Peripapillary Choroidal Thickness in Healthy Controls and Patients With Focal, Diffuse, and Sclerotic Glaucomatous Optic Disc Damage

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Objective: To examine peripapillary choroidal thickness in healthy controls and in patients with glaucoma who have focal, diffuse, and sclerotic optic disc damage.

Methods: Healthy controls (n=92) and patients with glaucoma who have focal (n=34), diffuse (n=35), and sclerotic (n=34) optic disc damage were imaged with spectral-domain optical coherence tomography (12° circular scan protocol centered on optic nerve head). Peripapillary choroidal thickness was measured as the distance between the automatically segmented retinal pigment epithelium/Bruch’s membrane and the manually outlined interface between the posterior choroid and the anterior border of the sclera in eyes in which the anterior scleral border was visible over more than 85% of the scan circumference.

Results: The anterior scleral border was visible in 76 controls (83%) and 89 patients (86%). Peripapillary choroidal thickness in healthy controls decreased linearly with age (−11 µm/decade; P < .001; r² = 0.16), with a predicted value of 137 µm at age 70 years (95% prediction interval, 62-212 µm). While this value was similar in patients with focal and diffuse optic disc damage (126 and 130 µm, respectively; P = .22 compared with controls), it was approximately 30% lower in patients with sclerotic optic disc damage (96 µm; P < .001 compared with controls).

Conclusions: The peripapillary choroid of patients with glaucoma who have sclerotic optic disc damage was approximately 25% to 30% thinner compared with that in patients with focal and diffuse optic disc damage and with that in healthy controls. The role of the choroid in the pathophysiology of sclerotic glaucomatous optic disc damage needs further investigation.


The choroid provides metabolic support to the prelaminar portion of the optic nerve head and may therefore play an important role in glaucoma. The development of spectral-domain optical coherence tomography (OCT) has recently improved the ability to visualize and measure the choroidal thickness in vivo, and several groups have previously reported subfoveal choroidal thickness measurements in healthy and diseased eyes. Because disturbed perfusion of the peripapillary choroid may play a role in the pathogenesis of glaucomatous optic neuropathy, peripapillary choroidal thickness (PCT) may be also be highly relevant in this disease.

Glaucomatous damage to the optic disc can manifest with different morphological patterns. In patients with focal optic disc damage, the neuroretinal rim has a localized notch inferiorly or superiorly, while the remaining tissue is relatively well preserved. In patients with diffuse damage, the cup is concentrically enlarged and there are no localized areas of neuroretinal rim loss or pallor. Patients with sclerotic damage have shallow cupping with marked areas of peripapillary atrophy. In patients with high myopia, progressive stretching of the posterior ocular tissues may contribute to a myopic type of glaucomatous disc damage characterized by a tilted appearance with shallow cupping and a myopic crescent of peripapillary atrophy. Groups of patients with distinct patterns of optic disc damage differ with respect to the incidence and severity of visual field and optic disc progression. They also have different demographic characteristics and risk factors. Morphological subtypes of glaucomatous optic disc damage may therefore help to differentiate more effectively within the wide clinical spectrum of open-angle glaucoma. In this article, we...
report PCT in patients with open-angle glaucoma who have focal, diffuse, and sclerotic types of optic disc damage compared with PCT in healthy controls.

METHODS

The data for this cross-sectional investigation were obtained from 2 ongoing studies at the Queen Elizabeth II Health Sciences Centre in Halifax, Nova Scotia, Canada. In accordance with the Declaration of Helsinki, the institutional research ethics board had approved the protocols, and all participants gave written informed consent.

PATIENTS

Data from patients with glaucoma were obtained from a prospective longitudinal study on progression with different types of optic disc damage. These patients were recruited from the glaucoma clinics. One of us (M.T.N.), masked to the patients’ identity and clinical information, selected consecutive participants based on optic disc stereo photographs. To be eligible for inclusion, at least 1 eye had to have focal, diffuse, or sclerotic optic disc damage. Other criteria included a diagnosis of open-angle glaucoma, including primary, pseudoexfoliative, or pigmentary glaucoma, best-corrected visual acuity equal to or better than 0.3 logMAR (20/40) in the study eye, refractive error within ±6.00 diopters (D) sphere and ±3.00 D astigmatism, and visual field damage (defined as Glaucoma Hemifield Test results outside normal limits or a mean deviation [MD] worse than −2.0 dB). Exclusion criteria were concomitant ocular disease, systemic medication known to affect the optic nerve and/or the visual field, and an MD worse than −20.0 dB. If both eyes were eligible, 1 eye was randomly chosen as the study eye.

CONTROLS

Healthy controls are being followed in another longitudinal study and had been recruited from patients’ relatives, church groups, and a local telephone company. They had normal eye examination findings, intraocular pressure lower than 21 mm Hg, best-corrected visual acuity equal to or better than 0.3 logMAR, refractive error within ±5.00 D sphere and ±3.00 D astigmatism, and normal visual fields (defined as Glaucoma Hemifield Test results within normal limits and an MD equal to or better than −2.0 dB). One eye was randomly selected as the study eye.

IMAGING

Subjects underwent imaging on a spectral-domain OCT system (Spectralis; Heidelberg Engineering) in high-resolution mode. The circular scans (12° diameter, corresponding to approximately 3.5 mm in a typical emmetropic eye) consisted of 1536 A-scans, and 16 images were averaged using automatic real-time image tracking.

Images were analyzed using Heidelberg Eye Explorer software (hraviewer version 5.3.2.0). First, files with the software-derived segmentations corresponding to the internal limiting membrane (upper segmentation line) and the retinal pigment epithelium/Bruch’s membrane (lower segmentation line) were exported. Subsequently, 1 observer masked to all clinical information (K.F.R.) manually edited the lower segmentation line such that it corresponded to the interface of the choroid and anterior sclera. Only that part of the circumference over which the anterior sclera was clearly visible was segmented. Where the anterior sclera was not clearly visible, the segmentation line was deleted. Three of us (P.H.A., A.S.R., M.T.N.) reviewed the segmentations and, if appropriate, made modifications by consensus. A second set of files was then exported, and PCT profiles were calculated from the difference between both sets of files.

ANALYSIS

Images were included in the analysis if the anterior border of the sclera was visible over more than 85% of the circumference. Multiple regression analyses were performed to estimate the relationships between PCT, age, and glaucoma. The severity of global visual field damage (ie, MD), thickness of the retinal nerve fiber layer, and axial length were evaluated as continuous covariates. All analyses were performed in the open-source environment R.

CONTROL AND PATIENT GROUPS

Data were available from 92 healthy controls and 103 patients with glaucoma. Of the latter, the disc damage was focal in 34 patients, diffuse in 35, and sclerotic in 34. For inclusion in the subsequent analyses, the anterior sclera had to be visible over more than 85% of the scan circumference, and images from 76 controls (83%) and 89 pa-
Patients (86%) met this criterion. There was no relationship between the proportion of visible sclera and OCT signal strength, age, or disease group (multiple regression, P > .10), and none of these variables was significantly different in patients who were excluded because of poor visibility of the anterior sclera (Friedman analysis of variance by ranks and χ² test, P > .10).

Relevant characteristics of the included subjects are given in Table 1. Patients were, on average, 15 years older than controls (P < .001) and had early to moderate visual field damage (median MD, −3.4 dB). Patients with focal optic disc damage had somewhat more advanced visual field damage than those with diffuse and sclerotic damage (median MD, −5.9 vs −3.4 and −2.3 dB, respectively; P < .01) and a lower global retinal nerve fiber layer thickness (median, 67 vs 75 and 71 µm, respectively; P < .05). Axial lengths were similar in the 4 groups of subjects (P = .41). Signal strength was highest in healthy controls followed by patients with focal, sclerotic, and diffuse loss (P < .001), although the differences were small.

The ethnic mix of patients and controls reflected the makeup of a Nova Scotian population; approximately 90% of participants were of Northern European ancestry.

### Table 1. Details of Healthy Controls and Patients With Glaucoma

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Controls (n = 76)</th>
<th>Focal (n = 33)</th>
<th>Diffuse (n = 27)</th>
<th>Sclerotic (n = 29)</th>
<th>All (n = 89)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>56.1 (44 to 65)</td>
<td>71.1 (60 to 79)</td>
<td>65.6 (54 to 76)</td>
<td>74.7 (68 to 79)</td>
<td>71.1 (61 to 79)</td>
</tr>
<tr>
<td>MD, dB</td>
<td>+0.57 (−0.14 to +1.15)</td>
<td>−5.5 (−10.7 to −3.2)</td>
<td>−3.4 (−4.5 to −2.2)</td>
<td>−2.3 (−5.2 to −1.7)</td>
<td>−3.4 (−6.5 to −2.1)</td>
</tr>
<tr>
<td>RNFL thickness, µm</td>
<td>98 (91 to 103)</td>
<td>67 (60 to 71)</td>
<td>75 (68 to 89)</td>
<td>71 (68 to 84)</td>
<td>71 (65 to 82)</td>
</tr>
<tr>
<td>Axial length, mm</td>
<td>23.8 (23.1 to 24.6)</td>
<td>24.0 (23.5 to 25.0)</td>
<td>23.8 (23.4 to 24.3)</td>
<td>23.9 (23.6 to 24.7)</td>
<td>23.9 (23.5 to 24.7)</td>
</tr>
<tr>
<td>IOP, mm Hg</td>
<td>17.2 (12.8 to 17.5)</td>
<td>15.0 (12.0 to 16.8)</td>
<td>15.4 (13.8 to 17.9)</td>
<td>15.1 (12.0 to 18.0)</td>
<td>14.8 (11.7 to 17.7)</td>
</tr>
</tbody>
</table>

### Table 2. Peripapillary Choroidal Thickness in Healthy Controls and Patients With Glaucoma

<table>
<thead>
<tr>
<th>PCT</th>
<th>Controls (n = 76)</th>
<th>Focal (n = 33)</th>
<th>Diffuse (n = 27)</th>
<th>Sclerotic (n = 29)</th>
<th>All (n = 89)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean (SD), µm</td>
<td>154 (40)</td>
<td>126 (44)</td>
<td>135 (57)</td>
<td>92 (30)</td>
<td>118 (48)</td>
</tr>
<tr>
<td>Median (IQR), µm</td>
<td>148 (130-180)</td>
<td>110 (94-154)</td>
<td>125 (100-147)</td>
<td>84 (70-107)</td>
<td>105 (88-141)</td>
</tr>
</tbody>
</table>

**GLOBAL PCT IN PATIENTS AND CONTROLS**

Summary statistics for PCT in controls and patients with glaucoma are shown in Table 2. In healthy controls, PCT declined with age at a rate of −11 µm/decade (95% CI, −5 to −17 µm/decade; P < .001) (Figure 2). Age explained approximately 20% of the nearly 4-fold variation in PCT between healthy individuals (r² = 0.16). The predicted mean PCT for a hypothetical 70-year-old healthy subject was 137 µm, with a 95% prediction interval of 62 to 212 µm. There were no significant differences between men and women (P = .24).

The age-related decrease of PCT appeared similar in patients with glaucoma (P = .59), but their PCT was thinner than that of healthy controls (−18 µm; 95% CI, −32 to −3 µm; P = .02) (Figure 2). The PCT predicted for a 70-year-old patient with glaucoma was 117 µm, with a 95% prediction interval of 27 to 208 µm.
In a multivariate analysis with age, glaucoma, and axial length as predictors, PCT decreased by 10 µm for each 1.0-mm increase in axial length (95% CI, −1 to −19 µm; \( P = .04 \)). Axial length explained 8% of the variance in the combined model. There was no statistical relationship between PCT and either MD or retinal nerve fiber layer thickness when these variables were added to the model (\( P = .85 \) and \( .33 \), respectively).

**PCT IN PATIENTS WITH FOCAL, DIFFUSE, AND SCLEROTIC OPTIC DISC DAMAGE**

Patients with sclerotic optic disc damage had the lowest PCT (difference compared with controls, −41 µm; 95% CI, −59 to −23 µm; \( P < .001 \)), followed by patients with focal disc damage (−13 µm; 95% CI, −31 to +5 µm; \( P = .22 \)) and diffuse disc damage (−5 µm; 95% CI, −25 to +14 µm; \( P = .62 \)) (Figure 3). The mean PCTs predicted for a hypothetical 70-year-old patient with focal, diffuse, and sclerotic disc damage were 126, 130, and 96 µm, respectively.

**PERIPAPILLARY VARIATION IN CHOROIDAL THICKNESS**

On average, the PCT tended to be greater superiorly and nasally and smaller inferiorly and temporally (Figure 4). The variation in choroidal thickness around the optic nerve head was moderate; the median ratios between the smallest and largest values were 0.55 in controls and 0.44, 0.46, and 0.36 in patients with focal, diffuse, and sclerotic optic disc damage, respectively. These differences were statistically significant (Kruskal-Wallis test, \( P < .001 \)).

**EXAMPLES**

The examples in Figure 5, Figure 6, and Figure 7 illustrate typical cases of focal, diffuse, and sclerotic disc damage. The OCT images show the software-derived segmentation of the internal limiting membrane and Bruch’s membrane as well as the manual segmentation of the anterior scleral border. The location of the scanning circle is shown in the infrared scanning laser ophthalmoscopic images, and the optic disc is shown in color photographs. The grayscales show the corresponding visual field damage.

**COMMENT**

The aim of this study was to investigate the thickness of the choroid around the optic nerve head in healthy controls and patients with 3 morphological types of glaucomatous optic disc damage. Most previous investigators have reported choroidal thickness measurements obtained from line or volume scans centered on the fovea.\(^9\)\(^{12},14\) However, given the role of the choroidal vasculature in the blood supply of the anterior optic nerve head, the peripapillary choroid may be a relevant target for investigation in patients with glaucoma.\(^{17}\)

Although differences in scan location, equipment, imaging parameters, and measurement procedures make it problematic to compare the thickness estimates with those from previous reports, the values estimated in our material compare closely to those reported by other groups. The most temporal part of the scan circle in our study was approximately 2.55 mm (median; interquartile range, 2.43-2.72 mm) nasal from the fovea. At a similar retinal locus, 2.50 mm nasal from the fovea, Margolis and Spaide\(^{14} \) reported a choroidal thickness of 170 µm from a group of 30 healthy subjects with an average age of 50 years, while Manjunath et al\(^{13} \) obtained a mean thickness of 157 µm in 34 healthy controls with a mean age of 51 years. Both of these estimates are close to our value of approximately 160 µm obtained by interpolating to an age of 50 years in our
data from healthy controls (Figure 2). In subjects of similar age to ours, Mwanza et al.\textsuperscript{26} reported mean choroidal thickness of 170 and 174 µm in controls and patients with glaucoma, respectively, at a location 3.0

Figure 5. Example of a patient with focal optic disc damage in the left eye. The mean peripapillary choroidal thickness was 155 µm. The retinal nerve fiber layer was thin (mean, 62 µm) with complete absence inferior-temporally. A, An optical coherence tomographic image shows the software-derived segmentation of the internal limiting membrane (dashed white line) and Bruch’s membrane (dashed blue line) as well as the manual segmentation of the anterior scleral border (blue dots). B, A scanning laser ophthalmoscopic image shows the location of the scanning circle. I indicates inferior; N, nasal; S, superior; and T, temporal. C, A color photograph shows the optic disc, which is notched inferiorly with a hemorrhage at the 6-o’clock position. D, The visual field shows extensive damage of the superior hemifield (mean deviation, −10.4 dB).

Figure 6. Example of a patient with diffuse optic disc damage in the left eye. The mean peripapillary choroidal thickness was 104 µm, and the mean retinal nerve fiber layer thickness was 77 µm. A, An optical coherence tomographic image shows the software-derived segmentation of the internal limiting membrane (dashed white line) and Bruch’s membrane (dashed blue line) as well as the manual segmentation of the anterior scleral border (blue dots). B, A scanning laser ophthalmoscopic image shows the location of the scanning circle. I indicates inferior; N, nasal; S, superior; and T, temporal. C, A color photograph shows deep concentric cupping of the optic disc. D, The visual field shows mainly diffuse damage with a mean deviation of −5.9 dB.
mm nasal from the fovea. All of these estimates are somewhat lower than those of Ikuno et al,27 who reported a mean of 227 µm from a group of 43 Japanese subjects (mean age, 39 years). In addition, the cross-sectional estimate of age-related choroidal thinning in our data (11 µm/decade; 95% CI, 5-17 µm) is similar to the rate of 16 µm/decade reported for subfoveal choroidal thickness measurements by Margolis and Spaide14 and to the rates of 13 and 16 µm/decade in controls and patients with glaucoma, respectively, reported by Mwanza et al.26 Also, the inverse relationship between PCT and axial length in our study (−10 µm/mm of axial length) was close to that estimated by the latter group (−12 µm/mm).

Our data show that PCT in patients with glaucoma who have sclerotic optic disc damage was approximately 40 µm lower than age-corrected normal values. In contrast, no significant differences compared with controls were seen in patients with focal or diffuse optic disc damage. Given that the age-related rate of choroidal thinning estimated from cross-sectional data is only approximately 10 to 20 µm/decade, the reduction of 25% to 30% seen in patients with sclerotic optic disc damage is substantial and adds to the evidence that there may be a connection between choroidal atrophy and glaucomatous optic disc damage of the sclerotic type.9,28

In patients with sclerotic optic disc damage, large choroidal vessels are often clearly visible ophthalmoscopically, suggesting a loss of choriocapillaris, smaller and medium-sized vessels, and pigmentary cells.21,29 This appearance has been described as choroidal sclerosis and has been linked to age-related atrophy of the choroidal circulation.9,30 In comparison with patients with other glaucomatous optic disc appearances, those with sclerotic disc damage have an increased resistance index as measured with color Doppler imaging in the ophthalmic artery, central retinal artery, and short posterior ciliary arteries31 as well as reduced pulsatile ocular blood flow.32 Sclerotic optic disc damage is associated with cardiovascular conditions, particularly systemic hypertension and ischemic heart disease,18,19 suggesting that small-vessel disease might be involved in the pathogenesis of this particular type of disc damage.

Mwanza et al26 did not identify a difference in choroidal thickness between patients with glaucoma and healthy controls. Similarly, Maul et al17 did not find differences in PCT between patients with established glaucoma and those with suspected glaucoma, even though choroidal thickness at the macula tended to be lower in those with established damage. One possible explanation for this discrepancy is that their samples may have included fewer patients with sclerotic optic disc damage compared with our study. The lower PCT in our patient group was almost entirely caused by the substantial reduction in patients with sclerotic disc damage; in patients with focal or diffuse optic disc damage, the differences from controls were small and not statistically significant.

The anterior boundary of the sclera was well visible in most subjects, but approximately 15% of subjects were excluded from the analysis because the boundary could not be distinguished with confidence. Because a thicker choroid may cause the anterior sclera to be less visible, it is possible that our averages underestimate the true val-
ues. However, the proportions of visible anterior sclera in the 4 groups of subjects were not markedly different and are therefore unlikely to have affected our findings. There is evidence that the recently developed technique of enhanced depth imaging can improve the visibility of more posterior tissues. Also, OCT systems with longer wavelengths (eg, 1080 nm) and better tissue penetration are being developed. These developments may further enhance the visibility of the choroidal layers and improve the feasibility of in vivo measurements.

Patients with myopic optic disc damage had not been included in the original study on progression with different disc types from which the current material was drawn, and we therefore cannot comment on choroidal thickness in these patients. The relationship between myopia (and myopic-type glaucomatous disc damage) and choroidal thickness may be a particularly interesting topic for future research.

In summary, our study identified a substantial reduction in PCT in patients with glaucoma who have sclerotic optic disc damage. This adds to the evidence that morphological patterns of optic disc damage may help to distinguish clinically meaningful subtypes of glaucoma within the diverse spectrum of the disease. Observations of patients over time are needed to investigate whether the reduced PCT observed in patients with sclerotic optic disc damage is part of the cause, or part of the consequence, of the glaucomatous disease process.

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