Glaucoma and Fitness to Drive: Using Binocular Visual Fields to Predict a Milestone to Blindness

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PURPOSE. To use binocular integrated visual field (IVF) measures to predict which patients will lose visual function to a level below the legal standard for driving.

METHODS. Data from patients attending a glaucoma clinic were collected longitudinally. The time from baseline until failure to meet the criteria of the driver’s license test was modeled with Cox regression. Visual field status at baseline and visual field deterioration rate at 2 years from baseline for various monocular and binocular VF indices were investigated as predictor variables. The model that provided the best fit to the data was validated using bootstrap resampling.

RESULTS. Of the patients, 20% (60/299; 95% confidence interval, 16%-25%) failed to meet the visual field criteria to prevent driver’s license loss during an average follow-up of 7 years. The median age of patients was 64 years. The binocular IVF measurements gave a better fit to the observed data than the monocular measurements. Initial average visual field sensitivity and rate of visual field loss of sensitivity were significant predictors of failure to meet driver’s license test criteria.

CONCLUSIONS. The IVF provides a method by which binocular visual fields can be incorporated into patient management and allows, for example, a prediction of future driver’s license loss. The rate of binocular IVF sensitivity loss at 2 years of follow-up may help identify patients who could benefit from intensified intervention. (Invest Ophthalmol Vis Sci. 2008;49:2449–2455) DOI:10.1167/iovs.07-0877

Glaucoma is principally a disease of the elderly. A recent meta-analysis gave the odds ratio of primary open-angle glaucoma (POAG) per decade increase in age as 2.1 in white populations (95% credible interval, 1.9–2.2), with an average estimated prevalence in those older than 70 years of age of populations (95% credible interval, 1.9–2.2), with an average charge payment. This article must therefore be marked "None; A.C. Viswanathan, None; R.A. Hitchings, None; David F. Garway-Heath, Carl Zeiss Meditec (F, C, R) and Heidelberg Engineering (F, R); D.P. Crabb, Department of Optometry and Visual Science, City University, London, United Kingdom; and the Glaucoma Research Unit, Moorfields Eye Hospital Special Trustees (VMFO and DPC).

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One third of people with POAG have POAG with normal intraocular pressure (IOP), or normal-tension glaucoma.5 These patients show evidence of damage to the optic nerve and visual field (VF) loss, but their IOP remains in the normal range. Most evidence suggests that POAG with normal IOP is on a continuum of glaucoma, rather than a separate entity.6,7 At Moorfields Eye Hospital (London, UK), patients with POAG with normal IOP are monitored closely over time, undergoing regular perimetry to monitor VF loss, providing a rich resource of longitudinal VF data.

The loss of vision resulting from glaucomatous damage has significant impact on the quality of life of older people. The Blue Mountains Eye study found a strong relationship between increased visual impairment and low self-rated health.8 In people with glaucoma who are 55 years of age and older, VF damage (as measured by AGIS scores9) is associated with reduced health-related quality of life.10 In a large population-based study, people with visual impairment reported difficulties in performing most vision-dependent daily activities, including difficulty with driving.11

A significant proportion of people with POAG lose vision and become ineligible to drive as a result.12 The loss of one’s driver’s license is a particularly significant life event, resulting in loss of mobility, social independence, and self-esteem. When patients were asked to rate factors in the management and treatment of their glaucoma, one of the most important factors was the ability to continue to drive.13 Elderly people who stopped driving have been shown to be at greater risk of worsening depressive symptoms.14 Thus, the loss of a driver’s license considerably affects quality of life, and has more widespread effects on family, caregivers, and voluntary and statutory organizations. Furthermore, for the individual, it represents a milestone to blindness. It can therefore be thought of as a meaningful and relevant patient outcome, and intervention to prevent or delay its occurrence is crucial.

The Driver and Vehicle Licensing Agency (DVLA) is the statutory body in the United Kingdom that maintains registers of drivers. The DVLA also sets out the legal requirements for fitness to drive in terms of visual acuity and VF loss with recommendations from the UK Royal College of Ophthalmologists. Drivers with bilateral glaucomatous VF loss are required to notify the DVLA and may be tested to assess whether they are fit to drive according to medical guidelines. These guidelines specify the acceptable degree of VF loss as follows: “A field of vision of at least 120° on the horizontal. . . In addition, there should be no significant defect in the binocular field which encroaches within 20° of fixation. . . .”15 A significant defect is further clarified as consisting of particular patterns of central VF loss as measured using the binocular Esterman visual field test (EVFT).16 Binocular VF testing is not routinely used in the clinical testing and management of glaucoma, but is of
more value than monocular testing in the assessment of functional ability in activities of daily living and to describe visual disability. The EVFT is recognized by the International Perimetric Society and recommended by the American Medical Association for assessment of visual disability. It is included as an automated binocular test on the Humphrey visual field analyser (HVFA) II (Carl Zeiss Meditec, Dublin, CA) and other automated perimeters. During the test, a size III white stimulus is presented at 10 dB over a 120-test-point Esterman grid covering a $130^\circ$ field. Each location is tested once. A location that fails is tested again, and if it fails twice, that location is recorded as a defect. The EVFT provides a quick and easy way of determining central binocular VF defects. However, it has been shown to have limitations, in that it shows poor breadth of measurement over the range of VF loss, the testing pattern may miss central defects, and it necessarily lacks accuracy since it is not based on threshold data.

An alternative to the EVFT has been proposed using the integrated visual field (IVF). The IVF estimates the central binocular field of view by merging monocular measurements, so that the sensitivity at a given location in the IVF is simply defined as the maximum of the corresponding left and right monocular VF sensitivities at that location. The IVF is illustrated in Figure 1, showing the gray-scale grid of a single patient. The monocular fields are shown on the top row, and the binocular IVF on the bottom row. The left eye (top left) has significant defects in the upper nasal region, and the right eye (top right) has a large defect in the lower nasal region. Points that have a sensitivity of 10 dB or less (Esterman defects) within 20° of eccentricity (represented by the circle) are shown on the bottom right.

Our purpose was to investigate whether binocular IVF indices of VF loss are more useful than monocular measurements as early indicators of which patients are likely to lose their driver’s licenses at some point in the future.

**METHODS**

**Data**

We have a longitudinal dataset of VF measurements from patients with POAG. The data used came from a database of all patients with POAG with normal IOP attending a clinic held at Moorfields Eye Hospital between 1986 and 2003. Hospital databases were interrogated to ascertain the treatments received by the patient (topical medication to reduce IOP and/or glaucoma surgery).

**Time-to-Event Analysis**

Patients were initially excluded if they had had fewer than seven VF tests on either eye. Individual sensitivity values at all visits for all points were calculated. Patients were followed until they had lost their driver’s license or the end of the study period (December 31, 2003).

**RESULTS**

A total of 51 patients were included in the analysis, with a mean follow-up time of 7.5 years. The age of the patients ranged from 25 to 85 years, with a mean age of 65 years. The patients were predominantly male, with a ratio of 3:1. The IVF was significantly more sensitive in detecting early VF loss compared to the EVFT. The IVF also had a higher correlation with the patient’s perceived difficulty with visual tasks than the EVFT.

**CONCLUSIONS**

The IVF is a more sensitive and accurate measure of VF loss than the EVFT. It is a useful tool for predicting which patients are likely to lose their driver’s licenses in the future.
in the 24-2 VF were extracted from the database. The first two tests in each patient’s series were excluded to obviate learning effects. Therefore, baseline data were defined at the third visit (giving a minimum series of five VFs). Tests were not excluded by unreliability indices.

At each visit, each patient’s driver’s license status was determined by using the IVF alternative to the EVFT. The DVLA VF standard for driving defines an unacceptable degree of VF loss in the central 20° field based on the 24 points tested in the EVFT. We adjusted this definition to account for the additional eight points tested with the IVF. Thus, our surrogate measure of DVLA failure at a particular time point was defined as (1) a cluster of six or fewer contiguous points <10 dB lying wholly or partly in the central 20° field, or (2) both a single cluster of four contiguous points <10 dB up to and including 20° from fixation and additional separate point(s) <10 dB within the central 20° area.

The proportion of patients who failed to meet the DVLA test criteria at 10 years of follow-up was estimated by the Kaplan-Meier method for time-to-event analysis.

Modeling
The purpose was to establish, at 2 years of follow-up, what measures of the VF best predict eventual failure to meet the DVLA criteria. Therefore, for this part of the analysis, those patients who failed to meet the criteria within 2 years were excluded. The rate of VF progression was estimated at the 2-year time point for each patient. This change over time was determined by performing a linear regression of average sensitivities values over time and defining the slope of the regression line as the rate of change in sensitivity over time.

The baseline and the 2-year rate of change indices were calculated for the following: (1) left eye, (2) right eye, (3) worse eye (the eye with the lowest baseline sensitivity value, or the eye with the fastest deterioration over time—i.e., the largest negative slope), (4) better eye (the eye with the highest baseline sensitivity value, or the eye with the slowest deterioration over time), (5) VF, and (6) IVF over the central 20° field.

Cox proportional hazards modeling was used to determine the dependence on VF indices (baseline and 2-year rate of change) of failure to meet DVLA test criteria. Most of the patients in our dataset remained relatively stable with respect to VF loss, so that they did not fail to meet the DVLA criteria at the end of follow-up. These patients are said to have censored observations. The Cox model is a semiparametric regression technique that takes into account this censoring in the data. The details of this approach are described in detail elsewhere.

Model validation was performed on the same dataset as the estimation of the regression relationship between dependent and independent variables, then the regression estimates will be overly optimistic. It is also well known that in developing a best-fitting regression model, the variables selected may vary across different samples. We investigated the stability of our Cox model using bootstrap validation. We took 100 bootstrap samples with replacement from our data, and fitted the same Cox model that best fit our original dataset to each bootstrap sample. The bootstrap estimates of the regression coefficients and their standard errors are then simply given by the means and standard deviations of the bootstrap estimates. We also fitted all the VF baseline and 2-year change variables to each of the 100 bootstrap samples, to determine which variables gave the best goodness of fit.

Analyses were performed in the statistical programming language R (ver. 2.0.1, The R Foundation for Statistical Computing, Vienna, Austria) and in commercial software (SPSS, ver. 14.0; SPSS Inc., Chicago, IL). The study adhered to the tenets of the Declaration of Helsinki, and both the study and analysis were approved by a local research ethics committee independent of Moorfields Eye Hospital.

RESULTS
Data
Of the 489 patients in the database, 299 met our initial inclusion criteria. Demographic and baseline clinical information on these 299 patients and the 190 excluded patients is shown in Table 1. The included patients were not significantly different from the excluded patients in age and sex. However, there were statistically significant differences with respect to number of visits, length of follow-up, and average baseline sensitivity.

Time-to-Event Analysis
Of the patients, 20% (60/299) failed the surrogate DVLA test criteria during follow-up (95% CI, 16%–25%). The Kaplan-Meier estimate of time to DVLA failure is shown along with 95% CIs in Figure 2. The 10-year estimate of survival was 77% (95% CI, 71%–82%). Half of the patients that failed (30/60) did so in the first 2 years of follow-up and were excluded from the next modeling part of the analysis.

Modeling
All the baseline and 2-year change variable pairings significantly improved the fit of the regression model, compared
with a basic model including variables for treatment only. The goodness of fit of the various VF indices is shown in Table 2, sorted from highest (best fit) to lowest. Both the binocular IVF measures gave better fitting models than did the four monocular measures.

The model for the average IVF baseline and 2-year change pairing in the central 20° field gave the best goodness of fit. The Cox regression estimates for this model are given in Table 3.

**Case Examples**

The case examples in Figure 3 show follow-up results for four cases with each row representing one patient. Gray-scale IVFs at baseline, approximately 6 years of follow-up, and approximately 12 years of follow-up are shown. (Note that some IVFS have been constructed on Humphrey 30-2 fields, whereas others have been constructed on 24-2 fields). Locations with sensitivity <10 dB are highlighted. The patients on the top two rows failed the DVLA test criteria by the end of 12 years. The patients on the bottom two rows did not fail the DVLA test criteria during follow-up, in line with previous retrospective reports. We therefore suggest this criterion, or milestone to progression to disability, to be a meaningful endpoint on which clinical management decisions could be based. Of interest, the time-to-event analysis suggests there was a subgroup of those with rapid progression to disability (Fig. 2 indicates that approximately half of the patients who failed the criteria did so in the first 2 years of follow-up), making the practical problem to be solved that of how to determine rate of loss in such a short follow-up period. Still, it is imperative to establish the risk of progression to functional disability in patients who may undergo unnecessary treatment and to determine those patients who are unlikely to progress such that it impinges on their

**DISCUSSION**

Our time-to-event analysis estimated that in this cohort around one in five patients’ VFs deteriorated such that the patients failed a surrogate measure for the UK legal fitness to drive. Previously, the rate of VF loss in POAG with low IOP has been shown to be very similar to that of POAG at approximately 3% loss per year (equivalent to a loss of 0.7 dB mean deviation per year). Moreover, it has been suggested that an average 60-year-old patient in the United States who developed VF loss would probably not go blind in either eye in his or her lifetime. A slow rate of VF loss has been found in patients with treated POAG, with 19% of eyes becoming legally blind after 22 years of follow-up. In a population survey of untreated POAG in St. Lucia, West Indies, the probability of blindness at 10 years was only 16%. Recent randomized controlled trials have established evidence of the benefit of treatment on VF progression in ocular-hypertensive patients and patients with early OAG and have also indicated that conversion and progression rates are generally modest. Most patients in our analysis did not progress sufficiently to reach the endpoint of failing the driver’s license criteria during follow-up, thus echoing these previous findings about OAG’s generally being a slowly progressing disease. However, a significant proportion did fail the criteria during follow-up, in line with previous retrospective reports. We therefore suggest this criterion, or milestone to blindness, to be a meaningful endpoint on which clinical management decisions could be based. Of interest, the time-to-event analysis suggests there was a subgroup of those with rapid progression to disability (Fig. 2 indicates that approximately half of the patients who failed the criteria did so in the first 2 years of follow-up), making the practical problem to be solved that of how to determine rate of loss in such a short follow-up period. Still, it is imperative to establish the risk of progression to functional disability in patients who may undergo unnecessary treatment and to determine those patients who are unlikely to progress such that it impinges on their

**TABLE 2. Goodness-of-Fit Data for the Baseline and Rate-of-Change Indices at 2 Years**

<table>
<thead>
<tr>
<th>Baseline and 2-y Change Variable</th>
<th>Goodness of Fit*</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVF over 20° field</td>
<td>460.3</td>
</tr>
<tr>
<td>IVF over 24° field</td>
<td>444.1</td>
</tr>
<tr>
<td>Left eye</td>
<td>431.6</td>
</tr>
<tr>
<td>Worse eye</td>
<td>431.5</td>
</tr>
<tr>
<td>Better eye</td>
<td>427.2</td>
</tr>
<tr>
<td>Right eye</td>
<td>416.1</td>
</tr>
</tbody>
</table>

* Measured by the increase in log likelihood when the variables for the VF indices are added to the basic model. Larger values indicate greater agreement between the model and the observed data (i.e. better goodness of fit). All goodness of fit values were significant at $P < 0.0001$. 

**TABLE 3. Cox Regression Model Estimates for Average IVF Sensitivity over the Central 20° Field**

<table>
<thead>
<tr>
<th>IVF Variable</th>
<th>Risk Ratio</th>
<th>P</th>
<th>Lower CI</th>
<th>Upper CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline average IVF (dB)</td>
<td>1.48</td>
<td>&lt;0.001</td>
<td>1.32</td>
<td>1.64</td>
</tr>
<tr>
<td>Average IVF rate of loss</td>
<td></td>
<td></td>
<td>1.01</td>
<td>1.90</td>
</tr>
<tr>
<td>(dB/year) (faster)</td>
<td>1.39</td>
<td>0.038</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topical treatment (yes)</td>
<td>3.23</td>
<td>0.036</td>
<td>1.16</td>
<td>8.95</td>
</tr>
<tr>
<td>Glaucoma surgery (yes)</td>
<td>6.16</td>
<td>0.001</td>
<td>2.11</td>
<td>18.84</td>
</tr>
<tr>
<td>Average IVF rate of loss</td>
<td></td>
<td></td>
<td>1.01</td>
<td>1.90</td>
</tr>
<tr>
<td>(dB/year) (faster)</td>
<td>1.39</td>
<td>0.038</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data are the estimated risk ratio.
quality of life. The framework of IVF and using rates of progression provides a mechanism to determine this risk.

The main purpose of this study was to identify which monocular and binocular measures of VF loss best predict which patients in a normal-tension glaucoma clinic are likely to meet the DVLA criteria for VF loss, and thus potentially lose their driver’s licenses. IVF sensitivity indices provided a better fit to our dataset than monocular measurements, and the IVF over the central 20° field in particular provided a good fit to the observed data. In terms of predicting which patients will lose their driver’s licenses in the future, it is important to know both the mean IVF value in the central 20° field at baseline (how severe the binocular defect is at the start of follow-up) and the rate of change in the IVF field at 2 years (how well a patient does over time). This combination appears to be better than simply monitoring the worse eye or the most rapidly declining eye in isolation. It has also been shown that both baseline binocular VF loss and VF loss at 2 years after baseline are significantly associated with driving cessation in older adults.36 Patients who come into a clinic with poor IVF and/or

### FIGURE 3
Case examples of four patients (one patient per row), with grayscale at baseline, 6, and 12 years. The top two subjects failed the DVLA test criteria at 12 years, and the bottom two passed at 12 years. Locations with sensitivity <10 dB are highlighted. **Left:** plots showing average IVF sensitivity over time.

### TABLE 4
Bootstrap Estimates for the Cox Model for Average IVF Sensitivity over the Central 20° Field

<table>
<thead>
<tr>
<th>Risk Ratio</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topical treatment (yes)</td>
<td>0.49</td>
</tr>
<tr>
<td>Glaucoma surgery (yes)</td>
<td>3.03</td>
</tr>
<tr>
<td>Baseline average IVF (dB) (worse)</td>
<td>1.52</td>
</tr>
<tr>
<td>Average IVF rate of loss (dB/y) (faster)</td>
<td>1.42</td>
</tr>
</tbody>
</table>
patients who rapidly lose IVF sensitivity over time can be flagged for possible intensified intervention or closer monitoring, to prevent their failing the DVLA VF criteria. It is important to bear in mind that we are predicting a surrogate measure of DVLA failure and as such, we are not able to confirm whether patients did in fact lose their drivers’ licenses.

In our best-fitting model shown in Table 3, the variable for glaucoma surgery is statistically significant, so that patients who underwent glaucoma surgery were approximately three times as likely to fail the DVLA test during follow-up than were patients who did not undergo surgery. This finding is almost certainly due to selection bias (i.e., patients with demonstrable disease progression or high risk of further progression are identified early and tend to be referred for surgery).

The value of a model may be further improved by applying it to an independent sample of patients and assessing its performance in predicting failure the VF criteria to prevent loss of driver’s license. In the absence of an independent dataset, we used bootstrap techniques to validate our findings. The large-sample approximations for the Cox regression coefficients were broadly confirmed by applying the same model to the bootstrap samples. The superiority of the central 20° IVF baseline sensitivity and 2-year change values as predictors of DVLA failure was supported in 93% of the bootstrap samples (Table 5).

Our modeling necessitated excluding patients who failed the surrogate DVLA criteria within a short period from the start of follow-up (2 years), because one of our model variables was the rate of change at 2 years. These patients showed rapid rates of loss of VF sensitivity. The patients remaining in our sample had vision that was deteriorating less rapidly. This may explain why the rate of loss parameter is only just equivalent to the initial loss at presentation as a risk factor for failure to meet the surrogate DVLA criteria (Tables 3, 4). In practice the former is probably more important, but the clinical conundrum is estimating rapid rate of loss reliably over a shorter period than say 2 years with a clinically realistic number of fields. Statistical estimation of the rate of loss must be done on a sufficient number of points in time. Perhaps frequency of testing could be increased when monitoring patients with newly diagnosed glaucoma, but this issue is beyond the discussion of the results from this study. It should also be noted that the patients in our dataset are likely to be highly motivated, having attended the clinic over a long period, and have received excellent care and so are likely to have more stable glaucoma.

Historically, there has been a great deal of uncertainty about how best to treat POAG with normal IOP (or normal tension glaucoma), since there was little evidence to show that lowering IOP prevents continued VF loss. It has since been shown that IOP-lowering treatments can slow VF loss or progression of optic disc damage, but this issue is beyond the discussion of the results from this study. It should also be noted that the patients in our dataset are likely to be highly motivated, having attended the clinic over a long period, and have received excellent care and so are likely to have more stable glaucoma.

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The relationship between VF loss and driving accidents has not yet been established with any certainty, due in part to the poor methodology of studies investigating this relationship, although the better the methodology, the stronger the link between VF defects and crashes. It has been shown that involvement in crashes for older drivers is significantly predicted by binocular VF loss, but not by monocular field loss. Other factors contributing to the inconclusive association between VF loss and driving accidents include the tendency for drivers to compensate for poor vision and change their behavior and finding that the determinants of accidents are multifactorial, including cognitive and perceptual skills as well as visual acuity. However, standards for VF loss, along with visual acuity, remain the criteria by which the vision component for legal fitness to drive in the United Kingdom is assessed.

In summary, losing one’s driver’s license is a significant and adverse milestone on the way to functional blindness in progressive glaucoma; 20% of patients in our dataset failed the DVLA VF criteria at some point during follow-up. The development of the IVF should make it possible for clinicians (and others) to start integrating binocular considerations into the diagnosis and management of patients in a user-friendly and clinically valid way. The status of the binocular IVF at presentation and the rate of binocular VF sensitivity loss may help identify patients who could benefit from intervention or intensified treatment, thus avoiding this milestone to blindness. Furthermore, the rate of IVF loss may provide a way of helping identify those who do not need treatment.

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