Relationship between peripapillary vessel density and visual function based on Garway-Heath sectorization in open-angle glaucoma

**Purpose:** To investigate the relationship between peripapillary vessel density (pVD) and visual field sensitivity (VFS) and between peripapillary retinal nerve fiber layer thickness (pRNFLT) and VFS, based on Garway-Heath sectorization in open-angle glaucoma patients. **Methods:** Sixty-six eyes of healthy subjects and 84 eyes of glaucoma subjects were included. All subjects underwent several eye examinations, including standard automated perimetry and optical coherence tomography angiography. Sectoral structure-function relationships based on the Garway-Heath sectorization were compared among normal subjects, the ‘mild glaucoma,’ and ‘moderate-to-severe glaucoma’ group. Multivariate analyses were performed for each sector to determine the factors related to VFS. The diagnostic abilities of vessel density parameters and RNFLT were evaluated by calculating the area under the receiver operating characteristic curves (AUROC). **Results:** The correlation between pVD-VFS and pRNFLT-VFS was statistically significant in the glaucoma group independent of the VFS sector. In the glaucoma group, VFS in the temporal sector was statistically related to pVD and pRNFLT and age ($R^2 = 0.721; P = 0.007, < 0.001, .15$, respectively). We found pRNFLT and age were significantly associated with VFS in glaucoma. The AUROC values of pVD in the inferotemporal sector of the total, mild, and moderate-to-severe glaucoma (0.843, 0.714, and 0.972, respectively) were comparable to pRNFLT in this sector (0.833, 0.718, 0.948, respectively). **Conclusion:** Since the relationship between pVD and VFS in the papillomacular area was significant, measuring pVD and RNFLT in the corresponding area will be valuable in expanding our pathophysiologic knowledge of the paracentral field defects in glaucoma.

**Key words:** Glaucoma, optical coherence tomography angiography, papillomacular area, peripapillary vessel density

Glaucoma is a progressive optic neuropathy that causes specific damage to optic nerve fibers resulting in visual field defects (VFDs).[1] Intraocular pressure (IOP), related mechanical, stress and vascular insufficiency of the optic nerve are the principal causes underlying the anatomical and functional damage in glaucoma. However, the exact mechanisms are unknown.[2,3] The visual field (VF) loss in normal-tension glaucoma (NTG) is more localized and manageable compared to high tension glaucoma.[4] Also, glaucoma patients with central field defects have higher systemic risk factors such as hypertension, migraine, Raynaud’s phenomenon, and sleep apnea than those with nasal step defects.[5] Since the retinal ganglion cell axons in the papillomacular bundle region correlate with central visual function, we speculated that an eye with a more vulnerable optic nerve vasculature might have VFDs in the more central area, including the papillomacular bundle region corresponding to the paracentral field.

The development of optical coherence tomography angiography (OCT-A) has enabled noninvasive measurements of vascular changes in the peripapillary or parafoveal area, and OCT-A has been increasingly used in retinal diseases and glaucoma.[6–8] Previous studies have revealed a significant association between abnormal vessel density (VD) in the peripapillary area and glaucomatous optic neuropathy.[9–11] Despite the importance of preserving the central field in glaucoma, the structural OCT image might have some limitations in obtaining these areas’ information.[12,13] In analyzing the relationship between VD and function in the papillomacular bundle region, the sectoral relationship between VD and visual field sensitivity (VFS) in glaucoma has not been discussed.

The present study had two primary purposes: 1) to sectorally compare the correlation between peripapillary vessel density (pVD) and VFS with that between peripapillary retinal nerve fiber layer thickness (pRNFLT) and VFS, and 2) to determine the factors related to VFS in the paracentral sector.
to evaluate the VFS determinants in each sector, including papillomacular bundle region. The secondary objective was to perform sectoral comparisons of the diagnostic abilities of pVD and pRNFLT based on the glaucoma severity.

Methods

Subjects: This was a prospective, cross-sectional, and comparative study in a single institute. The institutional review board of our institution approved this study, and all procedures were executed following the principles of the Declaration of Helsinki. We recruited patients with glaucoma (glaucoma group) and healthy subjects without glaucoma (control group) from our institution’s glaucoma clinic. Each patient was informed of the purpose and procedures of this study and provided written consent to participate. This study was registered as an intervention study in the ISRCTN registry. When both eyes were eligible, one eye was randomly selected for inclusion in the study.

All study participants underwent a complete ophthalmic examination, including measurement of best-corrected visual acuity (BCVA), slit-lamp examination, IOP measurement with Goldmann tonometry, gonioscopy, funduscopy, and standard automated perimetry. Central corneal thickness (CCT) was measured using ultrasonic pachymetry (Pachmate; DGH Technology, Exton, PA). Keratometry was performed with an auto kerato-refractometer (RK-F2; CANON, Kanagawa, Japan). Red-free RNFL photographs and optic disc photographs were also examined. OCT examinations were performed to measure pVD and pRNFLT.

For inclusion in the study, all subjects in the glaucoma group had to have a clinical diagnosis of glaucoma regardless of their current IOP levels. The inclusion criteria were: BCVA better than or equal to 20/40, spherical equivalent between −6.00 and +3.00 diopters (D) and cylinder correction within ±3.00 D, no media opacities, a normal anterior chamber on slit-lamp examination, and open-angles on gonioscopy. Exclusion criteria included non-glaucomatous neuropathies, retinal diseases, and prior intraocular surgery, except cataract surgery. Glaucoma was defined as asymmetric inter-eye cup-to-disc ratio ≥0.2, vertical cup-to-disc ratio >0.7, neural rim thinning, localized notching, disc hemorrhage, and RNFL defects with corresponding glaucomatous VF defects. An automated VF examination was performed with a standard 24-2 SITA program on a Humphrey 740 Visual Field Analyzer (HFA 740; Carl Zeiss Meditec, Dublin, CA). We defined glaucomatous VF based on the presence of two of the three following criteria: (1) an abnormal glaucoma hemifield test (a borderline score was not considered abnormal), (2) three continuous non-edge points (allowing for two-step nasal edge points) with P < 0.05 for the total deviation plot and P < 0.01 for at least one point, and (3) P < .05 for pattern standard deviation (PSD) on the SITA Standard test. Reliable VF tests had a false-positive rate < 15%, false-negative rate < 15%, and fixation loss < 20%. The severity of glaucomatous damage was classified as mild (VF mean deviation (MD) ≥ −6 dB) or moderate-to-severe (VF MD < −6 dB). The subjects’ eyes in the normal control group had an IOP < 21 mmHg, no glaucomatous optic disc changes, a normal VF, and no ocular disease history.

OCT-A imaging and pVD measurements: We used a swept source-OCT (SS-OCT, DRI OCT-1 Atlantis; Topcon, Tokyo, Japan) that uses infrared light with a wavelength of 1050 nm, at a rate of 100,000 axial scans (A-scans) per second to obtain OCT-A images. The infrared light signal has a wavelength longer than the conventional spectral domain-OCT, thus enabling deeper penetration of the retina and choroid. Its axial and transverse resolutions are 7 and 20 μm in tissue, respectively. Volumetric OCT scans were acquired from 6 × 6 mm cubes. Each cube consisted of 320 clusters of four repeated two-dimensional transverse scans (B scans) centered on the disc.

Two investigators reviewed all the scans for signal strength, segmentation error, loss of fixation, and motion artifact as part of the quality assessment. Eyes with poor image quality were excluded based on the following criteria: (1) poor fixation resulting in a double vessel pattern and motion artifacts, (2) media opacity obscuring the vessel signal in the field of view, or a signal strength index less than 7, and (3) segmentation error resulting in poor outlining of vascular networks. We detected blood flow by measuring intensity fluctuations from the scanned OCT images. In this technique known as OCT-A ratio analysis (OCTARA), calculations are based on the intensity values’ ratio across points within one scan and identical points in repeated scans. OCTARA provides a relative sensitivity advantage of the magnitude of ten to 50 times for medium to low blood flow.

We performed automated segmentation using OCT software to separate each layer of the retina. The peripapillary sector was defined as a 0.75 mm-wide elliptical annulus extending from the inner elliptical contour (optic disc boundary). To measure the pVD, we used the average and sectoral pVD values in the radial peripapillary capillary layer, which extends from the inner limiting membrane to the outer limit of the RNFL. The software automatically fit an ellipse to the disc margin based on the OCT en-face image. The software provided six peripapillary sectors based on the Garway-Heath map (temporal, T, 311° to 40°), superotemporal (ST, 41° to 80°), superonasal (SN, 81° to 120°), nasal (N, 121° to 230°), inferonasal (IN, 231° to 270°), and inferotemporal (IT, 271° to 310°).

We developed custom software using Microsoft Visual Studio 2012 and the C# language with a dot net library that calculates the average sectoral VD according to the Garway-Heath map sectors [Fig. 1]. This software required superficial vascular layer image data and a color VD map exported from the OCT-A instrument. The optic disc was detected automatically after
these two image files have been loaded. The user also had the option to manually set the optic disc location if the software failed to do so. The software then calculated the mean sectoral VD of the two ellipsoidal boundaries.

**RNFLT measurements:** We performed wide-angle scanning with SS-OCT to obtain circumpapillary RNFLT measurements. The wide-angle scanning uses a wide-angle 12 × 9 mm lens. SS-OCT automatically detects the disc’s center, after which it draws a peripapillary circle (3.46 mm diameter). The method for measuring RNFLT using the OCT protocol for glaucoma has been described elsewhere.\(^3,4\) We analyzed the average RNFLT and six sectoral RNFLTs (T, ST, SN, N, IN, and IT) matching the pVD sectors. A representative case of the peripapillary scan is presented in the Fig. 2.

**Sectoral Relationship between the structure (pVD and RNFLT) and VF defect:** The mean VFS in various sectors was defined as the average value of the differential light sensitivity (DLS) obtained at VF test locations corresponding
to pVD sectors. The VFS was expressed in unlogged 1/L scales (L, luminance measured in lamberts). The DLS at each tested location can be simply expressed as DLS = 10 × log10 (1/L) in decibels. The non-logarithmic 1/L value at each tested location was calculated by dividing the decibel reading by ten prior to deriving the antilogarithm. Using the segmentation by Garway-Heath et al., regional relationships between the VFS and each pVD or RNFLT were assessed, respectively. The HFA 24-2 test points were also grouped into six sectors.

**Statistical analysis:** We used the one-way analysis of variance (ANOVA) test to compare demographic and clinical data, OCT-A VD, and RNFLT among normal, mild, and moderate-to-severe glaucoma groups, and if the P value in the ANOVA test was less than 0.05, post hoc analysis (Tukey’s test) was performed. Categorical variables were compared using the Chi-square test. A Spearman’s correlation test was used to investigate the correlation of pVD-VFS and pRNFLT-VFS in each sector. In all regression tests assessing vasculature-function and structure-function relationships, pVD and pRNFLT were treated as the independent variables and the corresponding VFS as the dependent variable. When expressed in a linear unlogged 1/L scale, the VFS showed the structure-function relationship better, so we used linear regression analysis to evaluate the relationship between pVD or pRNFLT and VFS. We further compared correlation coefficients of pVD-VFS and pRNFLT-VFS of normal, mild, and moderate-to-severe glaucoma groups in each sector. We computed Pearson’s correlation coefficient and used Fisher’s z test to assess the significance of the correlation. We used the single and multiple linear regression analysis to evaluate if factors such as age, gender, spherical equivalent, CCT, hypertension, diabetes mellitus, pVD, and RNFLT were associated with VFS. The diagnostic abilities of the vessel density parameters and RNFLT for differentiating the normal control group and mild, moderate-to-severe, and total (mild and moderate-to-severe) glaucoma groups were evaluated by calculating the area under the receiver operating characteristic curves (AUROC). We used the SPSS version 20.0 (SPSS, Chicago, IL) to perform all statistical analyses, with statistical significance set at P ≤ 0.05.

**Results**

We studied a total of 66 eyes from healthy control subjects and 84 eyes from glaucoma subjects. Table 1 shows the demographic and clinical characteristics in normal control and glaucoma groups. We found statistically significant differences between normal control and glaucoma groups in VF mean deviation (MD), VF PSD, pVD, and RNFLT (P < 0.001). Other demographic and ocular factors, such as age, sex, laterality, IOP, SE, CCT, and history of hypertension and diabetes, were comparable between the groups.

We compared correlation in total, mild, and moderate-to-severe glaucoma with those of normal controls [Fig. 3]. Sectoral correlation coefficients of pVD-VFS and pRNFLT-VFS were significantly higher in total glaucoma than in normal subjects, except for pVD-VFS in sector 5 (P < 0.001, < 0.001 in sector 1; < .001, < .001 in sector 2; < .001, < .001 in sector 3; < .001, 0.018 in sector 4; 0.190, 0.042 in sector 5; 0.045, < .001 in sector 6). The correlation coefficient of pVD-VFS in sectors 1, 2, and 4, and pRNFLT-VFS in sector 2 were significantly higher in mild glaucoma than in normal control subjects (P = .014, .003, .036, respectively). The correlation coefficient of pVD-VFS in sectors 1, 2, and 3, and pRNFLT-VFS in sectors 3 and 6 were significantly higher in moderate-to-severe glaucoma than in normal control subjects. (P = .004, .004, .008, .022, .011, respectively).

A multivariate regression analysis [Table 2] showed that pVD, pRNFLT and age were significantly independent parameters on VFS in glaucoma, in sector 1 (R² = 0.721; P = 0.007, < 0.001, 0.015, respectively). In the other sectors, pRNFLT and age were significantly associated with VFS in glaucoma (R² = 0.808, P < 0.001; R² = 0.764, P < .001; R² = 0.706, P < .001; R² = 0.614, P < .05; R² = 0.601, P < .05, respectively in sectors 2 to 6).

The diagnostic ability of zonal pRNFLT and pVD to detect different stages of glaucoma are shown in Table 3. In sector 2, pRNFLT and pVD had the highest AUROC values of 0.718 and 0.714 respectively in early glaucoma, 0.948 and 0.972 respectively in moderate-to-severe glaucoma, and 0.833 and 0.843 respectively in total glaucoma. Also, in sector 2, the AUROC values of pVD of total, mild and moderate-to-severe glaucoma were comparable to those of pRNFLT (P = 0.759, 0.945, 0.163, respectively).

**Discussion**

The present study has shown that a statistically significant sectoral relationship exists between pVD and VFS and between pRNFLT and VFS in glaucoma regardless of VFS location. In the glaucoma group, the pVD is significantly correlated with VFS only on the temporal peripapillary sectors that represent most of the papillomacular area, and the pRNFLT and age are significantly associated with VFS in all sectors.
Table 1: Demographics and clinical characteristics in the normal control and glaucoma groups.

|                        | Control group                        | Glaucoma group                        | p<0.05 | p<0.01 | p<0.001 | p<0.0001 |
|------------------------|--------------------------------------|---------------------------------------|--------|--------|---------|----------|
| Age (years) *          | 54.4±15.0                            | 57.7±13.1                            | 61.2±13.7 | 0.053 |
| Sex (male/female) §     | 32/34                                | 22/20                                 | 24/18   | 0.679 |
| Laterality (right/left) | 42/24                                | 18/24                                 | 22/20   | 0.101 |
| Intraocular pressure (mmHg) *     | 14.2±3.7                             | 13.9±2.4                              | 15.5±5.7 | 0.170 |
| Spherical equivalent (D) *     | -0.4±2.2                             | -0.7±2.0                              | -1.2±2.6 | 0.213 |
| CCT (µm) *              | 543.7±33.1                           | 555.7±31.7                            | 546.9±43.6 | 0.324 |
| History of hypertension (n, %) b   | 10 (15.1)                            | 11 (26.2)                             | 15 (35.7) | 0.047 |
| History of diabetes (n, %) §     | 10 (15.1)                            | 7 (16.7)                              | 7 (16.7) | 0.969 |
| Visual field, MD (dB) *     | 0.2±1.0                              | -1.4±2.4                              | -13.9±6.0 | <0.001 |
| Visual field, PSD (dB) *     | 2.2±0.8                              | 3.6±2.5                               | 12.5±3.1 | <0.001 |
| pVD (%) *               |                                      |                                       |         |        |         |          |
| Sector 1 (T)            | 63.9±1.4                             | 62.7±2.9                              | 59.6±3.3 | <0.001 |
| Sector 2 (IT)           | 64.0±1.5                             | 61.6±4.5                              | 55.3±5.0 | <0.001 |
| Sector 3 (ST)           | 63.3±1.8                             | 62.5±1.9                              | 59.0±4.4 | <0.001 |
| Sector 4 (IN)           | 62.7±2.3                             | 61.3±3.9                              | 58.3±4.5 | <0.001 |
| Sector 5 (SN)           | 63.0±2.4                             | 62.3±3.6                              | 59.9±4.4 | <0.001 |
| Sector 6 (N)            | 63.1±1.9                             | 61.1±2.7                              | 60.4±3.6 | <0.001 |
| RNFLT (µm) *            |                                      |                                       |         |        |         |          |
| Sector 1 (T)            | 80.3±13.6                            | 74.7±13.1                             | 57.0±15.4 | <0.001 |
| Sector 2 (IT)           | 141.2±30.0                           | 110.4±39.5                            | 55.7±34.1 | <0.001 |
| Sector 3 (ST)           | 131.9±27.4                           | 116.5±26.2                            | 73.4±34.0 | <0.001 |
| Sector 4 (IN)           | 116.8±30.4                           | 105.6±28.9                            | 66.0±25.1 | <0.001 |
| Sector 5 (SN)           | 111.1±26.8                           | 98.8±20.6                             | 76.2±26.6 | <0.001 |
| Sector 6 (N)            | 76.9±14.9                            | 73.5±14.4                             | 60.2±20.1 | <0.001 |

Results of the numerical variables are presented as a unique value or as the mean±standard deviation. D=diopters, CCT=central corneal thickness, dB=decibel, MD=mean deviation, PSD=pattern standard deviation, pVD=peripapillary vessel density, RNFLT=retinal nerve fiber layer thickness, T=temporal, IT=inferotemporal, ST=supertemporal, IN=inferonasal, SN=superonasal, N=nasal. *Statistical significance was tested with the Chi-square test. †Statistical significance was tested with the one-way analysis of variance test. ‡Intergroup ANOVA testing was performed using the mean values. §P-value for the post hoc analysis of the mild stage in the glaucoma group; ¶P-value for the post hoc analysis of the normal subjects and mild stage in the glaucoma group; ‡‡P-value for the post hoc analysis of the normal subjects and moderate-to-severe stage in the glaucoma group; ‡§P-value for the post hoc analysis of the mild and moderate-to-severe stage in the glaucoma group.

Sakaguchi et al. has reported that the relationship between sectoral VD and functional VF is stronger than the RNFL-VFS relationship across all sectors, proposing that the VN could show a more uniform correlation with VFS than RNFLT and may be more advantageous than RNFLT in terms of its structure-function relationship in glaucoma. Akil et al. showed that the pVD using OCT-A could differentiate early glaucoma from pre-perimetric glaucoma. In early glaucoma, the present study showed that pVD and VFS were significantly correlated in all sectors, while pRNFLT and VFS were only significantly correlated in ST and IT sectors. Therefore, our findings suggest that vascular density is a more sensitive parameter than RNFLT for detecting functional damage in early glaucoma. Consistent with previous studies, our study shows that the average VD is an independent determinant of VF MD in glaucoma. Lee et al. showed that decreased VD was significantly associated with the severity of glaucomatous functional damage after adjusting for structural parameters, such as pRNFLT, rim area, and disc area. Global and sectoral VDs are thus meaningful measurements for evaluating the relationship between structure and function in glaucoma.

The present study revealed that glaucomatous papillomacular defects are significantly associated with corresponding VD as well as RNFLT. This finding differs from peripheral field defects which are strongly associated with only RNFLT. Pentado et al. observed that macular VD was significantly associated with central VFS in a multivariate analysis. Holló et al. also found that temporal VD significantly correlated with the corresponding VFS in glaucomatous eyes, suggesting that glaucoma-related vascular dysfunction in the particularly stable papillomacular area may start at an early stage. However, the previous studies lack a multivariate analysis to determine the factors associated with VFS.

In our study, the pRNFLT and pVD in the IT sectors show the best diagnostic performance for detecting glaucoma. This finding is consistent with previous studies showing the greatest AUROC in IT or ST sectors, which are more vulnerable to glaucomatous damage than other sectors.

The pVD-VFS relationship in the central field is independently and significantly correlated in our study, suggesting that VD in glaucomatous eyes with central defects must be considered as a significant factor affecting VF defects. In the previous
Table 2: Sectoral multivariate linear regression analysis of independent parameters on the VFS in normal and total glaucoma group.

| Sector | VFS | Normal | Total | Crude Regression Coefficient | Adjusted Regression Coefficient |
|--------|-----|--------|-------|------------------------------|---------------------------------|
| Sector 1 |     |        |       | β (p<0.05)                  | β (p<0.05)                      |
| Sector 2 |     |        |       |                              |                                |
| Sector 3 |     |        |       |                              |                                |

Statistical significant values are in bold type. Backward multiple linear regression method applied. Model assumption is fulfilled. Backward multiple linear regression by single linear regression. Adjusted regression coefficient by multiple linear regression. SPH: spherical equivalent, CCT: central corneal thickness, pRNFL: peripapillary retinal nerve fiber layer thickness, pVD: peripapillary vessel density, HTN: hypertension, DM: diabetes mellitus, T: temporal, IT: inferotemporal, ST: superotemporal, IN: inferonasal, SN: superonasal, N: nasal.
Table 3: Comparison of the regional diagnostic abilities for detecting different stages of glaucoma between peripapillary vascular density (pVD) and retinal nerve fiber layer thickness (pRNFLT)

| Stage          | Sector | pVD            | pRNFLT        | P*  |
|----------------|--------|----------------|---------------|-----|
|                | Total  | 0.746 (0.669-0.823) | 0.744 (0.666-0.821) | 0.959 |
|                | Sector 1 (T) | 0.743 (0.671-0.817) | 0.744 (0.666-0.821) | 0.959 |
|                | Sector 2 (IT) | 0.743 (0.671-0.817) | 0.744 (0.666-0.821) | 0.959 |
|                | Sector 3 (ST) | 0.743 (0.671-0.817) | 0.744 (0.666-0.821) | 0.959 |
|                | Sector 4 (IN) | 0.743 (0.671-0.817) | 0.744 (0.666-0.821) | 0.959 |
|                | Sector 5 (SN) | 0.743 (0.671-0.817) | 0.744 (0.666-0.821) | 0.959 |
|                | Sector 6 (N) | 0.743 (0.671-0.817) | 0.744 (0.666-0.821) | 0.959 |
| Mild           | Sector 1 (T) | 0.603 (0.489-0.717) | 0.624 (0.517-0.730) | 0.778 |
|                | Sector 2 (IT) | 0.603 (0.489-0.717) | 0.624 (0.517-0.730) | 0.778 |
|                | Sector 3 (ST) | 0.603 (0.489-0.717) | 0.624 (0.517-0.730) | 0.778 |
|                | Sector 4 (IN) | 0.603 (0.489-0.717) | 0.624 (0.517-0.730) | 0.778 |
|                | Sector 5 (SN) | 0.603 (0.489-0.717) | 0.624 (0.517-0.730) | 0.778 |
|                | Sector 6 (N) | 0.603 (0.489-0.717) | 0.624 (0.517-0.730) | 0.778 |
| Moderate-to-severe | Sector 1 (T) | 0.889 (0.825-0.953) | 0.863 (0.791-0.936) | 0.544 |
|                | Sector 2 (IT) | 0.889 (0.825-0.953) | 0.863 (0.791-0.936) | 0.544 |
|                | Sector 3 (ST) | 0.889 (0.825-0.953) | 0.863 (0.791-0.936) | 0.544 |
|                | Sector 4 (IN) | 0.889 (0.825-0.953) | 0.863 (0.791-0.936) | 0.544 |
|                | Sector 5 (SN) | 0.889 (0.825-0.953) | 0.863 (0.791-0.936) | 0.544 |
|                | Sector 6 (N) | 0.889 (0.825-0.953) | 0.863 (0.791-0.936) | 0.544 |

Variables are presented as the areas under the receiver operating characteristics curves (AUROC), with 95% confidence interval values provided in parentheses.

T= temporal, IT= inferotemporal, ST= superotemporal, IN= inferonasal, SN= superonasal, N= nasal. *Comparison of the area under the receiver operating characteristics curves using DeLong et al.’s method

There are several limitations to the present study. First, this study included patients with primary open-angle glaucoma who also had normal-tension glaucoma (NTG) that is more vulnerable to vascular insufficiency. Thus, there is a possibility for overestimation of the vessel structure-function relationship. Second, we were not able to exclude the effects of anti-glaucoma eye drops or other systemic vasoactive medications that can alter retinal vessel diameter. The relationship between pVD and VFS revealed in this study should therefore be interpreted with caution. Third, peripapillary atrophy may have affected pVD in myopic eyes. However, we excluded high myopia above -6D, so the effect on pVD of peripapillary atrophy was minimized. Fourth, in the sectoral relationship between the structure (pVD and RNFL) and VF defect, we used the Garway-Heath map to see which relationship is better. Therefore, the temporal sector could not be divided into upper-temporal and lower-temporal sectors along the histological horizontal raphe. Finally, this is a cross-sectional study and we cannot conclude that the observed pVD is the primary pathogenic mechanism in glaucoma and precedes IOP elevation or RNFL damage. Further longitudinal studies are required to tease out this distinction.

Conclusion

To the best of our knowledge, this is the first report to investigate the sectoral relationship between VD, RNFLT, and VFS in both glaucoma and normal subjects and compare their VFS with its associated factors to corresponding peripapillary regions based on the Garway-Heath map. Since the relationship between pVD-VFS in the papillomacular nerve fiber bundle region was significant, pVD using OCT-A in this area is the useful parameter to evaluate structure and function within the paracentral area in glaucoma.

Declaration of patient consent

The authors certify that they have obtained all appropriate patient consent forms. In the form the patient(s) has/have given his/her/their consent for his/her/their images and other clinical information to be reported in the journal. The patients understand that their names and initials will not be published and due efforts will be made to conceal their identity, but anonymity cannot be guaranteed.

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Conflicts of interest

There are no conflicts of interest.
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