Association Between Scanning Laser Polarimetry Measurements Using Variable Corneal Polarization Compensation and Visual Field Sensitivity in Glaucomatous Eyes

Christopher Bowd, PhD; Linda M. Zangwill, PhD; Robert N. Weinreb, MD

Objective: To compare the association between scanning laser polarimetry (SLP) retinal nerve fiber layer (RNFL) measurements and automated perimetry sensitivity using both SLP manufacturer-assumed fixed and subject-specific variable corneal polarization magnitude and corneal polarization axis values.

Methods: An SLP was modified to enable the measurement of corneal polarization magnitude and corneal polarization axis so that compensation for corneal birefringence could be corrected on a subject-specific variable basis. Seventy-three eyes from the University of California, San Diego, Diagnostic Innovations in Glaucoma Study with early glaucoma or suspected glaucoma (abnormal Swedish Interactive Threshold Algorithm [SITA] or full-threshold automated perimetry results and/or glaucoma-appearing optic disc by consensus grading of stereoscopic optic disc photographs) (mean [SD] SITA mean deviation, −2.74 [3.71] dB; range, 1.72 to −14.72 dB) were included. Subjects were imaged with SLP using the manufacturer-assumed fixed corneal compensation values and subject-specific variable corneal compensation values and tested with SITA automated perimetry. Scanning laser polarimetry and SITA data were obtained within 3 months of each other.

Main Outcome Measures: The relationship between regional SLP RNFL measurements (24 parameters) and corresponding regional SITA raw thresholds were evaluated using linear regression for both (fixed corneal compensation and variable corneal compensation) SLP configurations.

Results: No fixed corneal compensation SLP measurements were significantly associated with corresponding SITA visual field zone sensitivities after corrections for multiple comparisons. Seven variable corneal compensation RNFL parameters (superior, inferior, or mean RNFL thickness measurements) were significantly associated with their corresponding visual field zones with $R^2$ values ranging from 0.13 (ellipse average) to 0.20 (superior average).

Conclusion: Variable corneal compensation to correct for subject-specific corneal polarization magnitude and corneal polarization axis improves the relationship between SLP-measured RNFL thickness and visual function measured by SITA perimetry.

Arch Ophthalmol. 2003;121:961-966

Recently, optical imaging technologies have been developed that can provide quantitative information on retinal topography, and the relationship between measurements obtained using these instruments and visual function measured using automated perimetry has been investigated. One recent optical imaging technology, scanning laser polarimetry (SLP), indirectly measures retinal nerve fiber layer (RNFL) thickness by calculating the retardation of light reflected from the birefringent microtubules that support retinal ganglion cell axons and expressing this retardation in micrometers of thickness based on the relationship between retardation and histologically determined RNFL thickness in monkey eyes.1,2 The results from studies investigating the association between SLP measurements and full-threshold automated perimetry indexes show weak to moderate correlations.3-10

Part of the reason for weak correlations between SLP measurements and perimetry results may be the reliance of the commercially available SLP on a fixed compensator to minimize the effect of corneal birefringence on measurements of RNFL birefringence. To compensate for other sources of birefringence in the eye (the cornea, the lens, and the macular Henle fiber layer also are birefringent), the commercially available SLP (GDx Nerve Fiber Analyzer; Laser Diagnostic Technologies Inc, San Diego, Calif) uses a fixed compensator that assumes that all indi-
individuals have a slow axis of corneal birefringence 15° nasally downward with a magnitude of 60 nm. Recently it has become apparent that a wide variation of the corneal polarization axis (CPA) and corneal polarization magnitude (CPM) in healthy and glaucomatous eyes exists, suggesting that SLP measurements in a subset of the population are not properly compensated for corneal birefringence contributions.11-13 Weinreb et al14 recently showed that the incorporation of a variable corneal retardation compensator that allows compensation for each individual eye improved the ability of SLP RNFL thickness parameters to discriminate between eyes with glaucomatous standard perimetry results and healthy eyes (see also Greenfield et al15 and Garway-Heath et al16).

In this study we investigated the association between SLP-measured RNFL thickness and visual sensitivity (measured with automated perimetry using the Swedish Interactive Threshold Algorithm [SITA]) using both the fixed corneal compensator (FCC) SLP and the variable corneal compensator (VCC) SLP.37 We suspected that SLP–visual function relationships may be underestimated due, in part, to the inclusion of inaccurate measurements from subjects improperly compensated for corneal polarization artifacts by the FCC SLP. Therefore, we hypothesized that these relationships would improve using VCC compared with FCC because inaccurate measurements from subjects improperly compensated by the FCC were corrected using subject-specific VCC.

METHODS

SUBJECTS

Scanning laser polarimetry data from a total of 73 subjects from the University of California, San Diego, Diagnostic Innovations in Glaucoma Study with glaucomatous-appearing optic discs, glaucomatous visual field defects, or both, were evaluated at the Hamilton Glaucoma Center, Department of Ophthalmology, University of California, San Diego. One eye per subject was included by random selection. Thirty-two of the 73 subjects were men and 41 were women. Sixty-five subjects were white, 3 were Hispanic, 3 were of African descent, and 2 were self-reported as unknown. The mean (SD) age of the subjects was 67.0 (10.1) years (age range, 43.2-86.0 years).

Eyes were included if they had a glaucomatous-appearing optic disc defined as the presence of rim thinning, excavation, RNFL defects, or interocular cup-disc asymmetry greater than 0.2 (in which case the eye with the larger cup-disc asymmetry was studied) at the time of the study, or if they had at least one abnormal visual field result on SITA or full-threshold standard automated perimetry (defined as a corrected pattern SD outside of the 95% normal limits or a glaucoma hemifield test outside of the 99% normal limits) at the time of, or prior to, the SLP imaging date. The mean SITA mean deviation for the 73 eyes included was −2.74 dB (median, −1.94 dB; SD, 3.71 dB; SE, 0.43 dB; upper 95% mean, −1.87 dB; lower mean, −3.60 dB; and range, 1.72 to −14.72 dB), indicating early to moderate glaucoma. The mean SITA pattern SD was 3.81 dB (median, 2.28 dB; SD, 3.06 dB; SE, 0.36 dB; upper 95% mean, 4.52 dB; lower 95% mean, 3.10 dB; and range, 1.13-13.10 dB).

Prior to testing, all subjects underwent a complete ophthalmologic examination including slitlamp biomicroscopy, intraocular pressure measurement, dilated stereoscopic fundus examination, and stereoscopic photography of the optic disc. Only eyes with a visual acuity of 20/40 or better were included, and refractive error ranged from −7.0 to 5.25 diopters (D) (mean [SD], −0.79 [2.48] D). Eyes with coexisting retinal disease, uveitis, or nonglaucomatous optic neuropathy were excluded from this investigation. All participants had had experience with visual field testing using both full-threshold and SITA test strategies. The mean (SD) number of prior visual field tests performed was 11 (6.07) (range, 2-24). Ninety percent of the participants had 3 or more visual field tests prior to the test used for analysis in the current study. Scanning laser polarimetry imaging and SITA perimetry tests were conducted within 91 days of each other (mean [SD] days between tests, 17 [23.0] days; range, 0-91 days); 30% of the subjects had both tests within 7 days. Informed consent was obtained from all participants and all methods were approved by the University of California, San Diego, Human Subjects Committee and adhered to the Declaration of Helsinki for research involving human subjects.

MEASUREMENTS

Polarimetry images were obtained using a commercially available SLP (modified GDx; Laser Diagnostic Technologies Inc) that was modified so that the original fixed corneal compensator was replaced with a custom VCC as described by Zhou and Weinreb15 and Weinreb et al16. Briefly, the VCC SLP incorporates 2 adjustable linear retarders in the path of the measurement beam that, when adjusted, can compensate for the retardation of the cornea and lens. To determine eye-specific CPM and CPA, the compensating retarders were adjusted to 0 nm and the macula was imaged. The resulting retardation profile represented the additive effects of cornea, lens, and macular Henle fiber birefringence. The compensating retarders were then adjusted to minimize the effects of cornea and lens birefringence, thus providing a macular retardation profile with uniform low retardation. For each subject, the macula was imaged 3 times and the average CPM and CPA values from the 3 macular scans that resulted in adequate compensation were recorded. Nasally upward CPA values (degrees) were recorded as negative; nasally downward CPA values were recorded as positive. The macula was then imaged again using the subject-specific mean CPM and mean CPA values to assure that compensation was effective.

Next, 3 SLP images from each eye were obtained using both the FCC CPM and CPA values (60 nm and 15°, respectively) and the appropriate eye-specific VCC CPM and CPA values. The 3 images obtained using each technique were combined using standard software to create composite mean images used for analysis (1 mean image using FCC CPM and CPA values and 1 mean image using eye-specific VCC CPM and CPA values for each eye). The optic disc margin was outlined on each mean image by a trained technician for calculation of ellipse parameters. In 5 eyes the measurement ellipse, in its standard position 1.75 times the disc diameter, fell on areas of parapapillary atrophy. In these cases, the size of the measurement ellipse was increased up to 20% (horizontally or vertically) so that the measurement ellipse was clear of areas of atrophy.

We examined 20 parameters automatically provided by SLP software (GDx Version 2.0.01; Laser Diagnostic Technologies Inc). These parameters could be divided into raw thickness parameters (defined relative to the relationship between RNFL thickness and retardation) and ratio parameters (defined as ratios of regional measurements). Thickness parameters were as follows: superior maximum, temporal maximum, inferior maximum, nasal maximum, average thickness, total polar integral, superior integral, temporal integral, inferior integral, nasal integral, ellipse average, superior average, temporal average, inferior average, and nasal ratio. Parameter ratios were as fol-
lows: superior nasal, superior ratio (superior temporal), inferior ratio (inferior temporal), ellipse modulation, and maximum modulation. All of these parameters have been described in detail elsewhere.18

We also took the average RNFL thickness measures in 4 sectors measured at 1.7 times the diameter of the optic disc (approximate position of the SLP measurement ellipse) to correlate them specifically with visual field zones similar to those defined by Garway-Heath et al.19 These sectors were from 31° to 90° (called “superior temporal thickness”), from 91° to 120° (called “superior thickness”), from 241° to 270° (called “inferior thickness”), and from 271° to 330° (called “inferior temporal thickness”). The 4 RNFL sectors we used only approximate the optic nerve head divisions described by Garway-Heath et al19 because their mapping was defined at the scleral ring and our RNFL thickness measures were obtained at about 1.7 times the disc diameter in the parapapillary retina. Because the superior and inferior arcuate nerve fiber bundles veer temporally after leaving the optic disc, our superior temporal and inferior temporal sectors extend more temporally than those of Garway-Heath et al.

To investigate the relationship between SLP parameter measurements and SITA sensitivity using FCC and VCC SLP, we divided the visual field into 6 zones18 (Figure). Zone 1 (nasal visual field) corresponded to the temporal parapapillary retina. Zones 2 and 3 (superior nasal visual field and superior visual field, respectively) corresponded to the infero temporal and inferior parapapillary retinas, respectively. Zone 4 (temporal visual field) corresponded to the nasal parapapillary retina, and zones 5 and 6 (inferior visual field and inferior nasal visual field, respectively) corresponded to the superior and temporal parapapillary retinas, respectively.

We then correlated SLP measurements with the average raw SITA sensitivities in the appropriate visual field zones using linear regression based on the assumption that RNFL thickness is a predictor of visual sensitivity. Because the relationship between RNFL thickness and visual sensitivity might not be linear, we also fitted second-order polynomial curves to the distributions. Scanning laser polarimetry RNFL parameters and their corresponding visual field zones are given in the Table. For SLP modulation parameters (ellipse modulation and maximum modulation), measurements were compared with visual field hemifield asymmetry (superior sensitivity minus inferior sensitivity). For ratio parameters, measurements were compared with visual field regional sensitivity ratios (eg, sensitivity in the superior visual field zone divided by sensitivity in the nasal visual field zone).

The SITA perimetry was performed using the Humphrey Field Analyzer II 24-2 program (Carl Zeiss Meditec Inc, Dublin, Calif). Age-corrected SITA sensitivities were not used because SLP was not corrected for age. All SITAs were reliable with less than 33% fixation losses, false-positive responses, and false-negative responses.

**RESULTS**

The Table summarizes the relationships (R²) between SLP measurements, using both FCC and VCC, and SITA raw thresholds in corresponding visual field zones. For FCC SLP, one RNFL parameter was associated with SITA sensitivity at its corresponding visual field zones at the α level of .05 (inferior thickness) (R²=.007, P=.02). When compared with corresponding SLP visual field zones, only 4 FCC SLP parameters yielded R² values of 0.05 (an arbitrary descriptive cutoff) (inferior thickness, R²=.07; inferior ratio, inferior integral, and inferior average, all R²=.05).

For VCC SLP, 15 RNFL parameters were associated with the corresponding regional SITA sensitivity at the α level of .05. Of these, 7 were significantly associated at the level α of .002 (Bonferroni adjustment) (superior maximum, superior integral, inferior integral, ellipse average, superior average, inferior average, and inferior thickness). The R² values describing the relationships between these parameters and their corresponding visual field zones ranged from 0.13 (ellipse average) to 0.20 (superior average). Overall, 16 of 24 VCC SLP parameters yielded R² values of 0.05. Slopes of all regression lines with P≤.30 were positive.

When we fit second-order polynomial curves to the FCC and VCC RNFL thickness vs SITA sensitivity distributions, there was no apparent improvement in fit in R² values for 19 of 24 FCC parameters (mean [SD] change in R² for 19 of 24 FCC parameters, +0.001 [0.01]; range, 0-0.03) and 24 of 24 VCC parameters (mean [SD] change in R² for 24 of 24 VCC parameters, +0.015 [0.01]; range, 0-0.05). The 5 parameters that showed improvement with polynomial curve fitting using FCC SLP configuration were superior maximum thickness, superior integral, superior average thickness, superior thickness, and superior temporal thickness. For these 5 parameters, the R² between RNFL thickness and corresponding regional SITA sensitivities increased from R²=0.008 to R² greater than 0.16. Inspection of these data revealed that unusually high superior hemiretina measurements in a single eye, likely attributable to inappropriate corneal compensation by the FCC, resulted in the improved R² results. These unusual thickness measurements resulted in a U-shaped relationship between these FCC parameters and SITA sensitivity that is not theoretically plausible. When this eye was removed from the analysis, no improvements were observed; therefore, these data are not shown (mean [SD] change in R² for 24 of 24 FCC parameters, +0.008 [0.011]; range, 0-0.04).

In a previous study, Weinreb et al13 showed that age was more strongly linearly associated with VCC parameters than FCC parameters. We, therefore, included sub-
Association Between FCC SLP and VCC SLP RNFL Parameters and Visual Field Sensitivity Measured Using SITA Standard Perimetry

<table>
<thead>
<tr>
<th>SLP Parameter</th>
<th>Visual Field Zone(s)</th>
<th>FCC R²</th>
<th>FCC P Value</th>
<th>VCC R²</th>
<th>VCC P Value</th>
<th>VCC R² With Age</th>
<th>VCC Parameter P Value in Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior maximum</td>
<td>Mean 5, 6</td>
<td>0.008</td>
<td>.44</td>
<td>0.15</td>
<td>&lt;.001†</td>
<td>0.17</td>
<td>.001†</td>
</tr>
<tr>
<td>Temporal maximum</td>
<td>1</td>
<td>0.003</td>
<td>.66</td>
<td>0.05</td>
<td>.07</td>
<td>.18</td>
<td>.001†</td>
</tr>
<tr>
<td>Inferior maximum</td>
<td>Mean 2, 3</td>
<td>0.03</td>
<td>.12</td>
<td>0.06</td>
<td>.05‡</td>
<td>0.14</td>
<td>.005‡</td>
</tr>
<tr>
<td>Nasal maximum</td>
<td>4</td>
<td>&lt;.001</td>
<td>.85</td>
<td>0.004</td>
<td>.59</td>
<td>0.25</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Average thickness</td>
<td>Mean 1-6</td>
<td>0.002</td>
<td>.70</td>
<td>0.04</td>
<td>.10</td>
<td>.18</td>
<td>.001†</td>
</tr>
<tr>
<td>Total polar integral</td>
<td>Mean 1-6</td>
<td>0.007</td>
<td>.49</td>
<td>0.11</td>
<td>.004‡</td>
<td>0.22</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Superior integral</td>
<td>Mean 5, 6</td>
<td>&lt;.001</td>
<td>.85</td>
<td>0.15</td>
<td>&lt;.001‡</td>
<td>0.17</td>
<td>.001†</td>
</tr>
<tr>
<td>Temporal integral</td>
<td>1</td>
<td>0.003</td>
<td>.64</td>
<td>0.03</td>
<td>.18</td>
<td>0.16</td>
<td>.002‡</td>
</tr>
<tr>
<td>Inferior integral</td>
<td>Mean 2, 3</td>
<td>0.05</td>
<td>.07</td>
<td>0.14</td>
<td>.001†</td>
<td>0.19</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Nasal integral</td>
<td>4</td>
<td>0.007</td>
<td>.47</td>
<td>0.02</td>
<td>.21</td>
<td>.26</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Ellipse average</td>
<td>Mean 1-6</td>
<td>0.009</td>
<td>.43</td>
<td>0.13</td>
<td>.002‡</td>
<td>0.22</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Superior average</td>
<td>Mean 5, 6</td>
<td>&lt;.001</td>
<td>.91</td>
<td>0.20</td>
<td>&lt;.001‡</td>
<td>0.21</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Temporal average</td>
<td>1</td>
<td>0.002</td>
<td>.69</td>
<td>0.03</td>
<td>.14</td>
<td>.17</td>
<td>.001†</td>
</tr>
<tr>
<td>Inferior average</td>
<td>Mean 2, 3</td>
<td>0.05</td>
<td>.05</td>
<td>0.15</td>
<td>&lt;.001‡</td>
<td>0.19</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Nasal average</td>
<td>4</td>
<td>0.001</td>
<td>.78</td>
<td>0.04</td>
<td>.08</td>
<td>0.28</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Superior thickness</td>
<td>5</td>
<td>0.008</td>
<td>.46</td>
<td>0.12</td>
<td>.003‡</td>
<td>0.15</td>
<td>.004‡</td>
</tr>
<tr>
<td>Superior temporal thickness</td>
<td>6</td>
<td>0.01</td>
<td>.35</td>
<td>0.11</td>
<td>.004‡</td>
<td>0.14</td>
<td>.005‡</td>
</tr>
<tr>
<td>Inferior thickness</td>
<td>3</td>
<td>0.07</td>
<td>.02‡</td>
<td>.17</td>
<td>&lt;.001‡</td>
<td>0.20</td>
<td>&lt;.001†</td>
</tr>
<tr>
<td>Inferior temporal thickness</td>
<td>2</td>
<td>0.04</td>
<td>.08</td>
<td>0.07</td>
<td>.03‡</td>
<td>0.13</td>
<td>.007‡</td>
</tr>
<tr>
<td>Ratio parameters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Superior nasal</td>
<td>Mean 5, 6 + 4</td>
<td>0.03</td>
<td>.13</td>
<td>0.04</td>
<td>.07</td>
<td>0.08</td>
<td>.044‡</td>
</tr>
<tr>
<td>Superior ratio</td>
<td>Mean 5, 6 + 1</td>
<td>0.002</td>
<td>.69</td>
<td>0.001</td>
<td>.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inferior ratio</td>
<td>Mean 2, 3 + 1</td>
<td>0.05</td>
<td>.07</td>
<td>0.06</td>
<td>.04‡</td>
<td>0.07</td>
<td>.067</td>
</tr>
<tr>
<td>Ellipse modulation</td>
<td>Mean 5, 6-mean 2, 3</td>
<td>&lt;.001</td>
<td>.87</td>
<td>0.05</td>
<td>.049‡</td>
<td>0.06</td>
<td>.100</td>
</tr>
<tr>
<td>Maximum modulation</td>
<td>Mean 5, 6-mean 2, 3</td>
<td>0.008</td>
<td>.44</td>
<td>0.09</td>
<td>.009‡</td>
<td>0.10</td>
<td>.028‡</td>
</tr>
</tbody>
</table>

Abbreviations: FCC, fixed corneal compensation; RNFL, retinal nerve fiber layer; SITA, Swedish Interactive Threshold Algorithm; SLP, scanning laser polarimetry; VCC, variable corneal compensation.

*Zone 1 corresponds with temporal parapapillar SLP measurements; zone 2, interior temporal SLP measurements; zone 3, inferior SLP measurements; zone 4, nasal SLP measurements; zone 5, superior SLP measurements; and zone 6, superior temporal SLP measurements.
† P<.002 (a = .002 is the nominal P value for significant differences using the Bonferroni adjustment).
‡ P<.05 if P=.002.

In our population, using SLP with eye-specific variable corneal compensation increased the number of RNFL measures that were associated with visual field sensitivity compared with using SLP with fixed corneal compensation. The strength of the associations also increased. Using FCC SLP, only 1 parameter was associated with SITA-measured visual sensitivity with P = .05. When VCC SLP was used, some inferior, superior, and average thickness parameters were associated with visual sensitivity at both P = .05 and P = .002 (α-adjusted for multiple comparisons). Only 1 VCC-measured ratio parameter was associated with regional SITA measurements (inferior ratio, R² = .06, P = .04). The number of VCC parameters that were significantly associated with visual sensitivity decreased when age was included with them in a multiple regression model. However, the number of parameters with relatively small P values for association with visual sensitivity remained far greater using VCC compared with FCC (9 parameters with P = .05 including 1 parameter with P < .002).

The strengths of our reported structure-function associations (range for VCC thickness parameters without age: R² = .004 for nasal maximum to R² = .20 for superior average) were not higher than those previously reported in studies investigating FCC SLP and perimetry correlations. However, using VCC improved the structure-function relationship compared with using FCC, suggesting that SLP measurements using VCC are more representative of visual sensitivity than SLP measurements using FCC. Our moderate structure-function associations using VCC SLP were comparable to those reported in other studies using FCC SLP. This is likely because of the differences in study populations, methods, and glaucoma severity between studies. Kwon et al have suggested that the association between RNFL thickness measurements (measured using FCC SLP) becomes stronger as RNFL damage increases. The mean (SD)
SITA mean deviation of our patients (−2.7 [3.7] dB) suggests early to moderate glaucoma and may explain our relatively small effects. In addition, differences between our results and those of others may be partially attributable to our use of SITA instead of full-threshold automated perimetry, because the former method of testing has some characteristics different from the latter.

Using FCC SLP, we showed weak associations between RNFL measurements and visual sensitivity (all $R^2\leq0.07$). Bagga et al\textsuperscript{20} showed similarly weak associations between full-threshold automated perimetry mean deviation and FCC measurement for some parameters (eg, $R^2<0.09$ for symmetry, average thickness, and superior integral), although these associations were stronger for other parameters (eg, $R^2=0.16$ and 0.21 for superior average and inferior average, respectively). These authors also showed significant increases in SLP and perimeter associations using VCC compared with FCC.

We suspect that the primary reason for improved structure-function relationships using VCC SLP compared with FCC SLP is the decrease in the included number of subjects with inadequate corneal compensation. Because one result of inadequate corneal compensation is a general increase in full-field retardation, it is likely that using FCC SLP with subjects with visual field defects and real RNFL thinning, coupled with spuriously high RNFL retardation, decreases structure-function associations because such subjects appear normal with the use of SLP.

In the current study, only the association between RNFL thickness measurements and visual sensitivity increased significantly when using VCC. The association between SLP ratio parameters and visual sensitivity did not improve. There are 2 possible reasons for this finding. First, SLP ratio parameters are generally resistant to full-field increases in retardation resulting from inadequate corneal polarization compensation because they measure retardation in 1 retinal region relative to another retinal region. Therefore, the values of these parameters likely did not change very much using VCC compared with FCC. Second, it is possible that the visual field sensitivity ratios we chose to compare with SLP ratio parameters were not ideal. The former explanation is supported by data from other studies that show little improvement in the values and diagnostic precision (receiver operating characteristics [ROC] curve areas, sensitivities, and specificities) of ratio parameters when corneal polarization is adequately compensated compared with when it is not.\textsuperscript{14-16}

Recently, several SLP studies have demonstrated the effects of inadequate corneal polarization compensation on glaucoma discrimination. Weinreb et al\textsuperscript{14} using the VCC SLP technique described herein, showed that ROC curve areas for discriminating glaucomatous eyes from healthy eyes increased when using VCC. Specifically, ROC curve areas for SLP average thickness, superior integral, ellipse average, and superior average increased significantly using VCC compared with FCC, and ROC curve area for all parameters investigated ranged from 0.32 to 0.83 for VCC and from 0.33 to 0.78 for FCC. Similarly, in the current study, ROC curve ratios did not improve for SLP ratio parameters when using VCC compared with FCC.

In another study, Greenfield et al\textsuperscript{15} measured the CPA in individual eyes and included these values in a statistical model with each of several FCC SLP parameters. Including CPA in the associative models increased the ability of individual thickness parameters to discriminate between glaucomatous and healthy eyes. With CPA in the models, ROC curve areas for thickness parameters increased by about 0.07. A similar increase was not observed for ratio parameters. Further, correlations between visual field–corrected pattern SD (using full-threshold automated perimetry) and several thickness parameters were improved by about 25% when CPA was included in the models.

Finally, Garway-Heath et al\textsuperscript{16} showed a “double hump-like” pattern when measuring the parafocal region using FCC SLP. Because the true retardation pattern measured from the macular Henle fibers is radially symmetrical,\textsuperscript{14} this finding indicates inadequate corneal polarization resulting in residual corneal retardation using FCC. These authors subtracted the retardation, measured parfoveally, from the retardation measured in the parapapillary area and found increased sensitivities for detecting glaucomatous eyes at various specificities for FCC SLP measured mean retardation. In addition, they showed increased correlation of mean parapapillary retardation and full-threshold visual field mean deviation (using full-threshold or SITA automated perimetry) on the order of 300% after subtracting parafocal retardation for parapapillary retardation. The $R^2$ was 0.05 unadjusted and 0.18 adjusted, similar to the change in $R^2$ values shown between FCC and VCC for several parameters in the current study.

Overall, the results of the current study indicate that using macular imaging to individually compensate corneal retardation using SLP increases the strength of the association between SLP-measured RNFL thickness and visual function. These results, coupled with those of other studies,\textsuperscript{14-16} suggest that SLP with eye-specific corneal compensation is more accurate than FCC SLP, in turn suggesting VCC SLP as a possible improvement over FCC SLP as a clinical tool. Despite this improvement, one should keep in mind the importance of considering a number of variables (including clinical examination) when diagnosing and monitoring glaucoma, instead of relying on a single automated diagnostic test.

Submitted for publication August 25, 2002; final revision received February 11, 2003; accepted March 20, 2003.

This study was supported in part by grant EY11008 from the National Eye Institute, Bethesda, Md (Dr Zangwill).

Corresponding author: Christopher Bowd, PhD, Hamilton Glaucoma Center, Department of Ophthalmology, University of California, San Diego, 9500 Gilman Dr, La Jolla, CA 92039-0946 (e-mail: cbowd@eyecenter.ucsd.edu).

REFERENCES


©2003 American Medical Association. All rights reserved.

**Archives Web Quiz Winner**

Congratulations to the winner of our March quiz, Douglas Sakamoto, SLU Eye Institute, St Louis, Mo. The correct answer to our March challenge was endogenous endophthalmitis. For a complete discussion of this case, see the Clinopathologic Reports, Case Reports, and Small Case Series section in the April ARCHIVES (Subramaniam ML, Topping TM. Endogenous endophthalmitis after routine dental cleaning. *Arch Ophthalmol.* 2003;121:576-577).

Be sure to visit the Archives of Ophthalmology Web site (http://www.archophthalmol.com) and try your hand at our Clinical Challenge Interactive Quiz. We invite visitors to make a diagnosis based on selected information from a case report or other feature scheduled to be published in the following month’s print edition of the ARCHIVES. The first visitor to e-mail our Web editors with the correct answer will be recognized in the print journal and on our Web site and will also be able to choose one of the following books published by AMA Press: *Clinical Eye Atlas, Clinical Retina, or Users’ Guides to the Medical Literature.*