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Prediction of Macular Ganglion Cell Complex Thickness Using Humphrey Visual Field Sensitivity in Primary Open-Angle Glaucoma: An Observational Study.

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Abstract

Background: Macular ganglion cell complex (GCC) thickness and central visual field sensitivity are associated in glaucoma. A regression equation may quantify this relationship, but prediction from functional measurements requires careful interpretation. Aim: To examine the relationship between macular visual field sensitivity (VFS) and GCC thickness and describe a linear equation estimating GCC thickness in primary open-angle glaucoma (POAG). ***Materials and Methods***: This hospital-based observational study analysed 78 eyes with POAG at Ahalia Foundation Eye Hospital, Palakkad, Kerala, from December 2018 to November 2020. Average GCC thickness was measured using Cirrus HD-OCT and macular VFS as the mean sensitivity of 12 central Humphrey 24-2 test locations. Correlation and simple linear regression were performed using SPSS version 20. ***Results***: Mean GCC thickness was 71.74 ± 9.11 µm and macular VFS was 26.94 ± 6.32 dB. The Pearson correlation was r = 0.565 ($p < 0.001$), corresponding to approximately 31.9% of variance explained by a simple linear model. The reported equation was: predicted GCC thickness (µm) = 49.96 + 0.809 × macular VFS (dB). Mean predicted and observed GCC thicknesses were both 71.74 µm; their standard deviations were 5.14 and 9.11 µm, respectively. The source analysis reported p = 1.0 for comparison of group means; this does not establish individual prediction accuracy or model validation. ***Conclusion***: Macular VFS showed a moderate association with GCC thickness and yielded an in-sample linear estimate. The equation is exploratory and requires external validation before clinical predictive use.

Keywords: Primary open-angle glaucoma; ganglion cell complex; optical coherence tomography; Humphrey visual field; macular sensitivity; linear regression; prediction.

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INTRODUCTION

Primary open-angle glaucoma (POAG) is a progressive optic neuropathy involving retinal ganglion cell loss and characteristic visual field damage. It remains a major contributor to irreversible blindness, and clinical evaluation relies on complementary structural and functional tests [1–3]. Spectral-domain optical coherence tomography (SD-OCT) measures inner retinal structures, including macular ganglion cell complex (GCC) thickness, while standard automated perimetry measures sensitivity to visual stimuli [4,5].

Macular visual field sensitivity (VFS) and OCT-derived ganglion cell measurements have demonstrated significant structure–function associations in glaucomatous eyes [6–9]. Such associations offer a basis for estimating a structural measurement from a functional variable through regression. However, visual field sensitivity is expressed on a logarithmic decibel scale, and structure–function relationships may be nonlinear and influenced by retinal location, disease severity and measurement variability [10–14].

A linear prediction equation may be useful for describing the average relationship in a particular dataset, but statistical association alone does not establish accurate prediction in individual patients. Agreement, residual error, calibration and validation are additional requirements for clinical application [10,11,15]. The present study evaluated the correlation between macular VFS and average GCC thickness and examined an in-sample regression equation for estimating GCC thickness in eyes with POAG.

AIM AND OBJECTIVES

Aim: To assess whether macular VFS measured with Humphrey automated perimetry can be used to estimate average macular GCC thickness in eyes with POAG.

Objectives: To describe average GCC thickness and macular VFS; quantify their linear association; report the regression equation relating macular VFS to GCC thickness; and compare the reported distributions of observed and model-predicted GCC thickness.

MATERIALS AND METHODS

Study design, setting and sample

This hospital-based observational study was conducted at Ahalia Foundation Eye Hospital, Palakkad, Kerala, India, from December 2018 to November 2020. The sample comprised 78 eyes with POAG from patients aged 20–60 years. Original sample-size planning assumed a correlation coefficient of 0.3049, 80% power and 5% significance and reported a minimum requirement of 77; 78 eyes were analysed.

Eligibility and examination

Inclusion criteria were diagnosed POAG, age 20–60 years, intraocular pressure within normal limits at examination, spherical equivalent within ±5 D and cylindrical correction within ±3 D. Exclusions were angle closure, retinal disorders (including age-related macular degeneration and diabetic retinopathy), neurological disease affecting visual fields, prior ocular surgery, manifest strabismus and aphakia.

Demographic and clinical history were recorded. Examination included visual acuity, refraction, pupillary and slit-lamp assessment, Volk G-4 gonioscopy, Goldmann applanation tonometry and dilated optic nerve head examination with a +78 D lens. The Carl Zeiss Cirrus HD-OCT was used for 200 × 200-pixel optic disc cube and 512 × 128-pixel macular cube scans. Average GCC thickness was recorded from PanoMap analysis. OCT scans with signal strength below 6 were excluded.

Humphrey Field Analyser 24-2 automated perimetry provided the functional measurements. Fields were assessed using Anderson criteria and accepted reliability indices. Macular VFS was calculated as the average sensitivity of 12 central test locations, expressed in decibels. Mean deviation and foveal sensitivity were also documented. Structural and functional testing was performed on the same day.

Regression model and statistical analysis

Data were recorded in Microsoft Excel 2010 and analysed using SPSS version 20. Continuous measurements were summarised using mean, standard deviation and range. Pearson correlation assessed the linear relationship between macular VFS and average GCC thickness. Simple linear regression treated GCC thickness (µm) as the dependent variable and macular VFS (dB) as the independent variable. Statistical significance was set at $p < 0.05$.

The reported fitted model was: Predicted GCC thickness (µm) = 49.96 + 0.809 × macular VFS (dB). The intercept and slope were taken from the original regression output. The coefficient of determination was calculated as $r^2 = 0.565^2 \approx 0.319$. This is an in-sample explanatory measure, not an externally validated measure of predictive accuracy.

Ethical considerations

Approval was obtained from the Ethical and Scientific Committees of Ahalia Foundation Eye Hospital. Written informed consent was obtained from participants after explanation of the study procedures.

RESULTS

A total of 78 glaucomatous eyes were analysed. Mean age was 52.42 ± 8.89 years. The largest age group was 50–60 years (69.2%). Female and male observations accounted for 51.3% and 48.7%, respectively. Mean average GCC thickness was 71.74 ± 9.11 µm. Mean macular VFS was 26.94 ± 6.32 dB. GCC thickness ranged from 48 to 91 µm, while macular VFS ranged from 6 to 34.50 dB. GCC thickness and macular VFS showed a moderate positive correlation ($r = 0.565$; $p < 0.001$). Simple linear regression yielded an intercept of 49.96 and slope of 0.809 µm per dB. The squared correlation indicated approximately 31.9% in-sample explained variation. Mean predicted GCC thickness was 71.74 µm, equal to the observed mean by construction of the fitted model. The predicted values had a smaller standard deviation (5.14 µm) than observed GCC values (9.11 µm). The reported mean-comparison p-value was 1.0, which does not demonstrate accurate prediction at the individual-eye level.

Table 1. Demographic profile of the analysed sample

Characteristic	n	%
Age 20–30 years	2	2.6
Age 30–40 years	4	5.1
Age 40–50 years	18	23.1
Age 50–60 years	54	69.2
Female	40	51.3
Male	38	48.7

Table 2. Descriptive measurements relevant to regression

Variable	Mean ± SD	Minimum	Maximum	Median
Average GCC thickness (µm)	71.74 ± 9.11	48	91	73
Macular VFS (dB)	26.94 ± 6.32	6	34.50	28.33
Mean deviation (dB)	−5.56 ± 5.37	−24.89	1.58	−3.95

Table 3. Relationship of macular VFS with average GCC thickness

Observations	Pearson r	p-value	r^2 (derived)
78	0.565	<0.001	0.319

Table 4. Reported simple linear regression equation

Outcome	Intercept	Slope for macular VFS	Equation
GCC thickness (µm)	49.96	0.809 µm/dB	GCC = 49.96 + 0.809 × VFS

Table 5. Comparison of observed and fitted GCC thickness

Measurement	n	Mean (µm)	SD (µm)
Observed GCC thickness	78	71.74	9.11
Model-predicted GCC thickness	78	71.74	5.14

Table 6. Reported comparison of mean observed and predicted GCC thickness

Comparison	Reported p-value	Interpretation
Observed versus fitted means	1.0	No difference in reported means; not evidence of prediction agreement

Compiled detailed interpretation of Results tables

Table 1

Most observations were from individuals aged 50–60 years. The study population had a mean age of 52.42 ± 8.89 years and an approximately balanced sex distribution. These demographic characteristics describe the population in which the regression equation was fitted.

Table 2

Mean GCC thickness was 71.74 µm and mean macular VFS was 26.94 dB. Both measurements showed substantial variation across the 78 eyes. The reported mean deviation illustrates accompanying visual field impairment but was not an independent predictor in the specified single-variable model.

Table 3

The positive Pearson correlation ($r = 0.565$; $p < 0.001$) indicates that eyes with greater macular VFS tended to have greater GCC thickness. The derived r^2 of approximately 0.319 indicates that the fitted linear association accounted for about 31.9% of GCC variability in the analysed sample; the remaining variation was not explained by this single predictor.

Table 4

The reported regression intercept was 49.96 µm and slope was 0.809 µm per dB. Thus, the fitted equation estimated an average increase of 0.809 µm in GCC thickness for each 1-dB higher macular VFS. This slope describes association in the sample, not an effect of changing visual field sensitivity.

Table 5

Observed and fitted GCC thickness had identical reported means of 71.74 µm. Fitted values had lower dispersion (SD 5.14 µm) than observed measurements (SD 9.11 µm), reflecting the fact that a one-predictor regression does not reproduce all observed variability. These aggregate statistics do not provide individual prediction errors.

Table 6

The original analysis reported $p = 1.0$ for comparison of observed and predicted mean GCC thickness. A fitted ordinary least-squares regression with an intercept reproduces the observed outcome mean within the training sample. Consequently, equality of these means cannot be used to infer clinical equivalence, accuracy or external validity of individual predictions.

DISCUSSION

This study evaluated the possibility of estimating average macular GCC thickness from macular VFS in 78 eyes with POAG. A significant moderate correlation was observed ($r = 0.565$; $p < 0.001$), and the fitted equation was GCC thickness = 49.96 + 0.809 × macular VFS. Earlier studies have documented relationships between macular OCT parameters and central visual field sensitivity, providing a biological and statistical basis for examining regression models [6–9].

Interpretation of the regression relationship

The slope of 0.809 µm per dB indicates a positive association between functional sensitivity and structural thickness in the study sample. However, the correlation was moderate, and the derived r^2 of approximately 0.319 indicates that most of the variation in GCC thickness was not explained by macular VFS alone. Therefore, the equation is better interpreted as a description of the average sample relationship than as a precise estimator for an individual eye. Structure–function relationships in glaucoma are affected by differences between linear retinal thickness measures and logarithmic visual sensitivity scales. Previous research has shown that nonlinear models can sometimes fit the relationship more closely than a straight line, and that anatomical correspondence between field locations and retinal regions affects the strength of associations [7,10–14]. The linear equation reported here was not compared with alternative functional forms.

Observed and predicted GCC thickness

The observed and predicted GCC means were both 71.74 µm, while their standard deviations differed substantially (9.11 versus 5.14 µm). The source analysis reported a mean-comparison p-value of 1.0. This result should not be interpreted as confirmation of model accuracy: an ordinary least-squares model fitted with an intercept reproduces the outcome mean in its training data. Assessment of prediction requires individual residuals, error measures, calibration and testing in an independent sample, none of which were available in the reported aggregate results. In particular, no external or prospective validation was performed.

Clinical implications

The model demonstrates that central functional sensitivity contains information related to macular retinal structure, but it cannot replace direct OCT measurement. Structural imaging and automated perimetry provide distinct and complementary information in glaucoma assessment [4,5,15–18]. In settings where OCT measurements are unavailable, the equation should not be used to assign individual GCC thickness or make clinical decisions without further validation.

Strengths and limitations

The study used a defined POAG population, established OCT and Humphrey testing protocols, quality criteria and same-day structural and functional assessments. Limitations include the single-centre design, modest sample size, age restriction of 20–60 years, use of a single predictor, lack of sector-wise modelling, and absence of a healthy control group. The available aggregate data did not permit evaluation of residual distributions, confidence or prediction intervals, measurement agreement, out-of-sample performance or possible correlation between eyes from the same patient. The observational design also precludes causal interpretation.

CONCLUSION

Macular VFS was moderately correlated with average GCC thickness in eyes with POAG. The reported equation, GCC thickness (µm) = 49.96 + 0.809 × macular VFS (dB), summarised the in-sample linear association and accounted for approximately 31.9% of GCC variability. Equal observed and fitted means do not establish prediction accuracy. Independent validation and individual-level error analysis are necessary before this equation can be considered for clinical predictive use. OCT and automated perimetry should continue to be interpreted as complementary assessments.

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