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Association Between Ganglion Cell Complex Thinning and Vision-Related Quality of Life in Glaucoma

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KEY POINTS

Question: Do ganglion cell complex thickness changes on optical coherence tomography predict future vision-related quality of life among patients with open-angle glaucoma?

Findings: In this retrospective analysis of a longitudinal cohort of 236 eyes in 118 patients, baseline faster ganglion cell complex thickness changes were associated with lower vision-related quality of life after adjusting for severity of visual field damage at.

Meaning: These findings suggest assessment of ganglion cell complex thinning may be important in predicting vision-related quality of life.

ABSTRACT

Importance: Faster structural changes may be associated with worse vision-related quality of life in glaucoma patients.

Objectives: To evaluate the association between the rate of ganglion cell complex thinning and the vision function questionnaire in glaucoma.

Design: Retrospective analysis of a longitudinal cohort that was designed in October 2021

Setting: Patients were enrolled from the Diagnostic Innovations in Glaucoma Study and the African Descent and Glaucoma Evaluation Study.

Participants: 236 eyes of 118 patients with diagnosed or suspected glaucoma followed up with imaging for an average of 4.1 years from September 2014 to March 2020.

Main outcomes and measures: The vision function questionnaire was evaluated using the 25-item National Eye Institute Visual Function Questionnaire at the last follow-up visit. Ganglion cell complex thickness was derived from macular optical coherence tomography scans and averaged within 3 circle areas (3.4-degree, 5.6-degree, and 6.8-degree from the fovea) and superior and inferior hemiregions. Linear mixed-effects models were used to investigate the association between the rate of ganglion cell complex thinning and Rasch-calibrated vision function questionnaire score.

Results: The mean (SD) age was 73.2 (8.7) years, 65 (55.1%) were female and 53 (44.9%) were African American. Mean (95% CI) composite Rasch-calibrated NEI VFQ was 50.3 (45.9, 54.6). A faster annual rate of global GCC thinning in the better eye (95% CI) was associated with a higher disability of composite National Eye Institute Visual Function Questionnaire score (-15.0 (-28.4, -1.7) per 1 um faster: *P*=.03). When stratified by degrees from the fovea, 5.6-degree and 6.8-degree area was associated with the composite NEI VFQ Rasch-calibrated score (-14.5 (-27.0, -2.0) per 1 um faster: R^2=0.201, *P*=.03; -23.7 (-45.5, -1.9) per 1 um faster: R^2=0.196, *P*=.02, respectively), while 3.4-degree was not significant (-8.0 (-16.8, 0.8) per 1 um faster: R^2=0.184, *P*=.07) after adjusting for confounding factors.

Conclusions and relevance: These findings suggest that faster and sectoral central location of ganglion cell complex thinning provides useful information in determining the risk of functional impairment in glaucoma. Monitoring macular structure is useful for determining the risk of functional impairment in glaucoma.

Introduction

As a leading cause of blindness, glaucoma impairs not only the physical function but also the mental well-being of patients worldwide.[1] In an effort to investigate quality of life in patients, the National Eye Institute Visual Function Questionnaire (NEI VFQ) was developed to evaluate vision-related health status in patients with chronic eye diseases via a self-assessment questionnaire.[3,4]

The NEI VFQ has been used previously to investigate the impact of glaucoma on vision-related quality of life (VRQOL). Past studies revealed an association between glaucoma and a decreased VRQOL which reflects the impaired ability to perform daily tasks and a decreased sense of independence and wellness.[5-7] The Los Angeles Latino Eye Study showed that even mild visual field (VF) damage has a significant negative impact on VRQOL in glaucoma patients.[8] A few studies have also shown that faster VF loss led to a worse VRQOL outcome, implying a direct association between the functional defect caused by glaucoma and an impaired QOL, underscoring the necessity of clinically monitoring VF changes.[9-11] This correlation is especially concerning for patients with a central VF defect,[7] as the subjective feeling and the objective ability of the patients to maintain personal safety is highly dependent on central vision.

While the translation of a functional defect into a declined QOL is well established and expected, VF testing is subjective and prone to variability.[12] Moreover, adding 10-2 testing to a perimetry testing regimen to detect central visual field defect would almost double the testing time required which may not be feasible in clinical practice. Optical coherence tomography (OCT) thickness measurements, in contrast, tend to provide faster, more reliable and objective results and also are well correlated with VF change in glaucoma.[13] In addition, detectable structural change often precedes functional change, so the detection of OCT changes may allow more timely health intervention before actual VF loss and/or VRQOL decline occurs.[14,15]

We were thus interested in investigating whether there is a correlation between VRQOL and OCT measurements, particularly macular thickness, which is related to central vision. In this study, the association between the rate of macular GCC thinning and VRQOL was evaluated in glaucoma patients.

Methods

Participants

This is a retrospective, longitudinal cohort study of glaucoma suspect and POAG patients enrolled in the Diagnostic Innovations in Glaucoma Study (DIGS) and African Descent and Glaucoma Evaluation Study (ADAGES).[17,18] ADAGES and DIGS were designed with similar testing protocols, and all participants were assessed

longitudinally according to established protocols consisting of regular follow-up visits with clinical examination, imaging, and functional tests.[17] Data analysis for the current study was undertaken in November 2021, and all participants from the study who met the inclusion criteria described below were included. Written Informed consent was obtained from all study participants. The University of California, San Diego Human Subject Committee approved all protocols, and the methods described adhered to tenets of the Declaration of Helsinki. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

All study participants underwent annual comprehensive ophthalmologic evaluation including best-corrected visual acuity, slit-lamp biomicroscopy, dilated fundus examination, and stereoscopic optic disc photography in both eyes. Semi-annual evaluations included intraocular pressure (IOP) measurement, spectral domain-OCT (Spectralis, Heidelberg Engineering, Germany) imaging, and standard automated perimetry testing with Humphrey Field Analyzer 24-2 SITA standard test (Carl Zeiss Meditec, Dublin, CA). This study included participants with at least 2 years and a minimum of 4 follow-up OCT visits. Participants with primary open angle glaucoma (POAG) in both eyes or unilateral POAG with a diagnosis of glaucoma suspect in the contralateral eye were included (i.e., POAG/POAG or POAG/Glaucoma suspect). The better eye was defined by the better VF MD. Glaucoma suspects included eyes with elevated IOP (≥22mmHg) or glaucomatous-appearing optic discs (glaucomatous optic neuropathy) without the presence of repeatable glaucomatous VF damage. Eyes were classified as glaucomatous if they had repeatable (at least 2 consecutive) abnormal VF test results with evidence of glaucomatous optic neuropathy. Glaucomatous optic neuropathy was defined as excavation, the presence of focal thinning, notching of neuroretinal rim, or localized or diffuse atrophy of the retinal nerve fiber layer (RNFL) based on masked grading of optic disc photographs by 2 graders or clinical examination by a glaucoma specialist. An abnormal VF test was defined as a pattern standard deviation value at the 5% level or a Glaucoma Hemifield Test result outside normal limits. Glaucoma disease severity was classified as early (24-2 VF mean deviation (MD) >-6 dB) and moderate to advanced (24-2 VF MD≤-6 dB).

Inclusion criteria at study entry also included (1) older than 18 years of age, (2) open angles on gonioscopy, (3) best-corrected visual acuity of 20/40 or better, and (4) refraction ±5.0 diopters sphere and ±3.0 diopters cylinder. Exclusion criteria included (1) history of trauma or intraocular surgery (except for uncomplicated cataract or glaucoma surgery), (2) coexisting retinal disease, uveitis, or non-glaucomatous optic neuropathy, (3) other systemic or ocular diseases known to affect VF such as pituitary lesions or demyelinating diseases, (4) significant cognitive impairment; Parkinson’s

disease, Alzheimer's disease, dementia, or a history of stroke, or (5) axial length of 27 mm or more. Those with unreliable VFs and poor-quality OCT were also excluded.

Spectral-Domain Optical Coherence Tomography

The Spectralis SDOCT macula horizonal posterior pole scans acquired from September 2014 to March 2020 were used to obtain macula GCC thickness measurements The Posterior Pole Algorithm of the SDOCT obtains 61 horizontal B-scans (consists of 768 A-scans) spanning a 30°×25° area parallel to the fovea-Bruch's membrane opening axis. Segmentation of individual retinal layers was performed using the Glaucoma Module Premium Edition software. An 8×8 grid of thickness measurements centered on the fovea, provided that 64 3°×3° superpixels were present in the central 24×24° of the macula, was created. The GCC thickness measurements were calculated by adding the thickness measurement values of RNFL, ganglion cell layer, and inner plexiform layer. The central 24 superpixels were grouped into 3 concentric circles (3.4°, 5.6°, and 6.8° from the fovea) and the averaged GCC thickness was calculated for each sector.[19] The average thickness of the GCC was also calculated in the superior and inferior hemiregions (each 12 superpixels), and the global GCC was calculated using the average of superior and inferior hemiregions as shown in Figure 1. All images were processed and reviewed by the IDEA Reading Center. Segmentation of the macular layers was checked and corrected manually when possible. Images with non-centered scans, inaccurate segmentation that could not be fixed, or quality scores of 15 dB or less were excluded from the analysis.

Rasch Analysis of National eye institute visual function questionnaire

The vision-related quality of life (VRQOL) was evaluated using the 25-item NEI VFQ. This questionnaire was designed to evaluate the dimensions of self-reported vision-related health status that are relevant for patients with chronic eye diseases, including glaucoma.[3,4] The NEI VFQ consists of 25 vision-related questions that represent 11 subscales, with an additional single-item general health rating question. The 11 subscales are as follows; general vision, ocular pain, difficulty with near-vision and distance activities, limitations with peripheral vision and color vision, social functioning, driving difficulties, mental health symptoms related to vision, role limitations, and dependency. Each subscale consists of 1-4 items. Rasch analysis locates item difficulty and person ability on a logit scale. Person disability scores measured by the NEI VFQ were linearly rescaled ranging from 0 to 100 (eg, a score of 50 is equivalent to 50% of the highest disability score).[20,21] Rasch analysis was conducted using Andrich rating-scale models to acquire the estimates of the ability of

each item, perceived ability of each participants, and the category thresholds for each response category.[10,22] Items belonging to mental health symptoms related to vision, role limitations, and dependency were excluded, as previous study showed these items belong to a separate socio-emotional dimension, not directly related to visual functioning.[23] NEI-VFQ questionnaires were completed within 1 year of the last SDOCT.

Demographic and socioeconomic variables

Demographic data and socioeconomic and clinical questionnaires were collected at the time of the NEI VFQ. These questionnaires contained a survey about demographics, educational level, income, marital status, and health insurance coverage. These variables were categorized to include in the multivariable models as educational level (at least high school degree [yes/no]), income (<$25000 per year [yes/no]), marital status (married [yes/no]), and presence of health insurance (yes/no).[5] For comorbidities, we accounted for the presence or history of the following conditions: arthritis, asthma, cancers, depression, diabetes mellitus, heart disease, hypertension, and stroke. A simple summation score was calculated as the comorbidity index score.[24]

Statistical analysis

Patient and eye characteristics data were presented as mean (95% confidence interval (CI)) for continuous variables and count (%) for categorical variables. Estimates of rates of change for individual eyes were obtained by best linear unbiased prediction (BLUP) [25] Details about this model have been presented previously.[26,27] We were interested in whether the rates of GCC slope were predictive of disability in VRQOL, and which sector of GCC parameters were associated with VRQOL subscale. Linear mixed models estimate the average rate of change in an outcome variable using a linear function of time, and participant- and eye-specific deviations from this average rate are introduced by random slopes. The effect of potential predictors – age, gender, race, 24-2 VF pattern standard deviation (PSD), comorbidity index score, and socioeconomic variables (education level, income, marital status, and insurance)[6] were introduced in the multivariable model to affect patient perceptions about VRQOL. The strength of association was reported as R^2. Statistical analyses were performed using Stata version 16.0 (StataCorp, College Station, TX). All P values were two-sided.

Results

A total of 236 eyes of 118 participants (72 participants with bilateral POAG and 46 POAG/glaucoma suspects patients) were included in the analysis. Mean age (95% CI) was 73.2 (71.6, 74.8) years. 24-2 VF MD (95% CI) was -3.2 (-4.1, -2.3) dB for the better eye, and -8.6 (-9.9, -7.3) dB for the worse eye. While, 24-2 VF PSD (95% CI) was 3.8 (3.2, 4.3) dB for the better eye, and 8.0 (7.3, 8.8) dB for the worse eye. An average of 5.4 (5.1, 5.7) OCT images were obtained over 4.1 (4.0, 4.3) years of follow-up. Demographic and clinical characteristics of the participants are presented in Table 1.

Factors contributing to the NEI VFQ Rasch-calibrated composite score are summarized in Table 2. In the multivariable model, a faster rate of global GCC thinning in the better eye was associated with a higher disability of composite NEI VFQ Rasch-calibrated score (-15.0 (-28.4, -1.7) per 1 um faster rate of change/year: *P*=.03).

Table 3 summarizes the association between global or sectoral GCC slopes of better eye and NEI VFQ Rasch-calibrated score after adjusting for possible confounding factors including age, gender, race, number of glaucoma medications, visual field pattern standard deviation, education level, income, marital status, and comorbidity index. A faster annual rate of inferior GCC thinning in the better eye was associated with a higher disability of composite NEI VFQ Rasch-calibrated score (-28.4 (-49.5, -7.4) per 1 um faster: *P*=.009), while superior was not (-7.1 (-16.1, 1.9) per 1 um faster: *P*=.12). When stratified by degrees from the fovea, 5.6-degree and 6.8-degree area had the association with the composite NEI VFQ Rasch-calibrated score (-14.5 (-27.0, -2.0) per 1 um faster: R^2=0.201, *P*=.03; -23.7 (-45.5, -1.9) per 1 um faster: R^2=0.196, *P*=.02, respectively), while 3.4-degree was not significant (-8.0 (-16.8, 0.8) per 1 um faster: R^2=0.184, *P*=.07) after adjusting for confounding factors.

Discussion

In this longitudinal cohort study of 118 patients over a mean follow-up of 4.1 years, we investigated the relationship between the rate of GCC thinning and VRQOL in glaucoma patients. After adjusting for confounding factors, including baseline severity of visual field damage, faster GCC thinning and lower visual acuity were associated with a lower VRQOL. Specifically, a lower VRQOL was associated weakly with GCC thinning in the 5.6-degree and 6.8-degree central macular areas.

The function and structure of the macula is crucial in glaucoma, and it is known that glaucoma progression may be missed if the central 10 degrees of the VF and macular thickness are not monitored.[28] Further, it has been shown that NEI VFQ scores declined with a worsened 10-2 VF MD and with early macula damage.[7,29] Consistent with the current study, a previous study that compared retinal ganglion cell

and inner plexiform thickness with VRQOL interestingly found that the ganglion cell-inner plexiform layer loss (compared to a reference database) but not thickness was correlated with VRQOL.[30] The proposed theories for this finding include the greater effect of the pattern (rather than absolute thickness measurement) of macular damage, with a higher morbidity associated with diffuse rather than focal damage. In addition, attempting to relate absolute GCC thickness alone to QOL fails to account for variability in baseline macular thickness. If a patient has a thicker macula at disease onset, its absolute value at a given time point may not reflect the severity of thinning over time and how this has affected QOL.[29,30]

The current study is noteworthy in that we present a comparison of the slope of GCC thinning and NEI VFQ scores, thus addressing the aforementioned issue of patients who have a thicker macula and therefore whose absolute GCC thickness may not be reflective of the progression of disease. The result was not surprising, as the correlation between GCC thickness and VF defect in glaucoma has been well established.[19,31] With an even greater capability to provide reproducible values than VF testing, it is likely that OCT may provide better evaluation of risk of VRQOL impairment in glaucoma patients. Interestingly, the superior GCC thinning was found to have higher association than inferior GCC thinning with VRQOL decline in this study. This result is consistent with previous study,[11] showing association with central inferior area of the VF loss and VRQOL change. Hood et al. also showed that that inferior macular hemiregions are more vulnerable than superior hemiregions in glaucoma.[32] The loss of vision in the inferior area can have a significant impact on the ability to achieve daily activities such as reading and walking down stairs.[33]

This study evaluated the rate of GCC thinning based on the sectors surrounding the fovea, which demonstrated 5.6-degree and 6.8-degree area had association with VRQOL. Our finding is supported by the fact that macula vulnerability zone mainly consists of the measurement points within 5.6-degree and 6.8-degree area.[32] . Moreover, Mohammadzadeh et al. showed that the 5.6-degree area of GCC has a stronger relationship between structure and function with central VF than other sectors.[19] This also was confirmed in another study reported high association between VRQOL and central VF which supporting our finding.[7]

While there have been many studies investigating the relationship between functional metrics and QOL, the relationship between structural metrics and patient QOL is an area with limited research. Structural measures such as GCC and RNFL have the capability to detect glaucoma progression with greater predictability and objectivity than VF testing. Previous data is mixed as to whether RNFL thickness is associated with QOL. The studies by Hirneiss et al and Prager et al, which did not find an association with QOL measures and RNFL and RGC+IPL thickness, respectively,

were both cross-sectional studies.[30,34] This study, similar to that of Gracitelli et al which did find an association between the rate of RNFL thinning and change in NEI VFQ, is a longitudinal study and supports their conclusion that patients may notice a faster change which may influence their self-reported QOL.[6] Understanding the progression of structural changes is therefore more meaningful than absolute thickness values when assessing the impact on VRQOL, as intraindividual comparisons may be better than comparisons against a standardized set of values.

Although previous studies raised questions about the validity of using separate subscales items included in the NEI VFQ,[23,35] this approach allows clinicians to understand which aspects of life patients are suffering in from physical and mental standpoints. In earlier studies, decline in near vision, peripheral vision, driving, role limitations, and dependency were suggested to correlate with VF loss in glaucoma.[33] In the current subscale analysis, near vision, peripheral vision, social function, and driving were amongst the VRQOL measures most affected by GCC thinning. Reduced peripheral vision often is a major cause behind traffic accidents and other traumatic injuries in glaucoma patients. Notably, social function, which is closely related to mental wellness, was associated with the rate global and sectoral GCC thinning. This association reached significance even more uniformly than other subscales, showing the profound ways in which glaucoma can influence our patients' social interactions.

There are several limitations of this study. First, as with all other questionnaires, VRQOL is a subjective evaluation. Using a more objective test may provide a more accurate representation of disability with daily life in glaucoma. Second, we did not collect information on ocular surface diseases that may affect VRQOL, such as dry eye. Ocular surface disease was reported to increase with the number of glaucoma eye medications;[36] thus, we adjusted for the number of glaucoma eye drops as a confounding factor. Third, although we adjusted for potential confounding factors relevant to the VRQOL outcome, due to the complicated nature of QOL, there may be other factors that were not considered. Fourth, the Rasch score is a normalized score and is calculated based on the best and worst NEI-VFQ questionnaires in the population of each study. These scores may not be similar to those in other populations and, therefore, one should be cautious in generalizing the findings. Nevertheless, the magnitude of correlation can be used for comparison among different sectors in this study. Last, the data were collected prior to the study design. Therefore, we cannot eliminate the possibility that biases associated with data selection may affect the results.

In conclusion, a faster rate and central location of GCC thinning was associated, but weakly, with lower VRQOL in glaucoma patients. Understanding how

structural changes influence VRQOL is vital for understanding which patients may need more frequent observation and additional treatment to prevent visual disability and reduced quality of life.

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Table 1. Demographic and Baseline Clinical Characteristics of the Participants

Characteristic	n=236 eyes of 118 patients
Age, mean (SD), y	73.2 (8.7)
Gender (F/ M), No.	65/53
Race, No. (%)	
African American	53 (44.9%)
White	65 (55.1%)
LogMAR visual acuity	
better eye	0.07 (0.04, 0.09)
worse eye	0.10 (0.07, 0.13)
24-2 VF MD, dB	
better eye	-3.2 (-4.1, -2.3)
worse eye	-8.6 (-9.9, -7.3)
24-2 VF PSD, dB	
better eye	3.8 (3.2, 4.3)
worse eye	8.0 (7.3, 8.8)
Diagnosis for each eye, n (%)	
POAG/POAG	72 (61.0%)
POAG/Glaucoma suspect	46 (39.0%)
Number of glaucoma medications	
better eye	1.18 (0.95, 1.40)
worse eye	1.22 (0.99, 1.45)
Global GCC at baseline, um	
better eye	91.3 (88.9, 93.8)
worse eye	82.3 (79.6, 84.9)
Follow-up for OCT, years	4.1 (4.0, 4.3)
No. of OCT follow-up scans	5.4 (5.1, 5.7)
Education level, % with at least high school degree	97.5
Income, >$25 000, %	93.4
Marital status, % married	51.7
Insurance, % yes	100.0
Comorbidity index score	2.1 (1.8, 2.4)
NEI VFQ Rasch-calibrated score	
Composite score	50.3 (45.9, 54.6)
Subscales	
General health	34.3 (30.6, 38.0)
General vision	62.4 (57.7, 67.1)
Ocular pain	25.3 (19.4, 31.2)
Near vision	20.6 (16.2, 25.0)
Distance vision	27.1 (22.2, 32.0)
Peripheral vision	18.0 (12.6, 23.3)
Social function	10.6 (6.0, 15.2)
Color vision	4.7 (1.8, 7.6)
Driving	43.9 (37.5, 50.2)

Abbreviations: GCC, ganglion cell complex; LogMAR, logarithm of the minimum angle of resolution; MD, mean deviation; NEI VFQ; National Eye Institute Visual Function Questionnaire; OCT, optical coherence tomography; POAG, primary open angle glaucoma; PSD, pattern standard deviation; VF, visual field. Data are presented as mean (95% CI) unless otherwise indicated.

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Table 2. Univariable and Multivariable Models Assessing the Association with NEI VFQ Rasch-calibrated Composite Score

Variables	Univariable Model		Multivariable Model	
	Coefficient, 95% CI	P value	Coefficient, 95% CI	P value
Global GCC thinning rate per 1 um/year	-19.0 (-30.7, -7.2)	.002	-15.0 (-28.4, -1.7)	.03
Age per 10 years	1.5 (-3.5, 6.4)	.56	2.7 (-2.9, 8.3)	.34
Gender: female	6.0 (-2.5, 14.5)	.17	4.9 (-4.3, 14.1)	.29
Race: African Descent	5.9 (-2.6, 14.4)	.17	0.5 (-9.7, 10.8)	.92
Number of glaucoma medications (better eye)	-4.5 (-7.9, -1.1)	.01	-3.4 (-7.5, 0.7)	.10
Visual field PSD (dB)	1.0 (-0.1, 2.1)	.06	1.0 (-0.1, 2.0)	.08
Education level with at least high school degree, yes	-15.4 (-41.9, 11.1)	.25	-17.1 (-48.5, 14.3)	.28
Income with >$25 000, yes	-17.0 (-35.8, 1.9)	.08	-15.4 (-34.2, 3.4)	.11
Marital status with married, yes	-5.0 (-13.5, 3.5)	.25	1.2 (-8.3, 10.7)	.80
Comorbidity index score	2.5 (-0.2, 5.1)	.07	1.0 (-1.9, 3.9)	.50

Abbreviations: GCC, ganglion cell complex; NEI VFQ; National Eye Institute Visual Function Questionnaire; PSD, pattern standard deviation. Data are given as mean (95% CI).

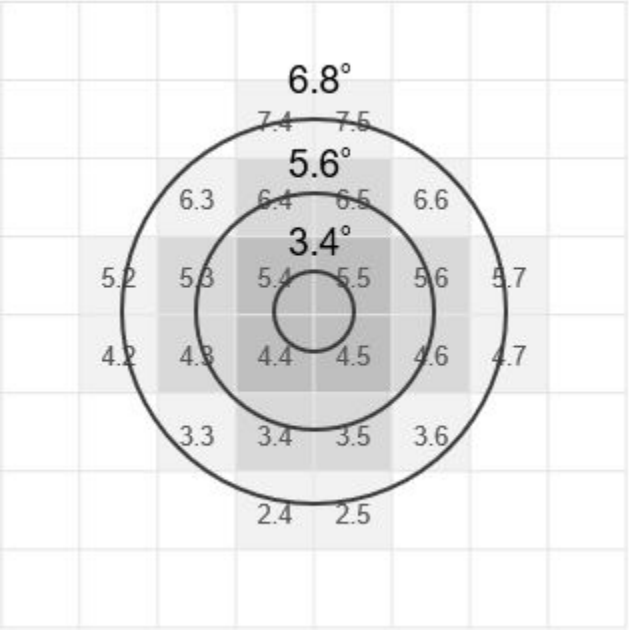
466 **Table 3. Association between Global or Sectoral GCC Slopes of Better Eye and NEI VFQ Rasch-calibrated Score**

	Global		Inferior		Superior		3.4-degree circle		5.6-degree circle		6.8-degree circle	
NEI VFQ Rasch-calibrated score	Coefficient, 95% CI	P value	Coefficient, 95% CI	P value	Coefficient, 95% CI	P value	Coefficient, 95% CI	P value	Coefficient, 95% CI	P value	Coefficient, 95% CI	P value
Composite score	-15.0 (-28.4, -1.7)	.03	-28.4 (-49.5, -7.4)	.009	-7.1 (-16.1, 1.9)	.12	-8.0 (-16.8, 0.8)	.07	-14.5 (-27.0, -2.0)	.02	-23.7 (-45.5, -1.9)	.03
Subscales												
General health	-3.4 (-15.0, 8.1)	.55	-6.4 (-24.8, 12.0)	.49	-1.7 (-9.3, 6.0)	.67	-3.7 (-11.2, 3.9)	.34	-3.7 (-14.5, 7.1)	.50	-3.3 (-22.2, 15.6)	.73
General vision	9.3 (-6.5, 25.1)	.25	17.6 (-7.6, 42.8)	.17	4.4 (-6.2, 15.0)	.41	10.7 (0.5, 20.9)	.04	8.7 (-6.1, 23.5)	.25	10.0 (-16.0, 36.0)	.45
Ocular pain	-9.8 (-28.3, 8.8)	.30	-18.8 (-48.3, 10.8)	.21	-4.5 (-16.9, 7.9)	.47	-2.0 (-14.2, 10.3)	.75	-9.6 (-27.0, 7.8)	.28	-18.0 (-48.3, 12.3)	.24
Near vision	-12.6 (-27.1, 1.8)	.09	-24.4 (-47.3, -1.5)	.04	-5.8 (-15.5, 3.9)	.24	-6.1 (-15.7, 3.4)	.20	-12.3 (-25.8, 1.2)	.07	-20.3 (-43.9, 3.3)	.09
Distance vision	-16.5 (-32.8, -0.3)	.05	-28.9 (-54.7, -3.1)	.03	-8.8 (-19.7, 2.1)	.11	-9.1 (-19.8, 1.6)	.10	-16.2 (-31.4, -1.0)	.04	-25.3 (-51.9, 1.3)	.06
Peripheral vision	-15.2 (-32.0, 1.7)	.08	-28.2 (-54.9, -1.4)	.04	-7.4 (-18.7, 3.9)	.20	-9.0 (-20.1, 2.1)	.11	-13.6 (-29.4, 2.3)	.09	-24.3 (-51.9, 3.2)	.08
Social function	-22.5 (-36.0, -9.0)	.001	-35.9 (-57.4, -14.3)	.001	-13.6 (-22.7, -4.5)	.004	-14.8 (-23.7, -6.0)	.001	-21.4 (-34.1, -8.8)	.001	-33.3 (-55.6, -11)	.004
Color vision	-2.2 (-11.9, 7.5)	.66	-6.0 (-21.5, 9.4)	.44	-0.2 (-6.7, 6.3)	.95	1.1 (-5.3, 7.5)	.73	-2.6 (-11.6, 6.5)	.58	-4.6 (-20.4, 11.3)	.57
Driving	-19.7 (-40.0, 0.7)	.06	-41.8 (-73.7, -9.8)	.01	-7.4 (-21.1, 6.3)	.29	-7.1 (-20.6, 6.4)	.30	-18.8 (-37.9, 0.2)	.05	-34.1 (-67.3, -1.0)	.04

Abbreviations: GCC, ganglion cell complex; NEI VFQ; National Eye Institute Visual Function Questionnaire. Data are given as mean (95% confidence interval).
*Adjusted to age, gender, race, number of glaucoma medications, visual field pattern standard deviation, education level, income, marital status, and comorbidity index.

FIGURE LEGENDS

Figure 1. The left image depicts the 3 areas defined to assess the macular thickness changes as a function of distance from the fovea: circle 1, 3.4-degree; circle 2, 5.6-degree; and circle 3, 6.8-degree. The right image depicts the inferior and superior hemiregions in this study.


6.8°
7.4
7.5
5.6°
6.3
6.4
6.5
6.6
3.4°
5.2
5.3
5.4
5.5
5.6
5.7
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3.3
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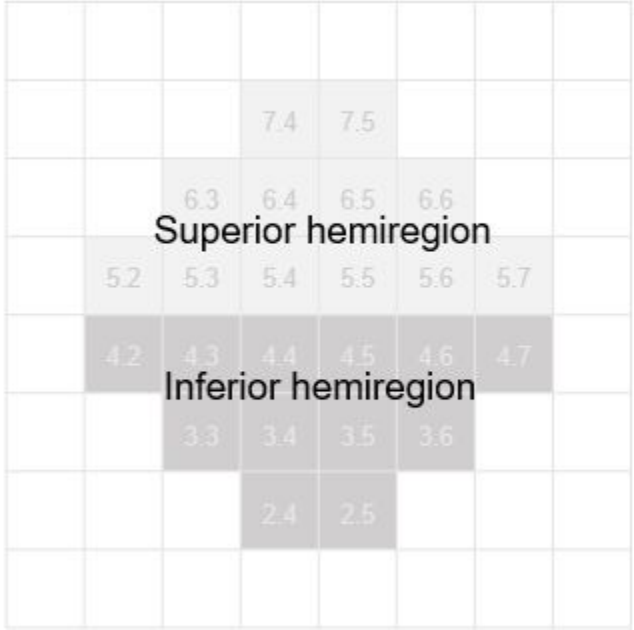
3.6
2.4
2.5


7.4
7.5
6.3
6.4
6.5
6.6
Superior hemiregion
5.2
5.3
5.4
5.5
5.6
5.7
4.2
4.3
4.4
4.5
4.6
4.7
Inferior hemiregion
3.3
3.4
3.5
3.6
2.4
2.5