Structure–Function Relationship and Diagnostic Value of Macular Ganglion Cell Complex Measurement Using Fourier-Domain OCT in Glaucoma

Na Rae Kim,[1] *Eun Suk Lee,*[1] *Gong Je Seong,*[1] *Ji Hyun Kim,*[1] *Hyong Gin An,*[2] *and Chan Yun Kim*[1]

Purpose. To assess the relationship between visual function and macular ganglion cell complex (GCC) thickness measured by Fourier-domain optical coherence tomography (OCT) and to evaluate the diagnostic value of GCC thickness for detecting early, moderate, and severe glaucoma.

Methods. Participants underwent reliable standard automated perimetry testing and OCT imaging with optic nerve head (ONH) mode and GCC mode within a single day. The relationship between structure and function was evaluated by comparing GCC thickness with mean deviation (MD) and visual field index (VFI), by regression analysis. The results were compared with those obtained for retinal nerve fiber layer (RNFL) thickness. The area under the receiver operating characteristic curve (AUC) was used to determine the relationship between disease severity and glaucomatous changes in RNFL and GCC parameters.

Results. One hundred three normal control subjects and 138 patients with glaucoma were included in the present study. Compared with linear models, second-order polynomial models better described the relationships between GCC thickness and MD ($P < 0.001$), and between GCC thickness and VFI ($P < 0.001$). A GCC pattern parameter, global loss volume (GLV), had the highest AUC for detecting early glaucoma. The AUC of mean GCC thickness for early glaucoma was higher than that of mean RNFL; however, the difference was not significant ($P = 0.330$).

Conclusions. A curvilinear function best described the relationship between VF sensitivity and GCC thickness. Macular GCC thickness and RNFL thickness showed similar diagnostic performance for detecting early, moderate, and severe glaucoma. (*Invest Ophthalmol Vis Sci.* 2010;51:4646–4651) DOI:10.1167/iovs.09-5053

Glaucoma is a multifactorial optic neuropathy characterized by the loss of retinal ganglion cells (RGCs) and their respective axons, which compose the retinal nerve fiber layer (RNFL).[1–5] A significant reduction in the RGC population can occur before visual field (VF) deficits are obvious, and structural loss can precede detectable function loss by up to 5 years.[6–9] Therefore, developing methods to quantify RGC-related glaucomatous changes could lead to glaucoma detection at an earlier stage and more accurate tracking of glaucoma progression.

The loss of RGCs can be visualized as localized or diffuse thinning of the RNFL.[10–12] RNFL thickness, as determined by optical coherence tomography (OCT), distinguished normal from glaucomatous eyes, even in the early stages of the disease.[13–17] A newer Fourier-domain (FD)-OCT has recently become available; this technique measures the thickness of the inner three retinal layers, which are collectively known as the macular ganglion cell complex (GCC).[18,19] The macular GCC is expected to target the cells directly affected by glaucoma in the area of their highest concentration. However, few studies have reported regression model results to confirm the precise nature of the structure–function relationship nor have any demonstrated the diagnostic relevance of GCC thickness to different severity grades of glaucoma.

In the present study, we therefore assessed the relationships between VF sensitivity and GCC thickness by FD-OCT (RTVue-100 GCC scan; Optovue Inc, Fremont, CA) and evaluated the diagnostic value of GCC thickness in early, moderate, and severe glaucoma. These results were compared with mean RNFL thickness measured by the system (ONH [optic nerve head] mode).

Methods

Subjects

Participants were consecutively enrolled from the Glaucoma-Cataract Clinic of Severance Hospital in the Yonsei University Health System from January 2009 to June 2009. The study was approved by our institutional review board and complied with the tenets of the Declaration of Helsinki. Patients provided written informed consent.

All subjects underwent applanation tonometry, gonioscopy, and fundus examination with a +90-D lens. Automated refraction, biometry measurement, and standard VF testing were performed. All eyes underwent FD-OCT (RTVue-100; Optovue) after pupillary dilation (minimum diameter, 5 mm). For each patient, all examinations were performed during a single day.

Normal eyes were defined as those with no family history of glaucoma in a first-degree relative, no history or evidence of intraocular surgery, and no retinal pathologic features. Normal eyes also had a best corrected visual acuity of 20/40 or better, with refractive error between +3.00 and −6.00 D, intraocular pressure (IOP) of 21 mm Hg or lower, normal-appearing ONH, and reliable normal VF test results with normal glaucoma hemifield results and a normal mean deviation (MD) and pattern standard deviation (PSD; $P > 0.05$). Glaucomatous eyes were defined as those with a glaucomatous VF defect confirmed by two reliable VF examinations and by the appearance of a glaucomatous

From the [1]Institute of Vision Research, Department of Ophthalmology, Yonsei University College of Medicine, Seoul, Korea; and the [2]Department of Biostatistics, College of Medicine, Korea University, Seoul, Korea.

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Corresponding author: Chan Yun Kim, Institute of Vision Research, Department of Ophthalmology, Yonsei University College of Medicine, 134 Shinchon-dong, Seodaemun-gu, Seoul, Korea, 120-752; kcyeye@yuhs.ac.

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optic disc with typical loss of neuroretinal rim as judged by slit lamp biomicroscopy (cup-to-disc ratio, >0.7; intereye cup asymmetry, >0.2; or neuroretinal rim notching, focal thinning, disc hemorrhage, or vertical elongation of the optic cup). IOP was not used as a criterion for glaucoma group. Glaucoma was categorized into three subgroups according to the modified Hodapp-Anderson-Parrish grading scale based on the MD of VFs.[20,21] Early glaucoma was defined as VF loss with an MD ≥ -6 dB, moderate glaucoma as an MD between -6 and -12 dB, and severe glaucoma as an MD worse than -12 dB.

Visual Field Examination

Standard VF testing was performed using automated static perimetry (Humphrey Field analyzer with Swedish Interactive Thresholding Algorithm [SITA] standard 24-2 test program; Carl Zeiss Meditec, Dublin, CA). The VF was considered reliable when fixation losses were less than 20%, and false-positive and -negative errors were less than 15%. Mean VF sensitivity was calculated by the perimetry software and expressed as MD, PSD, and VF index (VFI). A field defect was defined as having three or more significant ($P < 0.05$) non–edge-contiguous points with at least one at the $P < 0.01$ level on the same side of the horizontal meridian in the pattern deviation plot, classified as outside normal limits in the glaucoma hemifield test and confirmed with at least two VF examinations.

OCT Measurements

Mean GCC and RNFL thicknesses were measured by using FD-OCT (RTVue-100 software version: 4.0.5.39; Optovue), which acquires 26,000 A-scans per second and provides a 5-μm depth resolution in tissue.

RNFL thickness was determined by ONH mode, in which data along a 3.45-mm diameter circle around the optic disc was recalculated with a map created from en face imaging that used 6 circular and 12 linear data inputs. Mean, superior, and inferior RNFL thicknesses were calculated.

The GCC scan was centered 1-mm temporal to the fovea and covered a square grid (7×7 mm) on the central macula. GCC thickness was measured from the internal limiting membrane to the outer inner plexiform layer boundary, and mean, superior, and inferior GCC thicknesses were calculated. Two pattern-based diagnostic parameters were also obtained. Focal loss volume (FLV) was computed as the integral of deviation in areas of significant focal GCC loss divided by the map area. Global loss volume (GLV) was computed as the sum of negative fractional deviation in the entire area.[18]

Images were excluded when signal strength index was less than 35, overt misalignment of the surface detection algorithm occurred, or there was overt decentration of the measurement circle location.

Statistics

Data were discarded if the scan quality did not satisfy the criteria described earlier. When data from both eyes were eligible for analysis, one eye from each patient was randomly selected for data analysis.

Mean GCC and RNFL of normal eyes were compared with glaucomatous eyes by *t*-test. Analysis of variance (ANOVA) and the Scheffé post hoc multiple comparisons test were used to compared the different glaucoma severity groups.

The relationships between mean RNFL/GCC thickness and MD/VFI were evaluated with linear and nonlinear (second-order and third-order polynomial) regression analyses. Regression models were evaluated with the Akaike information criterion (AIC) and the extra-sum-of-square *F* test.[22,23] The *F* test was used to test whether the alternative nonlinear model (second-order polynomial or third-order polynomial) fit the data better than the linear model.[23] The regression equation was plotted to display the change in visual sensitivity according to the extent of RNFL or GCC damage.

Receiver operating characteristic (ROC) curves assessed the ability of RNFL and GCC parameters to detect glaucomatous changes in patients with various levels of glaucoma severity. An area under the ROC curve (AUC) value of 1.0 represented perfect discrimination, whereas an AUC of 0.5 represented discrimination that is no better than results obtained by chance. Differences in the diagnostic ability (AUC) of RNFL and GCC were tested for statistical significance by a previously described method[24] (all statistical analyses: SPSS for Windows, ver. 12.0.0, SPSS Inc, Chicago, IL). $P < 0.05$ was considered statistically significant.

Results

Subjects

During the enrollment period, a total of 604 eyes of 315 participants were examined. Twelve eyes were excluded because of poor OCT images (signal strength, <35). Thirty-one eyes were excluded because of poor scan centration (RNFL, $n = 1$; GCC, $n = 28$) or an epiretinal membrane ($n = 2$) that resulted in poor-quality images. Twenty-one eyes in which an erroneous RNFL or GCC profile of 0.0 μm was computed by

Table 1. Characteristics of Subjects

Variable	Normal ($n = 103$)	Glaucoma ($n = 138$)	P*	Early Glaucoma ($n = 55$)	Moderate Glaucoma ($n = 42$)	Severe Glaucoma ($n = 41$)	P†
Age, y	55.10 ± 12.76	58.54 ± 15.44	0.067	54.66 ± 14.19	60.52 ± 15.86	61.71 ± 15.87	0.051
Female sex, *n* (%)	62 (60.2%)	68 (49.3)	0.093	26 (47.3%)	20 (27.6%)	22 (53.7%)	0.799
IOP, mm Hg	14.28 ± 3.37	13.67 ± 3.40	0.169	14.11 ± 3.49	14.26 ± 3.30	12.48 ± 3.12	0.025
CCT, μm	544.48 ± 33.00	541.06 ± 39.55	0.593	541.41 ± 38.88	545.23 ± 36.36	536.24 ± 44.47	0.723
Spherical equivalent, D	−2.60 ± 3.96	−2.38 ± 4.18	0.738	−2.11 ± 3.55	−2.50 ± 5.09	−2.57 ± 4.01	0.902
Axial length, mm	24.55 ± 1.62	24.45 ± 1.93	0.677	24.42 ± 1.35	24.90 ± 2.69	24.04 ± 1.56	0.163
Anterior chamber depth, mm	3.40 ± 0.71	3.30 ± 0.56	0.254	3.26 ± 0.43	3.24 ± 0.63	3.42 ± 0.62	0.330
SAP-SITA MD, dB	−2.78 ± 2.53	−9.27 ± 6.78	<0.001	−3.44 ± 1.60	−8.49 ± 1.87	−17.91 ± 5.16	<0.001
SAP-SITA PSD, dB	2.40 ± 1.40	7.27 ± 4.35	<0.001	3.95 ± 2.29	7.72 ± 3.76	11.33 ± 3.32	<0.001
SAP-SITA VFI, %	97.26 ± 4.70	77.62 ± 23.46	<0.001	94.55 ± 4.32	82.59 ± 10.02	48.77 ± 22.13	<0.001
VCDR	0.55 ± 0.15	0.70 ± 0.19	<0.001	0.65 ± 0.18	0.67 ± 0.19	0.79 ± 0.19	0.007
HCDR	0.56 ± 0.16	0.67 ± 0.19	<0.001	0.61 ± 0.16	0.66 ± 0.19	0.77 ± 0.19	0.002
OCT disc area, mm^2	2.55 ± 0.52	2.54 ± 0.58	0.940	2.53 ± 0.52	2.62 ± 0.67	2.49 ± 0.57	0.611

Data are expressed as the mean ± SD. CCT, central corneal thickness; HCDR, horizontal cup-to-disc ratio; SAP, standard automated perimetry; VCDR, vertical cup-to-disc ratio.

* Difference between normal and glaucoma.

† Differences among severity level of glaucoma.

TABLE 2. Mean Thickness of RNFL and GCC, as Determined by OCT

	Normal (n = 103)	Glaucoma (n = 138)	P*	Early Glaucoma (n = 55)	Moderate Glaucoma (n = 42)	Severe Glaucoma (n = 41)	P†
RNFL, μm							
Mean	109.31 ± 12.60	86.36 ± 16.22	<0.001	93.15 ± 16.50	85.05 ± 15.85	78.60 ± 12.23	<0.001
Superior	113.43 ± 14.58	92.31 ± 19.67	<0.001	99.42 ± 21.21	90.36 ± 18.03	84.79 ± 15.91	0.001
Inferior	105.17 ± 13.48	80.25 ± 16.76	<0.001	86.88 ± 15.96	79.69 ± 17.92	71.94 ± 12.52	<0.001
GCC, μm							
Mean	95.08 ± 7.88	79.89 ± 10.66	<0.001	83.30 ± 9.27	80.13 ± 9.60	75.08 ± 11.79	0.001
Superior	94.52 ± 8.33	82.66 ± 12.69	<0.001	86.31 ± 10.06	82.26 ± 11.44	78.17 ± 15.55	0.007
Inferior	95.28 ± 9.26	77.16 ± 11.85	<0.001	80.32 ± 10.76	78.13 ± 11.02	71.91 ± 12.54	0.002
FLV, %	2.21 ± 3.12	7.79 ± 5.42	<0.001	5.91 ± 3.96	8.53 ± 5.49	9.55 ± 6.33	0.002
GLV, %	8.23 ± 5.87	21.62 ± 9.27	<0.001	18.06 ± 8.29	21.83 ± 8.01	26.17 ± 9.83	<0.001

Data are expressed as the mean ± SD.
* Differences between normal and glaucoma.
† Differences among severity level of glaucoma.

poor delineation were excluded for analysis (RNFL, n = 4; GCC, n = 17), as were four eyes in which a reversed cross-sectional image caused algorithm failure of the CCG scan. In addition, five eyes were excluded because of poor-quality disc photographs, poor-quality red-free RNFL photographs (n = 4), or unreliable VFs (n = 1).

One individual in the early glaucoma group was excluded from the analysis as an outlier with unusual GCC thickness, which was identified by visual inspection. This measurement was shown to be an influential value in the regression analysis by residual analysis. After we conducted regression analyses including the value and excluding the value, we decided not to include the outlier in the analysis, since the fitted line was affected by it.

Finally, a total of 241 eyes of 241 patients (total participants, N = 241; normal controls, n = 103; patients with glaucoma, n = 138) were included in the study. Glaucoma was categorized as early (n = 55), moderate (n = 42), or severe (n = 41), according to the modified Hodapp classification.[20,21]

The mean ages of the normal control subjects and glaucoma patients were 55.10 ± 12.76 and 58.54 ± 15.44 years, respectively. The mean VF MDs in the normal subjects and in the early, moderate, and severe glaucoma groups were −2.78 ± 2.53, −3.44 ± 1.60, −8.49 ± 1.87, and −17.91 ± 5.16 dB, respectively. Table 1 summarizes participant demographic characteristics.

OCT Measurements

RNFL and GCC measurements of the control and glaucoma groups are presented in Table 2. As expected, the mean RNFL thickness was highest in the control group and decreased as glaucoma severity increased (normal, 109.31 ± 12.60 μm; early, 93.15 ± 16.50 μm; moderate, 85.05 ± 15.85 μm; and severe, 78.60 ± 12.23 μm). Mean GCC thickness followed the same pattern (normal, 95.08 ± 7.88 μm; early, 83.30 ± 9.27 μm; moderate, 80.13 ± 9.60 μm, and severe, 75.08 ± 11.79 μm). Differences in RNFL and GCC parameters between normal and glaucomatous eyes were significant (all comparisons, $P < 0.001$), as were differences among glaucoma groups with various levels of severity (all comparisons, $P < 0.05$). Post hoc analysis revealed that mean RNFL thickness differed significantly between early and moderate glaucoma groups (P = 0.036), and all OCT parameters showed significant differences between early and severe disease ($P < 0.05$).

Relationship between Visual Sensitivity and GCC Thickness

The relationships between the perimetry global indices, MD and VFI, with OCT parameters were evaluated by regression analysis (Table 3). The structure–function relationship was better explained with nonlinear models when visual sensitivity MD (dB) was plotted against RNFL thickness (linear versus second-order model, P = 0.006; linear versus third-order model, P = 0.018). Nonlinear models also better explained the relationship between VF MD and GCC thickness (linear versus second-order model, $P < 0.001$; linear versus third-order model, $P < 0.001$). Second-order regression models showing structure–function relationships between VF MD and mean RNFL thickness and between VF MD and mean GCC thickness are displayed in Figure 1.

Similarly, nonlinear models better described the relationships between VFI and mean RNFL thickness (linear versus second-order model P = 0.007; linear versus third-order model

TABLE 3. Prediction of MD and VFI from OCT Parameters, by Regression Analysis

	Linear		Second-Order Polynomial				Third-Order Polynomial			
	R^2	AIC	R^2	AIC	F	P*	R^2	AIC	F	P†
MD										
RNFL mean	0.295	1488.758	0.314	1482.959	7.8285	0.006	0.312	1484.569	4.0957	0.018
GCC mean	0.255	1501.993	0.299	1488.285	16.030	<0.001	0.306	1486.910	9.765	<0.001
VFI										
RNFL mean	0.267	2006.794	0.286	2001.449	7.3656	0.007	0.285	2002.683	4.0563	0.019
GCC mean	0.259	2009.321	0.316	1991.455	20.468	<0.001	0.318	1991.844	11.055	<0.001

n = 241.
* Comparison of linear and second order models.
† Comparison of linear and third order models.

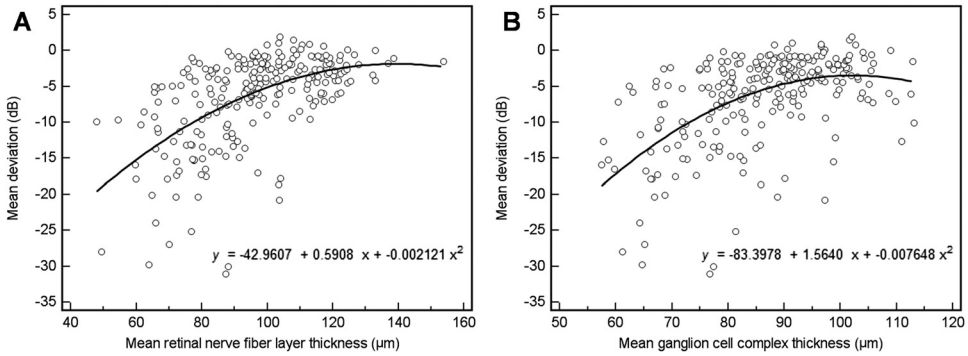

FIGURE 1. Second-order regression models of the relationships between VF MD and mean RNFL thickness (**A**) and between VF MD and mean GCC thickness (**B**) measured by OCT.

$P = 0.019$) and between VFI and mean GCC thickness (linear versus second-order model, $P < 0.001$; linear versus third-order model, $P < 0.001$). Figure 2 shows scatterplots of OCT measurements versus VFI fitted with the second-order regression equation.

Diagnostic Value of GCC and RNFL Thicknesses among Different Glaucoma Severity Groups

The diagnostic values of mean RNFL thickness and GCC parameters (mean thickness, FLV, and GLV) were compared with ROC curves (Table 4, Fig. 3). Of the OCT parameters, inferior GCC thickness was best able to discriminate glaucomatous changes between early glaucoma and normal eyes (AUC, 0.855; $P = 0.024$ versus superior RNFL thickness; $P = 0.031$ versus superior GCC thickness). The diagnostic value of mean GCC thickness (AUC, 0.834) appeared to be greater than that of mean RNFL thickness (AUC, 0.782), but the difference was not significant ($P = 0.330$). The RNFL and GCC parameters were similar in ability to diagnose moderate glaucoma. Inferior RNFL thickness (AUC, 0.963) was best able to diagnose severe glaucoma ($P = 0.009$ versus superior GCC thickness); mean RNFL thickness (AUC, 0.961) and mean GCC thickness (AUC, 0.916) were not significantly different in detecting severe glaucoma ($P = 0.214$).

DISCUSSION

In the present study, we found that peripapillary RNFL thickness and macular GCC thickness had similar structure–function relationships with VF sensitivity and similar diagnostic values for glaucoma detection. The GCC parameters (FLV, GLV, and mean, superior, and inferior thickness) readily identified glaucoma patients with early, moderate, and severe VF loss. Mean GCC thickness appeared to be a better predictor of early glaucoma than was mean RNFL thickness, but the difference was not significant.

Regression analysis has been effectively used to examine structure–function relationships during disease progression in cross-sectional studies.[23] The relationship between decibel light sensitivity and the number of ganglion cells appears to be curvilinear,[25,26] as does the relationship between VF sensitivity and neuroretinal rim measurements.[27–29] In addition, results in studies have demonstrated that second- and third-order regression models best describe the relationship between VF sensitivity and RNFL thickness.[23,30,31] These results are consistent with the idea that structural changes precede visual function changes, and visual function changes are less apparent in the early stages of structural damage.[32]

In the present study, curvilinear regression models of the relationship between RNFL and VF sensitivity were consistent with results from most of the previous investigations. Similarly, second- and third-order regression models of GCC thickness versus VF sensitivity yielded stronger structure–function associations compared with the first-order regression model. The correlation between VF sensitivity measured on a logarithmic scale (in decibels) with structural parameters measured on a linear scale accentuates changes at low decibel levels while minimizing changes at high decibel levels, accounting at least in part for the curvilinear relationship.[33] The VFI also showed a curvilinear relationship with GCC and RNFL thickness. It is based on total deviation and pattern deviation values and is expressed as a percentage after age correction and a weighting procedure.[34]

In other studies, investigators have reported that peripapillary RNFL measurements are significantly more accurate in glaucoma detection than is macular thickness.[35–37] The RTVue directly measures the thickness of the inner three retinal layers. By targeting cells directly affected by glaucoma in the area of their highest concentration, it is believed to detect glaucoma earlier. In a few studies, the diagnostic value of RNFL and GCC measurements has been compared with that of FD-OCT and the results have shown that diagnosis using macular GCC

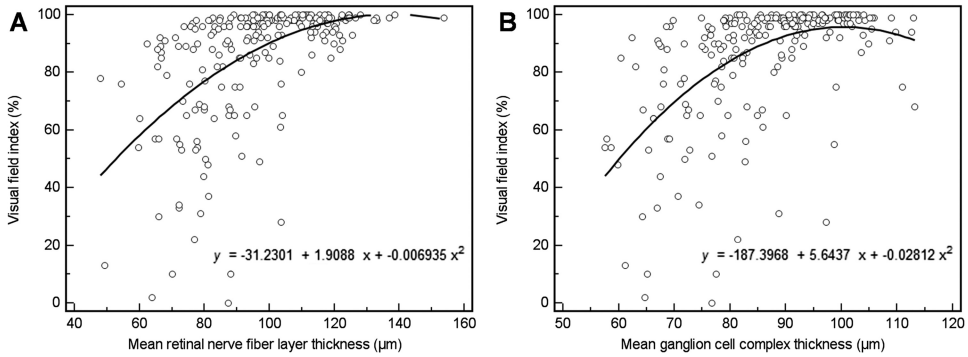

FIGURE 2. Second-order regression models of the relationships between VFI and mean RNFL thickness (**A**), and between VFI and mean GCC thickness (**B**) measured by OCT.

TABLE 4. Evaluation of OCT Parameters as Diagnostic Tests with the Area under the ROC Curve

	Normal versus Early Glaucoma	Normal versus Moderate Glaucoma	Normal versus Severe Glaucoma
RNFL			
Mean	0.782 (0.699–0.864)	0.893 (0.833–0.953)	0.961 (0.928–0.995)
Superior	0.723 (0.628–0.819)	0.836 (0.759–0.914)	0.905 (0.848–0.962)
Inferior	0.799 (0.724–0.873)	0.869 (0.802–0.937)	0.963 (0.927–0.999)
GCC			
Mean	0.834 (0.770–0.899)	0.895 (0.835–0.955)	0.916 (0.853–0.978)
Superior	0.739 (0.655–0.822)	0.826 (0.745–0.907)	0.850 (0.772–0.927)
Inferior	0.855 (0.792–0.919)	0.884 (0.821–0.946)	0.927 (0.870–0.984)
FLV (%)	0.819 (0.753–0.885)	0.880 (0.821–0.939)	0.905 (0.853–0.958)
GLV (%)	0.850 (0.791–0.908)	0.909 (0.858–0.961)	0.934 (0.888–0.981)

Data are the mean area under the ROC curve (95% CI), unless otherwise noted.

parameters is comparable with diagnosis using circumpapillary RNFL measurements.[18,19] In the present study, we observed similar AUC results for glaucoma detection between peripapillary RNFL and macular GCC thickness, irrespective of disease severity.

Mean GCC thickness appeared to be a better diagnostic marker for early glaucoma compared with RNFL thickness, although the AUC difference was not significant. This finding may be explained, in part, by GCC being a more direct measure of RGC integrity. Macular GCC parameters have a theoretical advantage over peripapillary RNFL parameters in diagnosis, because RGC loss occurs early in the pathogenesis of glaucoma. Further, early RGC loss typically gives rise to isolated damage in the paracentral areas (10°–20°). The macular GCC scan is centered on the fovea, covers a 7 × 7-mm grid on the central macula, and readily detects early GCC loss. However, the performance of mean GCC thickness in the diagnosis of early glaucoma must be studied further.

GCC thickness is a somewhat lesser indicator of severe glaucomatous damage than is RNFL thickness, because only approximately 50% of the RGCs are present in the macula, but nearly 100% of the RGCs are assessed in a peripapillary OCT RNFL scan. Although RTVue covers a relatively large representative macular area (7 × 7 mm), the entire RGC layer is not assessed; thus, diagnostic ability could be limited in advanced glaucoma with extensive GCC loss. For example, the diagnostic value of GCC and RNFL parameters may differ in cases of advanced glaucoma with extreme peripheral ganglion cell loss. The diagnostic value of GCC parameters in severe glaucoma should be studied further.

Macular GCC parameters may be better diagnostic indicators in cases of nonglaucomatous conditions with reduced RNFL thickness, such as extensive peripapillary atrophy in high myopia. In the present study, the percentage of patients with high myopia (spherical equivalents, ≤−6.0 D) was similar among glaucoma groups (early, 9.1%; moderate, 14.3%; severe, 9.8%; $P = 0.691$). Thus, the presence of myopic peripapillary atrophy appeared to have little effect on our results.

GLV and FLV are pattern-based parameters that reflect different aspects of GCC loss. They sum up the volume of GCC loss in the macula with differing levels of focality.[18] We observed higher diagnostic accuracy with GLV than with mean GCC thickness for glaucoma, regardless of disease severity. This finding is similar to that in another study in which better diagnostic abilities of FLV and GLV were reported in glaucoma patients with abnormal perimetric test results.[18] In some cases, pattern parameters are more sensitive or specific because thick maculopapillary bundles may attenuate mean GCC loss.

There were several limitations to this study, including a relatively small sample size. This cross-sectional study cannot provide longitudinal structural and functional data associated with GCC parameters. Although curvilinear functions best fit our data, structural parameters could not completely account for the variation in functional loss associated with glaucoma. The present study included normal controls and glaucoma patients, not comprising the full spectrum of glaucomatous damage including suspected glaucoma. Only Asian participants were included in the study; the role of race in determining structure–function relationships is not known. Tan et al.[18] reported that GCC parameter reproducibility did not differ between preperimetric and perimetric glaucoma patients. However, we did not assess this reproducibility of the GCC parameters, which may affect diagnostic ability according to glaucoma severity.

In conclusion, curvilinear functions best explained the relationship between VF sensitivity and GCC thickness. Macular

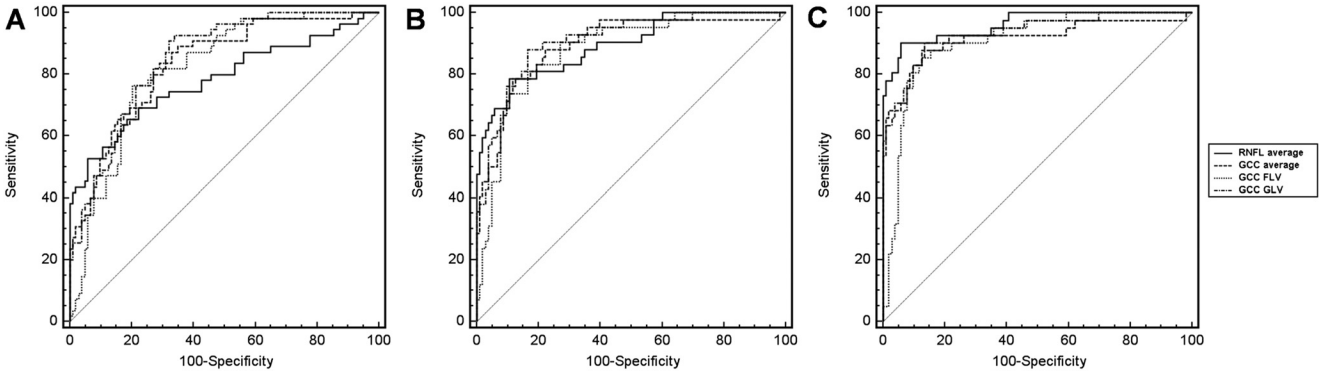

FIGURE 3. AUCs for mean RNFL thickness, mean GCC thickness, FLV of GCC, and GLV of GCC according to visual field sensitivity: normal versus early glaucoma (**A**), normal versus moderate glaucoma (**B**), and normal versus severe glaucoma (**C**).

GCC thickness was comparable to RNFL thickness for detection of early, moderate, and severe glaucoma. Thus, GCC and RNFL parameters may be considered complementary diagnostic tools.

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