Sensitivity to Changes in Progression Rate in the Ocular Hypertension Treatment Study

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PURPOSE. Trend analysis techniques to detect glaucomatous progression typically assume a constant rate of change. This study uses data from the Ocular Hypertension Treatment Study to assess whether this assumption decreases sensitivity to changes in progression rate, by including earlier periods of stability.

METHODS. Series of visual fields (mean 24 per eye) completed at 6-month intervals from participants randomized initially to observation were split into subseries before and after the initiation of treatment (the “split-point”). The mean deviation rate of change (MDR) was derived using these entire subseries, and using only the window length (W) tests nearest the split-point, for different window lengths of W tests. A generalized estimating equation model was used to detect changes in MDR occurring at the split-point.

RESULTS. Using shortened subseries with W = 7 tests, the MDR slowed by 0.142 dB/y upon initiation of treatment (P < 0.001), and the proportion of eyes showing “rapid deterioration” (MDR < −0.5 dB/y with P < 5%) decreased from 11.8% to 6.5% (P < 0.001). Using the entire sequence, no significant change in MDR was detected (P = 0.796), and there was no change in the proportion of eyes progressing (P = 0.084). Window lengths 6 ≤ W ≤ 9 produced similar benefits.

CONCLUSIONS. Event analysis revealed a beneficial treatment effect in this dataset. This effect was not detected by linear trend analysis applied to entire series, but was detected when using shorter subseries of length between six and nine fields. Using linear trend analysis on the entire field sequence may not be optimal for detecting and monitoring progression. Nonlinear analyses may be needed for long series of fields. (ClinicalTrials.gov number, NCT00000125.) (Invest Ophthalmol Vis Sci. 2013;54:1252–1259) DOI:10.1167/iovs.12-10218

The Ocular Hypertension Treatment Study (OHTS) was a randomized clinical trial that demonstrated the beneficial effect of IOP reduction to prevent or delay the onset of primary open-angle glaucoma.1,2 A second phase of the trial in which all participants were offered IOP-lowering medication, demonstrated that the rate of conversion to primary open-angle glaucoma (POAG) was lower in those participants who had been randomized initially to treatment, that is that delaying treatment in the observation group affected the average status negatively, especially in higher-risk participants.3 Major clinical trials in glaucoma, including OHTS, have formulated different criteria for classifying cross-sectional disease status and have used change in status as a basis for detecting change over time.1,4–7 However, such event-based criteria do not make full use of the available information; partly because they produce only a binary outcome (in this case, reaching POAG endpoint or not) and partly because they do not use all tests performed during the follow-up series. Additionally, some forms of event analysis define progression as a change in status from within to outside normal limits. These methods are less sensitive for participants whose baseline status is toward the upper end of the normal range. Therefore, trend analysis for evaluation of structural and functional damage in glaucoma has become the subject of increasing interest among clinicians and researchers.8,9 Rates of change provide objective, continuous variables quantifying progression, making use of all available data in the series. Such extra information about the rate at which patients progress may help predict future functional loss and vision-related quality of life, and aid clinicians when assigning management strategies for their patients. We previously have used trend analysis to show that participants reaching an event-analysis–based POAG endpoint in OHTS had significantly more rapid rates of functional change than those who did not,10 indicating that the rate of change is an effective measure of progression. We also have shown that treatment significantly slowed the rate of progression.11

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See the Appendix for the members of the Ocular Hypertension Treatment Study Group.

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In light of the increasing importance of trend-based analysis methods in glaucoma, it is imperative that those methods be validated and optimized as much as possible. OHTS provides an invaluable resource in this regard, since it contains biannual visual field (VF) test results for over 1000 participants with a median follow-up of 13 years. An effective trend-based analysis method should be able to detect changes in the rate of change while also having good specificity. The main OHTS outcome confirmed that initiation of ocular hypertension treatment improved outcomes (decreasing the probability of subsequently reaching a POAG endpoint), and so an effective analysis should be able to detect a slowing in rate of change occurring at this time point. For participants randomized initially to the observation group, the rate of decline in VF status should slow after the initiation of treatment.

Participants had normal VF tests at enrollment into OHTS. Consequently, an initial sequence of normal fields could reduce the magnitude of the rate of change of sensitivity before initiation of treatment. This could reduce the ability to detect a change in rate occurring after treatment commenced. In our study, we examine the extent of series length on the ability to detect a change in rate occurring at the time of initiation of treatment, when using linear trend analysis techniques.

METHODS
Baseline data and design of the OHTS have been described previously. All OHTS participants signed a statement of informed consent before study entry after having the risks and benefits of participation explained to them. The institutional review boards at each participating clinical site approved their respective informed consent statements and procedures. The study adhered to the tenets of the Declaration of Helsinki.

All subjects enrolled in the OHTS had to have at least two reliable fixation losses, false-negative, and false-positive responses (<33%), achromatic, automated VF test results (Humphrey Field Analyzer using the 30-2 testing pattern; Carl Zeiss Meditec, Inc., Dublin, CA) that were within normal limits during the qualifying period. The OHTS analysis dataset available for this study contained all VF tests and endpoint determinations in the OHTS database as of March 2009. From the full OHTS dataset (n = 1636), we first removed from further consideration any eye that reached an endpoint that was determined by the endpoint committee to be due to causes other than POAG (261 eyes of 202 subjects). We then selected only those follow-up VF tests that were considered reliable (false-positives, false-negatives, and fixation loss all <33%) if the Full Threshold Algorithm was used, false-positives <15%, false-negatives and fixation loss <33% if the Swedish Interactive Threshold Algorithm (SITA) was used).

A “Delayed Treatment Cohort” was formed, consisting of those eyes that had a change from observation to treatment at some point during follow-up. This analysis included eyes randomized initially to observation, and that began treatment either as a result of a POAG endpoint determination or at the transition between the first and second phases of OHTS (at which time treatment was offered to all originally untreated subjects in the observation arm). The visit at which an eye first was noted to be on treatment became known as the “split-point” for that eye.

For a given window length of W tests, four sequences of VF tests were analyzed per subject: BeforeW, the W most recent VF tests before the split-point; AfterW, the first W VF tests beginning at least 9 months after the split-point; BeforeAll, all VF tests before the split-point; and AfterAll, all VF tests beginning at least 9 months after the split-point. A 9-month gap was left between commencing treatment and the start of the “after” sequence to ensure that the participant’s treatment had a chance to stabilize, allowing their physician to determine a drug and dosage that resulted in attaining the target IOP. Subjects with fewer than W VF tests before and W VF tests after the split-point were excluded. We did not require that treatment be continuous once commenced.

Secondly, a “Continuous Treatment Cohort” was formed consisting of those eyes having no change in treatment status during the study; this, therefore, consisted of subjects randomized initially to treatment. For this cohort, the series was split chronologically into two equal parts, with a “split-point” halfway through the series. In this case, no gap to allow treatment to stabilize is needed. Therefore, the sequence AfterW consisted of all VF tests after the split-point.

Linear regression of mean deviation (MD) over time was performed separately for each of the four sequences for each of the eyes selected. MDs were considered to be equivalent between the two testing algorithms. The rate of change of MD (MDR [dB/y]) was recorded for each eye, together with the standard error of the slope estimate, and a determination of whether “rapid deterioration” occurred during that period (defined as an MDR worse than −0.5 dB/y that was significantly negative, with P < 0.05).

An effect of the initiation of treatment on MDR was sought using data from both eyes of each individual (where available). A paired comparison was performed to determine the change in MDR that occurred at the split-point. Specifically, the change in MDR given by MDR “after” minus MDR “before” was set as the outcome of a generalized estimating equation (GEE) regression with no independent variables. The resulting intercept term and value were used as estimates of the average change in MDR and its level of significance, respectively. This is analogous to a paired t-test comparing the two MDRs, but using a GEE regression to account for the fact that there may be correlated data from two eyes for the same participant. Additionally, the proportion of eyes for which “rapid deterioration” occurred was calculated. These proportions were compared between the “before” and “after” series using McNemar’s test.

This analysis was repeated for different window lengths W, ranging from W = 4 (assumed to be the shortest window length over which linear regression can provide a reasonable estimate of the rate of change) to W = 12 (the longest window length for which there were sufficient eyes with enough VF tests before and after their split-point). Note that as the window length W increases, the number of eyes for which there are sufficient VF tests in both sequences is reduced; therefore, the average MDR in the BeforeW and AfterW sequences varies depending on the value of W.

RESULTS
Table 1 gives the change in MDR at the split-point for the Delayed Treatment Cohort, together with the significance level of that change, for the shortened and complete sequences, for different window lengths W. In each case, only eyes with at least W VF tests in both their sequences BeforeW and AfterW were included. This means that the number of eligible eyes (n) and the average change in MDR observed in the entire sequence of fields vary with W, as seen in Table 1, due to different subsets of the complete dataset being eligible. It can be seen that using the shortened sequence length, a significant change in MDR is observed at the split-point, with the MDR in sequence AfterW being less rapid than the MDR in sequence BeforeW. This is consistent with the main finding of OHTS that a significant and beneficial treatment effect occurs. However, when the entire series of VF tests is used, there is no significant change in MDR at the split-point between sequences BeforeAll and AfterAll. As W increases, the magnitude of the apparent improvement in MDR decreases, until eventually it becomes nonsignificant when W > 10.

Table 2 shows the standard error of the estimates of MDR, averaged over all eyes and averaged over the two sequences (before and after the split-point). It is seen that when W is small, the error about the estimate of MDR in the shortened sequences is large. As the sequence length increases, the MDR
Results are presented when using only the W fields before and the W fields after the split-point for each sequence (“Shortened Sequence”), and when using all available fields (“Entire Sequence”). Note that the number of eyes included in the analysis (n) varies with W; since there must be at least W fields in the “Before” and “After” sequences for an eye to be included. Therefore the results using the entire sequence also vary with W. “Significance” gives the P value indicating whether the change in MDR is significantly different from zero, using a generalized estimating equation model. Testing was done every six months. Therefore, the time interval covered by the shortened sequences varied from 1.5 (W = 4) to 5.5 (W = 12) years.

Combining these two effects, Table 3 shows the proportion of eyes in the Delayed Treatment Cohort showing “rapid deterioration” before and after the split-point. It is seen that when W is too small, the variability in the slope estimate (as seen in Table 2) is so high that relatively few slopes reach a significance level of \( P < 0.05 \), and so fewer eyes are detected as showing “rapid deterioration.” When W is too large, the MDR is less likely to reach –0.5 dB/y over that time window, due to changes in the progression rate over that period, and so eyes that progress intermittently or for shorter periods again are missed. There then is no significant difference between the proportions of eyes flagged for “rapid deterioration” before and after the split-point, despite the presence of a known treatment effect that should be reducing the proportion of progressing eyes. When W is between approximately 6 and 9 (equivalent to 2.5 and 4 years of follow-up, respectively), the proportion of eyes detected as showing “rapid deterioration” before treatment was initiated is more than double the number detected when using the entire sequence. The proportion of eyes showing “rapid deterioration” in sequence Before\(_W\) was significantly higher than the proportion in sequence Before\(_\text{all}\) for window lengths \( 5 \leq W \leq 9 \) (\( P < 0.01 \) in each case). When W = 10, \( P = 0.01 \); when W = 11, \( P = 0.15 \); and when W = 12, \( P = 1.00 \). The proportion showing “rapid deterioration” in sequence After\(_W\) was lower than in sequence After\(_\text{all}\) when W = 4 (\( P < 0.01 \)), but not significantly different for other window lengths.

As noted in the Methods section, the number of available series depends on the window length W. To ensure that this did not bias the results, the analysis was repeated using different lengths W; but in each case only using the 394 series for which there were at least 10 examinations before and after the split-point. This minimum of 10 fields before the split-point also removes series for which treatment was initiated following an endpoint. As seen in Table 1, using W = 10 reveals a change in average MDR of 0.118 dB/y at the split-point. Consistent with the results above, using shorter windows revealed greater improvements in MDR, of 0.171 dB/y for W = 8, 0.272 dB/y for W = 6, and 0.365 dB/y for W = 4.

**Table 1.** The Mean MDR (Slope of Mean Deviation over Time) in the Sequence of Fields before the Split-Point and in the Sequence of Fields Starting at Least 9 Months after the Split-Point for the Delayed Treatment Cohort Using Different Window Lengths W

<table>
<thead>
<tr>
<th>W</th>
<th>n</th>
<th>Before(_W), dB/y</th>
<th>After(_W), dB/y</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>892</td>
<td>-0.230</td>
<td>-0.055</td>
<td>0.001</td>
</tr>
<tr>
<td>5</td>
<td>884</td>
<td>-0.265</td>
<td>-0.099</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>6</td>
<td>858</td>
<td>-0.249</td>
<td>-0.094</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>7</td>
<td>802</td>
<td>-0.231</td>
<td>-0.089</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>8</td>
<td>720</td>
<td>-0.204</td>
<td>-0.075</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>9</td>
<td>601</td>
<td>-0.192</td>
<td>-0.063</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>10</td>
<td>394</td>
<td>-0.196</td>
<td>-0.077</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>11</td>
<td>157</td>
<td>-0.172</td>
<td>-0.110</td>
<td>0.206</td>
</tr>
<tr>
<td>12</td>
<td>73</td>
<td>-0.181</td>
<td>-0.190</td>
<td>0.905</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>W</th>
<th>Before(_\text{all}), dB/y</th>
<th>After(_\text{all}), dB/y</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.084</td>
<td>-0.118</td>
<td>0.203</td>
</tr>
<tr>
<td>5</td>
<td>0.083</td>
<td>-0.119</td>
<td>0.189</td>
</tr>
<tr>
<td>6</td>
<td>0.084</td>
<td>-0.107</td>
<td>0.275</td>
</tr>
<tr>
<td>7</td>
<td>0.087</td>
<td>-0.091</td>
<td>0.796</td>
</tr>
<tr>
<td>8</td>
<td>0.090</td>
<td>-0.085</td>
<td>0.812</td>
</tr>
<tr>
<td>9</td>
<td>0.096</td>
<td>-0.075</td>
<td>0.289</td>
</tr>
<tr>
<td>10</td>
<td>0.102</td>
<td>-0.088</td>
<td>0.557</td>
</tr>
<tr>
<td>11</td>
<td>0.120</td>
<td>-0.119</td>
<td>0.978</td>
</tr>
<tr>
<td>12</td>
<td>0.167</td>
<td>-0.197</td>
<td>0.655</td>
</tr>
</tbody>
</table>

The sample size n varies with W, as reported in Table 1.

**Figure 1.** Box-and-whisker plots of the change in MDR occurring at the split-point, for different lengths of shortened window W. For each box, the *central horizontal line* represents the median value, the *box* covers the interquartile range, and the *whiskers* extend to the maximum and minimum values. The *gray horizontal line* indicates zero difference in MDR.
Figure 2 shows the series of MD for a sample participant in the study. A relatively stable period over the first few years of the study was followed by a period of rapid progression, resulting in POAG endpoint determination (by visual field and optic disc) and subsequent initiation of treatment at the date indicated by the gray vertical line. Using the entire sequence, the MDRs (the slopes of the blue lines in Fig. 2) were $-0.540$ dB/y before the split-point and $-0.542$ dB/y over the fields at least nine months after the split-point. Using the shortened sequence of length $w = 7$ fields, the MDRs (the slopes of the red lines in Fig. 2) were $-1.187$ dB/y in the last seven fields before the split-point and $-0.558$ dB/y in the first seven fields afterwards. The initial stable period and the later period of more rapid deterioration are combined, causing the overall rate to be less severe when using the entire sequence, making trend analysis less sensitive to the rapid progression in the later part of the pretreatment period.

Table 4 shows the change in MDR occurring at the split-point for the Continuous Treatment Cohort, in the same format as Table 1. These participants were offered treatment throughout both phases of the trial (hence, they have relatively slow rates of change). It is seen that using the shortened sequence, no significant change in rate is detected at the split-point. There is no reason to expect there to be a change in MDR when the split point is not associated with a change in treatment. Table 5 shows, in the same format as Table 3, the proportion of eyes with rapid deterioration.

Figure 2. The series of VF test results for a sample participant in the Delayed Treatment Cohort. The vertical gray line represents the first visit at which the subject was receiving treatment. The blue lines show the rate of change of mean deviation from linear regression over the entire sequences, before the split-point and commencing at least 9 months after the split-point. The red lines show the equivalent rates of change derived using the shortened sequences, that is the last seven fields before the split-point and the first seven fields at least 9 months after the split-point. Before the split-point, the red line is steeper than the blue line, showing that use of the shortened sequence makes trend analysis more sensitive to the rapid rate of change that occurred over this period. A change in rate is apparent at treatment onset using the shortened sequence, but not using the entire sequence. Note that when the split-point was caused by the subject reaching an endpoint, all confirmation fields were included in the $w$ sequence.

Discussion

Our results indicated that when linear trend analysis techniques are used, using the entire available sequence of VFs can decrease the sensitivity to detecting known changes in the rate of functional progression. Shorter sequences of only the more recent fields before the split-point may make linear trend analysis more sensitive to such changes, without compromising specificity. Series of between six and nine VFs provided the best sensitivity in this analysis. While shorter sequences could be expected to result in more “false-positive” cases wherein progression is flagged in stable eyes, no evidence of a significant reduction in specificity was found. To our knowledge, this is the first report suggesting that using the entire VF sequence may not be optimal for detecting and monitoring progression when using linear trend analysis techniques.

An implication of these findings is that the linear model for progression is suboptimal for long series of visual fields in ocular hypertensive eyes. This is not surprising, since such a model assumes a constant rate of change. Consider a 60-year-old patient, currently with an MD of $-5$ dB, progressing at $-1.0$ dB/y. Using a linear model and extrapolating the trend would imply that at the age of 40 their MD had been $+15$ dB, which...
TABLE 4.  The Mean MDR (Slope of Mean Deviation over Time) in the Sequence of Fields before the Split-Point and in the Sequence of Fields after The Split-Point for the Continuous Treatment Cohort, using Different Window Lengths W

<table>
<thead>
<tr>
<th>W</th>
<th>n</th>
<th>BeforeW, dB/y</th>
<th>AfterW, dB/y</th>
<th>Significance</th>
<th>BeforeAll, dB/y</th>
<th>AfterAll, dB/y</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1921</td>
<td>-0.082</td>
<td>-0.069</td>
<td>0.731</td>
<td>-0.039</td>
<td>-0.125</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>5</td>
<td>1890</td>
<td>-0.077</td>
<td>-0.063</td>
<td>0.631</td>
<td>-0.036</td>
<td>-0.119</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>6</td>
<td>1797</td>
<td>-0.081</td>
<td>-0.058</td>
<td>0.376</td>
<td>-0.039</td>
<td>-0.125</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>7</td>
<td>1730</td>
<td>-0.071</td>
<td>-0.057</td>
<td>0.541</td>
<td>-0.036</td>
<td>-0.119</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>8</td>
<td>1617</td>
<td>-0.063</td>
<td>-0.050</td>
<td>0.540</td>
<td>-0.035</td>
<td>-0.119</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>9</td>
<td>1508</td>
<td>-0.064</td>
<td>-0.062</td>
<td>0.919</td>
<td>-0.035</td>
<td>-0.087</td>
<td>0.010</td>
</tr>
<tr>
<td>10</td>
<td>1390</td>
<td>-0.042</td>
<td>-0.058</td>
<td>0.368</td>
<td>-0.041</td>
<td>-0.093</td>
<td>0.004</td>
</tr>
<tr>
<td>11</td>
<td>1231</td>
<td>-0.022</td>
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<td>0.034</td>
<td>-0.041</td>
<td>-0.087</td>
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<tr>
<td>12</td>
<td>986</td>
<td>-0.014</td>
<td>-0.056</td>
<td>0.005</td>
<td>-0.024</td>
<td>-0.072</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Results are presented when using only the W fields before and the W fields after the split-point for each sequence (“Shortened Sequence”), and when using all available fields (“Entire Sequence”). “n” shows the number of eyes included in the analysis, which varies with W (as in Table 1). “Significance” gives the P value indicating whether the change in MDR is significantly different from zero, using a generalized estimating equation model.

Table 5. The Proportion of Eyes Showing “Rapid Deterioration” in the Continuous Treatment Cohort (MDR Worse than –0.5 dB/y, Significantly Negative with P < 5%). Together with the P Value Comparing the Proportions before and after the Split-Point (Using McNemar’s test), for Shortened Sequences of W fields before and after The Split-Point and When Using the Entire Sequences

<table>
<thead>
<tr>
<th>W</th>
<th>BeforeW</th>
<th>AfterW</th>
<th>P</th>
<th>BeforeAll</th>
<th>AfterAll</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>3.7%</td>
<td>3.1%</td>
<td>0.287</td>
<td>4.3%</td>
<td>7.9%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>5</td>
<td>4.0%</td>
<td>4.3%</td>
<td>0.687</td>
<td>4.3%</td>
<td>8.0%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>6</td>
<td>5.3%</td>
<td>4.9%</td>
<td>0.644</td>
<td>4.4%</td>
<td>7.9%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>7</td>
<td>5.9%</td>
<td>6.0%</td>
<td>0.942</td>
<td>4.5%</td>
<td>7.5%</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>8</td>
<td>5.9%</td>
<td>6.4%</td>
<td>0.608</td>
<td>4.3%</td>
<td>6.7%</td>
<td>0.002</td>
</tr>
<tr>
<td>9</td>
<td>5.4%</td>
<td>6.3%</td>
<td>0.310</td>
<td>5.9%</td>
<td>6.6%</td>
<td>0.001</td>
</tr>
<tr>
<td>10</td>
<td>4.5%</td>
<td>5.3%</td>
<td>0.327</td>
<td>3.6%</td>
<td>6.2%</td>
<td>0.001</td>
</tr>
<tr>
<td>11</td>
<td>3.5%</td>
<td>4.5%</td>
<td>0.198</td>
<td>3.3%</td>
<td>5.4%</td>
<td>0.010</td>
</tr>
<tr>
<td>12</td>
<td>3.5%</td>
<td>4.5%</td>
<td>0.336</td>
<td>2.9%</td>
<td>5.4%</td>
<td>0.006</td>
</tr>
</tbody>
</table>
purposes, it may be possible to increase the series length (hence, reducing variability about the estimate of rate of change) without compromising sensitivity of detecting rapid progression. Another factor to be taken into consideration is that some patients produce more variable VFs than others, and so may require longer series for progression to become apparent.

The optimum analysis method and optimum series length could depend on disease severity. The main justification for not always using the first few fields in the series with linear analysis is that the patient may be stable for some time before progression begins, as in the example in Figure 2. A patient who already has developed a glaucomatous defect would be considered less likely to have a prolonged period of stability before progression accelerates. In addition, variability is much higher in more advanced disease, potentially making estimates of the rate of change based on fewer fields unreliable. As variability increases, robustness becomes more important, favoring linear models over nonlinear models with higher numbers of free parameters, but using longer series of fields to obtain more accurate estimates of the rate of change. Since this dataset does not contain a large number of cases of moderate or severe glaucoma, this conjecture would need testing in a different dataset.

Using the entire sequence, a significant change in MDR was observed at the split-point in the Continuous Treatment Cohort, with these eyes progressing more rapidly in the second half than in the first half of the study. No change in treatment status occurred during their sequence, as all patients in this cohort were treated from the start of the study (although the treatment given may have changed). It is possible that this is a chance characteristic of the data. However, even though the sample size is reduced when W is large, 986 eyes still would be considered more than adequate. It may be that this effect is caused by a significant number of those eyes beginning to progress towards the end of the sequence. It also could be indicative of nonlinearity of progression, with sensitivities accelerating downwards, as would be consistent with our previous findings in another dataset that the current MD is predictive of the rate of subsequent change. Finally, it also would be consistent with the presence of a learning effect causing sensitivities to rise over the first few fields of the sequence. This could explain partly the greater change in MDR when using, for example, W = 4 instead of W = 8. However, as W becomes quite large (7 or 8 fields), such participants will form only a small proportion of the sample size n, and so it is unlikely that this is driving the main conclusions of the analysis. Notably, when the same analysis was performed varying W but consistently using all series with at least 10 fields before and after the split-point, the change in MDR still was greater for smaller W.

Our study used MD to generate a measure of the rate of functional change, corresponding to disease progression. MD is useful as a global measure in clinical trials, such as the OHTS, but is insensitive to deterioration of small scotomas in individual patients. Clinically, change in MD would be just one of several measures used to determine whether changes in treatment are necessary. Point-wise changes are more variable. However, the same principle would apply, and nonlinear methods developed for MD are likely to have similar benefits when applied to point-wise data.

The main conclusion to be drawn from our study is that using the entire series of test results for linear trend analysis actually may be detrimental to early detection of rapid visual field change, especially when that progression is sporadic or preceded by a period of stability. At this early disease stage, rates of change were underestimated consistently when the entire sequence was used. Use of shorter sequences improved the ability to detect slowing of the rate of progression at the time treatment was initiated. By contrast, use of the shorter sequences did not cause a significant increase in the number of series for which a change in rate was detected in the absence of a change in treatment status. These results underscore the need for nonlinear models for progression, while also providing a method to reduce the problem until such models have been developed and validated. Such techniques could make trend analysis more sensitive to changes in the rate of progression, allowing earlier detection and implementation of appropriate treatments.

References


APPENDIX

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