Glaucosa

Diagnosis of Early-Stage Glaucoma by Grid-Wise Macular Inner Retinal Layer Thickness Measurement and Effect of Compensation of Disc-Fovea Inclination

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PURPOSE. To evaluate grid-wise analyses of macular inner retinal layer thicknesses and effect of compensation of disc-fovea inclination for diagnosing early-stage glaucoma.

METHODS. Spectral-domain optical coherence tomography measurements over a 6.0 × 6.0-mm macular area were prospectively obtained in 104 eyes of 104 patients with early-stage glaucoma with a mean deviation of −1.8 ± 1.9 dB and 104 eyes of 104 age- and refraction-matched normal subjects. Macular retinal nerve fiber layer (mRNFL), ganglion cell-inner plexiform layer (GCIP), and ganglion cell complex (GCC) thickness of the whole area and each subdivided macular grid were determined to compare diagnostic capability for glaucoma using receiver operating characteristic curves and various normal cutoff values for each layer thickness and number of grids flagged as abnormal. Diagnostic capability was then compared with that of circumpapillary RNFL (cpRNFL) measurements. Effects of compensation of inclination of disc-fovea line by reconfiguration of the macular grid were also studied.

RESULTS. Macular inner retinal layer analyses using 8 × 8 grids generally yielded higher diagnostic capability. Only the 8 × 8 grid GCC analyses using the various normal cutoff values yielded a sensitivity ≥ 0.90 with specificity ≥ 0.95 under several conditions in discriminating the glaucoma eyes. In glaucoma and normal eyes with both reliable cpRNFL and macular measurements, the best sensitivity/specificity were 0.98/0.95 for the 8 × 8 grid-mRNFL analysis and 0.93/0.96 for the 8 × 8 grid GCC analysis using various normal cutoff values, which were better than that (0.78/0.95) for clock-hour cpRNFL analysis (P = 0.001). Compensation of the disc-fovea inclination did not improve the diagnostic capability.

CONCLUSIONS. Grid-wise analysis of macular GCC—especially using 8 × 8 grids and normative data-based cutoff values—was very useful for diagnosing early-stage glaucoma, though compensation of the disc-fovea inclination had little effect.

Keywords: glaucoma, optical coherence tomography, inner retinal layers, grid

Optical coherence tomography (OCT) effectively detects glaucomatous optic neuropathy with early visual field damage.1-7 Optical coherence tomography-based glaucoma diagnosis is based mainly on analyzing the circumpapillary retinal nerve fiber layer (cpRNFL) thickness and/or optic disc morphology.8-12 Major retinal vessels in the circumpapillary area, however, may limit detection of early glaucomatous changes. Moreover, reliable and automatic determination of the anatomical disc margin or Bruch membrane’s opening, which is an important benchmark for cpRNFL measurements, may be difficult.13 On the other hand, analysis of detailed structure-function relationships is possible in the macular area, which contains ≥50% of the whole retinal ganglion cells.14 Measurements of OCT are less affected by retinal vessels and automatic determination of the fovea as the center of the analysis area is technically easier in the macular area without manifest pathological changes.

Current spectral-domain (SD)-OCT devices are equipped with software that provides automatic segmentation and thickness measurements of macular inner retinal layers, including the macular retinal nerve fiber layer (mRNFL), ganglion cell layer (GCL) + inner plexiform layer (GCIP), and the mRNFL + GCIP (ganglion cell complex, GCC).15-17 Several SD-OCT studies report significant decreases in the thicknesses of these layers in eyes with early-stage glaucoma, even in those lacking manifest visual field defects (VFD) in standard static automated perimetry.21,22

The diagnostic capability of macular GCIP or GCC has been studied based on the thickness of the layers over the whole macula,19,20,26 hemifield, or sectorial macular area,24-26 and macular GCIP or GCC measurements have similar glaucoma
Open-angle glaucoma patients fulfilling the following criteria were consecutively enrolled in each institute and underwent the same examinations as above. Inclusion criteria were: 1) accustomed to VF testing and producing reliable and reproducible VF test results with mean deviation (MD) of $\leq-6.0$ dB; 2) apparent glaucomatous changes in the optic disc with or without apparent RNFL defects confirmed by glaucoma specialists (MA, AJ) according to stereo-fundus photographs and digitally constructed red-free photographs. Apparent glaucomatous changes in the optic disc referred to here are a rim notch with a remaining rim $\leq 0.1$ of the disc diameter or a vertical cup-to-disc ratio $> 0.7$ in one eye with that of the fellow eye smaller by $\geq 0.2$ not explained by differences in disc size. Glaucomatous VFDs were not a concern when apparent disc findings and/or RNFL defects were wider than the major retinal vessel diameter at the disc margin; 3) eyes with refractive error $> -6.0$ D and $< 3.0$ D; and 4) no history of any other ocular pathologic changes that could affect the results of HFA or OCT examinations, including incisional intraocular surgeries or refractive surgeries. The Humphrey field analyzer 24-2 SITA standard program results were obtained within 3 months of the OCT examination, and glaucomatous VFDs were defined by 1) a cluster of $\geq 3$ points in the pattern deviation plot in a single hemifield (superior/ inferior) with $P < 0.05$, one of which must have been $P < 0.01$, 2) glaucoma hemifield test result outside of normal limits, or 3) abnormal pattern standard deviation with $P < 0.05$. If both eyes of a subject were eligible, we included the eye with better data quality in the SD-OCT examination.

Finally, macular OCT images fulfilling the criteria described below were obtained in 104 early-stage OAG eyes of 104/181 initially enrolled OAG patients. From all normal subjects meeting the inclusion criteria, we selected those matched to glaucoma patients in terms of age and refraction (within 1 year of age and 1 D of spherical equivalent). Thus, 104 age- and refraction-matched normal eyes of 104/261 normal subjects were selected (Table 1).

**OCT Measurements**

Optimal coherence tomography scanning was performed using a three-dimensional (3D) OCT-1000 Mark II (Topcon, Inc., Tokyo, Japan) after pupillary dilation with 1% tropicamide. Spectral-domain OCT datasets were obtained with the raster-scan protocol in which data were obtained in $6.0 \times 6.0$ mm$^2$ areas (128 scan lines each comprised of 512 A-scans) centered on the fixation point within approximately 2.5 seconds. The magnification effect was corrected according to the manufacturer-provided formula$^{31,32}$ based on refractive error, corneal radius, and axial length. Registration of fundus photographs and OCT images was automatically confirmed using an OCT projection image and localization of major retinal vessels. Measurements in the macula were repeated three times at several second intervals.

A similar raster scan was performed centered on the optic disc; and repeated three times. The disc center was determined as the barycenter of the closed spline curve fitted to seven manually determined points on the disc edge in a simultaneously obtained color fundus photograph by the nonmydriatic fundus camera function of the instrument used, and extrapolated in all OCT images thereafter.

Data influenced by eye movements, involuntary blinking, or saccade, indicated by breaks or shifting of the images or a straight line across the image, or those with a quality factor $< 60\%$ were discarded. Data with the best quality factor (given by the SD-OCT apparatus based on signal intensity) were adopted.

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**Materials and Methods**

**Subjects**

Data for normal subjects and open-angle glaucoma (OAG) patients were prospectively acquired from four institutes in Japan using the same selection criteria: the University of Tokyo (Tokyo, Japan), Kanazawa University (Kanazawa, Japan), Kyoto University (Kyoto, Japan), and Tajimi Municipal Hospital (Gifu, Japan). The study protocol was approved by each institution’s institutional review board and adhered to the tenets of the Declaration of Helsinki. Written informed consent was obtained from each subject after explanation of the study protocol.

We recruited self-reported healthy volunteers $\geq 20$ years of age. The following ocular examinations were performed at the first visit: refraction and corneal curvature (ARK-900; NIDEK, Tokyo, Japan), best-corrected visual acuity, axial length (IOL Master; Carl Zeiss Meditec, Inc.), biomicroscopy, intraocular pressure (IOP; Goldmann applanation tonometry), dilated funduscopy, and VF test (HFA 24-2 SITA standard program). Exclusion criteria were: contraindication to pupil dilation; IOP $\geq 22$ mm Hg; best-corrected visual acuity $\leq 20/25$; refractive error $\leq -6.0$ diopters (D) or $\geq +3.0$ D; unrelatable HFA results (fixation loss, false-positive, or false-negative $> 20\%$); VFDS suggestive of glaucoma according to Anderson and Patella’s criteria$^{24}$; history of intraocular or refractive surgery or ocular or systemic diseases that could affect the OCT results, including cataract or macular degeneration; and optic nerve or retinal abnormalities.

**Table 1. Characteristics of the Subjects**

<table>
<thead>
<tr>
<th>Glaucomatous Damage</th>
<th>Normal</th>
<th>Early-Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of subjects, eyes</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td>Women/men*</td>
<td>55/49</td>
<td>71/33</td>
</tr>
<tr>
<td>Age, y</td>
<td>57.6 $\pm$ 11.0</td>
<td>58.2 $\pm$ 10.2</td>
</tr>
<tr>
<td>Refraction, D</td>
<td>$-1.04 \pm 1.28$</td>
<td>$-1.41 \pm 2.12$</td>
</tr>
<tr>
<td>Mean deviation, dB†</td>
<td>$-0.15 \pm 1.17$</td>
<td>$-1.80 \pm 1.93$</td>
</tr>
</tbody>
</table>

Refraction indicates spherical equivalent of the subject eye. Mean deviation indicates mean deviation of a central 24-2 test program of Humphrey Field Analyzer. Intergroup difference was significant at *$P = 0.023$, $\chi^2$-test and *$P < 0.001$, Mann-Whitney U test. **Exclusion criteria were: contraindication to pupil dilation; IOP $> 24$ mm Hg (Goldmann applanation tonometry), dilated biomicroscopy, intraocular surgeries or refractive surgeries. The Humphrey field analyzer 24-2 SITA standard program results were obtained within 3 months of the OCT examination, and glaucomatous VFDs were defined by 1) a cluster of $\geq 3$ points in the pattern deviation plot in a single hemifield (superior/inferior) with $P < 0.05$, one of which must have been $P < 0.01$, 2) glaucoma hemifield test result outside of normal limits, or 3) abnormal pattern standard deviation with $P < 0.05$. If both eyes of a subject were eligible, we included the eye with better data quality in the SD-OCT examination.**
Analysis of the OCT Data

In the macula, the fovea was automatically identified in the OCT image as the sampling point with the thinnest retinal thickness adjacent to the fixation point, and the 5.5 × 5.5-mm square area centered on the fovea was analyzed. Eyes for which the analysis area exceeded the edge of the 6.0 × 6.0-mm data acquisition area were excluded. Macular retinal nerve fiber layer and GCIPL were automatically segmented16 and confirmed on all B-scan images by an experienced examiner (MH), and the layer thicknesses were determined at each sampling point. The 5.5 × 5.5-mm analysis area was divided into upper and lower hemiretina, 4 × 4, or 8 × 8 grids where the thicknesses of mRNFL, GCIPL, and GCC (mRNFL + GCIPL) were calculated as the mean thickness over all sampling point within each grid (Fig. 1).

Diagnostic Capability of mRNFL, GCIPL, and GCC

Receiver operating characteristic (ROC) curve analyses were performed to study the capability of mRNFL, GCIPL, and GCC to discriminate current glaucoma eyes from age- and refraction-matched normal eyes. The area under the ROC curve (AUC) was calculated for the whole analysis area, upper or lower hemiretina, or each of the 4 × 4 and 8 × 8 grids with varied cutoff levels of mRNFL, GCIPL, or GCC thickness. The area or grid with the greatest AUC was determined and sensitivity was calculated when specificity was 0.95 in the ROC curve. Then sensitivity/specificity was calculated in the same manner as above.

Comparison of cpRNFL and Macular Inner Retinal Layer Thickness Measurements

Results for mRNFL, GCIPL, or GCC were compared with those for cpRNFL in eyes of the same cohort of the subjects where eligible data for both macular and circumpapillary areas were obtained. Thickness of RNFL along a 3.4-mm diameter circle centered on the optic disc center was obtained from the raster scan data and averaged along the whole circumference or in sectors, each accounting for upper or lower 180°, 90°, or 30°, and the sector with the greatest AUC was determined and sensitivity was calculated when specificity was 0.95 in the ROC curve. Then the sensitivity/specificity was determined based on the number of abnormal sectors and normal data-based cutoff values (percentiles: 0.5th, 1st, 2.5th, 5th, or 10th percentile) of cpRNFL thickness established in a separate group of normal eyes35 similar to the analysis in the macular area.

Effects of the Compensation of Inclination of Disc-Fovea Line on Grid-Wise Analyses of Macular Inner Retinal Layer Thicknesses

The optic disc center and fovea were determined on the fundus photograph as described above and we calculated the angle between the line connecting those two points and the horizontal line, and positive angle indicates fovea is located below the horizontal line (Fig. 3a). The analysis area was then changed from 5.5 × 5.5 mm to 4.8 × 4.8 mm, so that the most peripheral grid locating at a corner of the square did not exceed the data acquisition area (6.0 × 6.0 mm), and grids were reconfigured in parallel with the line connecting the optic disc center and fovea (Fig. 3b). When any of the most peripheral grids exceeded the data acquisition area (6.0 × 6.0 mm), the eye was excluded from analysis.

The normative data based on the 0.5th, 1st, 2.5th, 5th, or 10th percentile cutoff values after correction of the inclination were separately constructed using data from the normal eyes33,34 for mRNFL, GCIPL and GCC, and sensitivity/specificity was calculated in the same manner as above.

Statistical Analysis

All statistical analyses were performed using (IBM SPSS Statistics 19; IBM Software, Japan, Tokyo) or the statistical programming language R (ver. 2.15.1; The R Foundation for Statistical Computing, Vienna, Austria).

Demographic data were compared between normal and OAG eyes by χ²-test or Mann-Whitney U test because their normal distribution was rejected by the Kolmogorov-Smirnov test. Sensitivities and specificities were compared using McNemar’s test. We used the AUC to evaluate the clinical usefulness of each condition, as suggested in a previous paper.36 Comparison of multiple AUCs was carried out using DeLong’s method.37 Values of P less than 0.05 were considered significant.

RESULTS

Analyses Using mRNFL, GCC, and GCIPL

Finally, 104 eyes of 104 OAG patients among 181 initially enrolled OAG patients were enrolled. Sixteen of 181 eyes (8.8%) were excluded because the analysis area exceeded the data acquisition area, and the other eyes were excluded because of inadequate image data quality due to several factors,
including blinking, eye movements or obvious segmentation error.

Results of ROC analyses with specificity equal to 0.95 and those using variant normative data–based cutoff values yielding the highest sensitivity with specificity \(\geq 0.95\) under the given conditions are listed in Tables 2, 3, and 4 for the analyses of mRNFL, GCIPL, or GCC, respectively.

For macular RNFL, the highest sensitivity with a specificity \(\geq 0.95\) (sensitivity/specificity \(\geq 0.88/0.95\)) was obtained using three or four contiguous 8 \(\times\) 8 grids outside the normative data–based 1st or 2.5th-percentile cutoff, respectively (Table 2).

For ganglion cell-inner plexiform layer, the highest sensitivity with specificity \(\geq 0.95\) (sensitivity/specificity \(\geq 0.80/0.96\)) was obtained using five contiguous 8 \(\times\) 8 grids outside the 2.5th percentile cutoff (Table 3).

For ganglion cell complex, only analyses using 8 \(\times\) 8 grids and normative data–based cutoff values yielded sensitivity \(\geq 0.90\) associated with specificity \(\geq 0.95\). That is, sensitivity/specificity equal to 0.90/0.95 was obtained using two or three contiguous 8 \(\times\) 8 grids outside the 0.5th or 1st percentile cutoff, respectively (Table 4). Further, sensitivity/specificity equal to 0.88 or 0.89/0.95 to 0.98 was obtained under several conditions using 8 \(\times\) 8 grids. The sensitivities/specificities obtained using the normative data-based 0.5th, 1st, 2.5th, 5th, and 10th percentile cutoff values for 8 \(\times\) 8 grids of GCC are plotted in Figure 4.

Adoption of 8 \(\times\) 8 grids yielded the highest sensitivity with specificity \(\geq 0.95\) for each macular inner layer, but only analyses using GCC attained sensitivity \(\geq 0.90\) with specificity \(\geq 0.95\) in the current subjects.

**Comparison Between cpRNFL and Macular Inner Retinal Layer Thickness Measurements**

Analyses using cpRNFL were performed in 86/104 OAG eyes and 77/104 normal eyes (Table 5), because cpRNFL measurement results satisfying the inclusion criteria were not obtained in 18 OAG and 27 normal eyes, probably because the cpRNFL measurements were performed after three repeated macular measurements.

Results of ROC analyses are shown in Table 6. The highest AUC (0.920) was obtained with inferotemporal 30° sector (seven o’clock in right eye orientation), which was not significantly different from those obtained with global average (0.892, \(P = 0.32\)), inferior 180° sector (0.883, \(P = 0.11\)), inferior 90° sector (0.891, \(P = 0.18\)). The highest sensitivity of 0.78 was obtained with specificity \(\geq 0.95\) using the 7 o’clock 30° sector. All sectors, including nerve fibers projecting the macular area, temporal 90° and 30° sectors located at 8, 9, or 10 o’clock, showed significantly smaller AUCs (0.662, 0.705, 0.564, and 0.626, respectively; \(P < 0.01\)) than that of global mean of cpRNFL (0.892).
The analyses using variant normative data–based cutoff values yielding the highest sensitivity with specificity
‡
0.95 under the given conditions are also listed in Table 6. The highest sensitivity with specificity
‡
0.95 obtained using various normative data–based cutoff values was 0.63 using 180
8
sectors. The largest sensitivity/specificity of 0.76/0.94 was obtained using at least one 30
8
sector outside the first-percentile cutoff, though specificity did not reach to 0.95.

On the other hand, the highest sensitivity with specificity
‡
0.95 obtained using mRNFL in the same eyes was 0.98 (sensitivity/specificity ¼ 0.98/0.95) using three contiguous 8
3
grids outside the 2.5th-percentile cutoff, while those obtained using GCC and GCIPL in the same eyes were 0.93/0.96 using three contiguous 8
3
grids outside the first-percentile cutoff, and 0.83/0.95 with three contiguous 8
3
grids outside the first-percentile cutoff, respectively.

The highest sensitivities of the mRNFL and GCC analyses were significantly higher than that of the cpRNFL analysis (0.98 vs. 0.78, \( P = 0.001 \) and 0.93 vs. 0.78, \( P = 0.001 \), respectively), while the same or a bit higher specificity of 0.95 or 0.96.

### Table 2. Diagnostic Capability of mRNFL Analyses Based on ROC Curves in Each Single Area or Grid Analyses Based on Various Normative Data–Based Cutoff Values in Single or Multiple Contiguous Grids

<table>
<thead>
<tr>
<th>Macular Area</th>
<th>Greatest–Smallest AUC (SE)</th>
<th>Sensitivity/Specificity (With 95% CI; Sensitivity at Fixed Specificity of 0.95)</th>
<th>Conditions*</th>
<th>Sensitivity/Specificity (With 95% CI; Highest Sensitivity at Specificity ≥ 0.95)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole area</td>
<td>0.944 (0.015)</td>
<td>0.76 (0.67–0.84)/0.95 (0.89–0.98)</td>
<td>5th percentile, the whole area</td>
<td>0.70 (0.60–0.79)/0.98 (0.93–1.00)</td>
</tr>
<tr>
<td>Upper or lower hemiretina</td>
<td>0.940 (0.016)–0.770 (0.032)</td>
<td>0.77 (0.68–0.85)/0.95 (0.89–0.98)</td>
<td>2.5th percentile, at least one hemiretina</td>
<td>0.80 (0.71–0.87)/0.98 (0.93–1.00)</td>
</tr>
<tr>
<td>4 × 4 grids</td>
<td>0.928 (0.018)–0.659 (0.038)</td>
<td>0.75 (0.66–0.83)/0.95 (0.89–0.98)</td>
<td>1st percentile, two contiguous grids</td>
<td>0.79 (0.70–0.86)/0.96 (0.90–0.99)</td>
</tr>
<tr>
<td>8 × 8 grids</td>
<td>0.919 (0.019)–0.513 (0.040)</td>
<td>0.72 (0.62–0.80)/0.95 (0.89–0.98)</td>
<td>1st percentile, three contiguous grids</td>
<td>0.88 (0.81–0.94)/0.95 (0.89–0.98)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2.5th percentile, four contiguous grids</td>
<td>0.88 (0.81–0.94)/0.95 (0.89–0.98)</td>
</tr>
</tbody>
</table>

CI, confidence interval.

* Conditions where the eyes were flagged as glaucomatous with respect to the normative data–based cutoff values and numbers of abnormal grids.
### Table 3. Diagnostic Capability of Macular GCIPL

<table>
<thead>
<tr>
<th>Macular Area</th>
<th>Analyses Based on ROC Curves in Each Single Area or Grid</th>
<th>Analyses Based on Variant Normative Data-Based Cutoff Values in Single or Multiple Contiguous Grids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Greatest–Smallest AUC (SE)</td>
<td>Sensitivity/Specificity (With 95% CI; Sensitivity at Fixed Specificity of 0.95)</td>
</tr>
<tr>
<td>Whole area</td>
<td>0.912 (0.019)</td>
<td>0.47 (0.37–0.57)/0.95 (0.89–0.98)</td>
</tr>
<tr>
<td>Upper or lower hemiretina</td>
<td>0.869 (0.025)–0.699 (0.037)</td>
<td>0.55 (0.45–0.65)/0.95 (0.89–0.98)</td>
</tr>
<tr>
<td>4 × 4 grids</td>
<td>0.884 (0.025)–0.580 (0.041)</td>
<td>0.56 (0.46–0.66)/0.95 (0.89–0.98)</td>
</tr>
<tr>
<td>8 × 8 grids</td>
<td>0.898 (0.022)–0.545 (0.041)</td>
<td>0.58 (0.48–0.67)/0.95 (0.89–0.98)</td>
</tr>
</tbody>
</table>

* Conditions where the eyes were flagged as glaucomatous with respect to the normative data-based cutoff values and numbers of abnormal grids.

### Table 4. Diagnostic Capability of Macular GCC

<table>
<thead>
<tr>
<th>Macular Area</th>
<th>Analyses Based on ROC Curves in Each Single Area or Grid</th>
<th>Analyses Based on Variant Normative Data-Based Cutoff Values in Single or Multiple Contiguous Grids</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Greatest–Smallest AUC (SE)</td>
<td>Sensitivity/Specificity (With 95% CI; Sensitivity at Fixed Specificity of 0.95)</td>
</tr>
<tr>
<td>Whole area</td>
<td>0.912 (0.019)</td>
<td>0.71 (0.61–0.80)/0.95 (0.89–0.98)</td>
</tr>
<tr>
<td>Upper or lower hemiretina</td>
<td>0.931 (0.018)–0.754 (0.054)</td>
<td>0.69 (0.59–0.78)/0.95 (0.89–0.98)</td>
</tr>
<tr>
<td>4 × 4 grids</td>
<td>0.934 (0.017)–0.650 (0.038)</td>
<td>0.76 (0.67–0.84)/0.95 (0.89–0.98)</td>
</tr>
<tr>
<td>8 × 8 grids</td>
<td>0.936 (0.017)–0.595 (0.040)</td>
<td>0.78 (0.69–0.85)/0.95 (0.89–0.98)</td>
</tr>
</tbody>
</table>

* Conditions where the eyes were flagged as glaucomatous in respect of the normative data-based cutoff values and numbers of abnormal grids.
In glaucoma, especially early-stage glaucoma, two contiguous grids and 1st percentile, three contiguous grids. See sensitivity equal to 0.90 and specificity equal to 0.96; 0.5th percentile, normative data–based cutoff values of 0.5th, 1st, 2.5th, 5th, and 10th percentile) and number of abnormal contiguous grids (1–7) to be diagnosed with glaucoma; 0.5%, 1.0%, 2.5%, 5.0%, and 10% indicate conditions of glaucoma. Almost identical sensitivity and specificity, diagnostic capability was not significantly improved under any conditions. Representative results with the highest or the second highest sensitivity were compared with and without correction of inclination, but diagnostic capability was not significantly improved under any conditions. Representative results with the highest or the second highest sensitivity and specificity are summarized in Table 8. Almost identical sensitivity and specificity, approximately 0.95, were obtained using reconstructed 8 × 8 grids of GCC or mRNFL in the 4.8 × 4.8-mm area and reconstructed normal data–based cutoff values after compensation of inclination of disc-fovea line.

**DISCUSSION**

Spectral-domain OCT allows for efficient analysis of the intraretinal layers in the macular region, and most previous studies report that GCC and GCIPL thicknesses yield reasonably reproducible measurements and are effective for diagnosing glaucoma, similar to cpRNFL analysis. In glaucoma, especially early-stage glaucoma, retinal thickness decreases in localized areas in the macular region and analyzing subdivided macular regions should improve sensitivity. Therefore, we compared the results of grid-wise analyses of mRNFL, GCIPL, and GCC thickness among 1 × 2, 4 × 4, and 8 × 8 grids.

Sensitivity at specificity equal to 0.95 determined on ROC curve with the largest AUC was higher than that obtained using various normative data–based cutoff values in the whole macula. On the other hand, adoption of ≥ 2 grids from multiple grids and certain normative data–based cutoff values yielded higher sensitivity with similar specificity, while greater grid size and higher number of contiguous grids flagged as abnormal tended to result in lower sensitivity and higher specificity. The criteria was based on 2 or more 8 × 8 grids outside normative data–based cutoff values, in which grid size was 2.4 × 2.4 roughly corresponding to the grid size of the HFA 10-2 program, showed better diagnostic performance than the others. Even smaller grid sizes might give better results. Because the grid size of the HFA 10-2 program is 2.0 × 2.0', however, OCT measurement results from retinal areas smaller than 2.0' × 2.0' may not be practical in diagnosing glaucoma based on the structure-function relationship using conventional VF testing.

Although there was no significant difference in the highest sensitivity with specificity ≥ 0.95 obtained using mRNFL and GCC thickness–based criteria, only the GCC thickness–based criteria yielded sensitivity ≥ 0.90 for discriminating early-stage OAG eyes with a mean MD of −1.8 dB from normal eyes. Combination of GCIPL and mRNFL, GCC, had a significantly higher sensitivity than GCIPL (0.90 and 0.80, respectively, P = 0.013) in the subjects of this study in early-stage of the disease.

According to the cpRNFL analysis, largest AUC was obtained with inferior sectors rather than temporal sectors. On the other hand, a global average of cpRNFL also showed no smaller AUC than those though the subjects were limited to the early-stage glaucoma. Those results may suggest a limitation of circle-wise sector analysis of cpRNFL in diagnosis of early-stage glaucoma.

To our knowledge, SD-OCT–based diagnostic performance with sensitivity ≥ 0.90 and specificity ≥ 0.95 is rarely reported, only in eyes of moderate glaucoma damage (MD of −8.99 ± 8.16 dB) or MD ranged from −15.87 to +0.07 dB with median of −4.58 dB or eyes with early-stage but manifest glaucoma visual field defects (MD of −2.5 ± 1.8 dB) using grid-wise analyses of peripapillary retinal nerve fiber layer thickness. Furthermore, mRNFL or GCC thickness–based criteria showed significantly better diagnostic performance than the best clock-hour cpRNFL–based criterion in the same eyes. These results adopting normative data–based cutoff values are readily applicable to clinical practice.

Inclusion of the disc-fovea line might be a critical issue in grid-wise analysis of the macula using SD-OCT. The present results, however, suggested that compensation of the inclination barely affected diagnostic performance. This finding might...
### TABLE 6. Diagnostic Capability of cpRNFL and Comparison With mRNFL and GCC

<table>
<thead>
<tr>
<th>Sector Width/Grid Pattern</th>
<th>Greatest–Smallest AUC (SE)</th>
<th>Sensitivity/Specificity (With 95% CI; Sensitivity at Fixed Specificity of 0.95)</th>
<th>Conditions*</th>
<th>Sensitivity/Specificity (With 95% CI; Highest Sensitivity at Specificity ≥ 0.95)</th>
</tr>
</thead>
<tbody>
<tr>
<td>cpRNFL</td>
<td>360°</td>
<td>0.892 (0.025)</td>
<td>0.57 (0.46-0.68)</td>
<td>0.95 (0.87-0.99)</td>
</tr>
<tr>
<td></td>
<td>180°</td>
<td>0.883 (0.020-0.822) (0.012)</td>
<td>0.65 (0.52-0.73)</td>
<td>0.95 (0.87-0.99)</td>
</tr>
<tr>
<td></td>
<td>90°</td>
<td>0.891 (0.026-0.662) (0.042)</td>
<td>0.64 (0.54-0.74)</td>
<td>0.95 (0.87-0.99)</td>
</tr>
<tr>
<td></td>
<td>30°</td>
<td>0.920 (0.022-0.564) (0.045)</td>
<td>0.78 (0.68-0.86)</td>
<td>0.95 (0.87-0.99)</td>
</tr>
<tr>
<td>mRNFL</td>
<td>8 × 8 grids</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GCC</td>
<td>8 × 8 grids</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Analyses were performed in the subjects listed in Table 5.

* Conditions where the eyes were flagged as glaucomatous with respect to the normative data-based cutoff values and numbers of abnormal sectors or grids.

Analyses were based on variant normative data–based cuttof values in single or multiple contiguous sectors/ grids.
and glaucoma eyes, and thus the clinical usefulness of the current optimum criterion requires further confirmation. Most of the current OAG patients had untreated normal IOP (normal tension glaucoma). Differences in the VFD pattern (i.e., differences in GCL damage distribution), between OAG patients with normal and elevated IOP, have been reported. 51 Thus, the current optimum criterion may not be optimum in a group of OAG patients with elevated IOP. Comparison of the diagnostic capability between cpRNFL and macular inner retinal layers or effects of compensation of the inclination could only be studied in ~85% of the subjects. Although no significant difference was detected in the degree of glaucomatous damage or ocular and systemic factors between those included and not included (Tables 1, 5, and 7), this somewhat decreased the power of detection. Longitudinal and horizontal density of sampling points of the OCT apparatus was not equal (128 × 512) and its optimized rearrangement might have a significant effect on the results.

In summary, the 5.5 × 5.5-mm macular area was subdivided in a grid-wise manner and measured by SD-OCT in up to 8 × 8 grids, and diagnostic capability for early-stage glaucoma (mean MD −1.8 dB) was compared based on ROC analyses and various normative data–based cutoff values for mRNFL, GCIPL, and GCC thickness in each grid and the number of abnormal grids, and diagnostic capability for early-stage glaucoma (mean MD −1.8 dB) was compared based on ROC analyses and various normative data–based cutoff values for mRNFL, GCIPL, and GCC thickness in each grid and the number of abnormal grids. The 8 × 8 grid-GCC analysis yielded a sensitivity ≥0.90 and specificity ≥0.95 under two conditions, that is, two contiguous grids outside the 0.5th percentile cutoff or three contiguous grids outside first-percentile cutoff of normative data. Compensation of physiological inclination of disc-fovea line did not significantly affect diagnostic capability in the current subjects.

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**References**


