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ORIGINAL ARTICLE

Correlation in Retinal Nerve Fiber Layer Thickness between Two OCT Units

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ABSTRACT

Purpose. It is expected that spectral-domain optical coherence tomography (SD-OCT) will replace time-domain (TD)-OCT in the near future. In this study, we applied a robust set of statistical analyses to evaluate the correlation between retinal nerve fiber layer (RNFL) thickness measurements obtained by SD-OCT and those obtained by TD-OCT in a Chinese population with different stages of glaucoma.

Methods. A total of 40 patients with primary open-angle glaucoma, 31 with primary angle-closure glaucoma (PACG), 31 with suspected glaucoma (GS), 25 with ocular hypertension (OH), and 52 normal subjects were enrolled in this prospective, cross-sectional study. Eyes of all participants were imaged by a single trained operator using the Stratus TD-OCT (fast RNFL scan mode) system and the Cirrus SD-OCT (optic disc cube mode) system during the same visit. The correlations between RNFL thickness measurements obtained from the two OCT instruments were assessed using Pearson correlation analysis and generalized estimating equation (GEE), mixed effect, linear regression models, after adjusting for the effect of individual variation.

Results. There was good correlation in RNFL thickness parameters between the two OCT devices, particularly in average RNFL thickness (Pearson Correlation, 0.8798 vs. GEE mixed model, 0.9470). The proposed GEE mixed model method showed better correlation than the Pearson correlation analysis in each RNFL thickness parameter between the two OCT measurements.

Conclusions. Although the RNFL thickness measurements obtained by the TD-OCT system correlated well with those obtained by the SD-OCT system, clinicians should be cautious when interpreting RNFL thickness data for any subject undergoing longitudinal follow-up with different OCTs.

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Key Words: correlation, Stratus OCT, Cirrus OCT, Taiwan Chinese population

Optical coherence tomography (OCT) is commonly used to measure retinal nerve fiber layer (RNFL) thickness.[1] Several cross-sectional studies have documented that time-domain (TD)-OCT devices, such as the Stratus OCT (Carl Zeiss Meditec, Inc., Dublin, CA), provide good diagnostic accuracy for glaucoma.[2–11] Recently, spectral-domain (SD)-OCT machines such as the Cirrus SD-OCT (Carl Zeiss Meditec, Inc) have become available.[12–14] Comparative studies have shown that the diagnostic power of the Cirrus SD-OCT is equivalent to that of the Stratus TD-OCT.[14–20] Furthermore, good agreement and correlation between TD-OCT-derived RNFL thickness measurements and those obtained with SD-OCT have been reported in many studies.[14–21] It is expected that spectral-domain OCT will soon replace time-domain OCT in clinical practice.[21] Patients who have been scanned with the Stratus OCT system will be scanned during follow-up with the Cirrus OCT system. However, each system has its own unique software for determining quantitative measurements of ocular structures. This fact will inevitably cause problems for clinicians when trying to compare data obtained from the two systems. In follow-up studies, clinicians will be faced with the challenge of interpreting whether the new measurements obtained with the SD-OCT system indicate improvement or progression of disease.

Although numerous studies have established that there is good agreement and good correlation in RNFL thickness between SD-OCT and TD-OCT, most studies relied on relatively simple statistical techniques to reach such a correlation. In addition, few cor-

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relation analyses have been conducted specifically in a Chinese population. Therefore, in this study, we applied a robust set of statistical analyses to evaluate the correlation between RNFL thickness measurements obtained by SD-OCT and those obtained by TD-OCT in a Chinese population with different stages of glaucoma.

SUBJECTS AND METHODS

This prospective cross-sectional study included 179 subjects. The glaucoma patients (n = 127) comprised 40 individuals with primary open-angle glaucoma (POAG), 31 with primary angle-closure glaucoma (PACG), 31 with suspected glaucoma (GS), and 25 patients with ocular hypertension (OH). All were receiving regular follow-up and treatment at the Department of Ophthalmology, China Medical University Hospital (CMUH). Normal controls (n = 52) comprised volunteers from among the staff at the CMUH. All study subjects were recruited during the period February 2010 to August 2010, and all procedures were performed according to the tenets of the Declaration of Helsinki. Informed consent was obtained from all participants, and the study was approved by the Institutional Review Board of the CMUH.

Each subject underwent a complete ophthalmic examination, including slitlamp biomicroscopy, gonioscopy, pachymetry, Goldmann applanation tonometry, dilated stereoscopic examination of the optic disc, and standard automated perimetry (Full Threshold program 30-2 mode, Humphrey Field Analyzer, model 750, HFA; Carl Zeiss Meditec, Inc.). Central corneal thickness was assessed using an ultrasound corneal pachymeter (Pacscan 300 AP; Sonomed, Lake Success, NY). Axial length (AXL), anterior chamber depth, and cornea curvature (K1 and K2) measurements were obtained using the Zeiss IOL Master (Carl Zeiss Meditec, Inc, Dublin, CA).

Subjects with a best-corrected visual acuity of <20/40, a spherical equivalent outside ± 5.0 diopters, and a cylinder correction >3.0 diopters were excluded. Patients with eyes with coexisting retinal disease, uveitis, or nonglaucomatous optic neuropathy (GON) were also excluded from this study.

Normal control eyes were defined as eyes with a normal-looking optic disc head and an intraocular pressure (IOP) ≤21 mm Hg in patients with a normal visual field result and without a history of increased IOP. A normal visual field was defined as a mean deviation (MD) and pattern SD (PSD) within 95% confidence limits, and a Glaucoma Hemifield Test result within normal limits.

Glaucomatous eyes were defined as those with GON and evidence of visual field loss. GON was defined as a cup-to-disc asymmetry between fellow eyes of >0.2, rim thinning, notching, excavation, or RNFL defect. Standard automated perimetry was performed with a Humphrey Field Analyzer using the central full threshold program 30 to 2. Visual field reliability criteria included fixation losses and false-positive and false-negative rates of <20%. The evaluation of glaucomatous visual field defects was made using criteria as described by Caprioli et al.[22]

Inclusion criteria for the POAG patients included an initial IOP higher than 22 mm Hg, presence of an open angle on gonioscopy, stereoscopic evidence of optic disc excavation typical of GON, and a reproducible glaucomatous visual field defect in the absence of any other abnormalities to explain the defect. Inclusion criteria for the patients with PACG included the following: (1) definitive gonioscopic findings demonstrating at least 180° of peripheral anterior synechiae; (2) an IOP of >21 mm Hg; and (3) GON with visual field loss consistent with optic nerve damage. Among the 62 eyes of the 31 PACG patients, 20 eyes were known to have experienced an acute attack (IOP >40 mm Hg) of angle closure within X months before enrollment into the study. The IOP in those patients was maintained within normal limits via laser treatment, glaucoma surgery, or antiglaucoma medication during the study period.

Ocular hypertensive (OH) eyes were defined in patients with an IOP >22 mm Hg, presence of an open angle on gonioscopy, and normal visual field test results. Glaucoma suspect (GS) eyes were defined in patients with evidence of an abnormal disc appearance consistent with glaucoma and a normal visual field.

Stratus TD-OCT and Cirrus SD-OCT Measurements

The Stratus TD-OCT (version A 4.0.1) system in this study comprised an infrared-sensitive video camera to provide a view of the scanning probe beam on the fundus, a low-coherence interferometer, a video monitor, a computer, and an image analysis system. The Stratus TD-OCT was calibrated to an axial resolution of ≤10 μm and a transverse resolution of 20 μm. Each Fast RNFL Scan captured three successive circular scans around the disc with A-scan measurements at 256 points per revolution over a total of 1.92 s. From the exported group of three scans, the most reliable scan was chosen for comparison. The Cirrus SD-OCT (software version 3.0) system used in this study uses spectral domain OCT technology to acquire OCT data with better resolution (5 mm compared with approximately 10 mm axial resolution in tissue) and is about 70 times faster (27,000 vs. 400 Ascans/s) than TD-OCT technology.[12] Three individual 200 × 200 cube Optic Disc Scans were obtained with the Cirrus OCT system. The Cirrus algorithms were designed to identify the center of the optic disc and to automatically place a calculation circle of 3.46 mm diameter around it. The anterior and posterior margins of the RNFL are delineated, and after extracting 256 A-scan samples from the data cube along the path of the calculation circle, the system calculates the RNFL thickness at each point on the circle.[14]

In all participants, RNFL measurements were obtained first with the Stratus OCT without pupil dilation and then with the Cirrus OCT on the same day within a 2 h time period by the same operator. Quality assessment of the two OCT scans was determined by an experienced examiner. Good quality scans had to have focused ocular fundus images, the signal strength needed to be >6, and a centered circular ring around the optic disc had to be present.

Statistical Analysis

To increase the precision of the estimates, RNFL thickness measurements from both eyes from each subject in the five groups were used for statistical analysis. The generalized estimating equation (GEE) method's multiple linear regression models (with the structure of the working correlation matrix specified as "Exchangeable") were used to compare the demographic data among the five groups.[23] The mixed effect model was used to establish the correlations between all measurements of the two OCT units and to adjust the potential individuals' variation by specified the "Intercept" as the random effect.[24] Pearson correlation analysis was used to evaluate the correlation between RNFL parameters obtained from one randomly selected eye from each subject using the TD-OCT system and parameters obtained using the SD-OCT system. The paired t-test was used to compare the differences in each parameter between the two OCT systems. All analyses, except for the mixed effect model, were performed using SPSS (version 18.0, software for Windows; SPSS Inc., Chicago, IL). The mixed effect model was analyzed by the SAS/STAT v 9.2 system using a "PROC MIXED" procedure (SAS Institute Inc., Cary, NC). All figures were created using the STATA v9.0 (Stata Corp, College Status, TX). Statistical significance was set at $p < 0.05$.

RESULTS

A total of 358 eyes from among 179 subjects were enrolled. As shown in Table 1, a total of 354 eyes from among 178 subjects had good quality, high signal strength OCT scans. There was a significant male predominance in all groups [46.2% (n = 24) in the control group; 40.0% (n = 10) in the OH group; 50.0% (n = 15) in the GS group; 65.0% (n = 26) in the POAG group; and 32.3% (n = 10) in the PACG group] ($p = 0.076$, chi-square test). The paired t-tests revealed significant differences ($p \leq 0.001$) in the signal strength in both eyes in all groups with the exception of the left eye (OS) in the POAG group between the two OCT systems. The mean age was 35.27 ± 15.29 years in the control group, 30.48 ± 14.09 years in the OH group, 34.97 ± 15.95 years in the GS group, 44.12 ± 14.31 years in the POAG group, and 64.42 ± 6.99 years in the PACG group. The results of the generalized linear model showed that mean age in the POAG group ($p = 0.002$) and in the PACG group ($p < 0.001$) was significantly greater than that in the normal group. The average MD was −1.08 ± 1.13 dB in the normal group, −0.85 ± 1.30 dB in the OH group, −1.90 ± 1.52 dB in the GS group, −5.51 ± 7.76 dB in the POAG group, and −4.46 ± 5.88 dB in the PACG group. The results of the GEE method's multiple linear regression model showed that there were significant differences in MD and PSD between the normal and POAG groups and significant differences in PSD between the PACG and GS groups; however, there were no significant differences in MD or PSD between the normal and OH groups. In addition, there were significant differences in central corneal thickness, refraction, AXL, and K1 values between OH and normal groups (all p-values <0.001); however, there was no significant difference in K2 value between normal and OH groups ($p = 0.062$).

Table 2 shows the RNFL thickness measurements obtained with the two OCT devices. The average and four-quadrant RNFL thicknesses in the POAG and PACG groups were significantly thinner than those in the normal group. In addition, the average, superior, and inferior quadrant RNFL thicknesses were significantly thinner in the OH and GS groups than in the normal group. There were also significant differences in average and four-quadrant RNFL thicknesses between the two OCT devises in the normal, OH, GS, and PACG groups. In the POAG group, there were significant differences in average, temporal, superior, inferior

TABLE 1.
Comparison of patient characteristics

	Normal (mean ± SD)	OH (mean ± SD)	GS (mean ± SD)	POAG (mean ± SD)	PACG (mean ± SD)
Patients screened (n/eye)	52/104	25/50	31/62	40/80	31/62
Poor signal strength (eye)	0	0	2	1	1
Patients enrolled (n/eye)	52/104	25/50	30/60	40/79	31/61
Eye (right/left)	(52/52)	(25/25)	(30/30)	(40/39)	(31/30)
Gender (male/female)	(24/28)	(10/15)	(15/15)	(26/14)	(10/21)
Cirrus signal strength OD	5.77 ± 0.65	5.28 ± 1.137	5.40 ± 1.07	5.20 ± 1.07	5.29 ± 1.01
Cirrus signal strength OS	6.52 ± 0.70	6.12 ± 1.20	6.30 ± 0.88	6.38 ± 1.18[a]	5.87 ± 1.01
Stratus signal strength OD	7.23 ± 1.06	6.96 ± 1.060	6.90 ± 1.09	6.23 ± 1.51	6.61 ± 1.43
Stratus signal strength OS	7.63 ± 1.29	7.16 ± 1.34	7.20 ± 1.32	6.97 ± 1.41[a]	7.27 ± 1.68
Age[b] (yr)	35.27 ± 15.29	30.48 ± 14.09 (p = 0.152)[c]	34.97 ± 15.95 (p = 0.923)[d]	44.12 ± 14.31 (p = 0.002)[e]	64.42 ± 6.99 (p < 0.001)[f]
Mean deviation[g] (dB)	−1.08 ± 1.13	−0.85 ± 1.30 (p = 0.392)[c]	−1.90 ± 1.52 (p = 0.005)[d]	−5.51 ± 7.76 (p < 0.001)[e]	−4.46 ± 5.88 (p < 0.001)[f]
Pattern standard deviation[g] (dB)	1.64 ± 0.48	1.82 ± 0.64 (p = 0.122)[c]	2.28 ± 1.48 (p = 0.013)[d]	5.63 ± 6.31 (p < 0.001)[e]	4.42 ± 3.45 (p < 0.001)[f]
Central cornea thickness[g] (μm)	547.47 ± 34.12	581.18 ± 34.95 (p < 0.001)[c]	539.65 ± 35.13 (p = 0.307)[d]	540.69 ± 35.21 (p = 0.343)[e]	530.66 ± 43.20 (p = 0.040)[f]
Refraction[g] (D)	−2.03 ± 2.73	−5.31 ± 3.51 (p < 0.001)[c]	−4.35 ± 3.49 (p = 0.001)[d]	−4.20 ± 4.13 (p = 0.004)[e]	1.74 ± 1.39 (p < 0.001)[f]
Axial length[g] (mm)	24.34 ± 1.27	25.98 ± 1.66 (p < 0.001)[c]	25.80 ± 1.40 (p < 0.001)[d]	25.78 ± 1.79 (p < 0.001)[e]	23.06 ± 0.94 (p < 0.001)[f]
K1[g] (D)	43.21 ± 1.56	42.17 ± 1.87 (p = 0.011)[c]	42.21 ± 2.22 (p = 0.024)[d]	43.14 ± 1.81 (p = 0.851)[e]	43.80 ± 1.67 (p = 0.104)[f]
K2[g] (D)	44.33 ± 1.73	43.44 ± 2.30 (p = 0.062)[c]	43.40 ± 2.19 (p = 0.039)[d]	44.24 ± 2.01 (p = 0.815)[e]	44.79 ± 1.69 (p = 0.223)[g]
Axis[g]	96.53 ± 73.95	96.84 ± 74.39 (p = 0.977)[c]	88.95 ± 72.76 (p = 0.477)[d]	96.63 ± 65.70 (p = 0.991)[e]	88.55 ± 50.33 (p = 0.277)[f]
Anterior chamber depth[g] (mm)	3.44 ± 0.33	3.49 ± 0.39 (p = 0.486)[c]	3.49 ± 0.43 (p = 0.543)[d]	3.53 ± 0.49 (p = 0.262)[e]	2.90 ± 0.47 (p < 0.001)[f]

[a]Paired t-test with p-value >0.05.
[b]Comparison by Generalized Linear Model.
[c]OH vs. normal.
[d]GS vs. normal.
[e]POAG vs. normal.
[f]PACG vs. normal.
[g]Comparison by GEE method.

TABLE 2.
Stratus OCT- and Cirrus OCT-derived RNFL thickness measurements in each group

	Normal (n = 52), mean ± SD	OH (n = 25), mean ± SD	GS (n = 31), mean ± SD	POAG (n = 40), mean ± SD	PACG (n = 31), mean ± SD
Stratus average	108.29 ± 8.18	102.79 ± 9.76 (p = 0.008)[a]	97.96 ± 10.57 (p < 0.001)[b]	75.08 ± 19.48 (p < 0.001)[c]	89.62 ± 19.12 (p < 0.001)[d]
Stratus superior	131.77 ± 16.12	123.92 ± 17.75 (p = 0.032)[a]	118.63 ± 17.57 (p = 0.001)[b]	92.33 ± 25.89 (p < 0.001)[c]	112.77 ± 26.20 (p < 0.001)[d]
Stratus temporal	91.38 ± 21.98	90.70 ± 25.65 (p = 0.949)[a]	82.02 ± 17.10 (p = 0.014)[b]	62.65 ± 22.98 (p < 0.001)[c]	68.57 ± 15.80 (p < 0.001)[d]
Stratus inferior	134.84 ± 14.84	124.86 ± 17.37 (p = 0.005)[a]	122.90 ± 18.66 (p = 0.001)[b]	87.54 ± 31.00 (p < 0.001)[c]	110.41 ± 34.90 (p < 0.001)[d]
Stratus nasal	75.27 ± 15.48	70.80 ± 17.57 (p = 0.313)[a]	67.75 ± 13.48 (p = 0.069)[b]	57.92 ± 14.43 (p < 0.001)[c]	67.05 ± 16.17 (p = 0.025)[d]
Cirrus average	97.88 ± 6.90[e]	91.9 ± 7.67[e] (p < 0.001)[a]	89.03 ± 8.27[e] (p < 0.001)[b]	71.66 ± 14.26[f] (p < 0.001)[c]	82.11 ± 14.49[e] (p < 0.001)[d]
Cirrus superior	120.36 ± 16.01[e]	111.08 ± 17.91[e] (p = 0.009)[a]	106.70 ± 15.60[e] (p < 0.001)[b]	84.80 ± 22.92[e] (p < 0.001)[c]	104.64 ± 20.62[e] (p < 0.001)[d]
Cirrus temporal	81.43 ± 17.23[e]	79.66 ± 18.69[e] (p = 0.668)[a]	73.08 ± 15.37[e] (p = 0.029)[b]	58.76 ± 15.56[g] (p < 0.001)[c]	63.05 ± 14.98[e] (p < 0.001)[d]
Cirrus inferior	122.25 ± 14.46[e]	111.88 ± 15.52[e] (p = 0.001)[a]	113.20 ± 16.32[e] (p = 0.002)[b]	83.03 ± 26.61[f] (p < 0.001)[c]	99.56 ± 28.70[e] (p < 0.001)[d]
Cirrus nasal	67.53 ± 8.74[e]	65.26 ± 9.94[g] (p = 0.330)[a]	63.72 ± 8.11[g] (p = 0.012)[b]	60.18 ± 8.60 (p < 0.001)[c]	61.13 ± 9.97[e] (p = 0.002)[d]

[a]OH vs. normal by GEE method.
[b]GS vs. normal by GEE method.
[c]POAG vs. normal by GEE method.
[d]PACG vs. normal by GEE method.
[e]Cirrus vs. Stratus with p-value <0.001 by GEE method.
[f]Cirrus vs. Stratus with p-value <0.01 by GEE method.
[g]Cirrus vs. Stratus with p-value <0.05 by GEE method.

TABLE 3.
Correlation between Stratus OCT- and Cirrus OCT-derived RNFL thickness measurements (one randomly selected eye from each subject in five groups)

Correlation coefficient (r)	Normal (n = 52)	OH (n = 25)	GS (n = 31)	POAG (n = 40)	PACG (n = 31)
Average	0.833 (<0.001)	0.779 (<0.001)	0.794 (<0.001)	0.915 (<0.001)	0.937 (<0.001)
Superior	0.833 (<0.001)	0.782 (<0.001)	0.807 (<0.001)	0.894 (<0.001)	0.927 (<0.001)
Temporal	0.908 (<0.001)	0.910 (<0.001)	0.874 (<0.001)	0.823 (<0.001)	0.780 (<0.001)
Inferior	0.582 (<0.001)	0.752 (<0.001)	0.790 (<0.001)	0.928 (<0.001)	0.922 (<0.001)
Nasal	0.760 (<0.001)	0.560 (0.004)	0.492 (0.006)	0.402 (0.010)	0.570 (0.001)
1 o'clock	0.715 (<0.001)	0.886 (<0.001)	0.831 (<0.001)	0.906 (<0.001)	0.863 (<0.001)
2 o'clock	0.893 (<0.001)	0.904 (<0.001)	0.930 (<0.001)	0.790 (<0.001)	0.847 (<0.001)
3 o'clock	0.832 (<0.001)	0.838 (<0.001)	0.643 (<0.001)	0.693 (<0.001)	0.745 (<0.001)
4 o'clock	0.884 (<0.001)	0.894 (<0.001)	0.788 (<0.001)	0.759 (<0.001)	0.732 (<0.001)
5 o'clock	0.770 (<0.001)	0.755 (<0.001)	0.935 (<0.001)	0.927 (<0.001)	0.894 (<0.001)
6 o'clock	0.653 (<0.001)	0.870 (<0.001)	0.752 (<0.001)	0.922 (<0.001)	0.861 (<0.001)
7 o'clock	0.675 (<0.001)	0.751 (<0.001)	0.792 (<0.001)	0.765 (<0.001)	0.901 (<0.001)
8 o'clock	0.728 (<0.001)	0.463 (0.020)	0.371 (0.043)	0.407 (0.009)	0.608 (<0.001)
9 o'clock	0.614 (<0.001)	0.454 (0.023)	0.480 (0.007)	0.395 (0.012)	0.394 (0.027)
10 o'clock	0.832 (<0.001)	0.743 (<0.001)	0.655 (<0.001)	0.556 (<0.001)	0.667 (<0.001)
11 o'clock	0.845 (<0.001)	0.782 (<0.001)	0.822 (<0.001)	0.665 (<0.001)	0.886 (<0.001)
12 o'clock	0.852 (<0.001)	0.777 (<0.001)	0.849 (<0.001)	0.832 (<0.001)	0.835 (<0.001)

thickness but not in nasal quadrant thickness, between the SD-OCT and the TD-OCT systems.

To compare our proposed model with the models used in other studies, one randomly selected eye from each subject in each group was used to further evaluate the correlation in RNFL thickness between the two OCT instruments (Table 3). In the normal group, there was a strong correlation between each SD-OCT-measured parameter and each TD-OCT-measured parameter (all parameters, r >0.5). In the other four groups, there were good correlations between most of the SD-OCT-measured parameters and most of the TD-OCT-measured parameters. However, weak correlations between the two devices were found in the nasal quadrant at the 8:00 and 9:00 o'clock positions in the OH, GS, POAG, and PACG groups.

We used GEE mixed effect model with "Intercept" as the only random effect to establish the correlations between Cirrus OCT (dependent variable) and Stratus OCT (independent variable) in all measurements, after adjusting for the effect of individual variation. We also added groups and their interaction terms with independent variable (Stratus OCT). All interaction terms were non-significant. That is, the highly significant linear relationship between Cirrus and Stratus did not differ among the five groups in all measurements. The final fitted linear regression lines for all measurements with R-squared values are shown in Table 4. To demonstrate the appropriateness of the method we used, we also presented the results of the square of the correlation coefficient (i.e., the coefficient of determination) corresponding to the two OCT systems. We found that the R-squared values were higher

TABLE 4.
Linear regression models between two OCT measurements

	Linear models	R-Squared[a]	$(r^*)^2$	p-Value
Average	Cirrus Ave = 20.0089 + 0.7038 * Stratus Ave	0.9470	0.8798	<0.001
Superior	Cirrus S = 13.1623 + 0.7986 * Stratus S	0.8765	0.8263	<0.001
Temporal	Cirrus T = 17.7265 + 0.6780 * Stratus T	0.9013	0.8082	<0.001
Inferior	Cirrus I = 17.2426 + 0.7660 * Stratus I	0.9103	0.8354	<0.001
Nasal	Cirrus N = 41.0602 + 0.3344 * Stratus N	0.7020	0.3982	<0.001
1 o'clock	Cirrus 1 = 14.0363 + 0.8156 * Stratus 1	0.8050	0.7715	<0.001
2 o'clock	Cirrus 2 = 19.9271 + 0.6770 * Stratus 2	0.8623	0.7870	<0.001
3 o'clock	Cirrus 3 = 21.4905 + 0.5536 * Stratus 3	0.8145	0.6596	<0.001
4 o'clock	Cirrus 4 = 15.3733 + 0.7296 * Stratus 4	0.8430	0.7498	<0.001
5 o'clock	Cirrus 5 = 9.1707 + 0.8866 * Stratus 5	0.8661	0.8661	<0.001
6 o'clock	Cirrus 6 = 13.4389 + 0.7939 * Stratus 6	0.8782	0.7492	<0.001
7 o'clock	Cirrus 7 = 22.9529 + 0.6228 * Stratus 7	0.8315	0.6493	<0.001
8 o'clock	Cirrus 8 = 37.3968 + 0.3406 * Stratus 8	0.6513	0.3516	<0.001
9 o'clock	Cirrus 9 = 42.0520 + 0.2732 * Stratus 9	0.7278	0.2537	<0.001
10 o'clock	Cirrus 10 = 35.8140 + 0.4790 * Stratus 10	0.5895	0.4939	<0.001
11 o'clock	Cirrus 11 = 23.0821 + 0.6895 * Stratus 11	0.8331	0.6881	<0.001
12 o'clock	Cirrus 12 = 2.1945 + 0.8782 * Stratus 12	0.7989	0.7577	<0.001

[a]R-Square value of fitted GEE method's mixed effects linear model.
*Pearson product moment correlation coefficient.

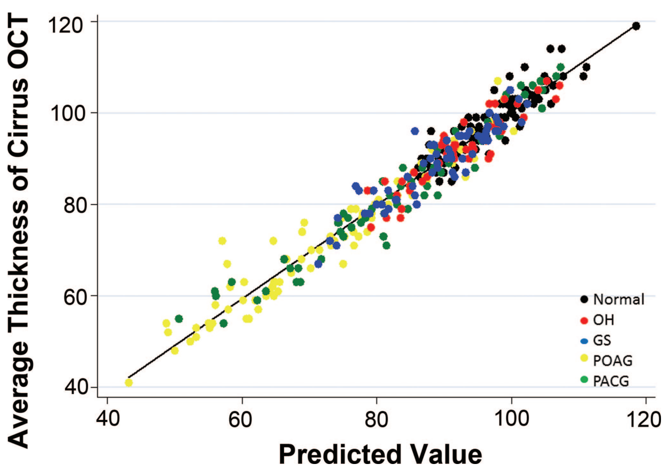

FIGURE 1.
Mixed effect model of average thickness, Cirrus OCT vs. Stratus OCT, r^2 = 0.9470.

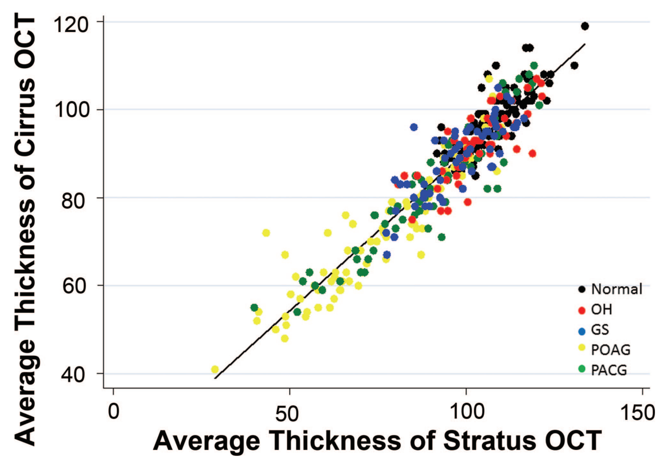

FIGURE 2.
Pearson correlation coefficient of average thickness, Cirrus OCT vs. Stratus OCT, r^2 = 0.8798.

than the corresponding square of the correlation coefficient in all RNFL thickness parameters. Fig. 1 shows the corresponding scatter plots with the fitted line for average thickness, and Fig. 2 shows the scatter plot of the Pearson correlation analysis for average thickness. In Fig. 3, we used a Bland-Altman plot to detect agreement between Cirrus and Stratus; however, there was a small systematic difference in the result. The Stratus minus Cirrus difference was proportional to RNFL thickness. For thinner RNFLs, Stratus measurements tended to be thinner than Cirrus measurements, whereas for thicker RNFLs, Stratus measurements tended to be thicker than Cirrus measurements.

DISCUSSION

To the best of our knowledge, our study is only one of a few that have compared TD-OCT-derived RNFL thickness parameters with those derived from SD-OCT in normal subjects and in patients with different types of glaucoma. We found that the RNFL thickness values obtained with the Stratus TD-OCT device were higher in almost every parameter and in patients with different types of glaucoma than the values obtained with the Cirrus SD-OCT device, which is consistent with the findings reported in previous studies.[15–21] We believe the discrepancy in measurements between the two devices might be related to an intrinsic difference in software edge-detection algorithms for measuring the RNFL and the precise location of the RNFL measured.[15,21] Although it is presumed that SD-OCT devices are more accurate than TD-OCT technology because the higher resolution images provide more accurate delineation of RNFL margins, future studies are need to clarify which instrument offers better accuracy in estimating the real RNFL thickness.[15,21]

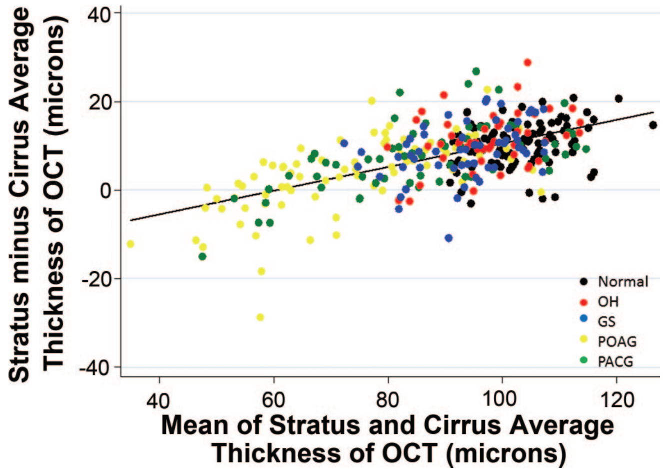

FIGURE 3.

Bland-Altman plot of the agreement of mean retinal nerve fiber layer thickness between Stratus OCT and Cirrus OCT.

Although some studies have tried to compare and evaluate the correlation between TD-OCT-derived RNFL thickness measurements and SD-OCT-derived measurements, different study designs, different statistical methods, and different study groups have resulted in different outcomes across studies.[15–21] Vizzeri et al. reported that correlations between RNFL parameters were strong, particularly for average RNFL thickness ($R^2 = 0.92$). They also found good agreement between the two instruments, with better agreement for average RNFL thickness than for sectorial RNFL parameters.[15] Sung et al.[19] found that average SD-OCT-derived RNFL thickness values correlated well with those obtained with the TD-OCT system (r, 0.94; $p < 0.001$), although the values differed significantly between the two machines. Knight et al.[21] found that SD-OCT-derived RNFL measurements correlated well with those obtained using a TD-OCT device, although they also noticed that there was a systematic difference in measurement values between the two instruments. The authors reported that SD-OCT-derived RNFL thickness values tended to be higher than the thickness values obtained with a TD-OCT device except when the RNFL was very thin, as in patients with severe glaucoma. They found that the systemic difference is not in a single direction, which was also reported by Zangwill et al.[25] However, Leung et al.[17] found poor agreement in RNFL thickness values between the SD-OCT system and the TD-OCT system, which was likely related to the inherent differences in the characteristics of the two OCT systems.

In this study, we evaluated the correlation between SD-OCT-derived RNFL thickness measurements and TD-OCT-derived measurements in POAG, PACG, OH, GS, and normal subjects. Our results show that each parameter measured by the SD-OCT correlated well with each parameter measured by the TD-OCT in the control group. In addition, most of the parameters measured by the SD-OCT system correlated well with those obtained by the TD-OCT device in the OH group (r, 0.560–0.910), the GS group (r, 0.492–0.935), the POAG group (r, 0.395–0.928), and the PACG group (r, 0.394–0.937). Furthermore, there was a significant, but mild correlation in nasal quadrant thickness at the 8:00 and 9:00 o'clock positions between the two devices among the four study groups (R^2 range, 0.402–0.570). A similar result was also found by Vizzeri et al.[15] (nasal quadrant thickness; healthy subject, $R^2 = 0.55$; patients, $R^2 = 0.54$). Many studies have found that there is marked variability in TD-OCT-measured nasal quadrant RNFL thickness.[15,26,27] A possible explanation for that phenomenon is that the angle of incidence of the illuminating beam is such that the RNFL is dimmer nasally, thus limiting the ability of the detection algorithm to consistently identify the RNFL at the same location over time.[15,26,27]

In this study, we used a robust set of statistical methods to more accurately investigate the correlation between SD-OCT-derived RNFL thickness measurements and TD-OCT-derived measurements. The strength of this GEE mixed effect model used in our study takes into account the problems associated with correlated data gathering from two eyes of the same subject, which could also adjust the effect of individual variation. Furthermore, we incorporated many variables that have a potential influence on the outcome variable into this model.[28–31] Several studies have reported that TD-OCT-measured RNFL thickness varies significantly with age, ethnicity, AXL, and optic disc area.[28,29] In addition, refraction has been noted to affect the RNFL thickness distribution.[29] Furthermore, OCT-measured RNFL thickness has been shown to correlate with visual field defects.[30] Even cornea thickness has been suggested to have some association with the correlations in RNFL thickness between the two devices.[31] Although our model is one of the first to confirm the correlation between TD-OCT-derived measures of RNFL thickness and thickness measurements derived from SD-OCT in a Chinese population based on this model, the real clinical application of Cirrus OCT should be addressed soon in the near future in our population. Moreover, although good correlation in RNFL thickness measurements between the two OCT units has been proved in many studies, RNFL thickness measurements obtained from a TD-OCT scan cannot be directly compared with measurements obtained from an SD-OCT scan. Therefore, follow-up Stratus TD-OCT scans are necessary to determine whether changes in RNFL thickness have developed and then a new baseline scan using an SD-OCT system needs to be performed so that measurements can be compared in the future.[21]

There were a few limitations in our study. First, we excluded data from poor signal scans. Therefore, it is inadequate to generalize the results to whole cases. Second, our study population is relatively small. To increase the precision of the GEE model, further studies with larger sample sizes should be conducted. Third, potential confounding factors exist, either from study patient chosen or from different analyzing mathematic models. However, the results from this study could be a good basis for further evaluation of the real application of Cirrus OCT in clinical practice.

In conclusion, although there was good correlation between TD-OCT-derived measures of RNFL thickness and those derived from SD-OCT, clinicians should be very cautious when interpreting RNFL thickness data for any subject undergoing longitudinal follow-up with different OCTs.

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