ABSTRACT

Aim To evaluate the diagnostic performances and correlations of retinal nerve fibre layer (RNFL) thickness measured by RTVue OCT and GDx variable corneal compensation (VCC).

Methods The total and regional RNFL thickness were measured by RTVue OCT and GDx VCC in 62 normal eyes and 72 glaucomatous eyes of Chinese subjects. The RNFL thickness profiles of normal and glaucomatous eyes by RTVue OCT are plotted. Correlations of RNFL thickness measured by RTVue OCT and GDx VCC were assessed using the Pearson correlation. The discrimination abilities of the two techniques for detection of glaucoma were compared by the area under the receiver operating characteristic curves (AUC).

Results RTVue OCT demonstrated double hump patterns in the RNFL profiles. In both normal and glaucomatous subjects, the peaks were located in the superotemporal (ST) and inferotemporal (IT) regions, and the troughs were located at the nasal (NU+NL) and temporal (TU+TL) regions. Despite poor agreement, a high correlation (r=0.821) was found between the mean RNFL measurements by RTVue OCT and GDx VCC. For RTVue OCT, the highest AUCs were mean RNFL (AUC=0.914) and inferior mean RNFL (AUC=0.909). The nerve fibre indicator (AUC=0.856) and inferior RNFL (AUC=0.852) achieved the highest AUCs among all the GDx VCC measurements. The mean RNFL in RTVue OCT had the greatest AUC in the two devices. There was a significant difference in comparing the AUCs of the mean RNFL thickness obtained by RTVue OCT and GDx VCC (p=0.009).

Conclusions Although there were absolute value differences in RNFL thickness, a high correlation was observed between RTVue OCT and GDx VCC. RTVue OCT shows a reasonable ability to distinguish normal from glaucomatous eyes.

Glaucoma is a characteristic optic neuropathy resulting in retinal ganglion cell death, which then leads to retinal nerve fibre layer (RNFL) thinning and optic nerve head cupping. RNFL loss is considered an early sign of glaucoma. Examination of RNFL is essential in detecting and monitoring glaucoma. Scanning laser polarimetry (SLP) and optical coherence tomography (OCT) are the imaging modalities designed to measure RNFL thickness.

OCT technology has changed considerably in recent years with the incorporation of spectral-domain (SD) imaging that offers significant advantages over the traditional time-domain (TD) OCT techniques. SD-OCT offers a faster acquisition speed and higher resolution than TD-OCT. The recently introduced RTVue (Optovue, Fremont, California) is one of several ultra-high-speed, high-resolution SD-OCTs, which can perform 26,000 A scans/s with a depth resolution of 5 μm.

The purpose of this study is to investigate the association between RTVue OCT and GDx variable corneal compensation (VCC; Carl Zeiss Meditec, Dublin, California) RNFL measurements. The diagnostic performances of the two devices for glaucoma detection were compared.

MATERIALS AND METHODS

Subjects

A total of 134 Chinese subjects were recruited in this non-interventional, cross-sectional study. One eye was selected randomly from each of 62 normal individuals and 72 with known glaucoma. All recruited subjects were examined during the period April to December 2008 in the Beijing Tongren Eye Center. The study was conducted in accordance with the ethical standards stated in the 1964 Declaration of Helsinki and approved by Tongren Hospital Clinical Research Ethics Committee with informed consent obtained.

All subjects underwent a full ophthalmic examination including visual acuity, refraction, intraocular pressure measurement with Goldmann tonometry, visual-field (VF) testing with Humphrey Field Analyzer and fundus examination with stereoscopic biomicroscopy of the ONH by slit lamp and indirect ophthalmoscopy. The inclusion criteria were best-corrected visual acuity no worse than 20/40 and spherical refractive error within the range of −6.00 to +3.00 D. Eyes were excluded if they exhibited signs of cataract and posterior pole pathology other than that attributed to glaucoma.

We grouped the eyes into the following two diagnostic groups: normal and glaucoma. The inclusion criteria for eyes in the normal group were as follows: intraocular pressure (IOP) 21 mm Hg or lower; normal optic disc appearance (no diffuse or focal rim thinning, cupping, optic disc haemorrhage or asymmetry of vertical cup/disc ratio >0.2); normal RNFL appearance (no RNFL defects); normal VF results; no history of glaucoma; no intraocular surgery; and no ocular pathology. Glaucomatous eyes showed IOP readings of at least 22 mmHg before medication, reproducible glaucomatous VF defects, and optic disc and RNFL appearance consistent with glaucomatous optic neuropathy. Among the 72 patients with glaucoma, 37 had primary open-angle glaucoma, 30 had primary angle-closure glaucoma, and five had secondary glaucoma. All recruited subjects had VF testing performed with the Humphrey Field
Analyzer (Humphrey Field Analyzer II, centre 24-2, SITA fast test program; Carl Zeiss Meditec, Inc.). A reliable Humphrey VF test is defined as having less than 20% fixation loss and less than 25% false-positive and false-negative errors. A VF defect was defined as having three or more significant (p<0.05) non-edge-contiguous points with at least one at p<0.01 on the same side of the horizontal meridian in the pattern deviation plot and classified outside normal limits in the Glaucoma Hemifield Test. Any detected field defect had to be confirmed in at least one consecutive VF test to be considered abnormal. Glaucoma severity was evaluated by the Hodapp–Parish–Anderson grading scale of severity of VF defects, and each enrolled subject was classified as early, moderate, or late stage glaucoma patient. The numbers of early, moderate and late stage glaucoma patient were 17, 34 and 21, respectively.

**RTVue-OCT measurements**

RTVue OCT uses a scanning laser diode to emit a scan beam with a wavelength of 840±10 nm to provide images of ocular microstructures. Unlike TD-OCT, SD-OCT uses a stationary reference mirror, and the OCT signal is acquired using a spectrometer as a detector. RTVue OCT is capable of high-speed imaging with an acquisition of 26 000 A scans per second. It offers a higher resolution than TD-OCT, and can provide a significant reduction in motion artefacts and an increased signal-to-noise ratio compared with TD-OCT.

In our study, the three-dimensional (SD) disc and nerve head map 4 mm diameter (NHM4) RTVue protocols were used. In the SD Disc scan presentation, the disc boundary was drawn and precisely determined by using the RPE endpoints visualised in the A-Scan and B-Scan. The resulting disc drawing was saved as the baseline for the NHM4 pattern. NHM4 is a pattern of radial scans combined with circular scans. The NHM4 protocol is composed of 12 radial scans 3.4 mm in length and six concentric ring scans ranging from 2.5 to 4.0 mm in diameter all centred on the optic disc. This scan configuration provides 9510 A scans, and areas between A scans are interpolated. A polar RNFL thickness map is provided. RNFL thickness parameters were included as follows: tempora—nasal—inferior—temporal (TSNIT) mean (total mean RNFL thickness), superior mean, inferior mean, the TSNIT SD and nerve fibre indicator (NFI).

**Statistical analysis**

Statistical analyses were performed using SPSS (version 11.0, SPSS, Chicago, Illinois) and Medcalc (version 9.3.2.0, MedCalc Software, Ghent, Belgium). Differences in age, refraction, VF mean deviation (MD), and mean RNFL thickness (measured with RTVue OCT and GDx VCC) between the diagnostic groups were evaluated with the independent-sample t test. The non-parametric receiver operating characteristic (ROC) curve was made, and the area under the receiver operating characteristic curve (AUC) was used to assess the ability to differentiate glaucoma eyes from normal eyes of each testing parameter. An AUC of 1.0 represents perfect discrimination, and an AUC of 0.5 represents chance discrimination. The method described by Hanley and McNeil was used to compare the AUCs. The correlation analysis was used for assessing the relation between RNFL measurements of RTVue OCT and GDx VCC. In all statistical analyses, p<0.05 was considered statistically significant.

**RESULTS**

**RTVue OCT RNFL profiles**

The baseline characteristics of the studied Chinese subjects are presented in table 1. For RTVue OCT, the RNFL parameter measurements of normal and glaucomatous eyes are shown in table 2. For GDx VCC, the RNFL parameter measurements of normal and glaucomatous eyes are shown in table 3. In tables 2, 3, the absolute value of mean RNFL obtained by GDx VCC was significantly smaller than that obtained by RTVue OCT in both the normal and glaucoma groups (p<0.001). It revealed a poor agreement between the two devices. The RNFL profiles of normal and glaucomatous eyes by RTVue OCT are plotted and shown in figure 1. RTVue OCT

<table>
<thead>
<tr>
<th>Table 1 Subject characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Normal</strong></td>
</tr>
<tr>
<td>Subjects (n)</td>
</tr>
<tr>
<td>Age (years): mean±SD</td>
</tr>
<tr>
<td>Refraction (D): mean±SD</td>
</tr>
<tr>
<td>Visual-field MD (dB): mean±SD</td>
</tr>
<tr>
<td>Visual-field PSD (dB): mean±SD</td>
</tr>
</tbody>
</table>

*Independent-sample t test.

**Mean values of RTVue optical coherence tomography parameter measurements in normal and glaucomatous subjects**

<table>
<thead>
<tr>
<th><strong>Mean±SD (μm)</strong></th>
<th><strong>Normal (n = 62)</strong></th>
<th><strong>Glaucoma (n = 72)</strong></th>
<th><strong>p Value</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean retinal nerve fibre layer</td>
<td>109.75±9.095</td>
<td>80.455±19.353</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Superior mean</td>
<td>112.590±10.381</td>
<td>83.337±20.438</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Inferior mean</td>
<td>106.927±9.140</td>
<td>77.575±19.734</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>TU</td>
<td>87.873±14.074</td>
<td>67.406±21.087</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ST</td>
<td>146.105±15.529</td>
<td>106.440±29.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SN</td>
<td>134.701±19.846</td>
<td>100.480±26.165</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>NU</td>
<td>81.677±14.150</td>
<td>59.022±16.240</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>NL</td>
<td>71.212±11.726</td>
<td>54.119±13.258</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>IN</td>
<td>126.435±17.658</td>
<td>91.402±22.943</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>IT</td>
<td>150.109±18.007</td>
<td>104.017±32.902</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>TL</td>
<td>79.957±12.569</td>
<td>60.681±18.795</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

*Independent-sample t test.

demonstrated double hump patterns in the RNFL profiles. In both normal and glaucomatous subjects, the peaks were located at the superotemporal (ST) and the inferotemporal (IT) regions, and the troughs were located at the nasal (NU+NL) and temporal (TU+TL) regions.

**Correlation analysis of RTVue OCT and GDx VCC mean RNFL measurements**

A scatter plot of mean RNFL thickness (TSNIT mean) measured by GDx VCC against the mean RNFL thickness measured by RTVue OCT in all subjects is shown in figure 2. Figure 2 shows a high correlation between the mean RNFL measurements, with a correlation coefficient of 0.821.

**Diagnostic performance of RTVue OCT and GDx VCC**

The AUCs of total and local RNFL thickness for distinguishing glaucoma patients from normal eyes were calculated and tabulated in tables 4, 5. For RTVue OCT, the highest AUCs were mean RNFL (AUC=0.914) and inferior mean RNFL (AUC=0.909). In contrast, the NFI (AUC=0.856) and inferior RNFL (AUC=0.852) achieved the highest AUCs among all the GDx VCC measurements. The mean RNFL in RTVue OCT had the greatest AUC in the two devices. There was a significant difference in comparing the AUCs of the mean RNFL thickness obtained by RTVue OCT and GDx VCC (p=0.009). The ROC curves comparing mean RNFL thickness measured by RTVue OCT and GDx VCC in distinguishing glaucoma from normal subjects are shown in figure 3.

**DISCUSSION**

Recently the new generation of OCT system, SD-OCT, began to apply to the diagnosis of glaucoma. Vizzeri et al examined the ability of RTVue, Cirrus and Spectralis SD-OCT to detect localised RNFL defects in glaucomatous eyes, and found that all SD-OCT instruments were able to confirm the presence of localised glaucomatous structural damage. Sehi et al compared RNFL thickness assessments and the distinguishing ability of RTVue OCT and Stratus OCT, and found that RTVue OCT had a similar diagnostic performance to that of Stratus OCT for glaucoma detection.

Compared with the Stratus OCT, RTVue OCT had a higher speed and resolution. González-García et al reported that good repeatabilities were found for RNFL thickness and ONH parameter measurements obtained by RTVue OCT and a good agreement between RTVue OCT and Stratus OCT measurements. In our study, we measured the total and regional RNFL thickness of Chinese subjects with RTVue OCT, and the results showed double hump patterns in the RNFL profiles. In both normal and glaucomatous subjects, the peaks were located at the superotemporal and the inferotemporal regions, and the troughs were located in the nasal and temporal regions. The result was consistent with the profiles measured with GDx VCC and Stratus OCT by Leung et al and with the red-free photographic studies by Jonas et al.

Because of differences in the measuring principles and methodologies between RTVue OCT and GDx VCC, the absolute values of GDx VCC measurement were smaller than those of RTVue OCT. Good repeatabilities were found for RNFL thickness and ONH parameter measurements obtained by RTVue OCT and a good agreement between RTVue OCT and Stratus OCT measurements.

![Figure 1](image1.png)  
**Figure 1** Retinal nerve fibre layer (RNFL) thickness profile of normal and glaucomatous eyes by RTVue optical coherence tomography.

![Figure 2](image2.png)  
**Figure 2** Scatter plot of the total mean retinal nerve fibre layer (RNFL) thickness measured by GDx variable corneal compensation (VCC) against the total mean measured by RTVue optical coherence tomography.

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**Table 3** Mean values of GDx variable corneal compensation parameter measurements in normal and glaucomatous subjects

<table>
<thead>
<tr>
<th>Mean±SD (μm)</th>
<th>Normal (n=62)</th>
<th>Glaucoma (n=72)</th>
<th>p Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean temporal—superior—nasal—inferior—temporal</td>
<td>57.013±5.132</td>
<td>45.417±10.417</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Superotemporal mean</td>
<td>70.72±6.844</td>
<td>53.67±15.527</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Inferotemporal mean</td>
<td>70.59±7.274</td>
<td>53.13±14.491</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Temporal—superior—nasal—inferior—temporal SD</td>
<td>26.34±3.644</td>
<td>17.76±6.823</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Nerve fibre indicator</td>
<td>14.56±7.830</td>
<td>50.08±30.26</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

*Independent-sample t test.
RTVue OCT. Many previous studies have demonstrated that the value measured by Stratus OCT was larger than that by GDx VCC.\(^5\)\(^\text{11}^\text{12}\) In our study, the agreement and correlation of mean RNFL thickness between the two devices were analysed in all normal and glaucomatous subjects, and results showed that they correlated highly, though they had a poor agreement. Leung \textit{et al.}\(^2^\) arrived at a similar conclusion that a high correlation of mean RNFL thickness existed between GDx VCC and Stratus OCT measurements (\(r=0.852\)).

OCT and SLP are two different imaging modalities designed to analyse the morphology of the ONH and the thickness of the RNFL. GDx VCC has been shown to distinguish well between healthy and glaucomatous eyes. Reus and Lemij\(^1^\) found a high distinguishing ability in detecting primary open-angle glaucoma (mean VF MD=\(-8.45\) dB) with GDx VCC. The AUCs of total mean RNFL thickness, superior RNFL thickness, inferior RNFL thickness and nerve fibre indicator (NFI) were 0.95, 0.94, 0.90 and 0.98, respectively. Medeiros \textit{et al.}\(^14^\) reported that the highest AUC for the GDx VCC in glaucoma detection (mean VF MD=\(-4.87\) dB) was NFI (AUC=0.91). The best distinguishing classifier has been reported to be the NFI—a support vector machine-derived parameter trained to distinguish between healthy and glaucomatous eyes. In Reus \textit{et al.'s} study,\(^15^\) the results showed that automated classification of measurements with GDx VCC may distinguish better between healthy and glaucomatous eyes than general ophthalmologists classifying stereoscopic optic disc photographs.

Many studies have also found a relatively high diagnostic performance in glaucoma detection with the time-domain OCT (Stratus OCT). Budenz \textit{et al.}\(^16^\) reported that the inferior RNFL thickness and the mean RNFL thickness achieved the highest AUCs (0.971 and 0.966, respectively) in glaucomatous subjects with a mean VF MD of \(-8.4\) dB. Medeiros \textit{et al.}\(^17^\) arrived at a similar conclusion in showing that the mean (AUC=0.91) and inferior (AUC=0.91) RNFL thickness had the best distinguishing ability for detection of glaucoma, with a mean VF MD of \(-4.96\) dB. Recently, some studies which compared the diagnostic performances of GDx VCC and Stratus OCT in the same study were reported consecutively. Badalà \textit{et al.}\(^18^\) reported that the highest AUCs for the Stratus OCT and GDx VCC in glaucoma detection (mean VF MD=\(-4.0\) dB) were the mean RNFL thickness (AUC=0.96) and the NFI (AUC=0.92), respectively. Deléon-Ortega \textit{et al.}\(^19^\) arrived at a similar conclusion in which the mean RNFL thickness (AUC=0.844) for Stratus OCT and the NFI (AUC=0.836) for GDx VCC had the best abilities for detection of glaucoma, with a mean VF MD of \(-3.8\) dB.

To date, few studies of diagnostic performance with RTVue OCT in glaucoma detection have been reported. In our study, the AUCs of all parameters obtained by RTVue OCT and GDx VCC were calculated and compared. For RTVue OCT, the total mean RNFL thickness (AUC=0.914) and inferior mean RNFL thickness (AUC=0.909) yielded the highest AUCs. Sehi \textit{et al.}\(^2^\) reported that the AUCs of mean, superior and inferior RNFL thickness using RTVue OCT were 0.88, 0.80 and 0.94 in glaucomatous subjects with mean VF MD of \(-9.2\) dB. Our result was in concordance with that of Stratus OCT mentioned above. Among the eight regions around the optic nerve head, the RNFL thickness of region IT (AUC=0.881) and ST (AUC=0.865) were the highest AUCs, and the RNFL thickness of region SU (AUC=0.783) and TL (AUC=0.805) were the lowest AUCs. The regions with the highest AUCs corresponded to the regions with the thickest RNFL, and the regions with the lowest AUCs corresponded to the regions with the thinnest RNFL. As the thickest RNFL regions, inferotemporal and superotemporal RNFL thickness had high abilities to distinguish glaucomatous eyes from normal eyes. This result was in concordance with the conclusion that the superior and inferior regions of the optic nerve head are anatomically more susceptible to glaucomatous damage.\(^2^\)\(^^\text{21}\) As with previous studies, the highest AUCs were NFI (AUC=0.856) in GDx VCC parameter measurements in our study. Compared with GDx VCC, the parameters of RTVue OCT have higher abilities to detect glaucoma.

### Table 4 Diagnostic performance of RTVue optical coherence tomography

<table>
<thead>
<tr>
<th>Area under the receiver operating characteristic curves±SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean retinal nerve fibre layer</td>
</tr>
<tr>
<td>Superotemporal mean</td>
</tr>
<tr>
<td>Inferotemporal mean</td>
</tr>
<tr>
<td>TL</td>
</tr>
</tbody>
</table>

### Table 5 Diagnostic performance of GDx variable corneal compensation

<table>
<thead>
<tr>
<th>Area under the receiver operating characteristic curves±SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean temporal—superior—nasal—inferior—temporal</td>
</tr>
<tr>
<td>Superotemporal mean</td>
</tr>
<tr>
<td>Inferotemporal mean</td>
</tr>
<tr>
<td>Temporal—superior—nasal—inferior—temporal SD</td>
</tr>
<tr>
<td>Nerve fibre indicator</td>
</tr>
</tbody>
</table>
Our study has several limitations. First, because ageing affects RNFL thickness, the difference in age between the normal and glaucomatous groups might have artificially improved the AUCs reported in our study. Second, the SITA fast strategy used in our study is not the gold standard for VF testing in glaucoma. Although checking time was saved, and the accuracy was sufficient for our study, the SITA standard strategy should be the better choice. Third, the old version of the GDx VCC was used in our study. As a recent version of OCT technology, RTVue OCT should be compared with the most recent version of the GDx VCC, so that more valuable clinical results can be obtained.

In conclusion, we measured the each region RNFL thickness with RTVue OCT and results demonstrated double hump patterns in the RNFL profile in both normal and glaucomatous subjects, the same as that measured with GDx VCC and Stratus OCT. Although there were absolute value differences in RNFL thickness between RTVue OCT and GDx VCC, our results showed that they were correlated highly. We studied the diagnostic performance of RTVue OCT and GDx VCC for detection of glaucoma and found that the total mean RNFL thickness and the inferior mean RNFL thickness had the highest abilities to discriminate glaucomatous eyes from normal ones for RTVue OCT and NFI for GDx VCC. Measurements of RNFL thickness with RTVue OCT and GDx VCC are not interchangeable in the diagnosis of glaucoma. Attention should be focused on the interpretation of RNFL thickness obtained from different measurement methods.

Competing interests None.

Patient consent Obtained.

Ethics approval Ethics approval was provided by the Tongren Hospital Clinical Research Ethics Committee.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES


Comparative study of retinal nerve fibre layer measurement by RTVue OCT and GDx VCC

Xiaozhen Wang, Shuning Li, Jing Fu, Gewei Wu, Dapeng Mu, Songfeng Li, Jian Wang and Ningli Wang

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