Biometric Features of Peripapillary Atrophy Beta in Eyes with High Myopia

Atsushi Nonaka, Masanori Hangai, Tadamichi Akagi, Satoshi Mori, Masayuki Nukada, Noriko Nakano, and Nagabisa Yoshimura

PURPOSE. To evaluate peripapillary atrophy β (PPA-β) characteristics in highly myopic eyes, using simultaneous confocal scanning laser ophthalmoscopy (cSLO) and enhanced spectral-domain optical coherence tomography (SD-OCT).

METHODS. The authors retrospectively analyzed 61 highly myopic (≥ -6.0 D) eyes without myopic retinopathy. cSLO fundus images were used to measure the distances from the foveal center to the temporal and nasal margins of the PPA-β zone; horizontal cross-sectional SD-OCT images, to determine the position where the inner plexiform layer (IPL) terminates within the PPA-β zone; and A-mode ultrasonography, to measure axial length.

RESULTS. The distance from the foveal center to the PPA-β zone temporal margin (2.68 ± 4.39 mm) correlated with the circumferential extent of PPA-β (P < 0.001, r = −0.49). The distance from the foveal center to the nasal margin (3.41 ± 5.60 mm) correlated with the ovality index of the optic disc (P < 0.001, r = −0.51) and with the axial length (P < 0.05, r = 0.26). PPA-β zone width (0.20 ± 0.05 mm) correlated with the circumferential extent of PPA-β (P < 0.001, r = 0.42), ovality index of the optic disc (P < 0.001, r = −0.68), and axial length (P < 0.05, r = 0.32). The IPL termination within the PPA-β zone was significantly closer to the optic disc when the circumferential extent of PPA-β was large (P < 0.01, r = 0.36).

CONCLUSIONS. Interindividual variations in biometric features of PPA-β in highly myopic eyes showed different associations with axial length, degree of disc ovality, and circumferential extent of PPA-β. (Invest Ophthalmol Vis Sci. 2011;52: 6706–6715) DOI:10.1167/iovs.11-7580

Myopia, the most common of all ocular problems, is a serious public health concern that is continuing to increase in prevalence, especially in certain young Asian populations.1 Myopia is associated with high risk of visual impairment caused by macular diseases such as chorioretinal atrophy, choroidal neovascularization, macular retinoschisis, macular hole, and retinal detachment.2 Myopia also predisposes to glaucomatous optic nerve damage, and such damage in myopic eyes is not only more prevalent but more severe than that among nonmyopic eyes.2–5 The appearance of the optic disc in myopic eyes differs significantly from the appearance of the optic disc in emmetropic or hyperopic eyes: discs in myopic eyes tend to be large in diameter, to be tilted, and to display shallow cupping and more concentric cupping.6 Additional characteristic findings related to the optic disc in eyes with myopia include a large area of peripapillary atrophy (PPA),6 step-configuration of the scleral bed,7 and peripapillary detachment of pathologic myopia.8 Such structural abnormalities in myopic eyes may contribute to the higher incidence of glaucoma in these eyes.

Of all these structural abnormalities characteristic of eyes with high myopia, a large area of PPA is most associated with glaucomatous optic neuropathy.9,10 especially open-angle glaucoma with normal intraocular pressure.11–15 Although PPA is often seen in normal eyes,11 PPA is seen more often and the area of PPA is larger in eyes with glaucoma compared with normal eyes, and PPA can progress as glaucomatous optic atrophy progresses.15–20 In addition, PPA is seen more often in highly myopic eyes than in eyes without refractive abnormality.21–24 Considering the increased risk for glaucoma in highly myopic eyes,3,5 PPA may be not only a hallmark of high myopia25,26 but also an important contributor to higher risk for glaucomatous damage.

Despite the importance of PPA in highly myopic eyes, to date the only information available about the structure of PPA in highly myopic eyes has been that obtained in a small histopathologic study, which found that in the area of PPA, Bruch’s membrane and the choriocapillaris were absent in highly myopic eyes and in both myopic and nonmyopic eyes, the area of PPA lacked photoreceptors and retinal pigment epithelium (RPE).27 We conducted the study reported here to analyze the structural characteristics of PPA in living patient eyes with high myopia, using advanced optical coherence tomography (OCT) technology to rapidly obtain high-quality images.28 Specifically, we obtained cross-sectional images of the PPA-β in highly myopic eyes by spectral-domain OCT (SD-OCT)29,30 using an enhanced SD-OCT system (Spectralis HRA+OCT; Heidelberg Engineering, Heidelberg, Germany) that concurrently performs scanning laser ophthalmoscopy (cSLO) and SD-OCT with speckle-noise reduction31 so that the biometric characteristics of the area of PPA-β could be examined.

METHODS

This observational case study was carried out in the Department of Ophthalmology of Kyoto University Hospital in Japan between October 2008 and March 2010. This study was approved by the Institutional Review Board and Ethics Committee of the Kyoto University Graduate School of Medicine. All investigations adhered to the principles of the Declaration of Helsinki.
Biometric Features of Peripapillary Atrophy Beta in Myopic Eyes

Patients
We retrospectively included data from examinations of highly myopic patient eyes (with refractive errors \( \geq -6.0 \) D spherical equivalent). Ophthalmologic examination data recorded for each patient included best-corrected visual acuity (BCVA) and the results of refraction, keratometry, slit-lamp biomicroscopy, applanation tonometry, gonioscopy, indirect ophthalmoscopy, fundus photography, A-mode ultrasonography, and visual field testing with standard automated perimetry using the 24 to 2 Swedish interactive threshold algorithm standard program in a visual field analyzer (Humphrey Field Analyzer; Carl Zeiss Meditec, Inc., Dublin, CA). All patients had also undergone simultaneous enhanced SD-OCT and confocal scanning laser ophthalmoscopy (cSLO).

To be included, eyes had to have BCVA of 20/40 or better and normal visual field. We excluded eyes with cataract, a history of ocular surgery, or degenerative myopia due to choriotidal atrophy or macular degeneration.

Measurements on cSLO and Enhanced SD-OCT Images
Structural characteristics of the area of PPA-\( \beta \) were determined by analyzing images obtained using simultaneous SD-OCT and cSLO, performed using an enhanced SD-OCT system (Spectralis HRA+OCT; Heidelberg Engineering). Measurements were made using the measurement features built into the system’s software, including linear measurements of the distance between two indicated points, corrected to account for the radius of corneal curvature.

We made three measurements on near-infrared reflectance (NIR) images of the fundus obtained by cSLO: the distance between the foveal center and temporal or nasal margin of the area of PPA-\( \beta \) (blue arrow in Fig. 1A); the distance between the foveal center and the nasal or temporal margin of the area of PPA-\( \beta \) (yellow arrow in Fig. 1A); and the width of the area of PPA-\( \beta \), measured as the distance between the nasal or temporal margins of the area of PPA-\( \beta \) (purple arrow in Fig. 1A).

We measured the ovality index of the optic disc\(^{3,5} \) and circumferential extent of the area of PPA-\( \beta \) as clock hours around the circumference of the optic disc on photographic images of the optic disc (Figs. 1B, 1C). The ovality index was calculated by dividing the shortest diameter of the optic disc by the longest diameter. The shape of the optic disc was classified as “round” when its ovality index was \( \leq 0.8 \) and classified as “oval” when its ovality index was \( \geq 0.8 \).\(^{52} \)

The area of PPA-\( \beta \) was classified as a “peripapillary crescent” when it encompassed fewer than 9 clock hours around the optic disc (Fig. 1B), and it was classified as a “peripapillary halo” when the area of PPA-\( \beta \) encompassed \( >9 \) clock hours around the circumference of the optic disc (Fig. 1C).

On cross-sectional images obtained by automatic real-time enhanced SD-OCT (which involves averaging 25 to 50 images obtained in the same location, to reduce speckle noise), we examined the structure of retinal layers and subretinal layers, including the RPE, Bruch’s membrane, choroid, and sclera, within the area of PPA-\( \beta \).

Within the area of PPA-\( \beta \), the sensory layers of the retina, including the ganglion cell layer (GCL), inner plexiform layer (IPL), inner nuclear layer (INL), and outer plexiform layer (OPL), terminated in stepwise fashion, ending in a blunt tip at a variable distance between the temporal margin and the nasal margin of the area of PPA-\( \beta \). Because the IPL was the most easily distinguishable of these layers on SD-OCT images (attributed to its high contrast to neighboring layers), we used the IPL to measure how far the subretinal layers extended into the area of PPA-\( \beta \), assigning the temporal margin of the PPA-\( \beta \) a value of zero (0) and the nasal margin a value of one (1).

Statistical Analyses
Statistical analyses were performed using an analytical software program (SPSS version 17.1; SPSS Inc., Chicago, IL). Linear measurements are expressed as mean \( \pm SD \) from the mean. Differences between two groups were analyzed statistically using the Mann-Whitney \( U \) test. Spearman’s rank correlation coefficient was used to describe relationships between two groups. A probability value of \( P < 0.05 \) was considered statistically significant for all analyses.

Results
A total of 61 highly myopic eyes of 48 Japanese patients (19 males and 29 females, ages ranging from 21 to 74 years) met criteria for inclusion in this study.

Measurements
Table 1 shows the patient characteristics and mean and range values for measurements in the 61 eyes. The study eyes varied considerably in distance from the foveal center to the temporal margin or the nasal margin of the area of PPA-\( \beta \) and in the width of the area of PPA-\( \beta \).

**Table 1. Measurements in 61 Highly Myopic Eyes with PPA-\( \beta \)**

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Mean ( \pm SD )</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial length, mm</td>
<td>27.10 ( \pm 1.10 )</td>
<td>25.3–30.3</td>
</tr>
<tr>
<td>Ovality index of optic disc</td>
<td>0.80 ( \pm 0.12 )</td>
<td>0.42–1.00</td>
</tr>
<tr>
<td>Circumferential extent of PPA-( \beta ), clock hours</td>
<td>7.41 ( \pm 2.61 )</td>
<td>4–12</td>
</tr>
<tr>
<td>Distance from foveal center to Temporal PPA-( \beta ) margin, mm</td>
<td>5.44 ( \pm 0.37 )</td>
<td>2.68–30.3</td>
</tr>
<tr>
<td>Nasal PPA-( \beta ) margin, mm</td>
<td>4.25 ( \pm 0.44 )</td>
<td>3.41–30.3</td>
</tr>
<tr>
<td>Optic disc center, mm</td>
<td>4.95 ( \pm 0.40 )</td>
<td>4.24–30.3</td>
</tr>
<tr>
<td>PPA-( \beta ) width, mm</td>
<td>0.79 ( \pm 0.41 )</td>
<td>0.20–30.3</td>
</tr>
<tr>
<td>IPL termination within PPA-( \beta )</td>
<td>0.51 ( \pm 0.23 )</td>
<td>0–1</td>
</tr>
</tbody>
</table>

IPL termination within PPA-\( \beta \), relative distance from the temporal margin (“0”) to the nasal margin (“1”) of the area of PPA-\( \beta \).

**FIGURE 1.** (A) NIR image of the fundus in an eye with high myopia. The yellow arrow indicates the distance between the foveal center and the temporal margin of PPA-\( \beta \), the blue arrow indicates the distance between the foveal center and the nasal margin of PPA-\( \beta \), and the purple arrow indicates the distance between the temporal and nasal margins of PPA-\( \beta \), in other words, the width of PPA-\( \beta \). (B, C) Photographic fundus images in an eye with a peripapillary crescent (B) and an eye with a peripapillary halo (C). In this study, PPA-\( \beta \) was classified as a peripapillary crescent when its circumferential extent around the optic disc was \( \leq 9 \) clock hours, and as peripapillary halo when it was \( >9 \) clock hours in extent. The ovality index was calculated by dividing the shortest diameter of the optic disc (green arrows) by the longest diameter (white arrows). In this study, the optic disc was classified as round when its ovality index was \( \geq 0.8 \) and as oval when its ovality index was \( <0.8 \).
Table 2 shows correlations among measurements and with patient age. The distance from the foveal center to the temporal margin of the area of PPA-β correlated significantly with circumferential extent of PPA-β \( (P < 0.001, r = -0.49; \text{Fig. 2A}) \) and with patient age \( (P < 0.01, r = -0.37; \text{Fig. 2B}) \). Patient age also correlated well with axial length and circumferential extent of PPA-β (Table 2).

The distance from the foveal center to the nasal margin of the area of PPA-β correlated strongly negatively with the ovality index of the optic disc \( (P < 0.001, r = -0.51; \text{Fig. 3A}) \) and weakly positively with axial length \( (P < 0.05, r = 0.26; \text{Fig. 3B}) \).

The width of the area of PPA-β on horizontal SD-OCT images was significantly positively correlated with circumferential extent of the area of PPA-β \( (P < 0.001, r = 0.42; \text{Fig. 4A}) \), negatively correlated with the ovality index of the optic disc \( (P < 0.001, r = -0.68; \text{Fig. 4B}) \) and positively correlated with axial length \( (P < 0.05, r = 0.32; \text{Fig. 4C}) \). PPA-β width also correlated well with distance from the foveal center to the temporal PPA-β margin, nasal PPA-β margin, and optic disc center (Table 2).

The distance from the foveal center to the optic disc center was >5.0 mm in 27 (44.3%) of the 61 eyes (range, 4.24–6.16 mm, average 4.95 ± 0.40 mm) (Table 1), and this distance correlated strongly positively with the distance from the foveal center to the nasal margin of the area of PPA-β \( (P < 0.001, r = 0.95) \), negatively with the ovality index of the optic disc \( (P < 0.001, r = -0.45) \) and positively with axial length \( (P < 0.05, r = 0.26) \) (Table 2).

### Terminus of IPL within the Area of PPA-β on SD-OCT

The point of termination of the IPL within the area of PPA-β in one patient eye is shown in Figure 5. This point of termination, which by definition could range between 0 (nasal margin of the area of PPA-β) and 1 (temporal margin of the area of PPA-β), averaged 0.51 ± 0.23 (Table 1). Location of the IPL terminus was significantly correlated with extent of the PPA-β around the circumference of the optic disc \( (P < 0.01, r = 0.36; \text{Fig. 6}) \), but not with age, axial length, or ovality index of the optic disc (Table 2).

### Characteristics of Eyes with Peripapillary Halo versus Crescent

Table 3 shows characteristics of highly myopic eyes with peripapillary halo (n = 14) and those with peripapillary crescent (n = 47). The groups differed significantly in patient age \( (P < 0.05) \), distance from the foveal center to the temporal margin of the area of PPA-β \( (P < 0.001) \), and width of the area of PPA-β \( (P < 0.05) \). Groups also differed in where the IPL terminated within the area of PPA-β on enhanced SD-OCT images \( (P < 0.01) \), with this point being closer to the optic disc (nasal margin of the area of PPA-β, assigned a value of “1,” vs. temporal margin, assigned a value of “0”) in eyes with peripapillary halo (Figs. 7A, 7B) compared with eyes with peripapillary crescent (Figs. 7C, 7D).

### Characteristics of Eyes with Round versus Oval Optic Discs

Table 4 shows characteristics of highly myopic eyes with round discs (n = 32) and those with oval discs (n = 29). The groups differed significantly in distance from the foveal center to the nasal margin of the area of PPA-β \( (P < 0.01) \), distance from the foveal center to the disc center \( (P < 0.01) \), extent of the area of PPA-β around the circumference of the

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**Table 2. Correlations of Biometric Parameters in Highly Myopic Eyes with PPA-β**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Axial Length (mm)</th>
<th>Temporal PPA-β Margin (mm)</th>
<th>Circumferential Extent of PPA-β (clock hours)</th>
<th>Optical Disc Center (mm)</th>
<th>Position of IPL Termination Age (y)</th>
<th>Age (y)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial length, mm</td>
<td>( r = 0.49 )</td>
<td>( r = 0.49 )</td>
<td>( r = 0.37 )</td>
<td>( r = -0.49 )</td>
<td>( r = 0.49 )</td>
<td></td>
</tr>
<tr>
<td>Ovality index of optic disc</td>
<td>( r = 0.60 )</td>
<td>( r = 0.60 )</td>
<td>( r = 0.62 )</td>
<td>( r = 0.68 )</td>
<td>( r = 0.60 )</td>
<td></td>
</tr>
<tr>
<td>Circumferential extent of PPA-β</td>
<td>( r = -0.68 )</td>
<td>( r = -0.68 )</td>
<td>( r = -0.68 )</td>
<td>( r = -0.68 )</td>
<td>( r = 0.60 )</td>
<td></td>
</tr>
<tr>
<td>Optic disc center (mm)</td>
<td>( r = -0.49 )</td>
<td>( r = -0.49 )</td>
<td>( r = -0.49 )</td>
<td>( r = -0.49 )</td>
<td>( r = 0.60 )</td>
<td></td>
</tr>
<tr>
<td>Position of IPL termination</td>
<td>( r = -0.49 )</td>
<td>( r = -0.49 )</td>
<td>( r = -0.49 )</td>
<td>( r = -0.49 )</td>
<td>( r = 0.60 )</td>
<td></td>
</tr>
<tr>
<td>Age (y)</td>
<td>( r = -0.49 )</td>
<td>( r = -0.49 )</td>
<td>( r = -0.49 )</td>
<td>( r = -0.49 )</td>
<td>( r = 0.60 )</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3. Characteristics of Eyes with Peripapillary Halo versus Crescent**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Round Discs (n = 32)</th>
<th>Oval Discs (n = 47)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial length, mm</td>
<td>( r = 0.36 )</td>
<td>( r = 0.25 )</td>
</tr>
<tr>
<td>Temporal PPA-β margin, mm</td>
<td>( r = 0.30 )</td>
<td>( r = 0.18 )</td>
</tr>
<tr>
<td>Circumferential extent of PPA-β</td>
<td>( r = 0.30 )</td>
<td>( r = 0.18 )</td>
</tr>
<tr>
<td>Optical disc center, mm</td>
<td>( r = 0.32 )</td>
<td>( r = 0.25 )</td>
</tr>
<tr>
<td>Position of IPL termination</td>
<td>( r = 0.26 )</td>
<td>( r = 0.15 )</td>
</tr>
<tr>
<td>Age (y)</td>
<td>( r = 0.26 )</td>
<td>( r = 0.15 )</td>
</tr>
</tbody>
</table>

**Table 4. Characteristics of Eyes with Round versus Oval Optic Discs**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Round Discs (n = 32)</th>
<th>Oval Discs (n = 47)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axial length, mm</td>
<td>( r = 0.36 )</td>
<td>( r = 0.25 )</td>
</tr>
<tr>
<td>Ovality index of optic disc</td>
<td>( r = 0.30 )</td>
<td>( r = 0.18 )</td>
</tr>
<tr>
<td>Circumferential extent of PPA-β</td>
<td>( r = 0.30 )</td>
<td>( r = 0.18 )</td>
</tr>
<tr>
<td>Optic disc center, mm</td>
<td>( r = 0.32 )</td>
<td>( r = 0.25 )</td>
</tr>
<tr>
<td>Position of IPL termination</td>
<td>( r = 0.26 )</td>
<td>( r = 0.15 )</td>
</tr>
<tr>
<td>Age (y)</td>
<td>( r = 0.26 )</td>
<td>( r = 0.15 )</td>
</tr>
</tbody>
</table>

**NS:** not significant.

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**Figures:**

- **Fig. 2A:**
- **Fig. 2B:**
- **Fig. 3A:**
- **Fig. 3B:**
- **Fig. 4A:**
- **Fig. 4B:**
- **Fig. 4C:**
- **Fig. 5:**
- **Fig. 6:**
- **Fig. 7A:**
- **Fig. 7B:**
- **Fig. 7C:**
- **Fig. 7D:**
were not. For example, PPA-disc margin,7,29,30 which could be attributed to age-related sensory retina, RPE, Bruch’s membrane, choroid, and sclera) at the PPA-disc in highly myopic eyes, which suggests that the area of degenerative changes in the Bruch’s membrane–RPE complex. This variety of terms might be explained, at least in part, by the varieties of biomicroscopic appearance of PPA, such as area, shape, and circumferential extent around the optic disc.

Biomicroscopically, PPA appears as an area of almost bare sclera and atrophic choroid with easily discernable large choroidal vessels. Histopathologically, a loss of RPE, substantially reduced photoreceptors, and severely attenuated choriocapillaris are seen within the area of PPA.33–36 PPA has also been characterized as altered alignment of retinal layers (e.g., sensory retina, RPE, Bruch’s membrane, choroid, and sclera) at the disc margin,29,30 which could be attributed to age-related changes in the globe, such as elongation of the ocular axis and degenerative changes in the Bruch’s membrane–RPE complex. Others found an association between the area of PPA and age or myopic refraction.14,21 In the study we report here, there were considerable interindividual variations in PPA characteristics (Table 1) and, although some PPA characteristics were associated with elongation of the ocular axis or with age, some were not. For example, PPA width was not associated with age, and the extent of PPA around the circumference of the optic disc (crescent versus halo shape) was not associated with axial length (Table 2).

### Distance from Foveal Center to Temporal Margin of PPA-β

Our study showed that greater distance from the foveal center to the temporal margin of the area of PPA-β was associated with greater circumferential extent of PPA-β around the optic disc in highly myopic eyes, which suggests that the area of PPA-β enlarges both circumferentially and temporally (Fig. 2). Acquired “myopic crescents” have been generally believed to be due to progressive mechanical stretching of the globe,37 although little is known about how the optic disc changes during long-term progression of myopia. According to Flede-lius and Goldschmidt,38 the temporal margin of an area of PPA-β could shift farther temporally during progression of myopia.

In our cross-sectional study, the distance from the foveal center to the temporal margin of the area of PPA-β was quite short: in 6 of our 61 eyes (9.8%) the distance from the foveal center to the temporal margin of the area of PPA-β was <3 mm and in 31 of the 61 eyes (50.8%) it was <3.5 mm. The correlations in our study between age, distance from the foveal center to the temporal margin of the area of PPA-β, and circumferential extent of PPA-β (Table 2) suggest that aging contributes to circumferential and temporal extension of the area of PPA-β in highly myopic eyes.

Moreover, in eyes with peripapillary halo compared with eyes with peripapillary crescent, we found a significantly shorter distance from the foveal center to the temporal margin of the area of PPA-β and a wider area of PPA-β, but almost the same distance from the foveal center to the optic disc center (Table 3). The mean age of patients with peripapillary halos was older by >10 years than the mean age of patients with peripapillary crescent, but the difference in mean axial length between the two groups was only 0.2 mm (not statistically significant). This finding is consistent with a previous finding that mean axial length increases by 0.029 mm/yr (0.29 mm/10 y) in subjects similar to ours in age and with eyes of similar axial length.39 These findings leave open the possibility that there could be a temporal shift in the temporal margin of the area of PPA-β as the result of progression of RPE atrophy (which has been seen histologically in areas of PPA). It would be interesting to perform longitudinal studies to determine whether circumferential PPA-β enlargement is due to aging or axial elongation and to evaluate for concurrent progression of RPE atrophy.

### Distance from Foveal Center to Nasal Margin of PPA-β (Optic Disc Margin)

In our study, the distance from the foveal center to the nasal margin of the area of PPA-β (which corresponds to the optic disc margin) was greater in eyes with longer axis or more oval optic disc. To determine whether this finding reflects only shortening of the horizontal dimension of the optic disc stemming from disc tilting, we also evaluated the distance...
between the foveal center and the disc center. We found that this distance also correlated with longer axis or more oval optic disc (lower ovality index of the optic disc) and with distance from the foveal center to the nasal margin of the area of PPA-β. Because the disc-to-macula distance is believed to be fairly consistent among normal eyes, optic disc size can be estimated from the disc-to-macula distance on fundus photographs, which averaged 4.78 mm (4.69–4.86 mm) in one group of normal eyes with a mean refractive error of −0.9 ± 1.7 D. In another group of eyes with refractive errors between −9.0 and +6.0 D, disc-to-macula distance was 4.62 mm (4.22–5.04 mm) and was not correlated with refractive error.

In our group of highly myopic eyes, disc-to-macula distance was highly variable, ranging from 4.24 to 6.16 mm (average, 4.95 ± 0.40 mm) (Table 1). In addition, in almost half (44.3%) of our study eyes this distance was >5.0 mm, which is almost the reported maximum distance in less myopic eyes. Thus, although differences in measurement techniques may account for some variations in findings among these studies, the disc-to-macula distance appears to be associated with a more oval optic disc (ovality index of the optic disc <0.8).

Distance to Nasal versus Temporal Margin of PPA-β from Foveal Center

The distance from the foveal center to the nasal margin of the area of PPA-β (comparable to the disc-to-macula distance) and the distance from the foveal center to the temporal margin of the area of PPA-β had opposite correlations in our study with age, axial length, ovality index of the optic disc, and circumferential extent of the area of PPA-β (Fig. 3): whereas the disc-to-macula distance was correlated with axial length and ovality index of the optic disc but not with age and circumferential extent of PPA-β, distance from the foveal center to the nasal margin of the area of PPA-β was correlated with age and circumferential extent of PPA-β but not with axial length or ovality index of the optic disc. Additionally, when we compared measurements in eyes with round discs and eyes with oval discs, we found that the distance from the foveal center to the nasal margin of the area of PPA-β was longer in eyes with oval compared with round discs, whereas the distance from the foveal center to the temporal margin of the area of PPA-β was almost the same for the two groups (Table 4).

Axial length is known to increase, even during adulthood, in highly myopic eyes, and as myopia progresses, the ovality index of the optic disc decreases (i.e., the disc becomes more oval), concomitant with an increase in the width of the area of PPA-β and nasal shift of the optic disc. Furthermore, the angle between upper and lower retinal vessel trunks becomes more acute during axial elongation, which suggests a nasal shift of the optic disc. An SD-OCT study showed oblique widening of the neural canal, creating a mismatch between the scleral canal opening and the neural canal opening. This mismatch between the two openings visualized on SD-OCT is consistent with findings in histologic studies that in myopic eyes, Bruch’s membrane and the choriocapillaris are absent within the area of PPA. These findings, along with the correlation of disc-to-macula distance with axial length and with...
the ovality index of the optic disc as just discussed, indicate that one mechanism for PPA-β enlargement is nasal extension.

**PPA-β Width**

In our study, the width of the area of PPA-β on horizontal scans was significantly greater in eyes with PPA-β extending farther around the circumference of the optic disc, in eyes with lower ovality index of the optic disc (i.e., more oval optic disc), and in eyes with longer axial length. As just discussed, the temporal margin of the area of PPA-β was nearer to the fovea in eyes with PPA-β extending farther along the circumference of the optic disc, and the nasal margin of the area of PPA-β was farther from the fovea center in eyes with longer axial lengths and more oval optic discs (lower ovality index of the optic disc). Our results regarding the association of PPA-β width with axial length are consistent with the results of studies by Jonas and colleagues, which showed significant correlations of the area of PPA with refractive errors. We have not found previous studies of the relationship of PPA-β width with the ovality index of the optic disc or circumferential extent of PPA-β.

**Termination of IPL within PPA-β**

Several studies have examined PPA structure using SD-OCT. In the study reported by Lee et al., retinal layers, including the GCL, IPL, INL, and OPL, were reported to end in a tapering fashion within the area of PPA-β in normal eyes. In our study, we were able to pinpoint termination of the IPL within the PPA-β (Figs. 5 and 7) and measure the relative distance of this termination point from the temporal margin (assigned a value of “0”) to the nasal margin (assigned a value of “1”) of the area of PPA-β. On our SD-OCT images, the outer nuclear layer consistently ended close to the termination of the IPL.

**TABLE 3. Characteristics of Eyes with Halo versus Crescent PPA-β**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Eyes with Peripapillary Halo</th>
<th>Eyes with Peripapillary Crescent</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes (patients), n</td>
<td>14 (13)</td>
<td>47 (37)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>4 (4)</td>
<td>18 (15)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>10 (9)</td>
<td>29 (22)</td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>52.90 ± 14.20</td>
<td>42.60 ± 12.40</td>
<td>0.05</td>
</tr>
<tr>
<td>Axial length, mm</td>
<td>27.30 ± 1.50</td>
<td>27.10 ± 0.90</td>
<td>NS</td>
</tr>
<tr>
<td>Ovality index of optic disc</td>
<td>0.74 ± 0.15</td>
<td>0.81 ± 0.10</td>
<td>NS</td>
</tr>
<tr>
<td>Distance from foveal center to</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporal PPA-β margin, mm</td>
<td>3.12 ± 0.31</td>
<td>3.53 ± 0.33</td>
<td>.001</td>
</tr>
<tr>
<td>Nasal PPA-β margin, mm</td>
<td>4.20 ± 0.59</td>
<td>4.24 ± 0.39</td>
<td>NS</td>
</tr>
<tr>
<td>Optic disc center, mm</td>
<td>4.93 ± 0.51</td>
<td>4.96 ± 0.36</td>
<td>NS</td>
</tr>
<tr>
<td>PPA-β width, mm</td>
<td>1.08 ± 0.53</td>
<td>0.71 ± 0.33</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>IPL termination within PPA-β</td>
<td>0.68 ± 0.26</td>
<td>0.46 ± 0.19</td>
<td>&lt;.01</td>
</tr>
</tbody>
</table>

Measurements are expressed as mean ± 1SD from the mean. NS, not significant; IPL termination within PPA-β, relative distance from the temporal margin (“0”) to the nasal margin (“1”) of the area of PPA-β.

**TABLE 4. Characteristics of Eyes with Round versus Oval Optic Discs**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Eyes with Round Discs</th>
<th>Eyes with Oval Discs</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes (patients), n</td>
<td>32 (27)</td>
<td>29 (24)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>17 (15)</td>
<td>5 (5)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>15 (12)</td>
<td>24 (19)</td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>43.60 ± 13.90</td>
<td>46.50 ± 12.90</td>
<td>NS</td>
</tr>
<tr>
<td>Axial length, mm</td>
<td>27.00 ± 1.10</td>
<td>27.30 ± 1.10</td>
<td>NS</td>
</tr>
<tr>
<td>Circumferential extent of PPA-β, clock hours</td>
<td>6.94 ± 2.54</td>
<td>7.93 ± 2.63</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

Measurements are expressed as mean ± 1SD from the mean. NS, not significant; IPL termination within PPA-β, relative distance from the temporal margin (“0”) to the nasal margin (“1”) of the area of PPA-β.
RPE, whereas the terminus of the IPL varied within the area of PPA-β. The lack of correlation between termination of the RPE and termination of the IPL is probably explained by the fact that the RPE must be healthy for survival of photoreceptors, but survival of the photoreceptors does not depend on the health of inner retinal layers.

We also found in our study that the IPL terminated farther from the temporal margin of the area of PPA-β in eyes with PPA-β extending around a greater circumferential extent of the optic disc (Fig. 6). Thus the position of IPL termination within the area of PPA-β could be related to temporal expansion of the area PPA-β. This leads us to hypothesize that the area of PPA-β enlarges temporally as well as nasally, but by a different mechanism. RPE atrophy is the most likely mechanism for temporal expansion, whereas nasal shift of the optic disc is the most likely mechanism for nasal enlargement of the area of PPA-β.

In conclusion, our cSLO and SD-OCT examinations of the characteristics of PPA-β in highly myopic eyes show relationships among width of the PPA-β, position of the PPA-β, ovality index of the optic disc, circumferential extent of PPA-β, peripapillary halo versus peripapillary crescent, and round versus oval disc shape. Limitations of this study are its retrospective nature, relatively small population size, limitation to highly myopic eyes without myopic retinopathy, and lack of long-term follow-up. In addition, the distances measured in our study using cSLO and SD-OCT must be viewed with caution because they were calculated by built-in imaging software and were not actual measured distances over the curvature of the eye. Nevertheless, our study is the first to report measurements obtained by simultaneous cSLO and enhanced SD-OCT in eyes with high myopia and PPA-β, and we believe that these measurements and associations will enhance understanding of PPA-β in such eyes. We think it would be valuable to investigate how PPA-β changes over time, with axial elongation.

References


