Anterior Choroidal Thickness Increased in Primary Open-Angle Glaucoma and Primary Angle-Closure Disease Eyes Evidenced by Ultrasound Biomicroscopy and SS-OCT

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PURPOSE. To compare the anterior and posterior choroid thickness (ACT and PCT, respectively) in primary open-angle glaucoma (POAG), primary angle-closure disease (PACD), and healthy control subjects.

METHODS. A total of 29 POAG patients (56 eyes), 37 PACD patients (64 eyes), and 34 healthy volunteers (68 eyes) were enrolled in this study; 50 POAG eyes were divided into 25 early/moderate-stage and 25 advanced-stage eyes by visual field loss, while 64 PACD eyes were classified as primary angle-closure suspect (PACS), 8 eyes; primary angle closure (PAC), 18 eyes; and primary angle-closure glaucoma (PACG), 38 eyes. Ultrasound biomicroscopy (UBM) was used to measure the ACT at a distance of 4 mm from the root of iris in all participants. ACT and PCT were measured using UBM and swept-source optical coherence tomography (SS-OCT), respectively. A 4-mm distance from the iris root was self-defined as the anterior choroid that well matched the real anterior choroid.

RESULTS. The mean ACT measured by UBM was 0.45 ± 0.057 mm in POAG eyes, 0.38 ± 0.050 mm in PACD eyes, and 0.30 ± 0.050 mm in healthy eyes. Both the POAG and PACD eyes had a thicker anterior choroid than healthy eyes (P < 0.01). Compared to early/moderate-stage eyes of POAG, advanced-stage eyes had similar ACT (P > 0.05). PACG eyes had a thinner anterior choroid than PAC/PACS eyes (P < 0.05). However, no statistically significant difference was noted for POAG, PACD, and normal control eyes’ PCT using SS-OCT (P > 0.05).

CONCLUSIONS. POAG/PACD eyes had a thicker anterior choroid than the controls. However, there was no significant difference in the PCT among the groups. The anterior choroid might play a role in the pathogenesis of glaucoma, warranting further investigation.

Keywords: glaucoma, ultrasound biomicroscopy, optical coherence tomography, choroid.

Glaucoma

Glaucoma is a common cause of irreversible blindness worldwide, which can be classified into primary open-angle glaucoma (POAG) and primary angle-closure disease (PACD) according to the angle structure.1 POAG is the predominant glaucoma in Europe and the United States, while Asian populations represent one of the highest rates of PACD, particularly in China.2

It is generally accepted that there are no differences in the macular, peripapillary choroid thickness between normal and POAG eyes.3,4 PACD contains a spectrum of anatomic variations, including primary angle-closure suspect (PACS), primary angle closure (PAC), primary angle-closure glaucoma (PACG), and acute primary angle closure (APAC), or acute angle-closure crisis (AACC).5-7

According to choroidal expansion theory of Arora et al.,8 posterior choroid may play an important role in angle-closure (AC) disease.5 Our research group found that APAC eyes had a thicker macular choroid than fellow eyes with a diagnosis of PACS.9 Moreover, PACS eyes that had a fellow eye suffering from an APAC attack had a thicker macular choroid than the healthy eyes.10 Zhou et al.11 and Huang et al.12 found that subfoveal choroidal thickness (CT) in all subtypes of PACD (PACS, APAC, PAC, and PACG) was greater than in control eyes. Furthermore, we also found that macular CT 7 days after trabeculectomy was significantly higher than before the surgery in PACG eyes.13 All these series studies indicated that the posterior choroid should be an important structure involved in the pathogenesis of PACD using enhanced depth imaging optical coherence tomography (EDI-OCT). On the other hand, in our latest preliminary study, we found that a thicker posterior choroid was significantly associated with a smaller iris area and greater anterior placement of the ciliary body, indicating that anterior segment parameters may also contribute to the development of PACD.14

As investigations of the posterior choroid cannot fully explain the pathogenesis of PACD, we wondered whether the anterior choroid is associated with PACD. As disruption in the normal outflow of aqueous humor (AH) is believed to cause changes of intraocular pressure (IOP), the anterior choroid adjacent to the trabecular meshwork and Schlemm’s canal, which constitute the AH outflow pathway, might be another important biometric factor in the pathogenesis of PACD or POAG.15,16

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were based on criteria proposed by Foster et al.6 The layer defects, and corresponding VF defects, and the diagnoses of PACD was diagnosed in open-angle or angle-closure eyes (by gonioscopy) with characteristic glaucomatous optic neuropathy (defined as the pigmented trabecular meshwork not seen for at least 180° on indentation gonioscopy in primary position), with peripheral anterior synechiae, elevated IOP but without glaucomatous optic neuropathy or VF defect; (3) PACG was defined as an eye with PAC together with evidence of glaucomatous optic neuropathy (defined as a vertical cup-to-disc ratio [CDR] > 0.7 and/or CDR asymmetry > 0.2, with glaucoma hemifield test outside normal limits, and with an abnormal pattern standard deviation with P < 0.05 in the healthy population). POAG was defined as the presence of a normal open angle on gonioscopy and UBM, increased IOP (usually > 21 mm Hg at the clinics), and glaucomatous optic nerve damage with corresponding typical VF defect, as confirmed by at least two reproducible VF tests. Subjects were excluded if they (1) had other ocular diseases (e.g., conjunctivitis, corneal diseases, fundus diseases; or (2) had had previous ocular surgery (e.g., iridectomy/iridotomy, trabeculectomy, cataract surgery).

**METHODS**

This cross-sectional study enrolled 29 consecutive POAG and 37 PACD patients at the glaucoma department of Zhongshan Ophthalmic Center between January 2016 and January 2017. Thirty-four healthy volunteers with no current or previous ophthalmic diseases were also enrolled in this study. All included eyes of healthy volunteers had a best-corrected visual acuity (BCVA) of 6/9 or better, IOP of <21 mm Hg, and a refractive error between −5 and +5 dioptries (D) (spherical equivalent, SE). All healthy volunteers had normal visual field (VF) in both eyes. This study was approved by the Ethical Review Committee of Zhongshan Ophthalmic Center and adhered to the tenets of the Declaration of Helsinki. All subjects received comprehensive ocular examinations that included a review of their medical history, BCVA, a slit-lamp examination, and a stereoscopic optic disc examination with a 90-dioptr lens. IOP was measured using a noncontact tonometer (NCT; Canon TX-20 Full Auto Tonometer; Canon, Tokyo, Japan). The axial length (AL) was measured using partial optical coherence interferometry (IOL-Master; Carl Zeiss Meditec, La Jolla, CA, USA). A refractive error examination was performed using an auto refractometer (KR-8900 version 1.07; Topcon Corporation, Tokyo, Japan). POAG or PACD was diagnosed in open-angle or angle-closure eyes (by gonioscopy) with characteristic glaucomatous optic neuropathy, diffuse or focal optic rim thinning, cupping, nerve fiber layer defects, and corresponding VF defects, and the diagnoses were based on criteria proposed by Foster et al.5 The definitions for each subgroup of PACD in the study were as follows. (1) PACS was defined as an eye in which appositional contact between peripheral iris and pigmented trabecular meshwork is greater than or equal to 180° under static gonioscopy; (2) PAC was defined as an eye with adhesive angles (defined as the pigmented trabecular meshwork not seen for at least 180° on indentation gonioscopy in primary position), with peripheral anterior synechiae, elevated IOP but without glaucomatous optic neuropathy or VF defect; (3) PACG was defined as an eye with PAC together with evidence of glaucomatous optic neuropathy (defined as a vertical cup-to-disc ratio [CDR] > 0.7 and/or CDR asymmetry > 0.2, with glaucoma hemifield test outside normal limits, and with an abnormal pattern standard deviation with P < 0.05 in the healthy population). POAG was defined as the presence of a normal open angle on gonioscopy and UBM, increased IOP (usually > 21 mm Hg at the clinics), and glaucomatous optic nerve damage with corresponding typical VF defect, as confirmed by at least two reproducible VF tests. Subjects were excluded if they (1) had other ocular diseases (e.g., conjunctivitis, corneal diseases, fundus diseases; or (2) had had previous ocular surgery (e.g., iridectomy/iridotomy, trabeculectomy, cataract surgery).

**UBM Examination and Anterior Choroid Defined**

A single experienced physician (G.C.), who was blinded to the clinical data of the subjects, performed the UBM (Quantel Medicine, Bozeman, MT, USA) examinations in the morning at approximately 10 AM. The UBM examination was conducted in a dimly lit room (illumination 60–70 lux) with all subjects lying in a supine position. UBM assessments in the central and 360° radiation of anterior segment were performed. Radial scans at the 12, 3, 6, and 9 o’clock positions centered over the limbus were obtained. The subjects were asked to rotate their eyes to the opposite direction to expose the anterior choroid, as in our previous study.17 The operator adjusted the contrast and noise during the examination to ensure clear images. The best image was selected by the examiner (G.C.) and the supervisors (F.L. and K.G.). All selected images were stored in the machine. The images were then analyzed using the Aviso Program (Quantel Medicine) manually.

In consideration of the anatomy of the ciliary body, a distance of 4 mm from the root of iris was self-defined as a pure anterior choroid, which had not been described before, as this site keeps away from the influence of the pars plicata and the retina.18,19 The anterior choroid was measured as follows (Fig. 1). (1) Through the root of the iris, a line was drawn parallel with the inner surface of the sclera. (2) The manual
segmentation function was used to delineate the posterior edge of the pars plana of the ciliary body and the sclerochoroidal interface. (3) The thickness of the choroid was measured at a distance of 4 mm (CT4) from the root of the iris.

Two operators (F.L. and K.G.) who were masked to the diagnosis and clinical data of the subjects independently measured CT4, as shown in Figure 1. By measuring the anterior choroid, we investigated interobserver variability of the anterior choroid imaging in all recruited eyes. We also investigated intraobserver reproducibility in the recruited eyes. Measurements of ACT were performed in two sessions over an interval of 3 weeks by the same physician (K.G.), who was masked to the previous results.

SS-OCT and Posterior Choroid Measurement

Images of the posterior choroid in the macular region were obtained using DRI-OCT (Atlantis, DRI OCT-1; Topcon, Tokyo, Japan) as in our previous study.20 The DRI-OCT system uses a tunable laser with a center wavelength of 1050 nm as a light source, with a tuning range of approximately 100 nm, and an 8-μm axial resolution in tissue. A three-dimensional (3-D) imaging scan procedure was performed with a raster scan pattern covering a 6 × 6-mm area centered on the fovea and composed of 256 B-scans, each containing 256 A-scans (a total of 65,536 axial scans/volume) (Fig. 2). According to the manufacturer’s recommendation, only images having a quality score greater than 45 out of 160 were included in the analysis in our study. All the examinations were performed in the morning at approximately 9 AM. Images with artifacts, such as motion artifacts, signal loss, and segmentation failure, were not included in the data analysis. Measurements of the posterior choroid thickness (PCT) were performed using the SS-OCT segmentation software (9.12.003.04). A 6 × 6-mm area of the subfoveal choroid was automatically created and was divided into 6 × 6 grids, and the mean thicknesses of subfoveal choroid were calculated for the 36 sectors of the grid (Fig. 2). All SS-OCT images obtained by automatic measurement using software were checked before we accepted them.

VF Examination

A single experienced physician (G.C.), blinded to the clinical diagnosis of the subjects, performed the VF examination. All POAG and PACD patients received standard automated perimetry (SAP) examination, using the Swedish interactive threshold algorithm standard 24-2 test on a Humphrey VF analyzer (Carl Zeiss Meditec, Dublin, CA, USA). The VF test was repeated for any abnormal results. Only reliable VF results (fixation losses < 20%, false-positive and false-negative rates of less than 10%) were accepted. The VF results of all subjects were recorded and qualitatively analyzed by two ophthalmologists (F.L. and K.G.). According to the glaucomatous VF loss classification, the results of VF were divided into early stage (mean deviation [MD] no worse than –6 decibels [dB]) or moderate (MD between –6 and –12 dB) or advanced stage (MD between –12 and –22 dB).21

Statistical Analysis

Statistical analyses were performed using SPSS software version 20.0 (SPSS, Inc., Chicago, IL, USA). The means and standard deviations (M ± SD) of the above parameters were calculated. Subsequently, the relationship was studied after adjusting for potentially confounding factors, such as age, sex, eye, and AL. The significance of differences among three groups was determined using ANOVA for normally distributed variables. Unpaired t-tests were used to detect the differences in the ACT between the subgroups of POAG eyes or PACD eyes. Analysis of covariance (ANCOVA) was used to calculate and compare the adjusted mean ACT for subgroups of POAG eyes or PACD.
eyes. Univariate linear regression and multivariate linear regression were used to determine potential participant characteristics that were associated with the ACT. Multivariate linear regression was applied using the generalized estimating equations (GEE) model, with 95% confidence intervals, taking into account the correlation between the measurements from two eyes. \( P < 0.05 \) was considered significant.

### Results

#### Demographic and Baseline Characteristics of the Study Subjects

This study successively included 58 eyes of 29 POAG patients, 74 eyes of 37 PACD patients, and 68 eyes of 34 normal subjects. However, 2 eyes of POAG and 10 eyes of PACD had poor UBM image quality. Therefore, 56 eyes of 29 POAG and 64 eyes of 37 PACD patients were eventually enrolled in the analysis. Sixty-four PACD eyes were classified into the following three groups: PACS, 8 eyes; PAC, 18 eyes; PACG, 38 eyes. Fifty out of 58 POAG eyes (8 eyes could not receive SAP examination due to poor visual acuity) were divided into the following two groups: early/moderate stage, 25 eyes; advanced stage, 25 eyes. The demographic and clinical examination data of these three groups are summarized in Table 1. The mean age of the enrolled normal, POAG, and PACD subjects was 36.35, 52.07, and 59.49 years, respectively. SE differed significantly among the three groups \( P < 0.01 \). As expected, a significant difference was noted in AL among the three groups \( P < 0.01 \).

#### Measurements of ACT in POAG/PACD and Normal Subjects

The interobserver variability test of data from two researchers showed good agreement in all three groups (Table 2). As shown in Supplementary Table S1, the intraobserver reproducibility of ACT measurements was good (ICC > 0.9). Comparisons of mean ACT of the three groups are shown in Table 2 and Supplementary Table S2. The POAG group had the greatest mean ACT at 0.45 ± 0.057 mm \( P < 0.01 \), followed by PACD (0.38 ± 0.050 mm) and normal eyes (0.30 ± 0.050 mm).

In POAG eyes, the ACT for different diagnoses is shown in Table 4. The PACS and PAC groups had a greater mean ACT at 0.40 ± 0.063 mm compared with the PACG group at 0.37 ± 0.041 mm \( P < 0.05 \), even after adjusting for age, sex, and AL. In PACD eyes, the ACT for different stages of VF loss is shown in Table 3. No significant difference was noted in ACT between early/moderate and advanced stages \( P = 0.325 \), even after adjusting for age, sex, eye, and AL \( P = 0.111 \). In PACD eyes, the ACT for different stages of VF loss is shown in Table 3. No significant difference was noted in ACT between early/moderate and advanced stages \( P = 0.325 \), even after adjusting for age, sex, eye, and AL \( P = 0.111 \). In PACD eyes, the ACT for different stages of VF loss is shown in Table 3. No significant difference was noted in ACT between early/moderate and advanced stages \( P = 0.325 \), even after adjusting for age, sex, eye, and AL \( P = 0.111 \). 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#### DISCUSSION

After the landmark study performed by Spaide and colleagues investigating the macular choroid with EDI-OCT,
TABLE 3. POAG Patients, ACT Measurements of Two Groups Divided by VF Loss Stage

<table>
<thead>
<tr>
<th>VF Loss Stage</th>
<th>n, Eyes</th>
<th>Mean ACT, mm, Mean ± SD Unadjusted</th>
<th>( P^* )</th>
<th>Mean ACT, mm, Mean ± SD Adjusted†</th>
<th>( P^† )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early/moderate</td>
<td>25</td>
<td>0.44 ± 0.044</td>
<td>0.044</td>
<td>0.44 ± 0.050</td>
<td>0.111</td>
</tr>
<tr>
<td>Advanced</td>
<td>25</td>
<td>0.46 ± 0.05</td>
<td>0.325</td>
<td>0.46 ± 0.05</td>
<td>0.111</td>
</tr>
</tbody>
</table>

* Unpaired \( t \)-test.
† Adjusted for age, sex, eye, and AL.

TABLE 4. PACD Patients, ACT Measurements of Two Groups Divided by Diagnosis

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Mean ACT, Mean ± SD Unadjusted</th>
<th>( P^* )</th>
<th>Mean ACT, Mean ± SD Adjusted†</th>
<th>( P^† )</th>
</tr>
</thead>
<tbody>
<tr>
<td>PACS/PAC</td>
<td>0.40 ± 0.063</td>
<td>0.104</td>
<td>0.40 ± 0.048</td>
<td>0.004</td>
</tr>
<tr>
<td>PACG</td>
<td>0.37 ± 0.041</td>
<td>0.0104</td>
<td>0.36 ± 0.049</td>
<td></td>
</tr>
</tbody>
</table>

* Unpaired \( t \)-test.
† Adjusted for age, sex, eye, and AL.

TABLE 5. Linear Regression Analysis to Determine the Correlation Between Variables and the ACT in POAG Eyes

<table>
<thead>
<tr>
<th>Variables</th>
<th>Univariate Linear Regression Coefficients (95% CI)</th>
<th>( P ) Value</th>
<th>Multivariate Linear Regression Coefficients (95% CI)</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>0.161 (0.000 to 0.001)</td>
<td>0.236</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sex, female/male</td>
<td>0.026 (−0.027 to 0.033)</td>
<td>0.847</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>AL, mm</td>
<td>−0.209 (−0.016 to 0.002)</td>
<td>0.12</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>MD, dB</td>
<td>−0.040 (−0.001 to 0.01)</td>
<td>0.782</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>SE, D</td>
<td>0.135 (−0.002 to 0.006)</td>
<td>0.328</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>VF loss severity</td>
<td>0.142 (−0.007 to 0.020)</td>
<td>0.325</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Early/moderate, advanced</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Insignificant variables were not present in multivariate regressions. CI, confidence interval.

TABLE 6. Linear Regression Analysis to Determine the Correlation Between Variables and the ACT in PACD Eyes

<table>
<thead>
<tr>
<th>Variables</th>
<th>Univariate Linear Regression Coefficients (95% CI)</th>
<th>( P ) Value</th>
<th>Multivariate Linear Regression Coefficients (95% CI)</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>−0.153 (−0.002 to 0.001)</td>
<td>0.226</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sex, female/male</td>
<td>−0.158 (−0.043 to 0.010)</td>
<td>0.21</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>AL, mm</td>
<td>0.090 (−0.010 to 0.02)</td>
<td>0.488</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>MD, dB</td>
<td>0.134 (−0.001 to 0.002)</td>
<td>0.34</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>SE, D</td>
<td>0.093 (−0.005 to 0.01)</td>
<td>0.462</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>PACS/PAC vs. PACG</td>
<td>−0.251 (−0.026 to 0.0003)</td>
<td>0.045</td>
<td>−0.035 (−0.05 to −0.015)</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Insignificant variables were not present in multivariate regressions; factors with statistical significance are shown in bold type (\( P < 0.05 \)). CI, confidence interval.

TABLE 7. Linear Regression Analysis to Determine the Correlation Between Variables and the ACT in Study Participants

<table>
<thead>
<tr>
<th>Variables</th>
<th>Univariate Linear Regression Coefficients (95% CI)</th>
<th>( P ) Value</th>
<th>Multivariate Linear Regression Coefficients (95% CI)</th>
<th>( P ) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>0.408 (0.001 to 0.003)</td>
<td>&lt; 0.001</td>
<td>0.335 (0.001 to 0.002)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Sex, female/male</td>
<td>0.040 (−0.017 to 0.030)</td>
<td>0.58</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>AL, mm</td>
<td>−0.088 (−0.012 to 0.005)</td>
<td>0.23</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>MD, dB</td>
<td>−0.389 (−0.004 to −0.002)</td>
<td>&lt; 0.001</td>
<td>−0.280 (−0.003 to −0.001)</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>SE, D</td>
<td>0.199 (0.002 to 0.010)</td>
<td>0.006</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

Insignificant variables were not present in multivariate regressions; factors with statistical significance are shown in bold type (\( P < 0.05 \)). CI, confidence interval.
increasing studies have demonstrated that choroidal structure and function may be involved in the pathogenesis of different types of glaucoma. Based on our results and previous studies, there were no significant differences in macular and peripapillary CT between POAG eyes and healthy controls. In addition, our previous studies have shown that the posterior choroid is associated with AC disease.

In the present study, we used UBM to investigate the anterior choroid in healthy, POAG, and PACD subjects, using SS-OCT to measure the posterior choroid, and compared their differences. To our knowledge, this is the first study to explore the changes in the ACT and PCT in POAG/PACD in the same patients and at the same time.

First, we found that both POAG and PACD patients had a thicker baseline anterior choroid than normal subjects. We hypothesized that the anterior choroid could be involved in both glaucoma suspects and glaucoma patients. In POAG patients, the uveoscleral outflow route of AH starts with the ciliary muscle, and then AH may flow across the sclera, within the suprachoroidal and suprachoroidal spaces, or into uveal vessels. The anterior choroid is a structure adjacent to the uveoscleral outflow pathway of AH. We speculated that in POAG eyes, due to damaged trabecular meshwork, anterior choroid vasculature must be expanded to contain more AH from both the conventional and uveoscleral outflow routes. Due to compensatory increased uveoscleral outflow and long-term elevated IOP in POAG eyes, the anterior choroid becomes thicker to drain more AH into uveal vessels. Therefore, a thicker anterior choroid could be the result of those changes. In view of the anatomic features of the anterior segment of PACD eyes, we speculated that a thick anterior choroid might be part of the reason why angle closure occurs in PACD eyes. In PACD eyes, a thicker anterior choroid, associated with a shorter AL, could give rise to varied degrees of angle closure. However, in POAG eyes, a longer AL could compensate for the anterior choroid factor. Therefore, although POAG eyes have a thicker anterior choroid than PACD eyes (P < 0.01), POAG eyes do not have angle closure.

In our study, the anterior choroid in POAG eyes was significantly thicker than in normal eyes. However, there was no difference in ACT measurement in different VF loss stages in POAG eyes, indicating a lack of association between the severity of glaucoma damage and the ACT in our study. Li and associates found no difference between the peripapillary CT in POAG eyes and perimetrically unaffected fellow eyes or healthy controls eye using SD-OCT. Similar conclusions were made in other studies measuring macular and peripapillary CT using SD-OCT, but Hirooka et al. found that the CT at 3 mm nasal from the fovea in normal-tension glaucoma eyes was significantly thinner than in normal subjects. By means of SS-OCT, neither macular nor peripapillary CT was associated with glaucoma severity. Therefore, we hypothesized that the increased ACT might be an initial factor that could damage the trabecular meshwork or anterior choroid vasculature and contribute to the pathogenesis and development of POAG.

In PACD subjects, PACG eyes had a thinner anterior choroid than PACS/PAC eyes (P = 0.0104), even after adjusting for age, sex, and AL (P = 0.004). As expected, in theory, long-term increased IOP in PACG eyes might reduce anterior choroidal blood volume and result in the thinning of the anterior choroid, consistent with posterior choroidal findings in our previous study and in a water-drinking test study. In previous histologic studies, Kubota and associates found a reduced parapapillary CT in secondary angle-closure glaucoma compared with a normal IOP control group, mainly due to a diminished choroidal vessel diameter and collapsed choriocapillary vessels.

Zhang and associates found that older age and longer AL were associated with a thinner posterior choroid, consistent with the study by Wei et al. However, in the correlation analyses between systemic/ocular factors and the anterior choroid measurement in our study, we found no significant correlation between age, sex, AL, MD, SE, or VF loss severity and ACT in POAG eyes (P = 0.236, P = 0.847, P = 0.123, P = 0.782, P = 0.328, P = 0.325, respectively). However, in PACD eyes, diagnosis (PACG versus PACS/PAC) (P = 0.001) was significantly associated with ACT, consistent with the findings of other studies. The anterior choroid of PACG eyes was significantly thinner than in PACS/PAC eyes. Therefore, we speculated that the anterior choroid might be a more sensitive indicator of progression in PACD eyes than in POAG eyes for prediction and follow-up.

The thickness of the posterior subfoveal choroid was measured using SS-OCT in normal, POAG, and PACD subjects. A previous study proposed by Arora et al. suggested that angle-closure eyes have a significantly thicker macular choroid than open-angle and normal eyes using SD-OCT. However, consistent with our results (Zhang XL, unpublished data, 2014) and others, there were no significant differences in PCT among the three groups using SS-OCT. Moreover, based on the anatomic relation between the anterior choroid and anterior chamber, we believe that anterior choroidal parameters are more likely associated with the pathogenesis and development of glaucoma than posterior choroid parameters.

There are several limitations to this study. (1) Because of the high IOP and weak physical and mental status of APAC patients, it is very difficult to obtain satisfactory images successfully. Therefore, we did not include APAC eyes in this study. (2) Since our results were obtained from a cross-sectional comparison, the distributions of the ACT during the entire lifetime of all subtypes of glaucoma require well-designed longitudinal studies for further investigation. (3) Topical or systemic anti-inflammatory drugs and antiglaucoma medications may influence the blood flow of the anterior uvea. Systemic use of corticosteroids could reduce CT in Vogt-Koyanagi-Harada disease. Therefore, the likely effects of these drugs on the anterior choroid require further investigation.

Overall, our present study has defined a novel parameter to measure the anterior choroid and provided useful information and characteristics regarding the anterior choroid of normal, POAG, and PACD eyes. The results indicate that both POAG and PACD patients have a thicker anterior choroid than healthy subjects. The anterior choroid is adjacent to the AH outflow pathway, indicating that the anterior choroid might be another important factor involved in the pathogenesis of glaucoma. Further studies are needed to confirm this hypothesis and to determine whether anterior choroidal parameters are associated with the development of glaucoma.
The Anterior Choroid Is Thicker in Glaucomatous Eyes

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