Properties of the Statpac Visual Field Index

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**PURPOSE.** To compare the properties of the visual field index (VFI) to those of mean deviation (MD) in patients with glaucoma.

**METHODS.** MD and VFI were calculated in data obtained from an ongoing longitudinal study in which patients with glaucoma (N = 109, 204 eyes) were observed for 9.8 years (median, 21 tests) with static automated perimetry. MD and VFI were compared in one test of each eye, and a subset of 30 tests were selected to compare the VFI with the judgments of eight experts who judged the percentage of the remaining visual field. In series of tests obtained over time, rates of change, statistical significance, evidence of nonlinearity, and variability were compared between both indices.

**RESULTS.** In single tests, MD and VFI were closely related (r = 0.88, P < 0.001). The relationship between both indices appeared linear, except in visual fields with MDs better than −5,0 dB where 29 (22%) of 129 eyes exhibited a ceiling effect (VFI = 100%). Based on this relationship, the predicted VFI for visual fields with MDs of −5, −10, and −15 dB were 91%, 76%, and 60%, respectively. The percentage of remaining visual field suggested by the VFI exceeded the range of the experts’ subjective judgments in 16 (53%) of 30 eyes. In series of tests obtained over time, rates of change with the two indices were closely related (r = 0.79, P < 0.001), and statistically significant reductions over time (P < 0.05) occurred in a similar number of eyes (92 [45%] with MD, and 87 [43%] with VFI). Of the 105 eyes with statistically significant (P < 0.05) negative trend in either MD or VFI, 74 (70%) showed such trends with both indices (κ = 0.69). The variability of MD and VFI increased with damage, and there was no evidence that change over time was more linear with VFI than with MD.

**CONCLUSIONS.** The VFI provides a simple and understandable metric of visual field damage, but its estimates of remaining visual field were more optimistic than those of the experts. Rates of change over time with both indices were closely related, but the reliance of the VFI on pattern deviation probability maps caused a ceiling effect that may have reduced its sensitivity to change in eyes with early damage. In this group of patients there was no evidence to suggest that the VFI is either superior or inferior to the MD as a summary measure of visual field damage. (Invest Ophthalmol Vis Sci. 2011;52:4030–4038) DOI:10.1167/iovs.10-6905

In patients with optic neuropathies such as glaucoma, the visual field is the most important functional measure of the severity of the disease and its progression. In conjunction with other tools such as gray-scale plots, total and pattern deviation probability maps, and ranked deviation analysis, global indices such as mean deviation (MD) are widely used to summarize and interpret various aspects of the visual field.

The MD expresses the overall reduction in sensitivity, averaged across the visual field, relative to a group of healthy, age-matched observers. Despite minor differences in how the MD is defined in various instruments, this index has become an accepted standard for describing the overall status of visual fields in individuals as well as in groups of patients enrolled in research studies.

A particular challenge in glaucoma is to estimate the rate of progression. Previous reports have highlighted large differences between the rates of change in individuals, both in treated and untreated patients with glaucoma. Most treated patients progress slowly, but a few show rapid changes that pose a much greater risk of visual disability. Statistical analyses of the trend in a single summary index of the visual field provide a simple and intuitive approach to judge whether the current management is likely to prevent visual disability.

Recently, Bengtsson and Heijl introduced a visual field index (VFI) for estimating rates of change in glaucoma. This index is meant to address several shortcomings of the MD and is incorporated into the Statpac software of the Humphrey Field Analyzer (HFA; Carl Zeiss Meditec, Dublin, CA). Unlike the MD, which is scaled in the original decibel units of measurement, the VFI expresses the amount of visual field loss as a percentage relative to the sensitivity of a reference group of healthy observers. A completely normal visual field would be associated with a VFI of 100%, whereas a perimetrically blind field would have a VFI of 0%. To reduce the potentially confounding effects of cataract, the VFI disregards reductions in sensitivity unless they are associated with a pattern deviation probability outside normal limits. Locations at which the pattern deviations are within the 95th percentile of healthy observers are treated as normal and assigned a value of 100%. In addition, locations in the center of the visual field are more heavily weighted and therefore make a greater contribution to the VFI than do those in the periphery.

The objective of this study was to determine the properties of the VFI for characterizing global visual field damage in glaucoma. We compared MD and VFI in single examinations (cross-sectional analysis) and investigated how both indices compare to each other in series of visual fields measured over a period of 10 years (longitudinal analysis).

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METHODS

Data
The data for this report were obtained from an ongoing prospective longitudinal study in which a cohort of patients with open-angle glaucoma are being followed. The visual field indices MD and VFI were calculated for the purposes of this report. Since the VFI is based on normative limits of total- and pattern deviation that are not in the public domain, these limits were estimated from a group of healthy controls who are followed in the same study.15

Patients were recruited consecutively from the clinics at the QEII Health Sciences Centre (Halifax, Nova Scotia, Canada). Inclusion criteria were a clinical diagnosis of open-angle glaucoma based on optic disc and visual field changes, an MD between −2.0 and −10.0 dB in at least one eye, and absence of other ocular disease. Controls were recruited from patients’ relatives, church groups, and a local telephone company. They had a normal finding in an eye examination and an IOP < 21 mm Hg. For both groups of participants, the inclusion criteria stipulated a best corrected visual acuity (VA) equal to or better than 6/12 (+/− 0.3 logMAR) and refractive error within ± 5.00 D sphere and ± 3.00 D astigmatism. In accordance with the Declaration of Helsinki, the Ethics Review Board of the QEII Health Sciences Centre approved the protocol, and all participants gave written informed consent.

Patients and controls were tested at intervals of 6 months with the full threshold strategy of the HFA. Both eyes were examined in patients, whereas in the controls only a randomly selected study eye was tested. For this report, visual fields were included if the MD of the baseline test was better than −20.0 dB and at least five tests were available.

Calculation of MD and VFI
Raw sensitivity values were exported from the HFA with PeriData (www.peridata.org) and transformed to total and pattern deviation by using published data on the relationship between age, sensitivity, and between-subject variance in a reference group of healthy observers.16 The MD was calculated as the weighted mean of the total deviation values, and the weight assigned to each location was the inverse of the variance in the healthy reference group.6

The VFI was calculated as described by Bengtsson and Heijl.14 At each location, the measured sensitivity was expressed as a percentage of the sensitivity expected in a healthy observer of the same age, and the VFI was calculated as the weighted mean of all locations with pattern deviation probability outside normal limits (<5%). The weights increased from 0.45 for the most peripheral locations to 3.49 for the four most central locations closest to fixation. Since pattern deviation calculations are unreliable with highly damaged visual fields, total rather than pattern deviation probability values were used with MDs worse than −20.0 dB.14

Total and pattern deviation probability limits were estimated, separately for each location, from the visual fields of our healthy control group. Because these limits are used to control for physiologic between-subject variation in the visual field, only a single test was used from each control. To minimize potential artifacts from lack of experience with static perimetry, the third test was selected. MD and VFI agreed closely with the values provided on the Statpac printouts (see the Appendix for a formal comparison).

Comparison of MD and VFI in Single Tests: Cross-Sectional Analysis
The relationship between MD and VFI in single tests was estimated from the third test in each series. Because both indices are derived from the same measured threshold data, orthogonal regression17 was used to derive an equation describing the relationship, irrespective of which index is selected to be the dependent or independent variable.

A subset of 30 tests that covered a wide range of MD and VFI values were selected to assess how the VFI compared with the judgment of experts. Statpac printouts of these visual fields, with the VFI masked, were then distributed to eight experts (see the Acknowledgments section) who were asked to provide a subjective judgment of the percentage of remaining visual field. Experts were at liberty to consider any information on the printout they might regard as relevant, including gray-scale plots, total and pattern deviation maps, and global indices (except the VFI, which had been masked). They were also instructed that their judgment should reflect their beliefs about the relative importance of central and peripheral, as well as superior and inferior, visual field damage. The median and range of the expert judgments were then compared with the VFI.

Comparison of MD and VFI in Series of Examinations: Longitudinal Analysis
To compare rates of change with the two indices, separate linear regressions were performed on the entire series of visual fields available for each eye. Rates of change were estimated from the slope of the regression line of MD (dB) and VFI (%) as dependent and age (years) as independent variable. The slope of the regression line (in dB/year with MD, and %/year with VFI) gave an estimate of the average rate of change over the entire follow-up.

To determine whether either MD or VFI were more sensitive to visual field deterioration, we compared the number of eyes with statistically significant negative slopes at P < 0.05, <0.01, and <0.001. Area-proportional Venn diagrams18 were constructed to visualize the proportions of eyes with significant negative slopes with MD or VFI for both indices.

To assess whether either MD or VFI provided a more linear fit to the series of tests over time, we compared the number of eyes with statistically significant deviations from linearity. Nonlinearity was tested by comparing the variance explained by a linear regression with that of a more complex model containing second- and third-order polynomials (F test).19 Evidence of nonlinearity was established if the more complex model explained a significantly greater proportion of variance than linear regression.

To estimate the variability of both indices, we first derived a best available estimate (BAE) of MD and VFI for each test in the series. Considering that each test is affected by random variability, an estimate of the true value at each time point can be obtained by forming a moving average from the observed value and the values obtained before and after it, such that a large proportion of random measurement error is smoothed out. The differences between the observed values and the BAES can then be regarded as residual random error. BAES were calculated with Lowess regression, a robust nonparametric and nonlinear technique20 that derives a weighted average over a moving window of tests (illustrated in the examples in Figs. 7–10).

Because the spread of the error distributions increased with visual field damage, quantile regression21 was then performed to estimate marginal quantiles (2.5%, 5%, 10%, 90%, 95%, and 97.5%) of the error distributions (dependent variable), with BAE as the independent variable. All analyses were performed in the free open-source environment R (http://cran.r-project.org, version 2.11.1).22 The quantreg package23 was used for quantile regression.

RESULTS

Demographic Details of Patients and Controls
Table 1 provides demographic details of the patients. In 95 (87%) of

| TABLE 1. Demographic Details of Patients with Glaucoma |
|----------------|------------------|
| N               | 109 patients (204 eyes) |
| Age, y          | 61.8 (52.4, 71.8) |
| Baseline MD, dB | −4.5 (−6.9, −2.7) |
| Follow-up, y    | 9.9 (5.4, 11.9) |
| Tests, n        | 21 (12, 24) |

Data are expressed as the median (interquartile range).
109 patients, both eyes met the inclusion criteria (baseline MD better than −20.0 dB, at least five tests available for analysis) and were entered in the analysis. In the remaining 14 patients, one eye had advanced damage at baseline (MD worse than −20.0 dB) such that only the better eye qualified for inclusion.

**VFI and MD in Single Visual Fields: Cross-Sectional Analysis**

In single visual fields, there was a close relationship between MD and VFI (Fig. 1, Spearman’s $r = 0.88$, $P < 0.001$). However, a ceiling effect was apparent with the VFI. Of 129 eyes with MD better than −5.0 dB, 29 (22%) had a VFI at the upper limit of 100%. For eyes with MD worse than approximately −5.0 dB, the relationship between both indices appeared linear and was best described by the equation $VFI = 106\% + 3.1 \times MD$, predicting VFIs of 91%, 76%, and 60% for visual fields with MDs of −5.0, −10, and −15 dB, with prediction intervals of approximately ±9%.

Except for 3 visual fields with MD > 0 dB, the VFI estimates of the percentage remaining visual field were higher than the median judgment of the experts, on average by 12%. In 16 (53%) of the 30 fields, the VFI was higher than the largest individual judgment of the eight experts (Fig. 2). Of note was the large spread in the experts’ estimates. In all visual fields with MD < −5 dB, the ranges were larger than 20%.

**VFI and MD in Visual Field Series: Longitudinal Analysis**

The mean and median rates of global visual field change in the patients with glaucoma were −0.27 and −0.18 dB/year with MD, and −0.84 and −0.20%/year with VFI, respectively (Fig. 3). Rates of change estimated from both indices were closely related (Spearman’s $r = 0.79$, $P < 0.001$). Of the 204 visual field series, 85 (42%) contained at least one test in which the VFI was 100%. When such series were excluded, the relationship between the rates of change estimated with both indices was $r_s = 0.1 + 3.7 \times r_{MD}$. Thus, for eyes with MD slopes of $-0.5, -1.0, -1.5,$ and $-2.0$ dB/year, the corresponding VFI slopes were approximately $-1.8\%$, $-3.6\%$, $-5.4\%$, and $-7.3\%$ per year.

The number of eyes with statistically significant negative trends in MD and VFI were similar (Fig. 4). For example, 92 eyes (45%) showed a negative MD slope significant at the 5% level, whereas 87 eyes (43%) had a negative VFI slope at the same significance (Fig. 4, left; $κ = 0.65$). The close agreement on the presence of a negative trend with MD and VFI remained similar when $P < 0.01$ and $<0.002$ were chosen as criteria for
statistical significance ($\kappa$, 0.67–0.73; Fig. 4, middle and right, respectively).

With both MD and VFI, variability increased with the level of visual field damage (Fig. 5). For a visual field with an $\text{MDBAE} \simeq 0$ dB, for example, the MD of a single test was likely to fall within ±1 dB 95% of the time. In contrast, with $\text{MDBAE} \simeq 10$ dB, this interval was more than twice as wide, ranging from approximately −8 to −12.5 dB. Because the VFI never exceeds 100%, the variability of this index was artificially reduced at the top of the scale, but the increased spread with more damaged visual fields was similar to that noted with the MD.

To investigate whether either MD or VFI would provide a more linear fit of visual field change over time, statistical tests for nonlinearity were performed by testing whether a quadratic or cubic polynomial explained a significantly larger variance than a linear model. The proportions of eyes in which this was the case were similar with the MD and the VFI (Fig. 6). Thus, there was no evidence that the temporal pattern of change was more linear with one index than with the other.

**Case Examples**

In Example 1 (Fig. 7), the visual field series showed a slow rate of global visual field change that was statistically significant with both indices. Over a period of nearly 13 years, the MD changed from −3.8 dB (first test) to −6.7 dB (last test), with a linear rate of change of −0.15 dB/year. The VFI changed from 95% to 88%, at a linear rate of −0.3%/year. With the MD, the temporal pattern of visual field change appeared nonlinear ($P = 0.04$), with a faster rate initially, but no evidence of nonlinearity was detected with the VFI ($P = 0.44$).

Example 2 (Fig. 8) illustrates a case with a rapid rate of change (−0.8 dB/year with MD; −3%/year with VFI). During the early follow-up, the rate appeared relatively more rapid with the MD than with the VFI, most likely owing to a ceiling effect with the latter index. Over the entire follow-up, the trend in both indices was nonlinear ($P = 0.005$ with MD; $P < 0.001$ with VFI).

Example 3 (Fig. 9) shows a case of localized progression in the central visual field that was poorly reflected in MD. The linear rates of change were +0.1 dB/year with MD ($P = 0.24$) and −0.8%/year ($P < 0.001$) with the VFI. The positive slope of the MD was most likely related to a sustained learning effect; the general height of this visual field improved, gradually, by approximately 3 dB during the course of the follow-up (not shown). Nonlinearity was evident with MD as well as VFI ($P = 0.02$ and $<0.001$, respectively).

Example 4 (Fig. 10) shows a slow rate of change in a visual field developing an early nasal step superiorly. The rates of change....
DISCUSSION

The purpose of this study was to compare the MD and VFI indices for estimating rates of change in glaucoma. Our results indicate that, in most patients, both indices provide equivalent information on the rate of visual field progression (Fig. 3). In addition, there were no substantial differences between the number of eyes in which MD and VFI showed statistically significant negative rates of change (Fig. 4), suggesting that both indices have similar capability to detect the presence of global visual field progression.

The increase in the variability of MD observed in damaged visual fields is consistent with previous reports. Our analysis suggests that in visual fields with a "true" MD near 0 dB, MDs from single tests are likely to fall into a 95% tolerance interval of ±1 dB, suggesting that a deterioration of more than 2 dB, from one test to the next, is unlikely to occur due to chance. When the true MD is near 5 dB, the tolerance interval is much broader (±3 dB, ±7 dB), suggesting that differences of up to 4 dB from one test to the next may be explained by variability. A similar picture emerged with the VFI. When the true value of the index was near 90%, the tolerance interval of single tests ranged from 85% to 95%, but this expanded with VFIs near 70%, to cover a range from 60% to 77%.

Because the VFI disregards loss of sensitivity at locations at which the pattern deviation is within normal limits, this index may be more resistant than the MD to diffuse visual field changes caused by cataract. This is an advantage for estimating the rate of glaucomatous change in patients who develop significant lens opacity during follow-up. In our sample, however, there were only very few patients in whom surgery was delayed sufficiently long for cataract to lead to a substantial reduction in MD. A previous report on this study population showed that, despite a 2-line postoperative improvement in VA, the mean improvement in MD after cataract surgery was <0.1 dB. Similar findings have been reported by others. In a population that is older, or more likely to delay cataract surgery until more...
advanced lens opacity has developed, the differences between rates of change with MD and VFI may well be larger.

The resistance of the VFI to diffuse visual field change caused by cataract comes at the cost of lesser sensitivity to diffuse visual field changes that may be an integral part of glaucoma-related visual field damage and its progression.15,29–32 In patients with firmly established focal visual field damage at the start of follow-up this is unlikely to be a practi-
cally important drawback, but it is likely to reduce the capability of the VFI to reflect glaucomatous progression in the early stages of the disease when focal losses may not yet be well established. In a substantial proportion of eyes with MDs better than $-5$ dB, the VFI was close to its maximum value of 100% (ceiling effect). This suggests that the VFI may underestimate the rate of change in eyes with initially normal visual fields that are developing glaucomatous damage. Because most eyes in our sample already had focal visual field damage at the beginning of the study, we are unable to test this hypothesis in our sample. Studies that investigate the development of glaucoma in patients with initially normal visual function would provide an ideal opportunity to do this.

Compared with the MD, the VFI places a greater weight on locations in the paracentral visual field (see Fig. 9, example 3), and arguably gives a more appropriate reflection of small but clinically important losses in this area. This weighting, however, does not make the VFI an index of functional vision. Both MD and VFI are indices of visual function, but not of functional vision. The VFI was designed to measure rates of change in glaucoma, but, as with MD, solid empiric evidence is needed to underpin how changes in this index affect real-world performance of visual tasks, self-perceived quality of vision, and life, and, ultimately, health-related outcomes. The intuitive percentage scale of the VFI may make it prone to be interpreted as a “percentage of remaining visual field,” but this, in our view, is an oversimplification. Caveats include that the VFI is scaled in reference to normative values that depend on the arbitrarily selected maximum stimulus intensity of the HFA (3200 cd/m$^2$) and are valid only for this instrument.

It is neither unambiguous nor straightforward to translate between clinical and functional scales, and the discrepancy between the experts’ intuitive judgment and the VFI further cautions against a too literal interpretation of the VFI’s percentage scale. Notwithstanding the substantial spread between experts’ judgments (which was larger than 20% in almost all cases), the VFI exceeded even the most optimistic estimate of eight experts in more than 50% of visual fields in our sample. These findings support the need for a more in-depth investigation of expert judgments on visual field loss, and how they accord with objective evidence from performance-based measures.

Rates of change with MD and VFI were closely related, and there was no evidence that the time course of change was more linear with one index or the other. The finding that statistically significant nonlinearity was observed in many series does not suggest, however, that a simple linear model is inferior to other, more complex, models for estimating the average global rate of change over a given period. The time course of visual field progression and how best to distinguish sudden and gradual patterns of change, are outside the scope of this report but remain topics of ongoing research.

Although the VFI has advantages and disadvantages compared to the MD, both are global indices that summarize the entire visual field. Such indices are useful for estimating the average rate of global change in glaucoma, but they are not well suited for detecting early evidence of visual field progression. Because visual field progression usually entails localized components, point-by-point analyses such as the glaucoma change probability or pointwise linear regression techniques may be more appropriate to detect the earliest signs of visual field progression in glaucoma.

Clinicians and researchers in glaucoma are universally familiar with the MD, and its strengths and limitations are well understood. Given the lack of distinct advantages of the VFI, at least in patients who do not develop clinically significant opacity during follow-up, we suggest that the MD be used in preference to the VFI when summary measures of global visual field damage and rates of change are reported in scientific publications.
values derived from our analyses (Fig. A1).

extracted from the Statpac printouts and compared with the

we selected a subset of 100 visual fields covering a large

MD and VFI performed in this report to the Statpac analyses,

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have been derived from a group of healthy controls under

VFI values in this report were calculated on data from healthy

APPENDIX

The visual field indices provided on the Statpac printouts are

based on proprietary normative values, whereas the MD and

VFI used in our calculations were based on a group of healthy controls under

observation in our center. To compare the calculations of MD and VFI performed in this report to the Statpac analyses,

we selected a subset of 100 visual fields covering a large spectrum of visual field damage. MD and VFI were manually extracted from the Statpac printouts and compared with the values derived from our analyses (Fig. A1).

Although the MD according to our calculations was system-

atically higher than that of Statpac, the mean difference (±0.21 dB; 95% confidence interval [CI], −0.27 to −0.15 dB; P <

0.001) was small and unlikely to be of practical importance. On

average, the differences between the VFI values were small (<0.1% for MD; 95% CI, −0.36% to 0.34%; P = 0.89), and although we appeared to overestimate the VFI at the top of its range, the differences were <5% in all cases.

References


Figure A1. Comparison of the MD and VFI calculations against values from the proprietary Statpac software.

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