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Examining Visual Field Loss in Patients in Glaucoma Clinics During Their Predicted Remaining Lifetime

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PURPOSE. To evaluate the proportion of patients in glaucoma clinics progressing at rates that would result in visual disability within their expected lifetime.

METHODS. This retrospective study used visual field (VF) series of at least 3 years' duration from 3790 UK patients in glaucoma clinics calculating rates of loss for each eye using linear regression of mean deviation (MD) over time. Residual life expectancies derived from the UK Office of National Statistics actuarial tables for each patient were combined with these rates to estimate predicted MDs at end of expected lifetime. The proportion of patients projected to progress to visual impairment (MD: -14 dB or worse) or statutory blindness (MD: -22 dB or worse) in both eyes before end of expected lifetime was calculated.

RESULTS. Only 3.0% (95% confidence interval [CI] 2.7%–3.4%) of patient eyes progressed at faster than -1.5 dB/year ($n = 7149$ eyes). Of those patients with both eyes followed, 5.2% (CI 4.5%–6.0%) were predicted to progress to statutory blindness, with a further 10.4% (CI 9.4%–11.4%) reaching visual impairment in their lifetime. More than 90% (CI 85.7%–94.3%) of patients predicted to progress to statutory blindness, had an MD worse than -6 dB in at least one eye at presentation.

CONCLUSIONS. This modeling exercise indicates that most patients in glaucoma clinics are not at high risk of progressing to statutory blindness. The likelihood of patients suffering impairment in their lifetimes is linked to VF loss at presentation, which illuminates the importance of reliably detecting significant VF defects in primary care.

Keywords: glaucoma, visual fields, perimetry, visual function, life expectancy

Treatments for glaucoma attempt to slow the rate of visual field (VF) loss, which normally involves reducing the only known modifiable risk factor for the condition, the IOP.¹ The main aim of treatment is to avert the threat of blindness and ensure that a patient's visual function, and quality of life, remains unaffected within his or her lifetime. Once diagnosed, all patients normally need lifelong treatment and monitoring so that any worsening of visual impairment can be detected and treatment can be changed accordingly. As a result, monitoring patients with glaucoma represents a major workload for eye services. Visual field testing (perimetry) is the only direct method for monitoring functional change in patients, and thus, to assess whether a treatment is succeeding in preventing future visual impairment. Levels of VF loss can be summarized using the mean deviation (MD) index. The MD is a weighted average of the differences between the measured and normal age-matched sensitivity values across the whole VF; the more negative the MD, the worse the level of VF damage. In the United States, statutory (legal) blindness continues to be defined as best-corrected visual acuity of 20/200 or worse, but also includes a definition based on VF limitation.² In particular, the widest diameter of the VF, in the better eye, must subtend an angle at least 20 degrees. The US Social Security

Administration (SSA) has recently determined that automated perimetry can be used for the latter, with an MD of -22 dB in the better eye corresponding to the VF definition of statutory blindness (a landmark used recently by another study).³

Many patients newly diagnosed with glaucoma are not at a high risk of blindness. Studies based on retrospective chart reviews have found that the proportion of patients that progressed to blindness during follow-up ranged from approximately 6% to 13%.⁴⁻⁶ However, these studies used data collected on manual perimetry, were based on relatively small numbers (all fewer than 300 patients) and were all carried out more than 10 years ago. Other estimates for VF loss in predicted lifetime can be extrapolated from more recently conducted prospective studies. The Early Manifest Glaucoma Trial (EMGT) found that the median progression rate of MD, even in patients without treatment, was slower than -0.5 decibels (dB) per year⁷; as an example, a patient with little VF damage at diagnosis (say, -2 dB) would take 40 years to reach an MD of -22 dB at this rate of decay, assuming a linear rate of VF deterioration (progression). Of course, 40 years is likely to exceed most patients' expected lifetimes when it is considered that the onset of glaucoma is usually toward the end of patients' lives. Obviously, there is large variation in rates of VF loss and

faster progressing patients are at greatest risk of visual impairment, yet the prevalence of these “fast progressors” in clinical practice is unclear. Cohort studies from Canada and California have indicated that less than approximately 5% of patients progress at a rate of -1.5 dB/year or worse.⁸⁻¹⁰ However, results from retrospective studies, which may reflect clinical practice more closely but are less well controlled, are less consistent; results from the New York Progression Study suggest that the prevalence of fast progressors ranges from 9% to over 25% (with the use of different exclusion criteria).¹¹⁻¹³ In addition, a recent review of clinical data from Sweden by Heijl and colleagues¹⁴ recorded more than 15% of patients progressing at a rate faster than -1.5 dB/year.

Taking treatment and monitoring costs into account, it is extremely important that resources are prioritized in favor of those patients who are at greater risk of suffering significant visual disability in their lifetime.¹⁵ In this context, information about rate (speed) of VF loss over a period of follow-up is clinically useful. Recent research has emphasized the clinical importance of this approach by recommending frequency and pattern of VF testing required over time so as to establish reasonable estimates of these rates.¹⁶⁻¹⁹ Once the rate of VF loss has been established, a natural next step is to consider the likelihood of a patient suffering visual disability within their expected lifetime. Incorporating estimates of life expectancy adjusted for age (residual life expectancy) in glaucoma care was suggested by Wesselink et al.,²⁰ but before now has not been implemented. Therefore, in this study, we attempted to estimate the proportion of patients under clinical care in glaucoma clinics that progress at a rate quick enough to result in serious visual impairment in their expected lifetime.

MATERIALS AND METHODS

Three separate Medisoft (Medisoft Ltd., Leeds, UK) VF databases from glaucoma clinics in Moorfields Eye Hospital in London, Cheltenham General Hospital Gloucestershire Eye Unit and Queen Alexandra Hospital in Portsmouth were made available for this retrospective study. The databases contained a total of 402,357 anonymized VFs from 75,857 patients recorded between 1989 and 2012. The study adhered to the tenets of the Declaration of Helsinki, was approved by a research governance committee of City University London and all anonymized data were transferred to a secure computer database. Only VFs recorded on the Humphrey Visual Field Analyzer (HFA; Carl Zeiss Meditec, Dublin, CA) with the 24-2 test pattern, a Goldmann size III stimulus, and the SITA (SITA Standard or SITA Fast) testing algorithm were included in the study. Unreliable VFs, defined here to have an HFA false-positive or false-negative score of 33% or more, or an HFA fixation loss score of 20% or more were excluded; 29.6% of the SITA Standard and Fast VF records were excluded from the study owing to these reliability criteria.

This study centered on VF progression, and, to be included in the study, one of each patient's eyes had to have a VF series that was at least 3 years long, with at least five VFs after discounting the first VF in order to attempt to obviate learning effects (improvements in results through the patient becoming more practiced at taking the tests).²¹⁻²³ The first recorded MD, having excluded the initial VF for learning effects, is subsequently referred to as the baseline MD, whereas the last recorded MD in the follow-up is denoted as the final MD. The study considered only VF data and no other clinical information. Therefore, it was not possible to confirm whether individuals in the database were *clinically* diagnosed with glaucoma or were glaucoma suspects. Thus, the baseline VF of each patient had to have an HFA MD or HFA pattern SD value

outside the established HFA 95% normal limits in at least one eye. Given that individuals had measurable VF damage at baseline and were followed regularly for at least 3 years in these glaucoma clinics, it is reasonable to assume that the vast majority in this study had glaucoma. Patients younger than 35 years were not included in the study.

Rates of MD loss were calculated in decibels per year (dB/y) by using ordinary least squares regression. It was assumed that the rate of change in MD would remain constant for the remainder of a patient's expected lifetime. Therefore, the MD at expected death was calculated as the observed rate of loss multiplied by the patient's residual life expectancy (see Fig. 1). It is important to use residual life expectancies to take into account patient age rather than use population age statistics, as the probability of dying at a particular age will not remain constant across all ages; for instance, the probability of a 10-year-old living to 78 is very different from an individual who has already lived to 76. Median life expectancies, based on age and sex, were collected from the UK Office of National Statistics²⁴; these were derived using the latest available English census data (2001) and survey data to estimate expectancies valid for the 2008 to 2010 period.

When assessing visual disability in a patient's lifetime, it is necessary to consider the VF loss in both eyes; a damaged VF in one eye will not necessarily impact on the overall visual function of a patient if the other eye remains healthy.²⁵ Methods for classifying overall VF damage into “moderate” or “severe” abound,²⁶⁻²⁸ but few offer thresholds that have an evidence base underpinning their link to visual impairment or offer any practical meaning to a patient. Nevertheless, recent results suggest that a patient with an MD less than -14 dB in their “better” eye (the eye with the least-damaged VF) is highly unlikely to satisfy the vision component of legal fitness to drive in the UK.²⁹ Hence, this threshold was used as a benchmark for “visual impairment” in the current study. A second MD benchmark for “statutory blindness” equal to -22 dB, as recommended by the US SSA,² was also used. To be classified as having visual impairment or statutory blindness, both patient eyes had to reach the necessary levels of VF loss. If patients had fewer than three VFs performed in one of their eyes, then their baseline MDs were recorded and the eyes were either deemed to be stable (i.e., progressing at a rate of 0 dB/y) or progressing (at a rate of -1.5 dB/y) representing a “best-” and “worst-” case scenario, respectively. In the event of no recorded VF for the other eye, the eye was recorded as either visually healthy for the “best-case scenario” or blind in the “worst-case scenario.” The open-source statistical environment R³⁰ was used for all statistical analyses.

RESULTS

The characteristics of the study sample of 3790 patients are given in Table 1.

Figures 2A and 2B show the distribution of patient eye follow-up times, patient residual life expectancies, and progression rates in all eyes, respectively. It is apparent from Figure 2B that the vast majority of eyes progressed at a rate between ± 0.5 dB/y (74%-95% binomial confidence interval [CI]: 73%-75%). A small proportion of patient eyes progressed at a rate worse than -1 dB/y (7.5% CI: 6.9%-8.2%) and only 3.0% (CI: 2.7%-3.4%) of eyes progressed at faster than -1.5 dB/y. It is worth noting that a considerable number of eyes recorded positive MD rates (33.3% CI: 32.2%-34.4%).

Of the 3359 patients with a VF series from both eyes (Table 2, Fig. 3; see Supplementary Material Clip S1 for an animated version of Fig. 3), only 5.2% progressed to statutory blindness (both eyes progressing to an MD worse than -22 dB) with a

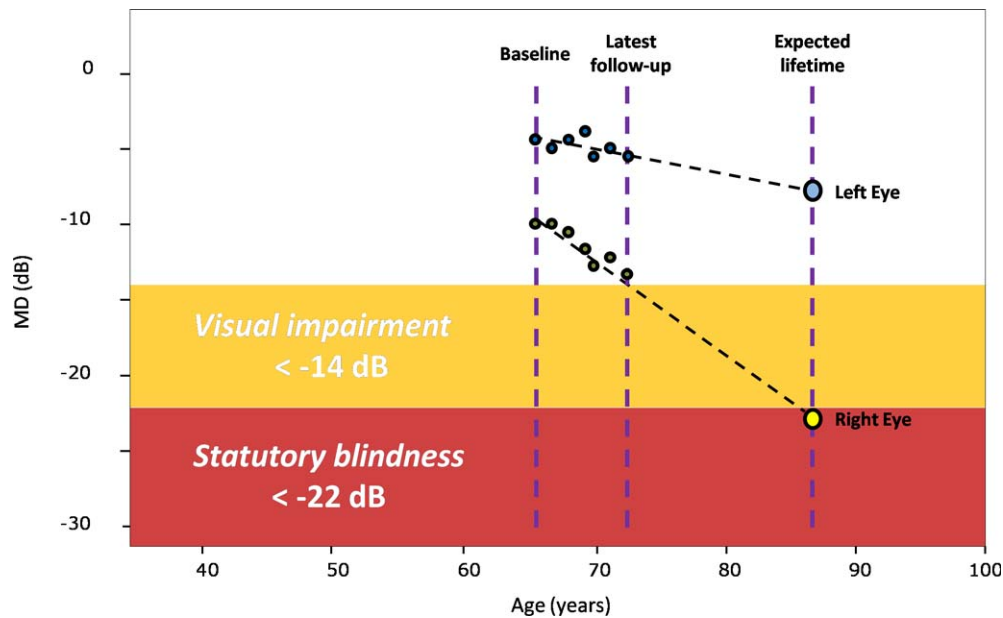


FIGURE 1. A schematic illustrating the analysis conducted in this study. Visual field series from the left and right eyes of a patient were used to estimate a linear rate of loss in each eye (dB/y). The patient’s median life expectancy was obtained from the UK Office of National Statistics,²⁴ and was used to predict the MD of each eye at expected time of death. In this illustration, the right eye was anticipated to progress into the statutory blindness stage by the end of the patient’s life. However, given that the left eye is progressing less quickly and has less VF damage at the outset, this patient would be unlikely to experience severe visual disability in the patient’s lifetime.

further 10.4% progressing to visual impairment (both eyes progressing to an MD level of worse than -14 dB) in their expected residual lifetime. The “best-case scenario” produced similar results to those just considering eyes with two series, but under the “worst-case scenario,” the number of patients at risk of statutory blindness increased to 7.1%, and a further 11.5% were at risk of visual impairment (Table 2). Interestingly, almost half of the patients with both eyes followed had at least one eye with a positive rate of change (49.0% CI: 47.3-50.7).

When just patients with series in both eyes tested were considered, 159 of the 175 patients (90.9% CI: 86.6%-95.1%)

who reached statutory blindness had an MD worse than -6 dB in at least one eye at baseline; this MD level is equivalent to what is considered to be at least a “moderate defect” for one criterion of the Hodapp-Parrish-Anderson index.²⁶ Patients who were predicted to progress to statutory blindness were approximately 70% more likely to have moderate damage (MD worse than -6 dB) in at least one eye at baseline than patients not predicted to progress to this stage (+ Likelihood Ratio: 1.7; 95% CI: 1.6-1.8). Put differently, only 1.1% (CI: 0.6%-1.6%) of the patients who were likely diagnosed with early VF defects, with an MD better than -6 dB in both eyes (44% of the study

TABLE 1. The Demographics of Patients Analyzed in the Study

Measure	Patients With Series in Both Eyes, n = 3359	Patients With a Series in One Eye Only, n = 431
No. of patients with glaucoma (VF defects) in both eyes (%)	2212 (65.9)	NA
No. of female patients (%)	1684 (50.1)	228 (52.9)
No. of patients from London (%)	3124 (93.0)	413 (95.8)
No. of patients from Cheltenham (%)	183 (5.4)	10 (2.3)
No. of patients from Portsmouth (%)	52 (1.5)	8 (1.9)
Median no. VFs recorded (IQR)	6 (5-8)	6 (5-8)
Median follow-up time (IQR)	7.1 y (5.2-9.1)	7.2 y (5.5-8.9)
Median baseline age (IQR)	65 y (56-72)	66 y (57-75)
Median final age (IQR)	71 y (62-78)	72 y (63-80)
Median residual life expectancy from final age (IQR)	16 y (11-22)	14 y (9-21)
Median baseline MD in better eye* (IQR)	-2.6 dB (-5.2 to -1.1)	-7.0 dB (-11.9 to -3.7)
Median baseline MD in worse eye* (IQR)	-6.9 dB (-12.5 to -3.8)	
Median final MD in better eye* (IQR)	-3.4 dB (-6.8 to -1.3)	-8.4 dB (-14.6 to -4.7)
Median final MD in worse eye* (IQR)	-8.7 dB (-14.8 to -4.6)	
Median rates of loss in better eye* (IQR)	-0.12 dB/y (-0.38-0.07)	-0.19 dB/y (-0.54-0.05)
Median rates of loss in worse eye* (IQR)	-0.15 dB/y (-0.46-0.08)	

IQR, interquartile range (the middle 50% of ordered values ranging from the first to third quartile).

* The better eye corresponds to the eye with the better MD at the baseline VF examination.

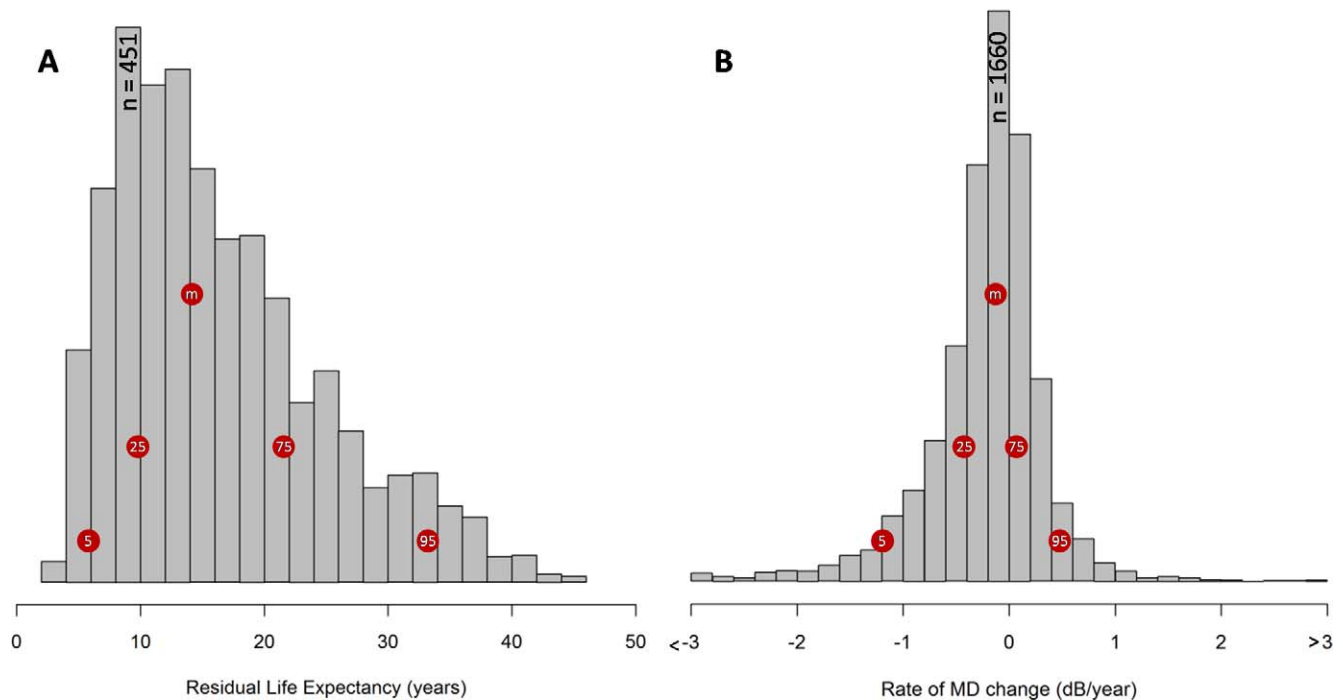


FIGURE 2. (A) Distribution of residual life expectancies for all 3790 patients included in the study and (B) the rate of progression of MD (dB/y) from all 7149 eyes. The distribution of life expectancies is positively skewed as a result of the increased prevalence of glaucoma in older patients. The red circles indicate the median (m) and other quantiles.

population), progressed to statutory blindness. Strikingly, almost 60% (CI: 52.0%–66.4%) of patients progressing to statutory blindness had one eye with an MD already worse than –14 dB in at least one eye at baseline.

DISCUSSION

This retrospective study of a very large number of VFs collected in different clinics over a 23-year period has provided a number of interesting findings. The modeling indicated that a small proportion of patients under clinical care in glaucoma clinics in the United Kingdom were estimated to be at high risk of progressing to a level of statutory blindness in both eyes during their predicted residual lifetime. The proportion of patients predicted to be at risk of progressing to statutory blindness in both eyes within the study was 5.2%, although this figure may be as high as 7.1% (“worst-case scenario”) depending on the reasons behind testing only single eyes in some patients. These results, from the perspective of the burden of diagnosed glaucoma, seem more optimistic than those of previous studies. For example, Kwon et al.⁵ predicted from their study that the number of patients becoming legally blind over a follow-up of 22 years could be as high as 19%, whereas others have also predicted higher proportions.^{4,6} The

different methodologies used in these studies conducted more than a decade ago are likely to explain the different results. For example, the previous studies did not use a modeling approach, were based on far fewer patients, used different definitions for legal blindness, and because they used “retrospective chart review” were very likely subject to selection bias. At the same time, it is tempting to explain the differences with the idea that modern therapies are improving patient prognosis in glaucoma. Despite small numbers reaching statutory blindness, it should be noted that a significant minority of patients (approximately one in six patients) in our study were predicted to develop VF loss that could affect their quality of life; for example, a level of impairment that would likely result in loss of a driving license in the United Kingdom.²⁹

Interestingly, the very wide distribution of rates of VF loss shown in Figure 2B is reminiscent of similar results shown in controlled prospective studies.^{7,9} However, the proportion of eyes that are very rapidly progressing appears substantially smaller than those of many other retrospective studies. The 3% of eyes highlighted in our study as progressing at faster than –1.5 dB/y was in contrast to the figures from the recent findings from the study by Heijl et al.¹⁴ in Sweden that estimated that 15% progressed at a rate faster than –1.5 dB/y and the New York Progression Study, which concurred that

TABLE 2. The Proportion of Patients Likely to Suffer VF Impairment in the Course of Their Lifetime

Visual Impairment at Death	% No Impairment (95% CI*)	% Visual Impairment (95% CI*)	% Statutory Blindness (95% CI*)
Including patients with a series for each eye only, n = 3359	84.4 (83.2–85.6)	10.4 (9.4–11.4)	5.2 (4.5–6.0)
All patients best-case scenario, n = 3790	84.9 (83.7–86.1)	10.0 (9.0–11.0)	5.1 (4.3–5.8)
All patients worst-case scenario, n = 3790	81.5 (80.2–82.8)	11.5 (10.4–12.5)	7.1 (6.2–7.9)

* 95% CIs were calculated using the normal approximation of a binomial distribution.

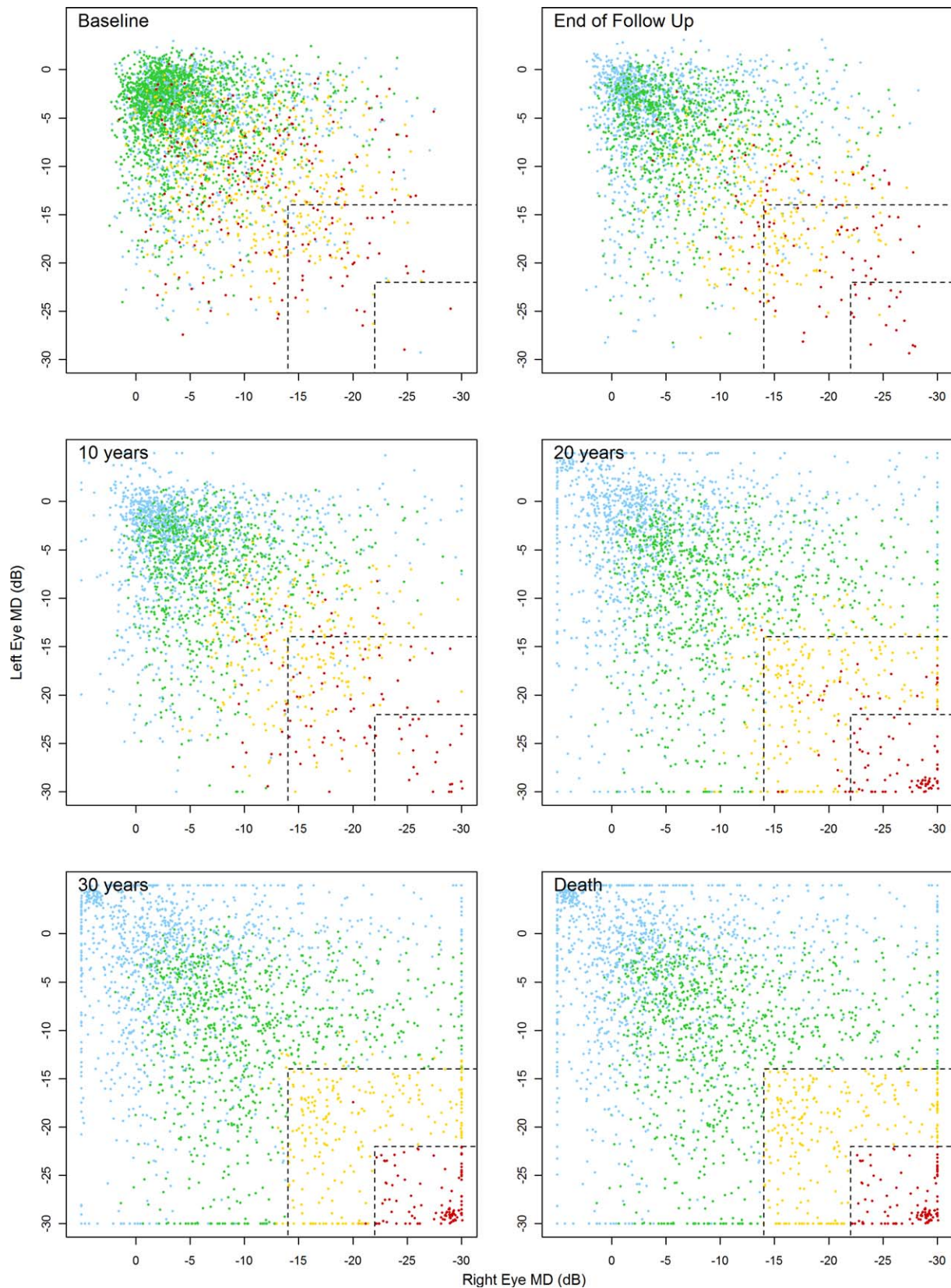


FIGURE 3. A series of scatterplots showing MD in left (*y*-axis) and right (*x*-axis) eyes at baseline, at the end of follow-up, through extrapolating current rates of MD deterioration, after 10, 20, and 30 years of follow-up and at the end of expected lifetime. Both eyes in the plot had to fulfill the original inclusion criteria. The patients are colored according to their visual disability status at expected time of death. *Blue* represents a patient where at least one of the eyes has a positive slope over time, *green* represents progression, but no significant impairment by the end of the patient's lifetime, *yellow* represents degradation to visual impairment (≤ -14 dB or worse in both eyes), and *red* corresponds to statutory blindness in both eyes (below -22 dB). It is worth noting that most of the *red* symbols are not found in the top left corner of the baseline plot where both eyes are at an early stage of glaucoma. See Supplementary Material Clip S1 for an animated version of this series of scatterplots.

this proportion was in excess of 9%.¹¹⁻¹³ There are several possible reasons behind this difference. First, a sizeable proportion of pseudoexfoliation glaucoma (associated with faster disease deterioration⁷) was present in the Heijl et al.¹⁴ study, not as commonly seen in the United Kingdom. Another possible cause is that the patients in these studies were diagnosed with more advanced glaucoma, although it is not really known whether those with advanced defects progress more quickly or whether they have reached a stage of more advanced impairment because they presented later. Our estimates of the “fast progressor” prevalence was more akin to those results from controlled clinical cohort studies.⁸⁻¹⁰

Remarkably, approximately half of all the patients sampled experienced an “improved” MD in at least one eye during their follow-up, as can be seen in Figure 3. These positive slopes can be explained by a combination of high variability associated with VF measurements³¹⁻³³ and learning effects, which can persist over 10 or more tests in some individuals.^{22,23} We attempted to control for the latter by adopting the common practice of removing each patient’s first recorded VF. However, there evidently remains a substantial difficulty in measuring rates of MD change. This has important implications for the utility of VF testing in clinical practice. Patients who struggle with VF testing and yield noisy measurements, or patients who just simply get better at doing tests over time, should be identified as soon as possible because they are using resources that might be better used elsewhere.

Approximately 90% of those patients predicted to be at risk of statutory blindness in their residual expected lifetime already had noteworthy VF damage (MD worse than -6 dB) in at least one eye at baseline (see Fig. 3). Most of these patients had advanced impairment (60% worse than -14 dB in at least one eye) at baseline. These statistics strongly suggest that a major contributory factor for the risk of future visual impairment, or statutory blindness, from glaucoma is late presentation of the disease. Other studies support this important notion^{34,35} and some have explored it in more detail, highlighting the real threat to blindness associated with the late detection of the disease.^{36,37} Indeed, given this was a study necessarily limited only to patients who were under clinical care, these results suggest that it is the many undiagnosed glaucoma sufferers who are at the greatest risk of blindness. This finding raises an interesting debate about how best to balance the use of VF resources in primary and secondary care, especially because we have estimated that only a minority of diagnosed patients in clinical care are in danger of being severely impacted by their condition during their lifetime. Specifically, it suggests that more resources should be directed toward detecting and case finding glaucoma. Moreover, although glaucoma is a chronic disease, our data highlight that those affected are, of course, typically elderly and have low residual life expectancy; the results from this study should reinforce the need for clinicians to consider life expectancy in their clinical management of the disease.²⁰

Results from clinical trials and prospective studies primarily inform clinical practice and decisions about health service delivery. Still, retrospective analysis of very large volumes of data collected from the everyday clinical milieu over long periods of time can provide interesting material and information to develop new hypotheses, as this report shows. It is already known that volunteers for prospective studies in glaucoma have better adherence to prescribed therapy than those in routine medical care,³⁸ so prospective studies and trials may even misrepresent the routine clinical situation. However, any retrospective study, including our own, will have issues with missing or incomplete data, although, in this case, this was largely offset by sheer volume of data; a significantly larger number of VFs were used compared with other past

retrospective studies. One consequent limitation of the retrospective study was that a small proportion of the patients studied had complete series in only one eye (431 of 3790 patients included in the study). Unfortunately, the reasons behind the other eye not being followed were disparate: the eye may have either had extensive damage that rendered VF tests uninformative, or else it may have been healthy and not tested frequently enough to meet the inclusion criteria. We tried to cater to both of these possibilities by providing both the “worst-case scenario” and “best-case scenario” results. Another issue associated with this retrospective analysis concerns the fact that full patient records were unavailable or not considered. As a result, analyses were based only on age, sex, and VF data. Some of the faster-progressing patients in our sample may have therefore had rapidly lowering MDs as a result of concomitant age-related eye disease, principally cataract. Also, a small minority of the study sample may not have had glaucoma, but this is unlikely given all subjects were monitored at specialist glaucoma clinics over at least 3 years. Furthermore, our findings must be tempered by the possibility that the baseline fields of the patients may not have been their first VF assessment; for instance, patients may have been transferred from a different clinical center.

One strength of our study is that the thresholds chosen for visual impairment and statutory blindness have some evidence-based justification attributed to them. Reaching levels of MD worse than -14 dB in both eyes has been shown to correspond highly with likely no longer being legally fit to drive in the United Kingdom, among difficulties carrying out various other visual tasks.³⁹⁻⁴⁴ Furthermore, -22 dB in both eyes is the point at which one qualifies for statutory blindness in the United States, so represents a significant milestone for patients. However, in spite of the fact that measured sensitivities are weighted toward fixation when calculating MDs, it is, of course, possible to have preserved visual acuity under these conditions; people who are diagnosed with legal blindness can still have some useable vision. In addition, it is important to emphasize that using the MD to define visual disability does not appreciate the spatial distribution of VF damage, which is important in a patient’s visual function, and ability to carry out different tasks.^{39,40,42,43} For example, VF loss close to fixation is particularly important, and eyes with this damage should be treated more aggressively, especially because the likelihood of further damage in the central VF is higher.⁴⁵

An assumption of our analysis involves the use of a linear rate of progression of MD over time. This may not reflect the true nature of glaucomatous deterioration given that there is some evidence to show patients tend to progress more quickly at older ages, although it is unknown whether this is a result of older age or more advanced VF deterioration.¹⁴ Nevertheless, linear regression of MDs is commonly used in clinical practice; the Glaucoma Progression Analysis software in the Humphrey Field Analyzer, for instance, presents this as “one method of Tracking Rate of Progression.”⁴⁶ Furthermore, studies suggest that linear rates of progression for summary measures are adequate,⁴⁷ and it is important to note that a linear decline in decibels represents an exponential decay in retinal sensitivity; although loss of sensitivity could occur at greater than an exponential rate, no research to date has suggested that another type of model should be used to measure the rate of decay of MD. In addition, previous work has shown that a linear model of VF progression tends to provide more robust estimates of future measurements than more complex models.^{48,49} This demonstrates a simple statistical principle that, although more complex models tend to provide better fits of existing data, linear models tend to be more useful at predicting future change. However, it is important to be aware that this MD regression does not imply a constant rate of

sensitivity loss; a loss of 1 dB implies much more damage going from -5 dB to -6 dB than from -25 to -26 dB, as a result of the logarithmic scaling used for the measurement. It is further noteworthy that the “future” forecasts based on current linear rates of VF loss may make our estimates of future prognosis in the patients studied overly pessimistic, as treatment is usually intensified if a patient is in danger of progressing to visual disability.¹⁵ On the other hand, the modeling takes no account of concomitant eye disease, which ultimately might precipitate levels of lifetime visual disability that are worse than those shown in our results. A technical limitation of the calculations is that life expectancies used were periodic and so the study assumes that the probability of dying at a given age will remain constant over time. It was also necessary to assume that mortality rates are independent of glaucoma as a condition, although this seems reasonable given results from other studies that have specifically looked at this.⁵⁰ Mortality rates could be affected by other morbidities that may be more common in individuals with glaucoma; it is further possible that fast progression rates may be symptomatic of poor general health or access to medical care, which may in turn affect life expectancy. However, more research is required to fully understand how life expectancy corresponds with rates of VF loss before this can be taken into consideration.

It is important to reflect on the generalizability of our results. First, the sample was composed only of patients from hospital care in the United Kingdom, and it should be further noted that the number of patients from hospitals in Portsmouth and Cheltenham were considerably fewer than those from Moorfields Eye Hospital in London. Of course, there is no guarantee that patients were treated equivalently across hospitals and thus our results mostly reflect observations in Moorfields Eye Hospital. Results are not directly applicable to countries with different demographics and different health care systems. On the other hand, London is a cosmopolitan city; the 2011 Census reported that more than one-quarter of the population of London did not identify themselves as British,⁵¹ so it could be postulated that there is a fair amount of diversity among the patients, although the lack of clinical data makes it impossible to determine this for certain. Another issue with the study, particularly when focusing on the finding that worse VF loss at baseline is associated with a higher risk of blindness, is that it is assumed that various factors that may have an effect on end state of disease, such as type of glaucoma and race of patient, were relatively uniform throughout the study. Unfortunately, it was not possible to control for these variables, but it is assumed, given the quantity of the data, that the findings overall represent a reasonable population estimate.

In conclusion, the main result from this modeling exercise suggests that most glaucoma patients under clinical care are not in considerable danger of suffering significant visual disability in their lifetime. This report certainly indicates that the great majority of patients who are followed in glaucoma clinics in the United Kingdom have stable VFs. There is, however, enormous variability in rates of VF loss and also in levels of VF damage at presentation. Patients who are in danger of significant VF impairment in their lifetime generally present with more severe VF damage and this may indicate that more resources should be concentrated toward detecting disease before it progresses beyond early damage. We hope that these results can inform the design of better health service delivery and suggest studies that should investigate improved allocation of VF testing resources.¹⁵ Furthermore, the results from this study illuminate very clearly the importance of reliably detecting significant VF defects, and other features of glaucoma, in primary care.³⁷

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