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ORIGINAL PAPER

Changes in circumpapillary retinal vessel density after acute primary angle closure episode via OCT angiography

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Abstract

Purpose To investigate the changes and evaluate the diagnosis value of circumpapillary vessel density (VD) in cases of acute primary angle closure (APAC).

Design Case–control study.

Methods APAC patients with a history of unilateral acute attack were enrolled. The eyes with acute episode constituted the case group while the contralateral eyes without attack consisted of the control group. Ophthalmic examinations including slit-lamp examination, best-corrected visual acuity, intraocular pressure and visual field were carried out. Retinal nerve fiber layer (RNFL), macular ganglion cell complex (GCC) were measured by spectral-domain optical coherence tomography, while VD was assessed by optical coherence tomography angiography.

Results The whole en face image vessel density (wiVD), circumpapillary vessel density (cpVD) and inside disk VD for both all vessels and capillary were all significantly lower in the APAC eyes compared to the fellow eyes ($P < 0.01$ for all). In APAC eyes, the wiVD, inside disk VD and cpVD both for all vessels and capillary were all positively correlated with RNFL and GCC thicknesses but negatively correlated with the mean deviation (MD), pattern standard deviation (PSD) and the duration of acute attack (all $P < 0.01$). From the ROC curve, the $cpVD_{cap,}$ $wiVD_{cap}$, $cpVD_{all}$ and $wiVD_{all}$ all showed comparable diagnostic ability with RNFL, GCC and MD to differentiate eyes with APAC from the fellow eyes (all $P > 0.05$). The inside disk VD_{cap} and VD_{all} demonstrated significant lower diagnostic ability than the $cpVD_{cap,}$ $wiVD_{cap}$, $cpVD_{all}$ and $wiVD_{all}$ (all $P < 0.001$).

Conclusions In APAC eyes, circumpapillary VD decreased significantly compared with the fellow unaffected eyes. They were significantly correlated with thicknesses of RNFL and GCC, and visual field MD and PSD in the APAC eyes. The patients with longer duration of acute attack were more likely to have lower cpVD. For APAC, the diagnostic ability of wiVD and cpVD was similar with RNFL, GCC and MD and was higher than inside disk VD.

Keywords Acute primary angle closure · Circumpapillary vessel density · Optical coherence tomography angiography

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Introduction

Glaucoma is the leading cause of irreversible blindness worldwide and primary angle closure glaucoma (PACG) accounts for one third of it. It is more popular in Asia which was estimated to affect 5.3 million people in 2020 [1]. A sudden elevated intraocular pressure (IOP) with ocular pain and headache is the typical symptom of acute primary angle closure (APAC). APAC may result in a permanent visual field defect if it is not managed promptly. However, even if the IOP is normalized, the retina ganglion cell death can still progress [2]. The two major hypotheses of the disease mechanisms of glaucoma are mechanical suppression and vascular hypotheses [3, 4]. The recently developed optical OCTA enables the study of microcirculation in the macula, circumpapillary retina and optic nerve head (ONH) [5, 6]. This method realizes the potential of direct measurement of the vascular changes in retina which could not be done in the past, and therefore may be able to test the aforementioned hypotheses. Various studies have proved that OCTA examination offers promising abilities for both diagnosis and progression monitoring of glaucoma with good reproducibility and repeatability [7, 8]. However, OCTA was mainly involved in studies about primary open angle glaucoma (POAG) and less was studied in primary angle closure glaucoma [7, 9]. The pathophysiology of glaucoma induced by ocular blood flow is different between PACG and POAG.

To the best of our knowledge, only a few studies showed a significant reduction of vessel density (VD) in optic nerve head (ONH) in eyes with a history of acute attack [10–14]. The changes of cpVD occurred before the thinning of retinal nerve fiber layer (RNFL) and macular ganglion cell complex (GCC) in APAC eyes [13]. Also, a lower cpVD at 2 months after acute attack was suggested to be a predictor of thinning of RNFL [10]. The evidence from these studies suggests that OCTA may be a powerful tool to assist the diagnosis and progression monitoring in APAC. The diagnostic ability of different regions of disk VD in APAC and the relationship of VD with other glaucoma parameters are deserved to be investigated. Therefore, based on the advantageous ability of OCTA in studying the retinal microvasculature, this study aimed to enrich the research for diagnosis value of circumpapillary VD compared with the traditional structural and functional parameters.

Methods

Patients

In this case control study, patients who visited our hospital from April 2019 to June 2020 with a history of unilateral APAC and underwent phacoemulsification and intraocular lens implantation (PEI) were included in this study. The case group was consisted of the APAC eyes and the fellow unaffected eyes comprised the control group. The inclusion criteria were (1) unilateral APAC resolved by PEI; (2) IOP less than 21 mmHg without glaucoma medications; (3) the unaffected eye had no symptoms or signs of acute angle-closure attack, glaucomatous optic neuropathy, or reproducible visual field (VF) loss. (4) reliable perimetry results with fixation loss $< 33\%$, false negative error rate $< 25\%$ and false positive error rate $< 15\%$). Patients were excluded when there was (1) a history of trauma, uveitis, retinal disease or intraocular surgery except phacoemulsification or laser peripheral iridectomy (LPI); (2) spherical equivalent refractive error greater than $+ 6$ or $- 6$ diopters; or (3) poor quality of optical coherence tomography (OCT) and OCTA and scans within signal strength index (SSI) < 48, poor clarity, poor segmentation and motion artifact.

An APAC episode was defined by the following criteria: (1) at least two symptoms of an acute angle closure attack (vision reduction, rainbow-colored halos around lights, ocular pain, nausea, vomiting and headache), (2) IOP at presentation more than 21 mmHg with signs of corneal edema, conjunctival injection, shallow anterior chamber and fixed dilated pupil, (3) at least three quadrants of angle closure confirmed by gonioscopic examination or ultrasound biomicroscopy (UBM). This study was conducted at Affiliated Eye Hospital, School of Ophthalmology and Optometry, Wenzhou Medical University, China. It was approved by the Institutional Review Board of the Wenzhou Medical University and in accordance with the tenets of the Declaration of Helsinki. The trial is registered at http://www.chictr.org.cn/index.aspx (unique registration number:ChiCTR2000039687).

Examinations

All participants enrolled underwent a complete ophthalmic examination, including slit-lamp biomicroscopy, best-corrected visual acuity (BCVA, measured by Snellen chart), IOP measurement (Goldmann applanation tonometry), gonioscopy and UBM (Suowei, Tianjin). Visual field examinations were carried out by the Humphrey perimetry. The axial length (AL) measurement using IOL master (Carl Zeiss Meditec; Germany). The retinal nerve fiber layer (RNFL), vertical cup-to-disk ratio (VCDR) and ganglion cell complex (GCC) thickness were assessed with spectral-domain optical coherence tomography (SD-OCT, RTVue-XR Avanti; Optovue, Inc, Fremont, California, USA). The RNFL thickness was analyzed by dividing it into eight sectors and the GCC thickness was divided into superior and inferior sectors.

Two blood pressure (BP) measurements obtained in a resting, seated position was taken at least 5 min apart using an Omron Automatic (model BP791IT; Omron Healthcare, Inc.) instrument. Mean arterial pressure (MAP) was calculated as MAP = 1/3 systolic BP + 2/3 diastolic BP, and mean ocular perfusion pressure (MOPP) was defined using the following equation: MOPP = 2/3 MAP–IOP.

Optical coherence tomography angiography

The Optical Coherence Tomography Angiography was performed by using RTVue-XR SDOCT (AngioVue, V 2017,1,0,155) for the optic disk area. The AngioVue offers noninvasive characterization of the retinal vasculature by detecting the motion of red blood cells to measure the different reflectance amplitudes between consecutive B scans. High resolution 3-dimensional OCT angiograms were generated by the motion contrast technique and the algorithm of split-spectrum amplitude-decorrelation angiography (SSADA). The all vessel density (VD_{all}) was defined as the proportion of blood vessels including large vessels and microvasculature in the "radical peripapillary capillary (RPC) segment." The capillary vessel density(VD_{cap})was the percentage area occupied by capillary after large blood vessel removal.

In this study, circumpapillary vessel density in the optic disk was analyzed in 4.5 mm × 4.5 mm OCTA area centered on the ONH. The whole en face image vessel density (wiVD) was measured over the entire optic disk scan area. The circumpapillary vessel density (cpVD) was calculated from an elliptical annulus with 1 mm wide extending from the ONH-centered concentric circles with an inner diameter of 2 mm. cpVD was divided into eight sectors (according to the Garway–Heath map).

Statistical analysis

The results were analyzed by SPSS software version 21 (SPSS Inc., Chicago, IL) and Medcalc 19.1 (MedCalc Software Ltd, Ostend, Belgium). Kolmogorov–Smirnov test was used to evaluated the normality of the numeric parameters. Categoric parameters were compared by chi-square test. Comparison of the variables between the APAC and fellow group was performed by using paired-*t* test or Wilcoxon singed-rank test. The correlations between the factors were analyzed by Pearson correlation. The diagnostic ability of glaucoma parameters and vessel densities was measured by receiver operating characteristic (ROC) curves. The data were presented as mean ± standard deviations (SD). P value < 0.05 was regarded as statistically significant.

Results

After excluding eight cases due to poor visual field examination performance (three cases) and poor OCTA image quality (five cases), 30 patients with unilateral APAC were included in the analysis. The mean age was 62.8 ± 7.6 years with female consisted the majority (83.3%). There were nine (30%) hypertension patients with a mean systolic blood pressure (SBP) of 140.0 ± 20.6 mmHg and a mean diastolic blood pressure (DBP) of 77.5 ± 10.2 mmHg. The mean heart rate was 74.9 ± 10.3 beats per minute. The mean MOPP was 52.2 ± 7.6 mmHg. All the included APAC eyes in our hospital were managed by PEI. The interval between the acute attack and phacoemulsification was 4.1 ± 3.8 days with a range of 1–15 days. And the disease course between acute attack and OCTA examination was 19.5 ± 11.8 months with a range of 3–38 months. The presenting IOP at this examination of the APAC eyes and the fellow eyes were all under 21 mmHg without medications and there were no significant

Table 1 Characteristics of APAC eyes and their fellow eyes ($N = 30$)

Variables	APAC eyes	Fellow eyes	*P* value
Acute attack			
IOPa, mmHg	52.5 ± 7.5		
Duration, days	4.5 ± 3.7		
Disease course, months	19.5 ± 11.8		
PEI, *n* (%)	30 (100%)	15(50.0%)	< 0.001
LPI, *n* (%)	2 (6.7%)	18 (60.0%)	< 0.001
Nd: YAG laser capsulotomy, *n* (%)	2 (6.7%)	1 (4.3%)	1.000
IOPe, mmHg	13.4 ± 3.5	13.9 ± 3.2	0.114
AL, mm	22.3 ± 0.7	22.3 ± 0.8	0.686
VCDR	0.6 ± 0.2	0.4 ± 0.1	< 0.001
BCVA, LogMAR	0.1 ± 0.1	0.1 ± 0.1	0.428
MD, dB	9.2 ± 7.3	3.1 ± 1.5	< 0.001
PSD, dB	5.1 ± 3.2	2.7 ± 1.0	< 0.001

APAC in acute primary angle closure, *IOPa* IOP when acute attack, *PEI* Phacoemulsification and intraocular lens implantation, *LPI* Laser peripheral iridotomy, *Nd: YAG* Neodymium: yttrium aluminum garnet, *IOPe* IOP when OCTA examination, *AL* Axial length, *VCDR* Vertical cup-to-disk ratio, *BCVA* Best-corrected visual acuity, *logMAR* Logarithm of the minimum angle of resolution, *MD* Mean deviation, *PSD* Patten standard deviation

differences between the two groups ($P = 0.114$). The VCDR, mean deviation (MD) and patten standard deviation (PSD) were statistically different between the APAC eyes and fellow eyes with a higher VCDR and worse VF results in the APAC eyes (all $P < 0.01$) (Table 1).

For the retinal structural and functional parameters, the global GCC and RNFL thicknesses were both significant thinner in the APAC eyes than in the fellow eyes ($P < 0.001$). And sectorally, the thickness of GCC in the superior and inferior sector, and RNFL in the eight sectors all showed thickness loss in the APAC group when compared with the fellow eyes. ($P < 0.05$ for all). The MD and PSD were both significant larger in the APAC eyes than in the fellow eyes ($P < 0.001$) (Table 2).

The wiVD, cpVD and inside disk VD both for all vessels ($wiVD_{all}$, $cpVD_{all}$, inside disk VD_{all}) and capillary ($wiVD_{cap}$, inside disk VD_{cap}, $cpVD_{cap}$) were all significantly lower in the APAC eyes compared to the fellow eyes (Table 3, $P < 0.01$ for all) (Fig. 1). The $cpVD_{cap}$ was significantly lower in APAC eyes (41.9%) than in fellow eyes (52.5%) ($P < 0.01$). Similar results were found for all circumpapillary sector vessel density measurements correspondingly ($P < 0.001$ for all).

The correlations of the six OCTA parameters including $cpVD_{cap}$, $cpVD_{all}$, $wiVD_{cap}$, $wiVD_{all}$, inside disk VD_{cap} and inside disk VD_{all} with the traditional four measures including RNFL, GCC thickness, MD and PSD were tested. It was found that they were all positively correlated with the mean RNFL and GCC thickness in the APAC eyes, and negatively correlated with the VF MD and PSD (all $P < 0.01$). Moreover, the correlations of $cpVD_{cap}$, $cpVD_{all}$, $wiVD_{cap}$, $wiVD_{all}$, inside disk VD_{cap} and inside disk VD_{all} with other factors were also tested such as IOP, AL, acute attack duration and disease course. Finally it showed that they were all negatively correlated with the duration of acute attack ($P < 0.01$) (Table 4).

The area under the ROC curves (AUC) and sensitivities at 80% specificity of the vessel density measurements to differentiate APAC from fellow eyes were shown in Table 5. From the ROC curve, the $cpVD_{cap}$, $wiVD_{cap}$, $cpVD_{all}$ and $wiVD_{all}$ all showed comparable diagnostic ability with the mean RNFL, GCC and MD (all $P > 0.05$). The inside disk VD_{cap} and VD_{all} demonstrated significant lower diagnostic ability than the $cpVD_{cap}$, $wiVD_{cap}$, $cpVD_{all}$ and $wiVD_{all}$ (all $P < 0.001$). Sectorally, the superotemporal, superonasal, inferonasal, nasal lower, inferotemporal, nasal upper, temporal upper and temporal lower $cpVD_{cap}$ displayed a descending order of the

Table 2 Comparison of RNFL, GCC thickness and VF between APAC eyes and fellow eyes ($N = 30$)

	APAC eye	Fellow eye	*P* value
GCC thickness, μm			
Global	84.4 ± 12.3	101.1 ± 9.8	< 0.001
Superior sector	84.8 ± 13.8	101.8 ± 10.0	< 0.001
Inferior sector	83.9 ± 12.3	100.5 ± 10.3	< 0.001
RNFL thickness, μm			
Global	79.6 ± 16.4	103.1 ± 7.4	< 0.001
Nasal upper sector	65.2 ± 17.4	83.9 ± 11.9	< 0.001
Nasal lower sector	65.2 ± 21.3	75.5 ± 8.1	0.015
Inferonasal sector	78.9 ± 20.8	112.5 ± 16.6	< 0.001
Inferotemporal sector	101.2 ± 24.8	140.2 ± 15.6	< 0.001
Temporal upper sector	69.9 ± 21.9	88.4 ± 13.1	< 0.001
Temporal lower sector	62.2 ± 14.3	72.9 ± 9.1	0.001
Superotemporal sector	103.6 ± 26.8	138.9 ± 15.3	< 0.001
Superosector	84.2 ± 19.5	112.3 ± 13.4	< 0.001
VF, dB			
MD	9.2 ± 7.3	3.1 ± 1.5	< 0.001
PSD	5.1 ± 3.2	2.7 ± 1.0	< 0.001

APAC in acute primary angle closure, *GCC* Ganglion cell complex, *RNFL* Retinal nerve fiber layer, *VF* Visual field, *MD* Mean deviation, *PSD* Patten standard deviation

diagnostic ability. However, only the diagnostic abilities of temporal upper and temporal lower were statistically significant lower than the diagnostic abilities of super temporal and super nasal ($p = 0.011$, 0.033, 0.007 and 0.014, respectively).

Discussion

In the present study, the circumpapillary vessel densities were significantly lower in all sectors of the circumpapillary region in APAC eyes than the control fellow eyes. For the structural changes, the RNFL and GCC were both significantly thinner in APAC eyes than the control fellow eyes. Moreover, the diagnostic abilities of the circumpapillary vessel density parameters for APAC were evaluated. It showed that the four parameters including $cpVD_{cap}$, $cpVD_{all}$, $wiVD_{cap}$ and $wiVD_{all}$ all possessed comparable diagnostic accuracy with RNFL and GCC. However, the diagnostic abilities of the inside disk VD_{cap} and inside disk VD_{all} were both lower than the $cpVD_{cap}$, $cpVD_{all}$, $wiVD_{cap}$ and $wiVD_{all}$.As ACG has a mechanical motive for the increased IOP, the role of blood flow may differ in ACG/APAC and POAG. The reduced cpVD in APAC eyes has been showed in some previous OCTA studies [10–13]. Two of those were longitudinal investigations which showed that cpVD was reduced from 1 to 6 weeks and from 2 to 8 months after APAC episode, as compared to the control fellow eyes. The vessel density of the diseased eye, however, did not change from 2 to 8 months after attack episode [10, 12]. The other three were cross-sectional studies which reported the cpVD decrease at 16.5 (2–120) days, 1 month and 7 days to 12 years after acute attack, respectively [11, 13, 14]. The OCTA examination in our study was conducted at or after 3 months (average 19.5 ± 11.8) after APAC episode. More importantly, the OCTA in this study enables the investigation of all the RPC flowing VD and capillary VD. In our study, six optic nerve head OCTA parameters including $cpVD_{cap}$, $cpVD_{all}$, $wiVD_{cap}$, $wiVD_{all}$, inside disk VD_{cap} and inside disk VD_{all} were all significantly lower in the APAC eyes than the fellow eyes. The results may indicate the parameters that we studied may be useful in monitoring the disease progression in APAC eyes. Nevertheless, the relationship between traditional glaucoma parameters and the diagnostic abilities of these six parameters have not been compared together in APAC eyes.

The correlation analysis showed that the cpVD was consistent with the report from Zhang et al. [11]. We both showed that after acute attack, the reduction of cpVD was significantly correlated with the thinning of the RNFL, GCC thickness and VF loss. In the study of Wang et al.[13], the cpVD was only correlated with PSD and MD but not correlated with RNFL and GCC thickness. The possible explanation of the difference may due to the longer period between the acute attack and the research enrollment in our study. The disease course was from 2 to 120 days (average 16.5 days) in Wang's study [13], and therefore the RNFL may still be influenced by retinal edema due to the acute attack. However, the disease courses were 3 months to 38 months in our study, so the effect of retinal edema as induced by the acute attack can be neglected. In the present study, cpVD was negatively correlated with the duration of acute attack. It is consistent with the results of Zhu et al. [14], that the longer the duration of

Table 3 Comparison of circumpapillary vessel density parameters between APAC eyes and fellow eyes ($N = 30$)

	APAC eye	Fellow eye	P value
$wiVD_{cap}$ (%)	41.5 ± 7.1	49.8 ± 2.0	< 0.001
$wiVD_{all}$ (%)	47.9 ± 6.8	56.6 ± 2.2	< 0.001
Inside disk VD_{cap} (%)	46.3 ± 5.7	49.5 ± 4.5	0.001
Inside disk VD_{all} (%)	55.6 ± 5.4	58.9 ± 3.7	0.004
$cpVD_{cap}$ (%)	41.9 ± 8.7	52.5 ± 2.5	< 0.001
$cpVD_{all}$ (%)	48.7 ± 8.4	59.1 ± 2.5	< 0.001
Nasal upper $cpVD_{cap}$ (%)	38.9 ± 8.7	48.0 ± 3.7	< 0.001
Nasal lower $cpVD_{cap}$ (%)	39.1 ± 7.9	48.5 ± 5.0	< 0.001
Inferonasal $cpVD_{cap}$ (%)	37.6 ± 12.6	51.2 ± 3.6	< 0.001
Inferotemporal $cpVD_{cap}$ (%)	46.6 ± 11.9	58.0 ± 3.2	< 0.001
Temporal upper $cpVD_{cap}$ (%)	48.5 ± 9.5	56.7 ± 3.5	< 0.001
Temporal lower $cpVD_{cap}$ (%)	48.2 ± 7.3	53.8 ± 4.1	< 0.001
Superotemporal $cpVD_{cap}$ (%)	41.9 ± 12.1	56.1 ± 4.2	< 0.001
Superonasal $cpVD_{cap}$ (%)	37.3 ± 11.7	50.8 ± 4.4	< 0.001
Average SSI	61.8 ± 9.7	65.1 ± 11.3	0.141

APAC in acute primary angle closure, *wiVD* Whole en face image disk vessel density, *cpVD* Circumpapillary vessel density, *SSI* Signal strength index

acute attack, the greater the damage on papillary microcirculation. This further suggests that it is necessary and urgent to timely manage acute angle closure glaucoma.

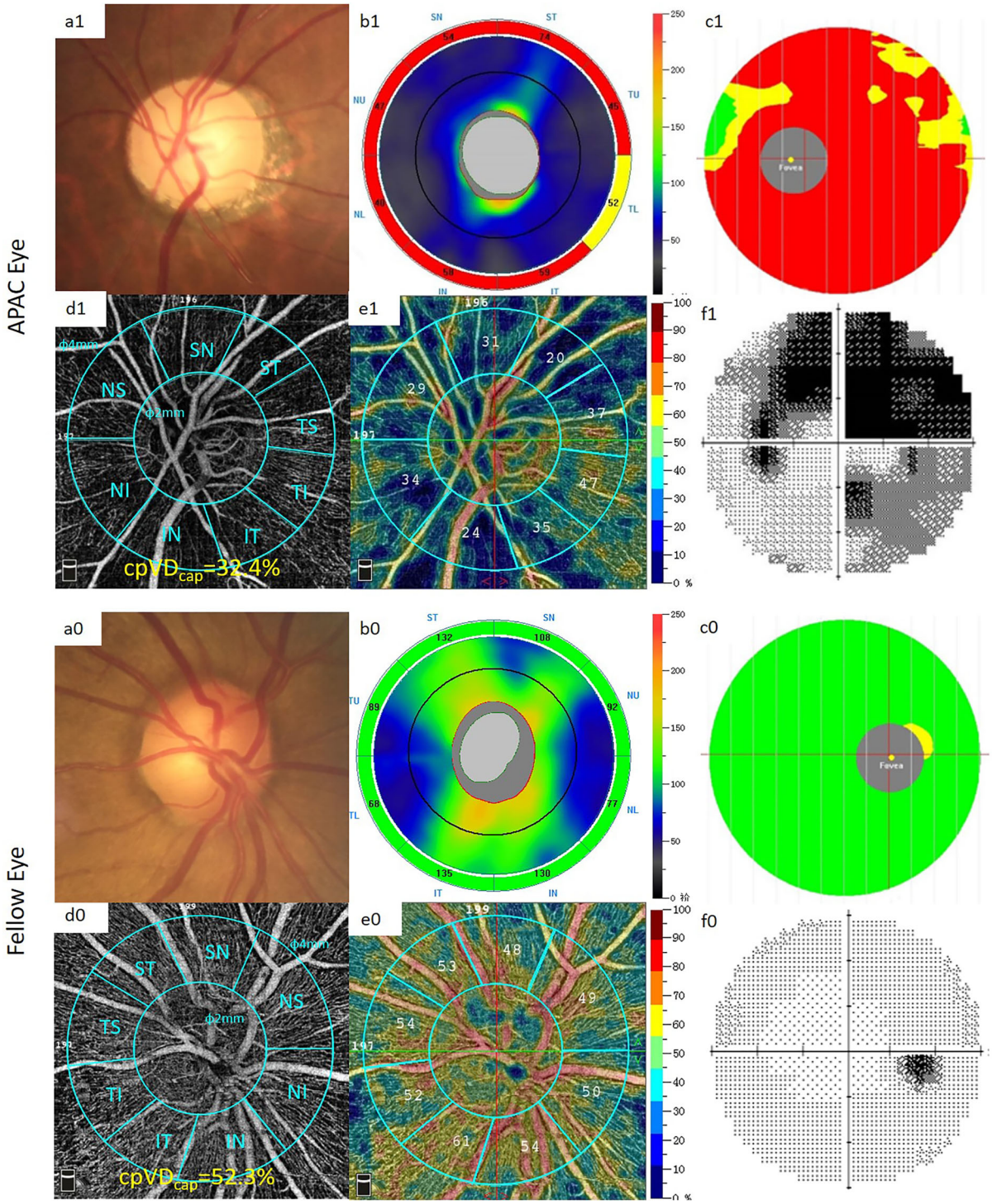
From the ROC curve, the circumpapillary VD showed optimal ability to differentiate APAC eyes from fellow unaffected eyes. Comparable diagnostic abilities of OCTA parameters were reported [8, 15]. Nevertheless, most of these were from POAG studies. Overall, the circumpapillary region showed to be the most discriminative region with the highest mean AUROC value (0.80 ± 0.09) among macular, inside disk and circumpapillary region. An improvement of the AUROC from this region is observed when a sectorial analysis is performed, with the highest AUROCs obtained at the inferior and superior sectors of the superficial capillary plexus in the circumpapillary region (0.86 ± 0.03 and 0.87 ± 0.10, respectively) [16]. There is limited literature on the utility of

Fig. 1 Representative images of an APAC eye after acute attack and the fellow control eye. Cup-to-disk ration was enlarged and the optic disk is pale in the acute angle closure eye (APAC) eye **a1** when compared with the fellow eye **a0**. Retinal nerve fiber thickness (RNFL) and ganglion cell complex (GCC) thickness were both lower in the APAC eye **b1** and **c1** than in the fellow eye **b0** and **c0**. **d1** and **e1** demonstrate the reduced overall and sectoral optic nerve head (ONH) optical coherence tomography angiography (OCTA) image of the APAC eye comparing with the fellow eye **d0** and **e0**. Corresponding visual field damage of the APAC eyes was shown in **f1** and **f0** displayed unaffected visual field

OCTA diagnostic abilities in APAC eyes. Rao et al. reported that in PACG, the diagnostic ability of macular vessel density was lower than GCC thickness, while $cpVD_{all}$ was comparable to RNFL thickness [17]. This was similar to our results in APAC eyes that the diagnostic abilities of cpVD and wiVD were comparable with RNFL, GCC and MD. Sectorally, superotemporal, superonasal, inferonasal, nasal lower, inferotemporal, nasal upper, temporal upper and temporal lower cpVDcap displayed a descending order of the diagnostic ability in our study which was similar with the previous studies in POAG [16]. Moreover, in our study, the diagnostic ability of inside disk VD was inferior to cpVD and wiVD. Also, our study showed that VD_{all} and VD_{cap} in RPC illustrated similar diagnostic ability. They may both reflect the damage of the optic nerve head microcirculation. We showed that glaucomatous vascular damage in APAC could be assessed using OCTA, and its added value as a complementary feature for diagnosis depends on the region of disk.

In our study, all the included APAC eyes underwent PEI. While in Zhang's study, 11 eyes underwent phacoemulsification and 6 eyes received trabeculectomy [11]. And Moghimi's study, patients were firstly managed by medication and LPI, if IOP elevated to > 21 mmHg during follow-up, then phacoemulsification was applied accordingly [10]. The IOP of APAC eyes and fellow eyes were all under 21 mmHg without glaucoma medication in the present study. There is evidence that the IOP-lowering eyedrops may affect ocular blood flow [18]. In this study, the impact of glaucoma eyedrops, IOP elevation and variance caused by different surgeries could be eliminated in APAC eyes. Compared with the above studies, this point is the advantage of our study.

This study has a few limitations. First, some of the fellow eyes received PEI, while the others accepted


APAC Eye
Fellow Eye
a1
b1
c1
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SN
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φ4mm
φ2mm
cpVD_cap=32.4%
cpVD_cap=52.3%
Fovea

Table 4 Correlations between VD and clinical parameters in APAC eyes ($N = 30$)

Variables	$cpVD_{cap}$		$cpVD_{all}$		$wiVD_{cap}$		$wiVD_{all}$		$IDVD_{cap}$		$IDVD_{all}$	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
RNFL	0.881	< 0.001	*0.890*	< 0.001	0.882	< 0.001	0.896	< 0.001	0.521	0.003	0.633	< 0.001
GCC	0.831	< 0.001	*0.818*	< 0.001	0.802	< 0.001	0.788	< 0.001	0.426	0.019	0.490	0.006
MD	−0.833	< 0.001	*−0.816*	< 0.001	−0.828	< 0.001	−0.812	< 0.001	−0.618	< 0.001	−0.677	< 0.001
PSD	−0.696	< 0.001	*−0.692*	< 0.001	−0.713	< 0.001	−0.705	< 0.001	−0.450	0.013	−0.550	0.002
IOPe	−0.269	0.151	*−0.259*	*0.168*	−0.269	0.150	−0.204	0.280	−0.054	0.776	−0.052	0.786
AL	0.131	0.491	*0.105*	*0.580*	0.102	0.593	0.069	0.719	0.328	0.077	0.213	0.258
IOPa	−0.219	0.244	*−0.171*	*0.365*	−0.233	0.215	−0.163	0.389	−0.055	0.774	−0.090	0.635
Duration	−0.655	0.001	*−0.643*	< 0.001	−0.641	< 0.001	−0.624	< 0.001	−0.492	0.006	−0.549	0.002
DC	0.06	0.752	*0.034*	*0.858*	0.029	0.878	−0.012	0.950	0.131	0.491	0.062	0.745
MOPP	0.266	0.155	*0.238*	*0.205*	0.239	0.204	0.196	0.299	0.442	0.014	0.330	0.075

r Pearson's correlation coefficient, *APAC* in acute primary angle closure, *RNFL* Retinal nerve fiber layer, *GCC* Ganglion cell complex, *MD* Mean deviation, *PSD* Patten standard deviation, *IOPe* IOP when OCTA examination, *AL* Axial length, *IOPa* IOP when acute attack, *DC* Disease course, *MOPP* mean ocular perfusion pressure, *IDVD* Inside disk vessel density, *wiVD* Whole en face image vessel density, *cpVD* Circumpapillary vessel density

Table 5 Diagnostic ability of vessel density parameters of optical coherence tomography and other parameters in differentiating APAC from fellow eyes ($N = 30$)

Variables	AUC	Sensitivity at 80% Specificity (%)	*P*
RNFL	0.895 (0.811–0.979)	83.3	< 0.001
GCC	0.883 (0.796–0.970)	80	< 0.001
MD	0.806 (0.693–0.919)	70	< 0.001
$cpVD_{cap}$	0.888 (0.801–0.974)	80	< 0.001
$cpVD_{all}$	0.890 (0.806–0.974)	80	< 0.001
$WiVD_{cap}$	0.851 (0.746–0.956)	80	< 0.001
$WiVD_{all}$	0.886 (0.799–0.972)	80	< 0.001
Inside disk VD_{cap}	0.653 (0.514–0.793)	46.7	0.041
Inside disk VD_{all}	0.701 (0.565–0.838)	56.7	0.007
Nasal upper $cpVD_{cap}$ (%)	0.813 (0.706–0.921)	66.7	< 0.001
Nasal lower $cpVD_{cap}$ (%)	0.838 (0.736–0.940)	73.3	< 0.001
Inferonasal $cpVD_{cap}$ (%)	0.842 (0.729–0.955)	80	< 0.001
Inferotemporal $cpVD_{cap}$ (%)	0.829 (0.716–0.942)	70	< 0.001
Temporal upper $cpVD_{cap}$ (%)	0.765 (0.646–0.884)	56.7	< 0.001
Temporal lower $cpVD_{cap}$ (%)	0.721 (0.590–0.853)	46.7	0.003
Superotemporal $cpVD_{cap}$ (%)	0.898 (0.823–0.973)	70	< 0.001
Superonasal $cpVD_{cap}$ (%)	0.887 (0.804–0.969)	83.3	< 0.001

RNFL Retinal nerve fiber layer, *GCC* Ganglion cell complex, *MD* Mean deviation, *wiVD* Whole en face image disk vessel density, *cpVD* Circumpapillary vessel density

LPI previously. Although the interval between the therapy and OCTA examination is longer than 3 months, this diversity may have some potential impact on the vessel density. Second, only one time point was investigated after acute attack. Hence, the information about longitudinal changes of vessel densities was lacking. Finally, the sample size is relatively small, and further studies with larger sample size are necessary to further justify the diagnostic ability of circumpapillary VD.

In conclusion, circumpapillary VD decreased significantly compared with the fellow unaffected eyes in APAC eyes. They were significantly correlated with thicknesses of RNFL and GCC. The patients with longer duration of acute attack were likely to have lower cpVD. For APAC, the diagnostic ability of wiVD and cpVD was similar with RNFL and GCC.

Author's contribution All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by [LN and PL], [YY, WP] and [JX, YKC, TL]. The first draft of the manuscript was written by [LN and LF] and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The data used to support the findings of this study are included within the article.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the Clinical Research Ethics Committee of the Affiliated Eye Hospital of Wenzhou Medical University, and followed the tenets of the Declaration of Helsinki in 1964.

Informed consent Informed consent was obtained from all individual participants included in the study. Patients signed informed consent regarding publishing their data and photographs.

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