·Clinical Research·

Comparison and interchangeability of macular thickness measured with Cirrus OCT and Stratus OCT in myopic eyes

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Abstract

• AIM: To investigate the difference of macular thickness measurements between Stratus optical coherence tomography (OCT) and Cirrus OCT (Carl Zeiss Meditec, Dublin, CA, USA) in the same myopic patient and to develop a conversion equation to interchange macular thickness obtained with these two OCT devices.

• METHODS: Eighty-nine healthy Chinese adults with spherical equivalent (SE) ranging from -1.13 D to -9.63 D were recruited. The macular thickness was measured by Cirrus OCT and Stratus OCT. The correlation between macular thickness and axial length and the agreement between two OCT measurements were evaluated. A formula was generated to interchange macular thickness obtained with two OCT devices.

• RESULTS: Average macular thickness measured with Stratus OCT (r=-0.280, P=0.008) and Cirrus OCT (r=-0.224, P=0.034) were found to be negatively correlated with axial length. No statistically significant correlation was found between axial length and central subfield macular thickness (CMT) measured with Stratus OCT (r=0.191, P=0.073) and Cirrus OCT (r=0.169, P=0.113). The mean CMT measured with Cirrus OCT was 53.63±7.94 μm thicker than with Stratus OCT. The formula $CMT_{Cirrus\ OCT}$=78.328+0.874×$CMT_{Stratus\ OCT}$ was generated to interchange macular thickness obtained with two OCT devices.

• CONCLUSION: Macular thickness measured with Cirrus OCT were thicker than with Stratus OCT in myopic eyes. A formula can be used to interchange macular thickness measured with two OCT devices in myopic eyes. Studies with different OCT devices and larger samples are warranted to enable the comparison of macular values measured with different OCT devices.

• **KEYWORDS:** myopia; macular thickness; spectral domain Cirrus OCT; time domain Stratus OCT; interchangeability

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INTRODUCTION

Myopia is a worldwide common ocular disorder [1]. It is well known to be related to various progressive maculopathy, *e.g.* choroidal neovascularization, retinoschisis, macular hole [2-4]. Therefore, long-term follow of myopic patient with repeated macular evaluation is important.

Optical coherence tomography (OCT) is a widely used technique that can measure retina thickness *in vivo* [5]. It has been emerging as an important diagnostic technique for macular diseases in recent years. Time domain OCT (TD OCT) used to be the first line technique of macular thickness measurement in clinical practice. Spectral domain OCT (SD OCT) is the latest generation of OCT that can measure retina with higher resolution than TD OCT. SD OCT is now replacing TD OCT as the most popular technique for macular thickness measurement. Stratus OCT (Carl Zeiss Meditec, Dublin, CA) and Cirrus OCT (Carl Zeiss Meditec, Dublin, CA, USA) are amongst the most commonly used OCTs. According to previous study[6], healthy young myopic eyes have thinner macular thickness, lower macular volume and thicker foveal thickness than emmetropic eyes based on OCT measuement. The evaluation of macular diseases in myopic eyes may be effected when using the parameter of macular thickness measured with OCT. Studies have also shown that macular thickness measured with Stratus OCT differed from Cirrus OCT due to different segmentation algorithm [7]. Macular thickness measured with these two OCT devices can not be compared directly. So far, no study has been performed to compare Stratus OCT and Cirrus OCT in macular thickness measurement in myopic patient. The purpose of this study was to investigate the difference of macular thickness measurement between Stratus OCT and Cirrus OCT in the same myopic patient and to develop a conversion equation to interchange macular thickness values obtained with these two OCT devices.

SUBJECTS AND METHODS

Subjects Eighty-nine healthy Chinese adults with spherical equivalent (SE) ranging from -1.13 D to -9.63 D were recruited in our study from June 2009 to February 2010. Only one eye from each subject was randomly selected. All subjects received complete ophthalmic examinations in Joint Shantou International Eye Center, which included visual acuity, intraocular pressure (IOP), refraction, axial length measured with IOL Master (Carl Zeiss Meditec Inc, Dublin, CA, USA), visual field test and dilated fundus stereoscopic examination. Examination with Stratus OCT and Cirrus OCT was performed on each eye on the same day. The study was designed following the ethical standards of the Declaration of Helsinki and approved by the local ethical committee with informed consent obtained before the study.

Inclusion and Exclusion Criteria All the included eyes have SE of less than -1.00 D and no other concurrent diseases. Subjects with best corrected visual acuity of less than 20/40, IOP over 21 mm Hg, family history of glaucoma, intraocular surgery, myopic macular degeneration, clinical evidence of glaucoma, visual field test of outside normal limit in glaucoma hemifield test (GHT), refractive surgery, age of less than eighteen, neurological diseases or diabetes were excluded.

Cirrus OCT Imaging The macular thickness was measured by Cirrus OCT (software version 3.0.0.64; Carl Zeiss Meditec, Dublin, CA, USA) using macula cube 512 A-scans ×128 B-scans protocol. Briefly, the protocol scans a 6 mm square grid by using 128 horizontal lines each consisting of 512 A-scan in approximately 2.5s with scanning speed of 27 000 A-scans per second. The highest axial resolution for Cirrus OCT is about 5 μm. Eye movements were monitored by reading the real-time fundus images. Images with misaligned vessels or segmentation errors within the scanning area were excluded and retaken. The signal for the scanned retina should be over 7. The average macular thickness and 9 subfield thickness according to Early Treatment Diabetic Retinopathy Study (ETDRS) was derived from the report generated by Cirrus OCT. All the Cirrus OCT scanning was performed by two trained ophthalmologists (Qiu KL and Wang G).

Stratus OCT Imaging In Stratus OCT (software version 4.0, Carl Zeiss Meditec) imaging, the Fast Macular Thickness Map protocol was used to measure macular thickness. The protocol uses six 6-mm radial spoke-like lines (oriented 30° apart) to scan macular. Each scanning line consists of 128 A-scans. The scanning speed for Stratus OCT is 400 A-scans per second with axial resolution of 10 μm. The signal for the scanned retina should be over 7. The 9 ETDRS subfield thickness and total macular volume were derived from the report generated by Stratus OCT. The average macular thickness was calculated according to the methods reported in previous studies[8,9]. All the Stratus OCT scanning was performed by one trained ophthalmologist (Qiu KL).

Visual Field Testing All the visual field tests were performed with the static automated white-on-white threshold 24-2 Swedish interactive thresholding algorithm (SITA) standard strategy (Humphrey Field Analyzer II; Carl Zeiss Meditec, Inc.). A visual field test was considered to be reliable when fixation loss, false positive and false negative were less than 20%. All the visual field tests for the included eyes were within normal limit or general reduction of sensitivity in GHT.

Statistical Analysis The statistical analyses were performed with commercially available software (SPSS ver. 13.0; SPSS Inc, Chicago, IL, USA). The mean values and standard deviations of each subfield and average macular thickness were calculated for both instruments. Paired *t*-test was used to compare retinal thickness of each subfield measured with both instruments. Bland-Altman plot was used to assess the agreement between the measurements with both instruments. A conversion equation was derived from the linear relationship of the central subfield macular thickness (CMT) measured with both instruments. Predicted SD OCT values were calculated based on the conversion equation and compared with the actual SD OCT values using Bland and Altman plot. $P<0.05$ was considered statistically significant.

RESULTS

Eighty-nine eyes from 89 subjects (40 females and 50 right eyes) met our inclusion criteria. The mean age, SE and axial length were 23.20y (95% CI 22.40 to 24.00, range: 18.00 to 40.00y), -4.70 D (95% CI -4.25 to -5.15, range: -1.13 to -9.63 D) and 25.48 mm (95% CI 25.25 to 25.71, range: 22.62 to 28.77 mm) respectively. SE correlated significantly with axial length (r=-0.807, P<0.001). Eighty-six subjects had visual field of "normal visual field" in GHT. Three subjects had visual field of "general reduction of sensitivity" in GHT. The characteristics of participants were presented in Table 1.

Macular Thickness Measurement with Cirrus OCT The mean macular volume and average macular thickness measured with Cirrus OCT for all study subjects was 10.00±0.46 mm^3 and 277.60±12.70 μm (range 249.00-317.00 μm) respectively. Macular volume (r=-0.220, P=0.039) and average macular thickness (r=-0.224, P=0.034) were found to be negatively correlated with axial length, while no significant correlation was found between CMT and axial length (r=0.169, P=0.113). Temporal (r=-0.237, P=0.025), superior (r=-0.265, P=0.012) and inferior (r=-0.284, P=0.007) outer macular thickness was also found to be negatively correlated with axial length respectively. Detailed information was shown in Table 2.

Table 1 Characteristics of study subjects $\bar{x} \pm s$

Parameters	Low myopia (*n*=24)	Moderate myopia (*n*=39)	High myopia (*n*=26)	*P*
SE (D)	-2.13±0.53	-4.48±0.68	-7.38±1.04	<0.001[a]
Axial length (mm)	24.50±0.79	25.30±0.70	26.64±0.77	<0.001[a]
Age (a)	23.13±3.44	23.56±4.00	22.73±3.97	0.690[a]
Sex（M/F）	14/10	22/17	13/13	0.818[b]

SE: Spherical equivalent. High myopia: SE≤-6.00 D; Moderate myopia: -3.00 D≥SE>-6.00 D; Low myopia: -1.00 D≥SE>-3.00 D. [a]One-way ANOVA test; [b]Chi-square test.

Table 2 Macular thickness measured with Cirrus OCT $\bar{x} \pm s$

Retinal parameters	All subjects (*n*=89)	Correlation with axial length (*n*=89)	
		r [a]	*P*
Temporal inner macula (μm)	302.83±12.89	-0.048	0.653
Superior inner macula (μm)	320.03±14.84	-0.101	0.348
Nasal inner macula (μm)	319.90±15.93	-0.124	0.249
Inferior inner macula (μm)	311.15±13.52	0.068	0.524
Temporal outer macula(μm)	256.54±12.23	-0.237	0.025
Superior outer macula(μm)	275.30±13.21	-0.265	0.012
Nasal outer macula (μm)	299.10±17.01	-0.155	0.146
Inferior outer macula (μm)	266.26±14.73	-0.284	0.007
CMT (μm)	249.37±16.27	0.169	0.113
Average macular thickness (μm)	277.60±12.70	-0.224	0.034
Macular volume (mm^3)	10.00±0.46	-0.220	0.039

CMT: Central subfield macular thickness. [a]Pearson's correlation analysis.

Table 3 Macular thickness measured with Stratus OCT $\bar{x} \pm s$

Retinal parameters	All subjects (*n*=89)	Correlation with axial length (*n*=89)	
		r[a]	*P*
Temporal inner macula (μm)	261.45±12.37	-0.122	0.254
Superior inner macula (μm)	275.60±14.14	-0.063	0.560
Nasal inner macula (μm)	274.71±15.13	-0.147	0.171
Inferior inner macula (μm)	272.53±13.54	0.167	0.118
Temporal outer macula (μm)	218.73±13.41	-0.328	0.002
Superior outer macula (μm)	246.20±14.37	-0.346	0.001
Nasal outer macula (μm)	263.98±16.42	-0.199	0.061
Inferior outer macula (μm)	225.92±15.01	-0.273	0.010
CMT (μm)	195.74±15.50	0.191	0.073
Average macular thickness (μm)	244.71±12.29	-0.280	0.008
Macular volume (mm^3)	6.93±0.35	-0.279	0.008

CMT: Central subfield macular thickness. [a]Pearson's correlation analysis.

Macular Thickness Measurement with Stratus OCT The mean macular volume and average macular thickness measured with Stratus OCT for all study subjects was 6.93±0.35 mm^3 and 244.71±12.29 μm (range 216.17.00-280.91 μm) respectively. Macular volume (*r* =-0.279, *P*=0.008) and average macular thickness (*r*=-0.280, *P*=0.008) were found to be negatively correlated with axial length. Temporal (*r*=-0.328, *P*=0.002), superior (*r*=-0.346, *P*=0.001) and inferior (*r*=-0.273, *P*=0.010) outer macular thickness was also found to be negatively correlated with axial length respectively. No statistically significant correlation was found between CMT and axial length (*r*=0.191, *P*=0.073). Detailed information was shown in Table 3.

Comparison of Macular Thickness Measurement with Cirrus OCT and Stratus OCT The mean macular thickness measured with Cirrus OCT for all subfields were thicker than with Stratus OCT. The mean CMT measured with Cirrus OCT was 53.63±7.94 μm thicker than with Stratus OCT. The mean macular volume measured with Cirrus OCT was 3.07±0.22 mm^3 larger than with Stratus OCT. The macular volume and all the macular subfields thickness measured with both OCT were all significantly correlated. No significant correlation was found between axial length and the difference of two OCT measurement for each subfield macular thickness. Detailed information was shown in Table 4.

Comparison of Predicted Cirrus OCT Macular Thickness and Measured Macular Thickness The existing sample was divided into two part according to patient code. Subjects apart with an interval of two codes were chosen for the second part. The first part included 60 subjects while the second part included 29 subjects. The mean SE for two part were -4.76 D (95% CI -4.19 to -5.34, range: -1.13 to -9.63 D) and -4.56 D (95% CI -3.83 to -5.29, range: -1.50 to -8.75 D) respectively. No significant difference in SE was found between two part (*t*-test, *P*=0.680). The first part was used to generate a conversion equation from the linear regression of the CMT measured with both instruments as follow: $CMT_{Cirrus OCT}$=78.328+0.874×$CMT_{Stratus OCT}$. The Coefficient of determination R^2 was 0.740. The residual variance was 8.491. For the second part of the sample, the predicted Cirrus OCT CMT was derived from the Stratus OCT CMT using the formula. The agreement between predicted Cirrus OCT CMT and actual Cirrus OCT CMT in the second part was assessed with Bland-Altman test (95% limits of agreement 25.6 μm) (Figure 1). No significant correlation was found between the difference of predicted-actual CMT and axial length (*r*=-0.011, *P*=0.573). The agreement between Cirrus OCT macular thickness and Stratus OCT macular thickness was also assessed (Figure 1).

DISCUSSION

In current study, we found macular volume and average macular thickness measured by Cirrus OCT and Stratus OCT were negatively correlated with axial length. No significant correlation was found between CMT and axial length. When comparing the values measured with Cirrus OCT and Stratus OCT, we found all the mean macular subfields thickness and the mean macular volume measured with Cirrus OCT were

Table 4 Comparison of macular thickness measurement with Cirrus OCT and Stratus OCT

Retinal parameters	Mean differences±SD (Cirrus OCT-Stratus OCT)	Correlations			
		Axial length with two OCT difference		Cirrus OCT with Stratus OCT	
		r^a	P	r^a	P
Temporal inner macula (μm)	41.38±6.50	0.137	0.201	0.868	<0.001
Superior inner macula (μm)	44.44±8.08	-0.075	0.482	0.846	<0.001
Nasal inner macula (μm)	45.19±8.04	0.034	0.751	0.865	<0.001
Inferior inner macula (μm)	38.62±8.01	0.167	0.119	0.825	<0.001
Temporal outer macula (μm)	37.81±8.98	0.167	0.117	0.758	<0.001
Superior outer macula (μm)	29.10±8.23	0.178	0.095	0.825	<0.001
Nasal outer macula (μm)	35.12±7.68	0.082	0.447	0.895	<0.001
Inferior outer macula (μm)	40.34±6.32	-0.013	0.900	0.910	<0.001
CMT (μm)	53.63±7.94	-0.026	0.811	0.876	<0.001
Macular volume (mm^3)	3.07±0.22	-0.021	0.542	0.894	<0.001

CMT: Central subfield macular thickness. [a]Pearson's correlation analysis.

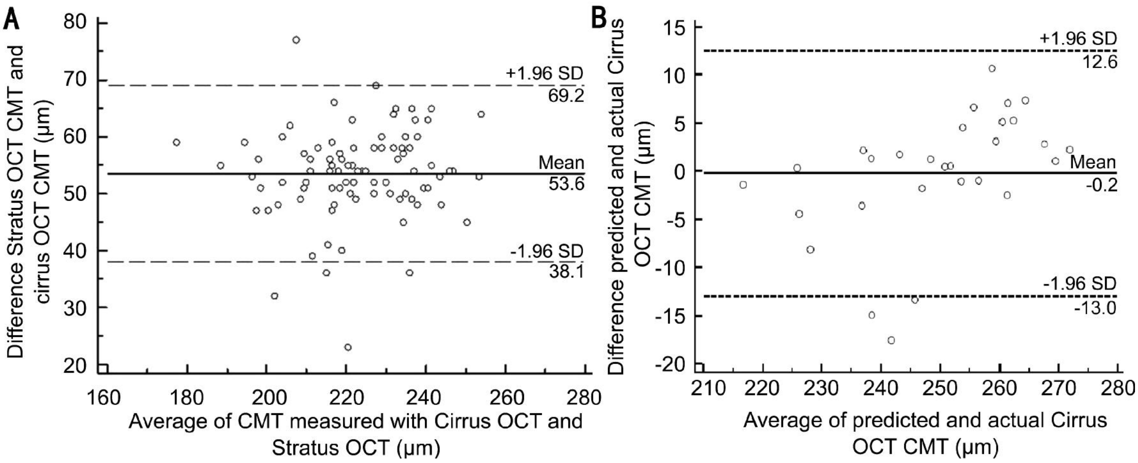

Figure 1 Bland-Altman plot showing the agreement between CMT measured with Stratus OCT and Cirrus OCT A: Agreement between CMT obtained with Cirrus OCT and Stratus OCT; B: Agreement between predicted and actual Cirrus OCT CMT.

larger than with Stratus OCT in myopic eyes. The macular volume and all the macular subfields thickness measured with both OCT were all significantly correlated. A conversion equation was generated to predict Cirrus OCT macular thickness from the values measured by Stratus OCT in myopic eyes. While poor agreement of macular thickness measurement was found between two OCT, better agreement was achieved by using the equation to transform Stratus OCT macular thickness into predicted Cirrus OCT macular thickness.

Previous studies based on TD OCT and SD OCT all suggested a negative correlation between average macular thickness and axial length [6,10-15]. The correlation between CMT and axial length was not evident according to these studies [6,10-15]. Present study used both TD OCT and SD OCT to investigate the correlation between macular thickness and axial length in the same subjects and demonstrated similar results with previous studies. The thinning of retinal thickness in myopic eyes may be caused by the stretching strength as the axial length increasing. Since central retina has more nerve fiber but fewer vessels, it is more resistant to the stretching. Myopia may have a significant effect on macular thickness measurement with OCT. Cautions should be exercised when applying on myopic patients the research results derived from emmetropic eyes.

Present study demonstrated a significant correlation between macular thickness measured with Stratus OCT and Cirrus OCT. However, macular thickness measured with Cirrus OCT was significantly thicker than Stratus OCT. The result is consistent with previous studies. It has been suggested by several studies that macular thickness measured with TD OCT and SD OCT were significantly correlated. But poor agreement between two OCT measurements was also found in these studies [16-20]. According to Abedi *et al* [16], the mean difference of CMT was 59.6±17.6 μm for Cirrus OCT and Stratus OCT in normal subjects. Forte *et al* [17] reported a mean difference of 39.2 ±25.8 μm between the macular thickness measured with spectral domain scanning laser ophthalmoscope OCT and Stratus OCT. Macular thickness obtained with two OCT can not be compared directly.

Previous studies suggested that the difference of macular thickness measurement was caused by different segmentation algorithm among OCT devices [7]. Stratus OCT identifies the inner segment/outer segment junction (IS/OS) as the outer border of retina, while Cirrus OCT use retinal pigment epithelium (RPE) as the outer border. The distance between IS/OS and RPE may represent the difference of two OCT measurement. Different scanning methods may also play a role in the discrepancy between two OCT measurements. Cirrus OCT scans retina with a higher speed, better resolution and more sampling frames. In contrast, Stratus OCT generates macular thickness map from only six radial scan lines. Present study did not find significant correlation between axial length and the difference of two OCT measurement for each subfield macular thickness. Axial length may not affect the difference of two OCT measurement of macular thickness.

A formula was generated based on the result of current study to predict the macular thickness measured with Cirrus OCT from the measurement of Stratus OCT. While poor agreement of macular thickness measurement was found between two OCTs, better agreement was achieved by using the formula to interchange the Stratus OCT measurement into Cirrus OCT value. Similar formulae were reported in previous studies [16,21]. Ibrahim *et al* [21] reported an equation: y=1.029x+72.49, where y is the predicted SD-OCT value and x is the average thickness in the Central subfields as measured by TD-OCT. According to the study by Abedi *et al* [16], StratusValue=0.76 (CirrusValue)-0.51. However, none of the equation was mainly based on myopic subjects. All subjects included in present study were otherwise normal myopia. As mentioned above, macular thickness measurement can be influenced by axial length. The formula in present study may be more accurate for myopic patient. Myopia is associated with various progressive macular disorders. Meanwhile, SD OCT is replacing TD OCT as the first line instrument for macular thickness measurement. Although the agreement between two OCTs improved after using the formula, the 95% limits of agreement was 25.6 μm and there were still a few outliers. The formula was not yet a perfect method to interchange the measurements between two OCTs. To enable long term follow of myopic patient, it is important to develop an ideal method to compare macular values measured with TD OCT and SD OCT.

Several limitations exist in the present study. One potential limitation is the relatively narrow range of age (18-40y) of our study cohort. Thus, our results may not fit elder myopic subjects. It's not clarified whether age will influence macular thickness[22-26]. In the present study, age range was narrow but matched in each groups. This may reduce the influence of age on macular thickness measurements. Several SD OCT devices with different segmentation algorithms in macular measurement are now commercially available. The results of present study based on only two OCT devices. This may limit the application of our results when comparing macular values obtained with different SD OCT and TD OCT devices. Present study did not exclude participants with visual field of "general reduction of sensitivity" in GHT. Previous study had demonstrated that otherwise normal myopic eye could have "abnormal" visual field test [27]. The visual field results of "general reduction of sensitivity" in the three subjects are not typical glaucomatous change but may be caused by myopia instead.

In summary, present study suggested a negative correlation between axial length and average macular thickness measured by both Cirrus OCT and Stratus OCT. While no significant correlation was found between CMT and axial length. Macular thickness measured with Cirrus OCT were thicker than with Stratus OCT in myopic eyes. A formula can be used to convert macular thickness measured with two OCT in myopic eyes. Studies with different OCT devices and larger sample are warranted to enable the comparison of macular values measured with different OCT devices.

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