Correlation of Blue-on-Yellow Visual Fields With Scanning Confocal Laser Optic Disc Measurements

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Purpose. Visual field defects and changes in the optic nerve head are signs of glaucoma. It has been shown that blue-on-yellow (B–Y) perimetry can reveal visual field defects earlier and shows them larger than does white-on-white (W–W) perimetry. The Heidelberg retina tomograph (HRT) can produce three-dimensional images of the optic disc. The aim of this study was to find out how B–Y perimetry results correlate with optic disc parameters in comparison with W–W perimetry results.

Methods. One randomly chosen eye was evaluated in each of 40 normal subjects and 37 patients with ocular hypertension and different stages of glaucoma. B–Y and W–W visual fields (program 30-2) were obtained with a Humphrey perimeter. B–Y perimetry results were adjusted for the patient’s age and lens transmission index measured with a lens fluorometer. The B–Y visual field adjusted mean deviation (MD) was calculated as the difference between the measured and expected mean sensitivity values, predicted by the regression model fitted in normal subjects. The HRT with software version 1.11 was used to acquire and evaluate topographic measurements of the optic disc.

Results. The cup shape measure showed strongest correlation with the MD of both the B–Y and W–W visual fields. The multiple correlation coefficients from quadratic regression were 0.65 for both visual fields. Except for peripapillary retinal nerve fiber layer measurements, the statistically significant correlations of the B–Y visual field indexes with other HRT parameters were equal to or better than those of W–W perimetry.

Conclusions. B–Y perimetry MDs are well correlated with optic nerve head parameters measured with the HRT. In early stages of glaucoma, most HRT variables were better correlated with the B–Y MD than with the W–W MD. Invest Ophthalmol Vis Sci. 1997;38:2452–2459.
cells. These isolated cells are selectively more vulnerable to glaucomatous damage or, because of undersampling, have minimal overlap of their receptive fields; therefore, functional loss occurs even if there is proportionately greater loss of other cells.26

Several reports have described a moderate to fairly good correlation between optic disc, RNFL, and W–W visual field parameters.27–29 These promising techniques, B–Y perimetry and confocal optic disc tomography, should provide a new method for measuring functional and structural characteristics. In 1995, Tsai et al30 investigated the relation between W–W and B–Y visual field sensitivity and optic disc parameters using the HRT (software version 1.10). The software has been considerably revised since then. The new standard reference plane has been shown to be better at separating patients with different stages of glaucoma.31 In addition, several new structural characteristics have been provided for estimation of the optic disc. To our knowledge, the correlation between B–Y visual field indexes and optic disc and RNFL descriptive parameters (e.g., cup shape measure, cup volume, rim volume, mean depth below curved surface, maximal cup depth, height variation along the contour line, mean RNFL thickness, and RNFL cross-sectional area) have not been reported so far.

The purposes of this study were to determine how results of B–Y perimetry correlate with optic disc parameters and to compare the strength of the association of the ONH morphologic variables with the B–Y and W–W visual field mean defect variables.

METHODS

We evaluated 1 randomly chosen eye in 40 nonglaucomatous subjects with a mean age of 57 years (range, 29 to 84 years). Criteria for subject eligibility consisted of normal findings in the ocular examination, a normal W–W visual field, no family history of glaucoma, no history of ocular or neurologic disease, no history of diabetes or other systemic diseases, and no history of use of any medications known to affect the visual field sensitivity or color vision. No restriction was placed on visual acuity. The lowest visual acuity due to lens changes was 0.2.

In addition to nonglaucomatous subjects, we examined 37 patients with a mean age of 60 years (range, 30 to 82 years). Ten patients had ocular hypertension (intraocular pressure >22 mm Hg on three or more occasions) with a normal optic disc, a normal RNFL, and normal W–W visual fields. Twenty-three patients had primary open-angle glaucoma with elevated intraocular pressure and glaucomatous optic disc damage and no apparent contribution from other ocular or systemic disorders. They were divided into three groups according to W–W visual field defects: early glaucoma in nine patients with a mean deviation (MD) <−5 dB; moderate glaucoma in six patients with MD 5 to 10 dB; and advanced glaucoma in eight patients with MD >10 dB. In addition, four patients with ocular hypertension and normal W–W visual fields, but an abnormal RNFL or optic disc, were added to the early glaucoma group. Table 1 gives more information about the patient groups.

Our investigation followed the tenets of the Declaration of Helsinki, and informed consent was obtained from all participants after the nature of the study had been explained.

We obtained W–W and B–Y visual fields using a modified Humphrey field analyzer (model 610; Humphrey Instruments, San Leandro, CA) and program 30-2. Details of the B–Y test procedure have been previously published.19–25 B–Y perimetry was performed with a 100-cd/m² yellow background and a size V blue (440-nm) stimulus.

W–W visual field MD was obtained using the statistical package provided by Humphrey Instruments. The calculation of B–Y visual field MD was based on results of nonglaucomatous subjects enrolled in this study. Variability of the static perimeter threshold is known to increase with distance from fixation.39 We therefore decided to use the 24-2 test data to obtain a more precise model of the normal B–Y visual field. In nonglaucomatous subjects, W–W perimetry was carried out during the first visit. To obtain data for the program 24-2 test, we subtracted respective peripheral location values from program 30-2 data.

In conventional W–W perimetry, the deviations of the threshold values are corrected for aging. In B–Y perimetry, however, the lens-induced absorption of the blue light may show large variability in subjects of similar age.40,41 We previously presented a procedure to estimate absorption of the blue light in an individual lens by measuring the autofluorescence of the crystalline lens.41

The fluorometry of the lens is based on the assumption that the maximal autofluorescence is approximately the same in the anterior and posterior parts of the lens, and any difference in autofluorescence intensity between the anterior and posterior parts can be attributed to a loss of exciting and fluorescent light in the lens. The autofluorescence of the lens was measured using our fluorometer; its optical system and the technique of lens fluorometry have been previously described.40,41 The fluorometer produces a graphic fluorescence profile that consists of anteroposterior juxtacortical peaks and a central plateau. A lens transmission index (LTI) was calculated from the ratio between the heights of the posterior and anterior autofluorescence peaks.

We have shown previously that the reference level for correcting B–Y perimetry results can be determined
were used. Therefore, in this study we calculated the focal planes. Image acquisition time was approxi-

more precisely using lens fluorometry than using age alone. However, it was evident that the variability was further decreased when both variables (LTI and age) were used. Therefore, in this study we calculated the age- and LTI-adjusted MD from the B-Y visual field (program 24-2) total mean sensitivity (MS) values as follows. First, a linear regression model was fitted in the normal subjects in which the dependent variable was the B-Y visual field MS and the regressor variables were age and LTI. The expected MS was obtained from the estimated regression coefficients a, b, and c as expected MS = a + b X LTI + c X age. Second, the age- and LTI-adjusted MD was calculated as the difference between the actual and the expected MS values (MD = MS − expected MS) for each subject in all clinical groups.

The HRT (software version 1.11) was used to ac-

The HRTCALC Utility Version 1.03 (Heidelberg Engi-

The following information was collected. The disc area was defined as the total area within the contour line. The cup area was defined as the total area of parts within the contour line that were located below the reference plane. The rim area was defined as the difference between disc area and cup area. The cup volume was defined as the total volume of parts within the contour line that were located below the reference plane. The rim volume was defined as the total volume of parts within the contour that were located above the reference plane (the reference plane was used as the lower limit for the measurement). The mean depth below curved surface was defined as the mean cup depth below the curved surface. The maximal cup depth was defined as the mean depth of the 5% of pixels with the highest depth values within the contour line (the depth was determined relative to the curved surface). Cup shape measure, or third moment, was defined as the frequency distribution of depth values relative to the curved surface of parts located inside the contour line. The height variation along contour line was defined as the difference in height between the most elevated and the most depressed points of the corrected contour line. The mean RNFL thickness was defined as reference height minus the mean height of contour. The RNFL cross-sectional area was defined as the mean RNFL thickness multiplied by the length of the contour line.

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MD were the regressor variables. The linear and the quadratic terms of the regressors were included in the models to allow for significant departures from linearity in the association. The multiple correlation coefficient from a model including either B-Y or W-W visual field MD (linear and quadratic term) was used to describe the strength of the association between the ONH morphologic variable and the visual field defect measure in question. A forward stepwise procedure was used to find the order of significance of the B-Y and W-W visual field MD variables.

To evaluate the strength of the association of B-Y and W-W visual fields with the HRT parameters in the early stages of glaucoma, we made a further analysis in which the patients with advanced glaucoma were excluded and linear correlation coefficients between the visual field measures and morphologic variables were calculated.

This study was of a descriptive nature, designed to evaluate the strength of the associations between the structural and functional measures and the clinical implications of these associations. Therefore, we considered that it was not meaningful to test statistically null hypotheses of zero correlations. Hence, the estimated correlation coefficients are presented without any probability values.

RESULTS

The fitted regression line for the expected B-Y visual field MD values in normal subjects was \( 19.31 + 0.123 \times \text{LTI} - 0.122 \times \text{age} \) (in years).

The standard errors of these coefficients were 5.32, 0.030, and 0.058, respectively. The residual standard deviation about the line was 3.09. The multiple coefficient of determination \( (R^2) \) of the model was 0.72. There was a strong correlation \( (R = 0.78) \) between the age- and LTI-adjusted B-Y visual field and W-W visual field MD values (Fig. 1). The W-W visual field MD values and the age- and LTI-adjusted MD values of the B-Y visual field showed the highest correlation with the cup shape measure; the \( R^2 \) values from quadratic regressions were 0.65 and 0.65, respectively (Figs. 2 and 3).

The structural variables under study can be divided into three broad categories with respect to their observed relations to the visual field measures (Table

FIGURE 1. Scatterplot of the association of white-on-white (W-W) visual field mean defect (MD) values with the lens- and age-adjusted blue-on-yellow (B-Y) visual field MD values in the five clinical groups.

FIGURE 2. Scatterplot of the association of the white-on-white (W-W) visual field mean defect (MD) values with the cup shape measure in the five clinical groups.

FIGURE 3. Scatterplot of the association of the lens- and age-adjusted blue-on-yellow (B-Y) visual field mean defect (MD) values with the cup shape measure in the five clinical groups.
TABLE 2. Multiple Correlation Coefficients of B-Y and W-W Visual Field Mean Deviations (MD) With Tomographic Data From Quadratic Regression Models* (n = 77)

<table>
<thead>
<tr>
<th>Tomographic Parameter</th>
<th>MD of B-Y Visual Field</th>
<th>MD of W-W Visual Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Cup shape measure</td>
<td>(-)0.65</td>
<td>(-)0.65</td>
</tr>
<tr>
<td>Mean cup depth below curved surface (mm)</td>
<td>(-)0.35</td>
<td>(-)0.16</td>
</tr>
<tr>
<td>II Cup/disc area ratio</td>
<td>(-)0.59</td>
<td>(-)0.56</td>
</tr>
<tr>
<td>Rim area (mm²)</td>
<td>(+)0.54</td>
<td>(+)0.49</td>
</tr>
<tr>
<td>Rim volume (mm³)</td>
<td>(+)0.54</td>
<td>(+)0.52</td>
</tr>
<tr>
<td>Cup area (mm²)</td>
<td>(-)0.52</td>
<td>(-)0.50</td>
</tr>
<tr>
<td>Cup volume (mm³)</td>
<td>(-)0.34</td>
<td>(-)0.29</td>
</tr>
<tr>
<td>Maximum cup depth (mm)</td>
<td>(-)0.30</td>
<td>(-)0.25</td>
</tr>
<tr>
<td>III RNFL cross-sectional area (mm²)</td>
<td>(+)0.48</td>
<td>(+)0.61</td>
</tr>
<tr>
<td>Mean RNFL thickness (mm)</td>
<td>(+)0.49</td>
<td>(+)0.62</td>
</tr>
<tr>
<td>Height variation along contour line (mm)</td>
<td>(+)0.44</td>
<td>(+)0.48</td>
</tr>
</tbody>
</table>

* + or — sign in parentheses indicates the direction of the linear component of the association.

RNFL = retinal nerve fiber layer; B-Y = blue-on-yellow; W-W = white-on-white.

2). In the first class were the cup shape measure and the mean cup depth below curved surface, which were more strongly associated with the B-Y visual field MD than with the W-W visual field MD. However, in these cases, W-W terms also were selected by the stepwise algorithm. Of all structural parameters considered, the linear term of the B-Y visual field MD had the strongest correlation with the cup shape measure (linear R = 0.65). Both the linear and quadratic terms of the W-W visual field MD were significantly associated with the cup shape measure, but the quantitative increment in the value of the multiple correlation coefficient from W-W perimetry results was small (multiple R = 0.70 after including both W-W terms).

The second class consisted of variables that were also more correlated, but not substantially so, with the B-Y visual field than with the W-W visual field MD. However, in these cases, W-W terms also were selected by the stepwise procedure. These parameters were cup:disc area ratio, rim area, rim volume, cup area, cup volume, and maximal cup depth.

In the third category were three structural variables that were more correlated with the W-W visual field MD than with the B-Y visual field MD. The linear term of the W-W visual field MD had the statistically strongest correlation with the RNFL cross-sectional area (linear R = 0.54) (Fig. 4), mean RNFL thickness (linear R = 0.53), and height variation along the contour line (linear R = 0.48). The quadratic term of the W-W visual field MD had some impact, with the RNFL cross-sectional area and mean RNFL thickness, on the linear term (multiple R = 0.61 and R = 0.62, respectively). In all these three variables, addition of the B-Y terms did not improve the fit of the regression.

Scatterplots (Figs. 2, 3, 4, 5) show that the advanced glaucoma group greatly influenced the associations. It was this patient group that made the associations of W-W visual field values with the HRT parameters deviate from a linear pattern. When patients with advanced glaucoma were excluded from the analysis, the associations were linear and the correlation coefficients (ordinary

FIGURE 4. Scatterplot of the association of the white-on-white (W-W) visual field mean defect (MD) values with the retinal nerve fiber layer (RNFL) cross-sectional area in the five clinical groups.

FIGURE 5. Scatterplot of the association of the lens- and age-adjusted blue-on-yellow (B-Y) visual field mean defect (MD) values with the retinal nerve fiber layer (RNFL) cross-sectional area in the five clinical groups.
TABLE 3. Correlation Coefficients (Pearson’s R) of B–Y and W–W Visual Field Mean Deviations (MD) With Tomographic Data (the Eight Subjects With Advanced Glaucoma Excluded; n = 69)

<table>
<thead>
<tr>
<th>Tomographic Parameter</th>
<th>MD of B–Y Visual Field</th>
<th>MD of W–W Visual Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Cup shape measure</td>
<td>-0.46</td>
<td>-0.37</td>
</tr>
<tr>
<td></td>
<td>Mean cup depth below</td>
<td>-0.28</td>
</tr>
<tr>
<td></td>
<td>curved surface (mm)</td>
<td>-0.12</td>
</tr>
<tr>
<td>II Cup/disc area ratio</td>
<td>-0.45</td>
<td>-0.30</td>
</tr>
<tr>
<td></td>
<td>Rim area (mm²)</td>
<td>0.57</td>
</tr>
<tr>
<td></td>
<td>Rim volume (mm³)</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>Cup area (mm²)</td>
<td>-0.43</td>
</tr>
<tr>
<td></td>
<td>Cup volume (mm³)</td>
<td>-0.28</td>
</tr>
<tr>
<td></td>
<td>Maximum cup depth (mm)</td>
<td>-0.14</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.02</td>
</tr>
<tr>
<td>III RNFL cross-sectional area (mm²)</td>
<td>0.27</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>Mean RNFL thickness (mm)</td>
<td>0.51</td>
</tr>
<tr>
<td></td>
<td>Height variation along contour line (mm)</td>
<td>0.14</td>
</tr>
</tbody>
</table>

RNFL = retinal nerve fiber layer; B–Y = blue-on-yellow; W–W = white-on-white.

Pearson’s R) decreased considerably, more so for the W–W perimetry results (Table 3).

DISCUSSION

In glaucoma, the anatomic loss of neural tissue accompanies deterioration of function. Previous reports have described a correlation between optic disc, RNFL, and achromatic visual field parameters. Compared with other disc parameters, the disc rim area was found to be most highly correlated with visual field MD by several investigators. The correlation coefficient between disc rim area and W–W visual field MD determined in this study was in concordance with previously reported results.

The introduction of confocal optic disc tomography has provided a new range of structural characteristics for estimation of the optic disc. Tsai et al reported that peripapillary retinal height, rim area, and rim:disc area were highly correlated with W–W and B–Y visual field MD when both normal subjects and glaucoma patients were included in the analysis. With only glaucoma patients in the analysis, the correlation coefficient between peripapillary retinal height was the only parameter significantly correlated with the visual field MD. Weinreb et al investigated the association between RNFL measurements and W–W visual field loss in 55 patients with primary open-angle glaucoma and found no significant association between RNFL cross-sectional area and global measures of visual field loss. Brigatti and Caprioli evaluated patients with early to moderate glaucoma using the HRT and W–W perimetry. They found the cup shape measure to be the only parameter correlating statistically significantly with the visual field indexes. No significant correlation was found between mean RNFL height and the visual field indexes. The discrepancies between our results and these studies may be explained by the differences in ONH parameters used and differences in population.

Detectable RNFL and optic disc abnormalities usually precede the criteria considered to be typical glaucomatous field loss in conventional W–W perimetry. The introduction of B–Y perimetry and confocal optic disc tomography seem to provide new techniques for measuring functional and structural characteristics. Tsai et al reported that rim area, rim:disc area, and peripapillary retinal height measured using the HRT (software version 1.10) were highly correlated with B–Y visual field MD when both normal subjects and glaucoma patients were included in the analysis. Spearman rank-order correlation coefficients for B–Y visual field MD were 0.56, 0.45, and 0.51, respectively. The multiple correlation coefficients determined in our study between B–Y visual field MD and rim area, rim:disc area, and mean RNFL thickness were 0.54, 0.59, and 0.49, respectively. In both studies, the RNFL parameters correlated slightly better with W–W perimetry results, but the optic disc parameters (rim area and rim:disc area ratio) were better correlated with B–Y perimetry results.

In this study, B–Y perimetry results correlated well with ONH parameters measured with a confocal scanning laser tomograph. In view of some previous studies indicating that B–Y perimetry may precede W–W visual field loss, we expected the B–Y visual field MD value to be correlated better with the structural HRT parameters than the W–W visual field index. The results of this study indicate that with all five clinical groups included in the analysis, the superiority of B–Y perimetry over W–W perimetry is not distinct. However, it was obvious from the scatterplots that the advanced glaucoma group greatly influenced the associations. Without the advanced glaucoma patients, the differences of the correlation coefficients of B–Y and W–W visual fields with the HRT parameters increased, suggesting that B–Y perimetry might add information beyond that of W–W perimetry, particularly in early stages of glaucoma.

Moreover, the scatterplots (see Figs. 1, 2, 3, 4, 5) show that 8 of 13 patients (62%) with early glaucoma and 3 of 10 patients (30%) with ocular hypertension, but only 4 of 40 normal subjects (10%), had an age- and LT-adjusted MD of B–Y visual field of <-5 dB. Although in scatterplots with W–W MD the ocular hypertension and early glaucoma patients, by definition, were clearly separated from the patients with
moderate glaucoma, in the scatterplots with B–Y MD this separation was no longer distinct. In fact, the B–Y MD of some patients with ocular hypertension and early glaucoma approached that of the patients with moderate glaucoma.

Visual field defects and changes in ONH and RNFL are widely regarded as important signs of glaucoma. In this study, the statistically significant correlations between structural and functional characteristics were obtained. However, statistically significant correlations do not necessarily mean that it is possible to predict accurately one value on the basis of another. The highest correlation of $R = 0.65$ yields an $R^2$ value of 0.423, meaning that the one variable can account for only $<43\%$ of the variance observed for the other variable. When the advanced glaucoma patients were eliminated from the data set, correlations were considerably reduced. The highest correlation was $R = 0.46$, which yields an $R^2$ value of approximately 0.21. This means that nearly $80\%$ of the variance of one variable cannot be accounted for on the basis of the other variable. Thus, in early stages of glaucoma, the ability to predict functional properties on the basis of structural measures, or vice versa, is quite poor. This suggests that to provide a full characterization of glaucomatous damage, both structural and functional measures are important.

In conclusion, the results of this study indicate that the structural optic disc parameters as measured with the HRT are well correlated with B–Y visual field test results. Moreover, our results suggest that B–Y perimetry may be more sensitive than W–W visual field testing in reflecting the development and progression of glaucomatous optic neuropathy. Further investigation is needed with more subjects to confirm our results.

**Key Words**

blue-on-yellow perimetry, confocal optic disc tomography, glaucoma, optic nerve head, short-wavelength automated perimetry

**References**

Blue-on-Yellow Visual Field and Optic Disc


