-matching technique to include the PACS and normal eyes (in the fellow eyes group, the sex ratio was 3/18, age SD 6.3 years, and central AC depth SD 0.32 mm). In case of bilateral PACS, one eye was chosen in accordance with the matching process. PACS eyes did not have any prophylactic laser peripheral iridotomy.

We excluded patients who received topical or systemic medication that could affect the iris or angle configuration at the time of the study, including cholinergics or anticholinergics; adrenergic agonists or antagonists; serotonin, norepinephrine, and dopamine releasers, or precursors or reuptake inhibitors; monoamine oxidase inhibitors; opioid agonists or antagonists, and histamine receptor antagonists. We excluded eyes with previous intraocular laser or surgery.

All study participants underwent a complete ophthalmic examination, including objective and subjective refraction, slit-lamp biomicroscopy, intraocular pressure (IOP) measurement, gonioscopy, fundus examination, and A-scan ultrasound biometry. Iris color was classified as brown (light or dark brown color taking up more than half of the iris), intermediate (brown color equal to or less than half of the iris), and blue (blue or gray iris without brown color). Refraction was measured using an AR-360 autorefractometer (Nidek Co., Gamagori, Japan), gonioscopy using a Goldmann three-mirror lens and a Posner lens by a single observer (FA), and A-scan ultrasound biometry using an OcuScan RxP (Alcon Inc., Forth Worth, TX). Each included eye was imaged with a Pentacam, as well as an AS-OCT (Visante OCT Model 1000; Carl Zeiss Meditec Inc., Dublin, CA). Scheimpflug imaging was performed in bright conditions (approximately 4,000 lux) with a regular 3D scan protocol (50 images within 2 seconds). Because of the brightness of the Pentacam light source, measurements under dark conditions were not possible. Parameters of the printout retained for the analysis were central AC depth, peripheral AC depth, front keratometry, back keratometry, front asphericity, and back asphericity. Peripheral AC depth was calculated by averaging the 20 measurements at 18-degree intervals and 4-mm distance from the center of the measurement area. AS-OCT imaging was performed with the anterior segment single protocol (6 mm deep, 16 mm wide, 256 A-scans per line) by one observer (FA). The scan line was adjusted manually to bisect the pupil. The sets were acquired first in bright conditions (~4,000 lux, physiologic miosis) and then under dark conditions (~1 lux, physiologic mydriasis). An internal fixation target was used with the subject's refractive correction to perform the measurements in a nonaccommodative state. The dark measurements were made after 5 minutes of dark adaptation. Thus, 8 cross-sectional images of the iris were obtained at 0-, –45-, 90-, 135-, 180-, 225-, 270-, and 315-degree meridians. Iris volume was estimated as described previously.[14,18] Angle configuration, including angle opening distance at 500 μm (AOD 500), and trabecular-iris space at 500 μm (TISA 500), also was evaluated with AS-OCT. AOD 500 is the distance from the corneal endothelium to the iris surface perpendicular to a line drawn at 500 μm from the scleral spur. TISA 500 is the area bound anteriorly by the AOD 500, posteriorly by a line drawn from the scleral spur perpendicular to the plane of the inner scleral wall to the iris, superiorly by the inner corneoscleral wall, and inferiorly by the iris surface. These two parameters and the pupil diameter were obtained using the AS-OCT internal specific software.

Data Analysis

The one-sample Kolmogorov–Smirnov test was used to assess the normality of the parameter measurements. Student's *t*-test was used for mean comparisons. The χ^2 test was used for the analysis of qualitative variables. We measured the linear relationship between two variables using the Pearson product moment correlation. The statistical significance of r was tested using a *t*-test. Multivariate regression analyses were used to identify the predictors of angle narrowing (relative change in AOD 500) with physiologic pupil dilation. First, the predictive variables (age, sex, iris color classified as brown or others, diagnosis classified as fellow eyes or PACS eyes, baseline pupil size, ratio of change in iris volume to change in pupil diameter, and central AC depth) were tested using univariate analysis. Statistical significance was set at $P \leq 0.05$. The predictive variables shown to be significant by univariate analysis then were entered in the final multivariate equation. We used SPSS statistical software version 17.0 (SPSS Inc., Chicago, IL) for data analysis.

RESULTS

Patient Characteristics

We enrolled in our study 21 fellow eyes of patients with acute angle closure; 40 age-, sex-, and central AC depth-matched PACS eyes; and 40 age- and sex-matched normal open-angle eyes. Of the 21 fellow eyes 13 were classified as PACS, six were classified as primary angle-closure eyes (eyes with an angle in which more than 270° of the posterior trabecular meshwork cannot be seen, with features indicating that trabecular obstruction by the peripheral iris had occurred, such as peripheral anterior synechiae, elevated intraocular pressure, iris whirling, glaukomfleken lens opacities, or excessive pigment deposition on the trabecular surface, and with normal-appearing optic discs and a normal standard automated perimetry), and two were classified as primary angle-closure glaucoma (primary angle closure with evidence of glaucoma). Six of the fellow eyes received glaucoma medications (6 received monotherapies, including prostaglandin analogs in 5, and beta-blockers in 1). The subjects' demographic data are shown in Table 1. All study participants were Caucasians.

Static and Dynamic Biometric Characteristics

Static and dynamic biometric measurements are shown in Table 2. Central AC depth, corneal curvature, corneal

Table 1. Demographic Characteristics

	Fellow Eyes	PACS Eyes	Open-Angle Eyes	*P* Value
Age (Mean ± SD)	64.2 ± 6.3	63.1 ± 7.9	64.9 ± 8.3	0.66
Sex (male/female)	3/18	6/34	6/34	0.88
Iris color				
Brown	10/21	22/40	21/40	0.68
Intermediate	7/21	11/40	10/40	0.54
Blue	4/21	7/40	9/40	0.4
Ethnic origin: Caucasian	21/21	40/40	40/40	>0.9

asphericity, axial length, and lens thickness did not differ significantly between fellow eyes and PACS eyes. In light conditions, the fellow eyes had a slightly narrower peripheral AC than the PACS eyes (peripheral AC depth 1.09 ± 0.29 vs. 0.93 ± 0.3 mm, $P = 0.05$; AOD 500 141 ± 28 vs. 126 ± 26 μm, $P = 0.04$). Open-angle eyes had a significantly higher central AC, peripheral AC depth, and axial length than the fellow eyes and PACS eyes ($P < 0.004$). Open-angle eyes had lower lens thickness than the fellow eyes ($P = 0.02$).

When going from light to dark, the mean iris volume increased significantly in the fellow eyes (from 45.34 ± 2.1 to 47.68 ± 3.2 mm^3, $P < 0.01$), whereas it decreased significantly in most PACS eyes (from 45.01 ± 2.2 to 42.11 ± 2.3 mm^3, $P < 0.01$) and in all open-angle eyes (from 44.68 ± 1.16 to 41.67 ± 1.20 mm^3, $P < 0.01$). The mean iris volume change per millimeter of pupil dilation was −1.19 ± 0.51 (95% confidence interval [CI] −1.34 to −1.04) in the open-angle group, −1.03 ± 0.48 (95% CI −1.19 to −0.86) in the PACS group, and +0.78 ± 0.43 (95% CI 0.58–0.97) in the fellow eyes group. The distributions of iris volume change per millimeter of pupil dilation among the PACS eyes, fellow eyes, and open-angle eyes are displayed in Figure 1. Iris volume increased in 90% and decreased in 10% of the fellow eyes. Iris volume increased in 7.5% of the PACS eyes, did not change or decreased slightly (iris volume changed from −0.25–0 mm^3/mm of pupil dilation) in 7.5% of the PACS eyes, and decreased clearly (iris volume change <−0.50 mm^3/mm of pupil dilation) in 85% of the PACS eyes. The iris volume decreased in 100% of the open-angle eyes.

The relationship between angle narrowing and the ratio of change in iris volume to change in pupil diameter after pupil dilation was examined by linear regression analysis. Iris volume increase per millimeter of pupil dilation correlated significantly with AOD 500 decrease after pupil dilation, both in the PACS eyes and in the fellow eyes ($r^2 = 0.51$, $P < 0.001$, Fig. 2). It is interesting to note from Figure 2 that the relationships between change in iris volume to change in angle configuration evaluated separately in PACS and fellow eyes (white and gray circles) exhibited similar changes. Clearly, in these two conditions, the less the iris volume decreases or the more the iris volume increases with physiologic pupil dilation, the narrower the angle becomes. However, as shown in Figure 1, iris volume increases after pupil dilation in most fellow eyes, whereas iris volume decreases after pupil dilation in most PACS eyes, explaining that angles close significantly more after pupil dilation in fellow eyes.

Predictors of Angle Narrowing Under Darkness

The results of the univariate and multivariate regression analyses are shown in Table 3. The variables associated significantly with angle narrowing under darkness (AOD 500 decrease) with univariate regression were iris color (angles of brown eyes close more), diagnosis (angles of fellow eyes close more), and the ratio of change in iris volume-to-change in pupil diameter (angles of eyes with more iris volume increase per millimeter of pupil dilation close more). These three predictive variables then were entered in the multivariate regression

Table 2. Biometric Characteristics

				P (*t*-Test)		
	PACS Eyes (Mean ± SD)	Fellow Eyes (Mean ± SD)	Open-Angle Eyes (Mean ± SD)	PACS vs. Fellow Eyes	PACS vs. Open-Angle Eyes	Fellow Eyes vs. Open-Angle Eyes
ACD central (mm)	2.08 ± 0.28	2.14 ± 0.32	2.88 ± 0.41	0.47	<0.0001	<0.0001
ACD peripheral miosis (mm)	1.09 ± 0.29	0.93 ± 0.3	1.28 ± 0.28	0.05	0.0038	<0.0001
Km front (diopter)	43.83 ± 0.85	43.72 ± 0.91	44.09 ± 1.08	0.46	0.2351	0.1858
Km back (diopter)	−6.34 ± 0.16	−6.26 ± 0.21	−6.41 ± 0.26	0.13	0.1510	0.0263
Q front (*q* values)	−0.25 ± 0.15	−0.32 ± 0.17	−0.24 ± 0.22	0.12	0.8129	0.1517
Q back (*q* values)	−0.44 ± 0.17	−0.54 ± 0.22	−0.47 ± 0.28	0.07	0.5641	0.3241
Lax (mm)	22.31 ± 0.89	22.36 ± 0.65	23.32 ± 0.75	0.8	0.0001	<0.0001
Lens thickness (mm)	4.95 ± 0.76	5.12 ± 0.87	4.69 ± 0.55	0.45	0.0836	0.0215
Iris volume – miosis (mm^3)	45.01 ± 2.2	45.34 ± 2.1	44.68 ± 1.16	0.574	0.4039	0.1181
Iris volume – mydriasis (mm^3)	42.11 ± 2.3	47.68 ± 3.2	41.35 ± 1.20	<0.001	0.1857	<0.0001
Δ Volume (%)	−6.4%	+5.2%	−7.4%	<0.001	>0.1	<0.001
Pupil diameter miosis (mm)	2.4 ± 0.9	2.3 ± 0.9	2.6 ± 1.1	0.68	0.3762	0.2872
Pupil diameter mydriasis (mm)	5.2 ± 1.4	5.3 ± 1.2	5.4 ± 1.8	0.77	0.5807	0.8198
ΔV / Δ Ø pupil (mm^2)	−1.03 ± 0.48	+0.78 ± 0.43	−1.19 ± 0.51	<0.0001	0.15	<0.0001
AOD 500 miosis (μm)	141 ± 28	126 ± 26	588 ± 111	0.04	<0.0001	< 0.0001
AOD 500 mydriasis (μm)	67 ± 22 (−52%)	41 ± 17 (−68%)	468 ± 107 (−20%)	<0.001	<0.0001	< 0.0001

ACD, AC depth; ACD peripheral miosis, peripheral AC depth estimated with the Pentacam in bright conditions; Km, keratometry; Lax, axial length; Q, asphericity; ΔV/ΔØ pupil, ratio of change in iris volume to change in pupil diameter.

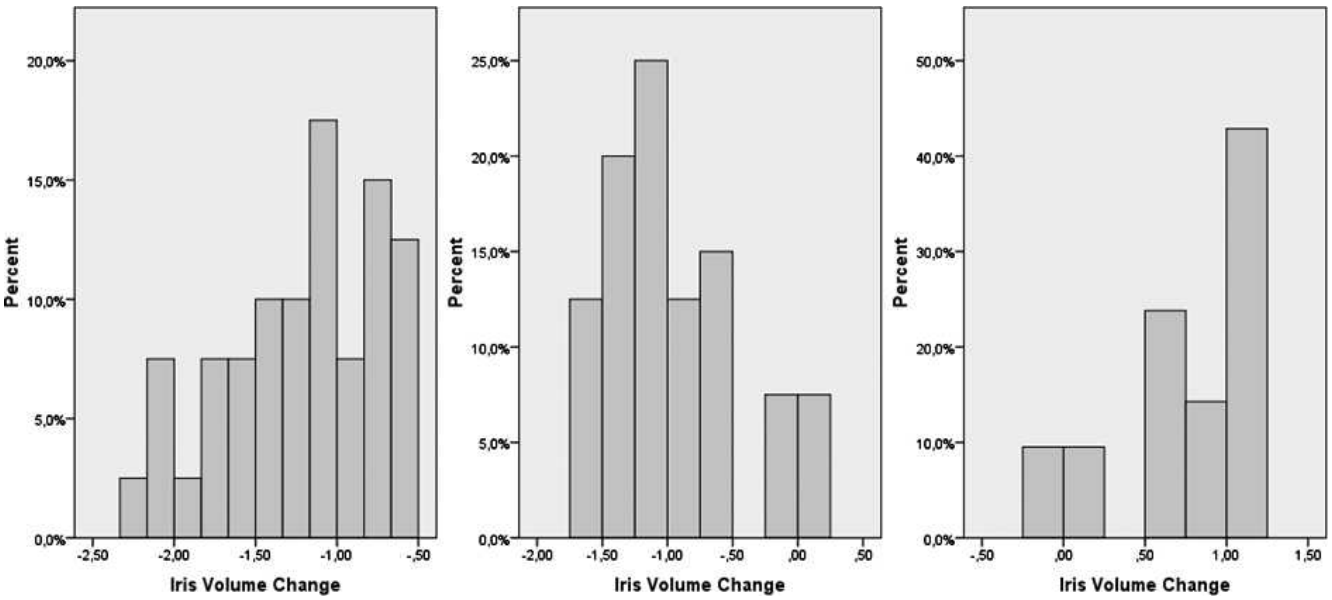

Figure 1. Distribution of iris volume change per millimeter of pupil dilation (mm^3 per mm) among the open-angle (*left*), PACS (*middle*), and fellow (*right*) eyes (percent of the eyes in each group).

analysis. Independent predictors of angle narrowing when going from light to dark were the eye population (fellow eyes, $P = 0.005$) and the iris volume increase per millimeter of pupil dilation ($P = 0.015$).

Discussion

Anatomic risk factors for angle closure, angle-closure glaucoma, or acute angle closure do not explain adequately why most people with small eyes and gonioscopically narrow angles never have angle closure, whereas a small proportion of eyes with comparable biometric characteristics have angle closure, angle-closure glaucoma, or acute angle closure.[7–12] Recent studies have provided strong evidence that the dynamic response of the iris under physiologic conditions, particularly during pupil dilation, could explain that a small proportion of anatomically predisposed eyes have angle closure. Quigley et al. found, using AS-OCT iris radial sections, that the iris cross-sectional area is nearly two times smaller after physiologic or pharmacologic pupil dilation, but that angle-closure eyes have

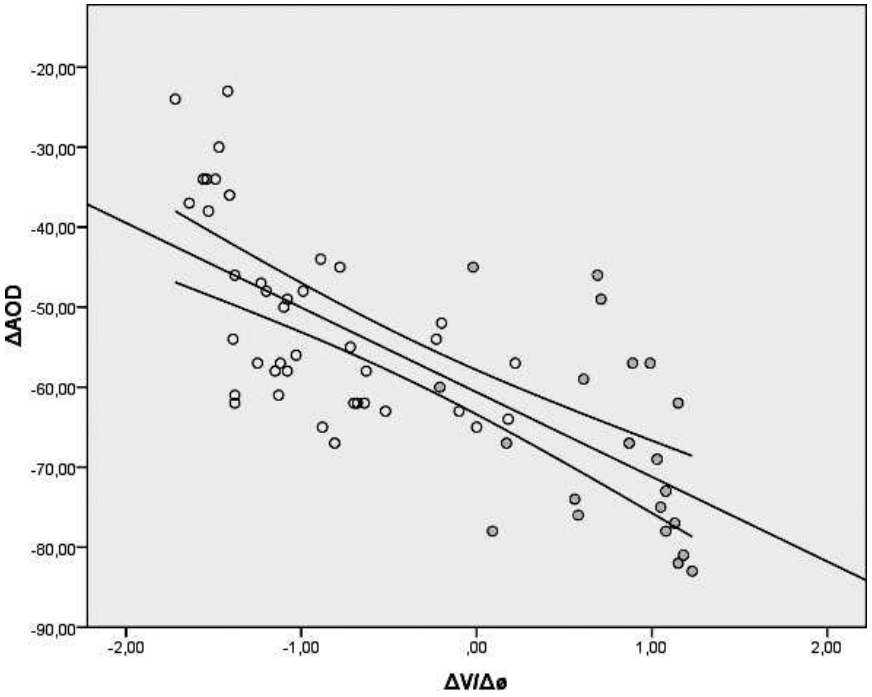

Figure 2. Linear regression analysis showing the relationship between angle narrowing (changes in angle opening distance at 500 μm) and the ratio of change in iris volume to change in pupil diameter (mm^3 per mm) after physiologic pupil dilation in PACS (*white circles*) and fellow (*gray circles*) eyes ($r^2 = 0.51$, $P < 0.001$). The CIs are shown above and below the regression line.

less iris area change.[13] They presumed that iris volume decreases in proportion to cross-sectional area decrease and, therefore, suggested that a smaller reduction of iris volume with pupil dilation favors irido-trabecular apposition. In another report, they estimated iris volume from the iris cross-sectional area in 90 subjects with angle closure or open-angle glaucoma, as well as glaucoma suspects and controls, and found that 90% of the subjects had a loss of iris volume when going from light to dark, whereas 10% had a gain in volume.[1] Angle-closure subjects were more likely to have iris volume increase or less iris cross-sectional area decrease. In a further study, we used customized software to estimate the whole iris volume from AS-OCT data, and we found that iris volume usually increases after pharmacologic pupil dilation in narrow-angle eyes predisposed to angle closure (i.e., fellow eyes of acute angle-closure patients), whereas iris volume always decreases in healthy open-angle eyes.[14] Independent predictors of increase in iris volume after pupil dilation were eyes predisposed to angle closure compared to open-angle eyes, larger pupil diameter, and brown eyes. We and others suggested that the behavior of the iris found in our study likely explains that a small proportion of narrow-angle eyes have angle closure, whereas the majority with the same biometric characteristics do not.[14–16]

However, we did not evaluate and compare iris volume and angle change with pupil dilation in narrow-angle eyes at high risk of angle closure to narrow-angle eyes having a lower risk of angle closure, which was studied in this report. As eyes at high risk of angle closure, we investigated fellow eyes of patients with primary acute angle closure. Several large observational studies have shown that such eyes have a much higher risk of chronic or acute angle closure than asymptomatic narrow-angle eyes.[19–22] PACS eyes without any signs of angle closure or angle-closure glaucoma were chosen as asymptomatic narrow-angle eyes. Epidemiologic studies have demonstrated that only a small proportion of PACS eyes will have further development of angle closure or angle-closure glaucoma.[10,11] To isolate the role of the nonanatomic risk factors, we studied PACS eyes that were age-, sex-, and central AC depth-matched to the fellow eyes of acute angle-closure patients.

We used AS-OCT and the Pentacam to evaluate the anterior segment anatomy before pupil dilation and, thus, to match the PACS eyes to the fellow eyes. With the Scheimpflug camera, a complete and reproducible assessment of the AC could be made, including the central and peripheral AC depth, corneal curvature, and corneal asphericity.[23–27] Measurements of peripheral AC depth also are possible with AS-OCT, but this is not done automatically by the AS-OCT internal software, and instead must be done manually by drawing a line from the endothelium to the iris surface at a given distance to the center of the AC. Therefore, we used the Pentacam, which allows automatic measurements of the peripheral AC depth, as well as other measurements not available with AS-OCT, such as the corneal asphericity. By contrast, AS-OCT provides direct measurements of the angle, whereas those given by the Pentacam are measured by extrapolating from the corneal endothelial and anterior iris surfaces, since the Pentacam does not allow one to visualize directly the angle recess and scleral spur. Previous studies have shown that the agreement between the angle measurements provided by the Pentacam and those provided by other methods, such as gonioscopy, AS-OCT, and ultrasound biomicroscopy, may be limited.[17,28,29] Therefore, we used the relative change in AOD 500 to evaluate angle narrowing after pupil dilation. Moreover, because of the brightness of the Pentacam light source, measurements under dark conditions are not possible with this imaging method.

In our previous work in which we estimated iris volume, we used pharmacologic pupil dilation. In the present study, physiologic dilation (darkness) was used to obtain mydriasis.

Table 3. Univariate and Multivariate Regressions for Change in AOD 500

	Dependent Variables (Δ AOD 500)		
	Unstandardized Coefficients		Significance
Predictor Variables	**β**	**SE**	**(*P*)**
Univariate regression:			
Age	−2.322	.674	0.188
Sex	1.589	.578	0.342
Iris color (brown vs. others)	−4.756	.420	**0.038**
Diagnosis (FE vs. PACS)	−2.970	.286	**0.008**
Baseline pupil size	−2.263	.887	0.471
ΔV / Δ Ø pupil	−3.192	.424	**0.014**
AC depth	5.675	1.928	0.086
Multivariate regression:			
Iris color (brown vs. others)	−4.858	0.687	0.080
Diagnosis (FE vs. PACS)	−2.980	0.249	**0.005**
ΔV / Δ Ø pupil	−3.146	0.432	**0.015**

Bold numbers signify numbers with $P < 0.05$. FE, fellow eyes; β, beta.

This method was preferred here because it is closer to common physiologic conditions, and because eyes can be studied without laser iridotomy. Since iridotomy eliminates pupillary block, decreases iris curvature and tension, and increases iris mobility, we can suppose that iridotomy may change the results of iris evaluations. The magnitude of iris volume change found in our study conducted with physiologic pupil dilation (up to +5.2% in the fellow eyes group) was slightly less significant than that found in the previous study conducted with pharmacologic pupil dilation (up to +11.1% in the fellow eyes group). As pupil dilation was less important with physiologic mydriasis, and as iris volume is related to change in pupil diameter, we can hypothesize that the different method used for pupil dilation explains the range of iris volume changes.

Age-, sex-, and AC central depth matching led to nonstatistically significant differences in axial length, spherical equivalent, corneal curvature, and corneal asphericity between the two groups. Therefore, we can estimate that the usually described anatomic risk factors of angle closure were comparable in the two groups of eyes. It should be noted that, before pupil dilation, peripheral AC depth evaluated with the Pentacam, and AOD and TISA 500 evaluated with AS-OCT were slightly smaller in the fellow eyes than in the PACS eyes. This could indicate differences in iris root insertion or differences in iris peripheral thickness despite comparable iris volume under light conditions. Under dark conditions, angles of fellow eyes closed dramatically more than did those of PACS. In the two groups of patients, the relationships between changes in iris volume and changes in angle configuration were similar: the iris volume increase per millimeter of pupil dilation was an independent predictor of angle narrowing under darkness. Since iris volume increases after physiologic pupil dilation in most fellow eyes, whereas it decreases in most PACS eyes, angles of fellow eyes are more likely to close in darkness. When estimating iris volume changes in normal open-angle eyes, we found that 100% of these eyes had a clear decrease in iris volume with physiologic pupil dilation. In contrast, only 85% of PACS eyes had a decrease in iris volume with physiologic pupil dilation, whereas 15% showed virtually no change or a slight increase in iris volume. Longitudinal studies have shown that a small proportion of PACS cases will have further development of PAC, PAC glaucoma, or acute angle closure. We suggest that PACS eyes, having uncommon iris

behavior and, being more likely to close in darkness, could be those that will have further development of PAC, PAC glaucoma, or acute angle closure. Longitudinal studies are needed to verify this hypothesis.

In summary, our study showed that PACS eyes and eyes at high risk of angle closure with similar anatomy usually do not respond similarly to physiologic pupil dilation because of differences in iris behavior. These differences in iris behavior under physiologic conditions could explain that a small percentage of narrow-angle eyes will have angle closure, whereas the majority of eyes with the same biometric characteristics will not. Longitudinal studies evaluating whether iris volume change with darkness could be used to identify narrow-angle eyes that will have peripheral anterior synechia, angle closure, angle-closure glaucoma, or acute angle closure would be required to validate this hypothesis. Since estimating iris volume change when going from light to dark is a rather simple and safe test, it will be interesting to evaluate, in a prospective manner, whether it could be used to identify narrow-angle eyes that will have angle closure and need prophylactic iridotomy.

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