Author Response: On Alternative Methods for Measuring Visual Field Decay: Tobit Linear Regression

The authors thank Russell and Crabb1 for their thoughtful comments about our paper published in the June issue of IOVS.2 We are grateful for this opportunity to respond to their suggestions.

Crabb and coworkers (McNaught et al.3) have previously published on pointwise models to fit longitudinal visual field loss in glaucoma. They concluded that linear regression is the best fit compared with other models, including exponential. The exponential model that Crabb et al. used in their study is fundamentally different from the one we reported. The exponential model that they reported took the form of \( y = a + be^{x} \) (linear exponential), whereas our model takes the form of \( y = e^{-a \times be^{x}} \) (nonlinear exponential), where \( y \) is visual sensitivity, \( x \) is time, and \( b \) the rate-of-change coefficient. In the former case, the exponential fit has a convex upward shape, whereas the latter has a concave upward shape, as in classic exponential decay. The nonlinear exponential model seems a more appropriate way to model these data and may be the reason it overwhelmingly fits the data better than the simple linear model in our study. Additional data supporting this conclusion are given below.

Russell and Crabb suggest that the nonlinear exponential model works well in advanced visual field loss (as in the Advanced Glaucoma Intervention Study, AGIS), because of the “floor” (zero decibel) effect found in advanced visual field loss. We performed a similar analysis in a separate set of visual field series from patients at UCLA (Caprioli J, et al. IOVS 2011;52: ARVO E-Abstract 4410). Compared with AGIS, these patients with much less severe visual field abnormalities with an initial average mean defect of −5 dB compared with −11 dB in AGIS). We also found, based on the Akaike information criteria (AIC) for these 22,086 data series, that the exponential model provided better data fits than the linear model 95% of the time.

Russell and Crabb made a reasonable suggestion to use a Tobit linear regression model.4 This is based on the modeling of a theoretical data series presented in their letter that describes a very specific set of conditions: a linear drop of sensitivities to the “floor” of threshold measurements, which subsequently and consistently remain at 0. In this example, the Tobit regression, which censors the “floor” effect, is best. Of course, this pattern does not predominate in real life, even in patients with advanced field loss. When we reanalyzed the AGIS visual field data and performed Tobit fits for all 21,006 data series, we found that, based on the AIC, the exponential model performed better than the Tobit model in 82% of the data series. Hence, the Tobit model shows an improvement over the simple linear fits, but the exponential model still provided the best fit for the preponderance of the data. We again performed the Tobit linear regression in the UCLA data set of less advanced glaucoma; and, based on the AIC, exponential fits were better 92% of the time. An issue with the Tobit fits is that since, after a certain time-point, it may censor sensitivities that are above 0, it cannot be used to make meaningful predictions in visual fields with moderately advanced, but not absolute, loss.

We further analyzed the fits for the combined AGIS and UCLA visual field data series (n = 798 eyes with mean follow-up, 9.4 years; mean number of visual field examinations per eye, 15.2; and total number of data series, 43,092) and found the following proportions of best fits based on the AIC: nonlinear exponential, 88.1%; linear, 0.2%; linear exponential, 3.1%; and Tobit, 8.5%. One can see that the nonlinear exponential model clearly predominated. When simple linear is compared only to the linear exponential, the results are: linear 62.4% versus linear exponential 37.6%, which explains the published findings of McNaught et al.3

The exponential decay model, where the rate is proportional to the volume of visual function that remains, seems to mimic the pathophysiology of glaucoma. Patients with chronic glaucomas under treatment rarely go completely blind; rather, they approach perimetric blindness asymptotically, with some visual sensitivity usually preserved. Hence, the exponential decay model seems generally more appropriate than the linear model, which plunges through the “floor,” or the Tobit, which plunges to the “floor.”

Finally, Russell and Crabb1 suggest that the exponential decay shape may also be a result of multiple treatments. However, the exponential model also predominated in patients under treatment in the UCLA group, wherein, as opposed to AGIS, only a minority had had surgery. Certainly, Russell and Crabb would also agree that we wish to model glaucoma patients under treatment.

We propose that a possible area for future work is to use a combination of models at different locations throughout the visual field, depending on their goodness of fit. The authors thank Russell and Crabb for their insightful suggestions and the Editor for the opportunity to respond.

Joseph Caprioli1
Dennis Mock1
Elena Bitrian1
Abdelmonem Affti2
Fei Yu1,2
Kourosh Nouri-Mahdavi1
Anne Coleman1

Departments of 1Ophthalmology and 2Biostatistics, The University of California, Los Angeles, Los Angeles, California. E-mail: caprioli@ucla.edu

References


Citation: Invest Ophthalmol Vis Sci. 2012;53:118. doi:10.1167/iovs.11-9240