Retina

Macular Measurements Using Optical Coherence Tomography in Healthy Chinese School Age Children

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Purpose. To evaluate macular thickness/volume in a Chinese population of primary school children using optical coherence tomography (OCT), and assess its association with age, sex, spherical equivalent refraction (SE), body mass index (BMI), and intraocular pressure (IOP).

Methods. Healthy Chinese children (n = 806) from six randomly selected primary schools in Chongming County, Shanghai, China, were enrolled. Comprehensive standardized ophthalmic examinations included visual acuity, cycloplegic refraction, IOP, and fast macular scans using Stratus OCT. Mean values for the nine Early Treatment Diabetic Retinopathy Study (ETDRS) areas, foveal minimum thickness, and macular volume were calculated.

Results. OCT data from right eyes with high-quality scans were evaluated in 720 children (89.3% of total participants; 46.5% boys). Macular thickness and volume were normally distributed. The mean foveal minimum thickness was 140.0 ± 12.3 μm. There were significant differences between the boys and the girls in mean foveal volume (P = 0.023) and sectoral macular thickness in all the quadrants of the inner ring (P < 0.001 and P = 0.001) and temporal outer quadrant (P = 0.009). SE refraction correlated positively with inner and outer macular thickness and total macular volume (P < 0.001) and negatively with central macular volume (P = 0.012). BMI correlated significantly only with outer macular thickness (r = 0.074, P = 0.048). No age- and IOP-related differences were found in the macular parameters.

Conclusions. OCT demonstrated that macular thickness/volume was normally distributed in this sample of Chinese children, with variations in sex and SE. The variables in macular thickness/volume should be considered when diagnosing and monitoring school-aged children with diseases that affect the macula. (*Invest Ophthalmol Vis Sci.* 2011;52:6377–6383) DOI: 10.1167/iovs.11-7477

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Optical coherence tomography (OCT) is a noninvasive test that can provide precise measurements of macular and retinal nerve fiber layer (RNFL) thickness in vivo. Use of OCT has risen, and it is now widely used clinically around the world. The advantages and characteristics of this technique have been described in depth elsewhere.[1–3] OCT helps ophthalmologists diagnose retinal diseases by detecting small changes in retinal and macular morphology, such as thickness and volume. Therefore, data documenting normal macular measurements and variations associated with demographic and ocular variables in healthy subjects will help clinicians identify and characterize pathologic changes. Many investigations have been made previously in adults from different countries and regions; however, normal measurements in Chinese school-aged children are scarce.[4–7] In general OCT provides reliable, accurate, and repeatable measures in children.[8–10] It is imperative that measures be documented in children, since ocular development occurs continually, and macular parameters in children differ from those in adults.[11–14] Although there are a few studies that have reported normal macular thickness and variations with demographic and ocular variables in children, to the best of our knowledge, there are no published studies providing data on Chinese children.

In this study, we sought to report normal macular measurements in a sample of healthy Chinese school age children by using high-resolution OCT. In addition, we evaluated the impact of age, sex, spherical equivalent refraction (SE), intraocular pressure (IOP), and body mass index (BMI) on OCT parameters. We believe that our findings will be helpful for interpreting macular parameters for diagnosis and management in Chinese school-aged children and will be valuable for distinguishing differences in macular measurements among the different races.

Materials and Methods

Subject Recruitment

Six primary schools located in Chongming County, Shanghai, China, were identified by using a randomized sampling procedure. The total number of students from the six schools was 1462, with a distribution from the six school being 388, 244, 238, 229, 183, and 180. We intended to select 50% of the 1462 children for examination using a random number table. Estimating an exclusion rate of approximately 10%, we selected approximately 55% children (50%/0.9) for the examination process: 213 (54.9%) of 388, 134 (54.9%) of 244, 131 (55.0%) of 238, 126 (55.0%) of 229, 101 (55.2%) of 183, 99 (55.0%) of 180, and a total of 806 (55.1%) of the 1462 children were invited to participate and all agreed to do so. The participants who had congenital ocular abnormalities, low OCT signals, alignment problems, and intraocular pressure more than 21 mm Hg were excluded. Finally, 192 (90.1%) of 213, 115 (85.8%) of 134, 113 (86.3%) of 131, 110 of (87.3%) 126, 87 of (86.1%) 101, 89 (89.9%) of 99, and a total of 720 (89.3%) of 806 invited children who agreed were included. Written informed consent was obtained from the legal guardians, and verbal consent was obtained from the children at the time of examination. Our study complied with the Declaration of Helsinki.

Ocular Examination

All participants underwent a complete ophthalmic examination, including a detailed assessment of far and near visual acuity, slit lamp biomicroscopy, dilated fundus examination with direct ophthalmoscopy, cycloplegic refraction, and IOP measurements. Best corrected visual acuity (BCVA) was assessed monocularly using linear logMAR charts if the child's uncorrected visual acuity (UCVA) was lower than 1.0 (<20/20). A Haag-Streit slit lamp (Köniz, Switzerland) was used to examine the anterior segment. IOP was examined by noncontact tonometry (Nidek, Gamagori, Japan). Pupillary dilation was induced by three cycles of tropicamide 0.5% (1 drop), administered 5 minutes apart. Twenty to 30 minutes after administration of the eye drops, the autorefractometer (RK-F1; Canon; Tokyo, Japan) was set to generate five valid readings of refraction, and the median value given by the instrument was used for analysis.

OCT Measurements

Macular thickness scans were performed through dilated pupils (Stratus OCT 3, software version 4.0.1; Carl Zeiss Meditec, Inc., Dublin, CA) with fast macular scan protocol. This protocol consists of six individual line scans regularly arranged in a radial pattern, with a default scan length of 6 mm. The scans were equally spaced through a central axis overlying the center of the macula, and each line scan was composed of 128 single A-scans. Total acquisition time for each fast macular scan was 1.92 seconds. Each participant's head was fixed on the sustainer, upright with the eye focusing on an internal fixation target without blinking and eye movement while six radial retinal scans were performed. An average of the six radial scans was used for subsequent analysis. Every participating child's refractive power was compensated for by adjusting the focus knob to a value closest to spherical value of the eye examined, even though some studies have shown that this does not affect macular thickness measurements significantly.[15] All scans were performed using a default axial length of 24.46 mm. Retinal thickness over the macula in each scan was automatically determined by an algorithm as the distance between the vitreoretinal interface and the boundary corresponding to the photoreceptor inner–outer segment junction.[16] After completing individual scanning, the macula was automatically divided into three concentric regions (Fig. 1A). The central disc, referred to as the fovea, was a region with a radius of 1 mm. The inner and outer rings had outer radii of 3 and 6 mm, respectively, and were equally segmented into four quadrants (superior, nasal, inferior, and temporal) by two reticules. As a result, the 6-mm-diameter macula was divided into nine areas (F, TI, SI, NI, II, TO, SO, NO, and IO) in three concentric rings as defined by the Early Treatment Diabetic Retinopathy Study Group (ETDRS), and the mean thickness was presented for each of the nine sectors.

Definitions and Statistical Analysis

SE was defined as spherical power plus half-negative cylinder power. Emmetropia was defined as an SE between −0.5 D and +0.5 D, myopia as an SE less than -0.5 D, and hyperopia as an SE greater than +0.5D. Levels of myopia included low myopia, defined as $-3 \text{ D} < \text{SE} \leq -0.5$ D, and moderate to high myopia, defined as SE of at least −3 D.[17] Parameters in the OCT3 summary report were obtained. Only complete and well-centered scans with signal strengths of at least 7 from the right eye of each child were used. The results are expressed as the mean ± SD (SPSS, ver, 17.0; SPSS Inc., Chicago, IL). The one-sample Kolmogorov-Smirnov test was used to test normal distribution. The intersex differences were assessed by independent-samples *t*-test. Analysis of variance (ANOVA) with Bonferroni post hoc test was used to compare mean thickness across the regions and quadrants in age, sex, and SE groups. Pearson partial analysis was used to assess the relationship between OCT measurements and age, SE refraction, IOP, and BMI.

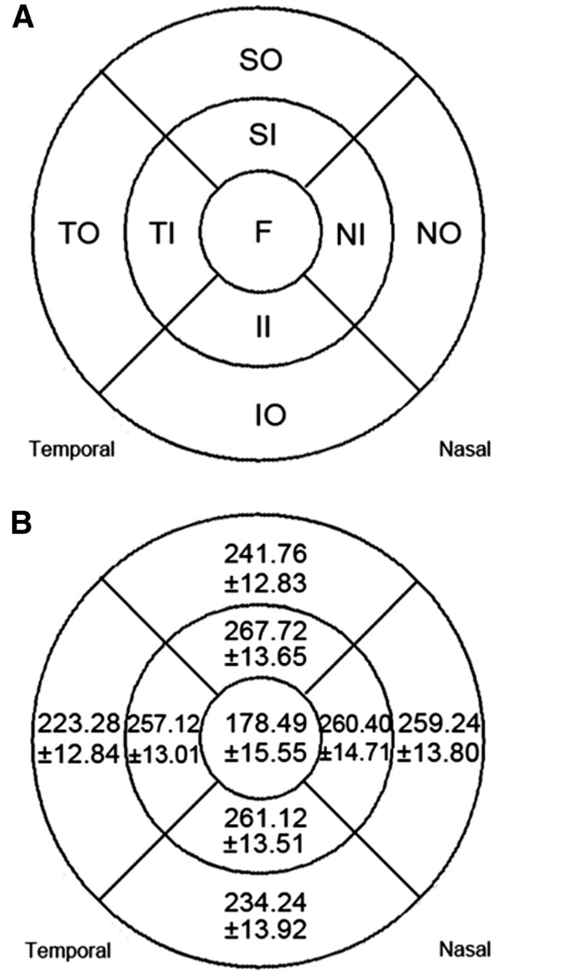

Figure 1. (**A**) Macular map, automatically divided into nine ETDRS sectors. F, foveola; TI, temporal inner sector; SI, superior inner sector; NI, nasal inner sector; II; inferior inner sector; TO, temporal outer sector; SO, superior outer sector; NO, nasal outer sector; IO; inferior outer sector. Areas TI, SI, NI, and II form the inner ring; areas TO, SO, NO, and IO form the outer ring. (**B**) Mean and standard deviations of macular thickness (in micrometers) in nine areas in 720 healthy children.

$P < 0.05$ was considered statistically significant. All tests were two-tailed.

Results

Of the 806 participants examined, 720 (89.3%) primary school children aged 6 to 13 years were selected for analysis, including 385 (53.5%) girls and 335 (46.5%) boys. Eighty-six (10.7%) children were excluded due to low OCT signal strength (n = 36), alignment problems (n = 28), abnormal pupil (n = 1), congenital glaucoma (n = 5), and intraocular pressure greater than 21 mm Hg (n = 16). Compared with those excluded, the included children were significantly older and had lower IOP. Groups did not vary significantly in sex, spherical equivalent, and body mass index (Table 1). There were no significant differences in age (P = 0.56), sex (P = 0.78), and BMI (P = 0.29) among the 806 participants compared with the 656 nonparticipants.

Macular thickness and volume were normally distributed (Kolmogorov-Smirnov test), with a relatively wide range of the measured parameters. The mean age, SE, IOP, and BMI (girls versus boys) were 8.63 ± 1.64 years (8.61 ± 1.65 vs. 8.67 ±

TABLE 1. Characteristics of Included and Excluded Children

	Included (*n* = 720)	Excluded (*n* = 86)	*P**
Sex, % female	53.5	53.5	0.998
Age, y	8.63 ± 1.64	7.98 ± 1.73	<0.001
Spherical equivalent, D	−0.36 ± 1.64	−0.35 ± 1.71	0.08
Intraocular pressure, mm Hg	16.01 ± 2.49	16.99 ± 3.13	0.02
Body mass index, kg/m^2	17.37 ± 2.90	17.54 ± 2.75	0.41

Data are mean ± SD.
* Independent Sample *t*-test.

1.63), −0.36 ± 1.64 D (−0.37 ± 1.56 vs. −0.35 ± 1.73), 16.01 ± 2.49 mm Hg (16.24 ± 2.50 vs. 15.74 ± 2.44), and 17.37 ± 2.90 kg/m^2 (16.98 ± 2.73 vs. 17.82 ± 3.03), respectively. There were no significant differences in mean age and SE refraction between the boys and girls (independent-samples *t*-test, $P = 0.62$ and $P = 0.90$, respectively). However, the mean IOP and BMI were significantly higher in the boys than in the girls (Independent-samples *t*-test, $P = 0.006$ and $P < 0.0001$, respectively).

Macular thickness measurements, displayed as the mean and SD in all nine regions, are presented in Figure 1B. Within the inner region, the superior macular thickness was thicker than inferior, nasal, and temporal quadrants. In the outer region, the nasal macular thickness was the greatest, followed by that of the superior, inferior, and temporal quadrants.

The macular measurements stratified by sex are presented in Table 2. The minimum foveal thickness, foveal volume, and average inner ring and temporal outer quadrant macular thickness were significantly higher in boys. There was no significant difference in total macular volume between sexes. The macular measurements stratified by age (Table 3) show that no significant difference was found among age groups. Macular measurements stratified by SE are presented in Table 4. Children with hyperopia had higher average inner and outer ring macular thickness and total macular volume. No significant difference was found in minimum foveal thickness or foveal volume.

The relationships between macular measurements and age, IOP, SE, and BMI were analyzed by Pearson partial correlation analysis (Table 5). Age and IOP did correlate significantly with foveal minimum, macular thicknesses of all the ETDRS sectors, and the foveal or total macular volumes (with adjustment for sex, SE, BMI, and IOP for the former and for sex, SE, BMI, and age for the latter). None of the macular measurements displayed a significant correlation with age in either sex, whereas only inner inferior macular thickness had a positive correlation with age after adjustment for SE, BMI, and IOP in the boys ($r = 0.11$, $P = 0.037$).

SE refraction correlated positively with macular thicknesses of all the ETDRS sectors except the foveola and total macular volumes (with adjustment for age, sex, BMI, and IOP). In addition, the correlation of refraction with foveal minimum and foveal thickness (with adjustment for age, sex, BMI, and IOP) was marginally negative, and was significantly negative with foveal macular volume (with adjustment for age, sex, BMI, and IOP). BMI did not correlate significantly with foveal minimum, average inner macular thickness, or both foveal and total macular volumes, with the exception of positively correlating with superior inner macular thickness and nasal and inferior outer macular thickness (with adjustment for age, sex, SE refraction, and IOP).

DISCUSSION

In this study of Chinese school-aged children, macular thickness and volume measured by Stratus OCT (Carl Zeiss Meditec, Inc.), both were normally distributed. To avoid discrepancies in measurements obtained from different OCT devices, we compared our results only with previously published data from the Stratus OCT. Besides, it is important to note differences in sample size, age range, refractive state, race, and methodology. In comparison with studies of the white children conducted in small sample size[9,10,18,19] and two large population-based studies of multiracial children with narrow age range,[14,20] we found approximately 14.9 to 26 μm thinner mean foveal minimum in Chinese children (Table 6). The mean foveal macular thickness was also thinner than that found in most previous studies in white children,[9–10,14,18–20] but was slightly thicker (~2.5 μm) than results found in African-American children.[10] Compared with studies with small sample size[22–24] and a large population-based Handan Eye Study[4] of Chinese adults, the

TABLE 2. Differences in Macular Measurements by Sex

Parameters	Girls (*n* = 385)	Boys (*n* = 335)	Total (*n* = 720)	*P** for Sex Difference
Thickness, μm				
Total	249.4 ± 11.4	252.0 ± 11.5	250.6 ± 11.5	0.003
Foveal minimum	138.1 ± 12.2	142.2 ± 12.1	140.0 ± 12.3	<0.001
Foveola	176.2 ± 15.5	181.1 ± 15.3	178.5 ± 15.6	<0.001
Inner region				
Average	259.2 ± 11.9	264.3 ± 12.5	261.6 ± 12.4	<0.001
Temporal	254.9 ± 13.2	259.6 ± 12.4	257.1 ± 13.0	<0.001
Superior	266.2 ± 12.9	269.5 ± 14.3	267.7 ± 13.7	0.001
Nasal	257.1 ± 14.3	264.2 ± 14.3	260.4 ± 14.7	<0.001
Inferior	258.6 ± 12.8	264.0 ± 13.8	261.1 ± 13.5	<0.001
Outer region				
Average	239.6 ± 12.6	239.6 ± 12.2	239.6 ± 12.4	0.94
Temporal	222.1 ± 13.1	224.0 ± 12.4	223.3 ± 12.8	0.009
Superior	242.1 ± 13.1	241.4 ± 12.5	241.7 ± 12.8	0.47
Nasal	259.6 ± 14.1	258.9 ± 13.5	259.2 ± 13.8	0.49
Inferior	234.9 ± 14.2	233.5 ± 13.5	234.2 ± 13.9	0.20
Volume, mm^3				
Foveola	0.147 ± 0.016	0.150 ± 0.017	0.148 ± 0.017	0.02
Total macula	6.86 ± 0.33	6.90 ± 0.33	6.88 ± 0.33	0.14

Data are mean ± SD.
* Independent Sample *t*-test.

Table 3. Macular Thickness and Volume by Stratus OCT in 720 Healthy Eyes by Age

Parameters	6 (n = 96)	7 (n = 113)	8 (n = 108)	9 (n = 146)	10 (n = 174)	≥11 (n = 83)	P*
Thickness, μm							
Total macula	252.2 ± 9.9	250.8 ± 11.3	251.1 ± 11.9	250.4 ± 12.4	249.5 ± 10.5	250.3 ± 13.1	0.87
Foveal minimum	137.9 ± 11.3	138.4 ± 11.1	141.7 ± 12.4	140.5 ± 12.7	140.3 ± 12.8	141.2 ± 13.1	0.23
Foveola	175.8 ± 14.4	176.4 ± 14.0	180.6 ± 15.7	178.9 ± 16.0	178.8 ± 16.1	180.1 ± 16.6	0.21
Inner region							
Average	261.5 ± 10.3	261.2 ± 12.7	262.0 ± 12.5	262.0 ± 13.1	261.1 ± 11.9	261.9 ± 14.3	0.28
Temporal	257.8 ± 10.7	256.5 ± 12.7	257.6 ± 12.5	257.7 ± 12.6	256.9 ± 12.5	255.8 ± 17.7	0.77
Superior	268.2 ± 12.4	267.9 ± 13.3	268.0 ± 13.8	267.4 ± 15.0	267.4 ± 12.7	267.7 ± 15.0	0.55
Nasal	259.3 ± 11.9	260.2 ± 16.0	261.1 ± 14.7	260.7 ± 15.4	260.1 ± 14.2	261.0 ± 16.1	0.20
Inferior	260.8 ± 11.5	260.0 ± 14.1	261.3 ± 13.2	262.0 ± 14.3	260.2 ± 13.4	263.1 ± 14.3	0.11
Outer region							
Average	243.0 ± 11.6	240.5 ± 11.7	240.2 ± 12.8	238.9 ± 13.2	237.8 ± 11.3	238.7 ± 13.8	0.43
Temporal	226.7 ± 12.3	223.7 ± 12.4	223.6 ± 12.3	222.1 ± 12.4	222.1 ± 13.3	222.8 ± 14.1	0.70
Superior	244.2 ± 11.5	242.4 ± 12.1	242.0 ± 12.4	241.2 ± 14.2	240.2 ± 11.9	241.7 ± 14.7	0.88
Nasal	262.1 ± 12.1	260.5 ± 13.0	259.9 ± 14.8	258.8 ± 15.4	257.5 ± 12.4	257.7 ± 14.9	0.29
Inferior	238.8 ± 13.7	235.5 ± 12.8	235.5 ± 14.6	233.3 ± 14.4	231.5 ± 12.7	232.7 ± 14.9	0.13
Volume, mm^3							
Foveola	0.150 ± 0.015	0.150 ± 0.015	0.150 ± 0.018	0.150 ± 0.015	0.150 ± 0.018	0.150 ± 0.017	0.26
Total macula	6.95 ± 0.30	6.90 ± 0.32	6.90 ± 0.34	6.87 ± 0.35	6.84 ± 0.30	6.87 ± 0.37	0.77

Data are mean ± SD.
* Partial correlation analysis, adjusted for sex, refraction, IOP, and BMI.

mean foveal minimum in the present study was approximately 9.1 to 23.2 μm thinner and the mean foveal macular thickness was approximately 10 to 20 μm thinner, with the exception that the mean foveal macular thickness in our study was similar with that in the Handan study.[4] (Table 6). These discrepancies can be largely explained by race and age differences.

Topographically, the central macula was the thinnest, followed by the outer ring. The inner ring was the thickest. It is notable that there were quadrant-specific variations in both the inner and outer rings, regardless of sex and age. There were no large differences among inner ring quadrants, whereas the thickness in the nasal quadrant of the outer ring was much greater than that of the other three quadrants within the outer ring. This finding is consistent with documented patterns in most Stratus OCT studies[9–12] and in the latest Spectral OCT (Carl Zeiss Meditec, Inc.) studies.[25,26] Ooto et al.[25] speculated that greater asymmetry of the macular thickness of the outer ring compared with that of the inner ring may be due to the vertically symmetric, but horizontally asymmetric, anatomic nature of the RNFL. Superior and inferior arcuate bundles of nerve fibers are crowded within the inner nasal region and along the papillomacular bundle within the outer nasal region of the macular and optic disc.

Both clinic- and population-based studies have consistently documented differences between the sexes in macular thickness regardless of age, with men/boys having thicker retinas than woman/girls.[11,12,14,26,27] Our findings of sex-related differences in Chinese primary school children are consistent

Table 4. Macular Thickness and Volume by Stratus OCT in 720 Healthy Eyes by Refraction

	Hyperopia (n = 198)	Emmetropia (n = 251)	Low Myopia (n = 224)	Moderate to High Myopia (n = 47)	P*
Thickness, μm					
Total macula	253.3 ± 11.0	252.2 ± 10.8	247.3 ± 11.4	246.6 ± 12.4	<0.001
Foveal minimum	139.4 ± 11.5	139.4 ± 11.8	140.2 ± 13.0	145.0 ± 14.7	0.051
Foveola	177.6 ± 14.5	177.8 ± 14.8	178.8 ± 16.5	184.5 ± 18.1	0.050
Inner region					
Average	263.1 ± 11.9	263.2 ± 12.1	259.0 ± 12.7	259.2 ± 13.4	<0.001
Temporal	258.5 ± 11.7	258.7 ± 13.9	254.8 ± 12.5	253.4 ± 13.5	<0.001
Superior	270.2 ± 13.4	268.9 ± 13.5	265.1 ± 13.1	263.5 ± 15.3	<0.001
Nasal	262.0 ± 14.6	262.1 ± 13.3	257.5 ± 15.9	258.5 ± 14.7	<0.001
Inferior	261.6 ± 12.5	262.9 ± 13.5	258.7 ± 14.3	261.5 ± 12.8	0.012
Outer region					
Average	243.5 ± 12.1	241.2 ± 11.5	235.6 ± 11.9	234.1 ± 13.3	<0.001
Temporal	227.1 ± 12.1	224.8 ± 11.7	219.1 ± 12.2	219.0 ± 17.7	<0.001
Superior	245.0 ± 12.4	243.1 ± 12.2	238.2 ± 12.7	237.6 ± 14.1	<0.001
Nasal	262.6 ± 13.7	261.1 ± 13.3	255.4 ± 13.2	253.6 ± 14.5	<0.001
Inferior	239.3 ± 13.9	235.8 ± 12.4	229.7 ± 13.1	226.1 ± 15.8	<0.001
Volume, mm^3					
Foveola	0.150 ± 0.016	0.150 ± 0.016	0.150 ± 0.018	0.150 ± 0.018	0.012
Total macula	6.97 ± 0.32	6.92 ± 0.31	6.78 ± 0.32	6.74 ± 0.35	<0.001

Data are mean ± SD. Hyperopia, SE ≥ +0.5 D; emmetropia, −0.5 D < SE < +0.5 D; low myopia, −3.0 D < SE ≤ −0.5 D; moderate to high myopia: SE < −3.0 D.
* Partial correlation analysis, adjusted for age, sex, IOP, and BMI.

TABLE 5. Correlations between Macular Measurements and Age, SE, IOP, and BMI

	Age		SE		IOP		BMI	
	r*	***P****	***r***†	***P***†	***r***‡	***P***‡	***r***§	***P***§
Macular thickness, μm								
Total macula	0.006	0.87	0.25	<0.001	0.003	0.93	0.067	0.07
Foveal minimum	0.045	0.23	−0.07	0.051	−0.02	0.65	0.005	0.89
Foveola	0.047	0.21	−0.07	0.050	−0.02	0.66	0.001	0.98
Inner region								
Average	0.040	0.28	0.16	<0.001	0.006	0.88	0.052	0.12
Temporal	0.013	0.77	0.15	<0.001	0.027	0.47	0.043	0.25
Superior	0.022	0.55	0.18	<0.001	0.004	0.92	0.077	0.04
Nasal	0.048	0.20	0.15	<0.001	−0.02	0.59	0.061	0.10
Inferior	0.060	0.11	0.09	0.012	0.012	0.75	0.006	0.88
Outer region								
Average	−0.029	0.43	0.31	<0.001	0.001	0.99	0.074	0.048
Temporal	−0.014	0.70	0.28	<0.001	0.004	0.92	0.067	0.074
Superior	0.006	0.88	0.27	<0.001	−0.01	0.84	0.048	0.20
Nasal	−0.040	0.29	0.25	<0.001	0.004	0.92	0.078	0.038
Inferior	−0.057	0.13	0.33	<0.001	0.001	0.99	0.079	0.034
Volume, mm^3								
Foveola	0.042	0.26	−0.09	0.012	−0.01	0.73	−0.003	0.94
Total macula	−0.011	0.77	0.29	<0.001	0.003	0.93	0.071	0.056

Data are *P*-values and correlation coefficients of partial correlation analysis.
* Adjusted for sex, refraction, IOP and BMI.
† Adjusted for age, sex, IOP and BMI.
‡ Adjusted for age, sex, refraction, and BMI.
§ Adjusted for age, sex, refraction, and IOP.

with this observation. The difference in macular thickness was found mainly in the foveal minimum, central macula, inner ring, and temporal outer quadrant, but not in the overall outer ring, which also holds true for many other studies both in adults and children.[12,14,20,23,25] As the thickness of RNFL in the foveola and the inner ring are relatively thin compared with the outer ring, the anatomic configurations of the retinal layers beneath the RNFL, which constitute most of the macular thickness, may be responsible for the intersex difference. The probable reason for a lack of sex difference in the outer ring thickness may be attributable to the superior and inferior arcuate configuration of the RNFL.[25] However, in the recent, large, population-based Handan Eye Study, Duan et al.[4] found significant intersex differences in macular thickness, both in the inner and outer rings. Therefore, the layer responsible for the sex difference in retinal thickness is unclear and needs further investigation.

We found no correlation between age and macular thicknesses in all the quadrants of the ETDRS sectors and macular volume ($P = 0.11$–0.88). However, in a population-based study of Australia children, Huynh et al.[14] reported a significant positive correlation between age and macular thickness ($r = 0.09$, $P = 0.0006$). But the study population consisted of children that were within a 1-year age range (6 years old), and the rather small effect size ($r^2 = 0.0081$) cannot demonstrate the great effect of age on macular thickness. Furthermore, population-based Handan study, Duan et al.[4] reported that age correlated positively with mean foveal thickness, but negatively with inner and outer macular thicknesses. The inverse relationship with age may be due to the thickening of the internal limiting membrane (ILM) and the centripetal force of the posterior vitreous resulting in elevation of the fovea,[22] and the loss of ganglion cells and the thinning RNFL outside the central macula with aging.[28]

It is of interest that Ooto et al.[25] initially reported an intersex difference in the relationship between age and macular measurements, specifically that macular thickness had a negative correlation with age only in the men. It seemed that macular parameters in the women were more resistant to age-dependent decay than in the men. However, this was not the case in our study, as we found no significant correlation with age in either sex. This discrepancy may result from the different characteristics of the study sample. Ooto et al. included adult subjects, whereas the children enrolled in our study were in growth phase, and no evident age-dependent decay after adjustment for other effects on macular measurements was evident. Ideally, performing longitudinal studies is a better method for investigating the effect of age on macular thickness and volume.

In the present study, we found that macular thicknesses of all the quadrants of the ETDRS sectors except the foveola subfield were decreased with increasing negative SE refraction, and hyperopic eyes had the largest OCT measurements. The same trend held true for total macular volume. However, foveal minimum, foveal thickness, and foveal macular volume became greater with increasing myopic refraction. This interesting but somewhat paradoxical result is in accordance with findings from previous studies.[22,21,29,30] The exact mechanism remains unclear, yet some plausible speculations have been proposed. First, the stretch mechanism is popular. Wu et al.[22] speculated that the stretching and flattening tendency of the internal limiting membrane results in elevation of the foveola and fovea, which renders a thicker foveola subfield on OCT measurements. Thinner macula of the inner and outer rings may be due to the stretching of a similar volume of retina over a larger area and a decreased number of photoreceptors.[21] Second, the anatomic characteristics of the macula may also be important. The foveal area is absent of vasculature, which may leave foveal pits very deformable in response to retinal stretching. This has been further suggested by Springer and Hendrickson[31–33] through experiments of macular modeling in young primates that had experimentally induced myopia. Third, subfoveal blood–retinal barrier (BRB) permeability was found in form-deprived myopic tree shrews.[34] Therefore, the increase in foveal minimum and foveal macular thickness may be due to pathologic subfoveal chorioretinal changes. Last, chorioretinal

Table 6. Reported Macular Thickness and Volume by Stratus OCT in Healthy Eyes of Children and Chinese Adults

Studies	Race/ Ethnicity	Mean Age in Years (Range)	*n*/Eyes	Foveal Minimum	Foveola Thickness	Average Inner Ring	Average Outer Ring	Foveal Volume	Total Volume
Chopovska, et al.[18]	White	12 ± 4.1 (6–17)	20/20	163.1 ± 19.6	199.6 ± 15.6	NS	NS	NS	NS
Huynh, et al.[14]	East Asian	6.7 ± 0.4 (6–7)	245/245	154.9	186.7	262.3	237.0	0.147	6.83
	White	6.7 ± 0.4 (6–7)	1009/1009	163.0	196.0	265.2	237.5	0.154	6.87
Eriksson, et al.[9]	White	NS (5–16)	55/55	166 ± 15	204 ± 19	279 ± 13	245 ± 12	NS	7.11 ± .35
El-Dairi, et al.[10]	Black	8.6 ± 3.1 (3–17)	114/154	NS	176	NS	NS	NS	6.87 ± 0.3
	White	8.5 ± 3.1 (3–17)	154/109	NS	198	NS	NS	NS	6.96 ± 0.4
Huynh, et al.[20]	Mixed*	NS (11–14)	2068/2068	161.6 ± 19.9	197.4 ± 18.7	271.9 ± 15.0	239.5 ± 13.5	NS	NS
Ecsedy[19]	White	9.36 ± 1.4 (7–12)	10/20	164.7 ± 16.7	199.6 ± 14.5	273.1 ± 13.5	249.9 ± 9.8	NS	7.1 ± 0.3
Luo, et al.[21]	Chinese	11.5 ± 0.5 (11–12)	104/104	157.0 ± 19.2	NS	NS	NS	0.15 ± 0.01	6.65 ± 0.39
Wu, et al.[22]	Chinese	29.6 ± 6.3 (18–40)	40/40	149.1 ± 15.2	187.6 ± 17.8	NS	NS	NS	7.10 ± 0.34
Lam, et al.[23]	Chinese	48.4 ± 14.7 (42–54)	26/26	163.2 ± 18.8	198.0 ± 17.43	278.9 ± 17.4	254.5 ± 16.5	NS	NS
Xie, et al.[24]	Chinese	23.3 ± 6.3 (NS)	6/12	149.2 ± 17.0	188.8 ± 15.5	279.5 ± 15.8	247.2 ± 17.0	NS	NS
Duan, et al.[4]	Chinese	46.4 ± 9.9 (30–83)	2230/2230	150.3 ± 18.1	176.4 ± 17.5	255.3 ± 14.9	237.7 ± 12.4	0.139 ± 0.014	6.76 ± 0.52
Present	Chinese	8.63 ± 1.64 (6–13)	720/720	140.0 ± 12.3	178.5 ± 15.6	261.6 ± 12.4	239.6 ± 12.4	0.148 ± 0.017	6.88 ± 0.328

Data are mean ± SD. NS, not specified.

* 60.5% Caucasian, 14.3% East Asian, 7.1% Middle Eastern, 18% other.

atrophy may partly account for the increased retinal thinning with myopia. However, this situation occurred in high myopia. Considering that only a small number of children had severe myopia in our study, we conclude that this was negligible.

No significant correlation between macular parameters and IOP were found in the present study ($P = 0.47$–0.99), which is consistent with previous studies.[12,27] The result demonstrated that, the effect of IOP on macular thickness and volume was small and within the normal range (no more than 21 mm Hg). We speculate that another important reason for this was that macular thickness was affected only in later stages of glaucoma and was less sensitive at earlier stages of glaucoma.[2] Consequently, macular thickness was relatively normal, even at earlier stages of glaucoma, not to mention in healthy populations.

To the best of our knowledge, only Wong et al.[27] evaluated the correlation between macular thickness and BMI. They documented that larger BMI was associated with significantly thicker foveal thickness ($r = 0.22$, $P < 0.05$). However, no similar trend was found in our study after adjusting for age, sex, SE refraction, and IOP. We found that BMI correlated positively with macular thickness in the superior inner, nasal outer, and inferior outer sectors. The disparity may be attributable to the sample differences in age, BMI, sample size, and statistical methods. Wong et al. included 117 subjects with a mean age of 40.6 ± 16.4 years and a mean BMI of 22.7 ± 3.15 kg/m^2. They performed Pearson correlation tests between BMI and macular measurements without adjustment for age, sex, and refractive state. All three of these facts may affect the macular parameters. Consequently, a real correlation may be concealed by these facts. However, 720 healthy young children with a mean age of 8.63 ± 1.64 years and a mean BMI of 17.37 ± 2.90 kg/m^2 were enrolled in our study. Importantly, we performed Pearson partial correlation, which can uncover true relationships between two variables.

The main strength of this study is its relatively large sample size, similar sex distribution, and uniformity of measurements procedures. A potential limitation of the present study was that ocular axial length was not included in the measurements. As measurements in the axial direction do not depend on the refraction or axial length of the eye,[35] the errors of macular parameters induced by ocular axial length in the present study should be minimal. Nonparticipation bias is another limitation. However, there were no significant differences in age, distribution of the sexes, and BMI between participants and nonparticipants. Macular measurements obtained from the present study can be used as a normal reference.

In conclusion, we found that macular measurements were normally distributed with quadrant-specific variations in this sample of Chinese children. The mean foveal minimum thickness in the present study was smaller compared with published data from studies of white children and Chinese adults: 14.9 to 26 μm and 9.1 to 23.2 μm thinner, respectively. The boys had greater macular thickness in all quadrants of the inner ring and foveal volume than did the girls, with similar values in the other regions. Macular thickness in the inner and outer rings and total macular volume decreased, with more negative SE refraction. Age, IOP, and BMI had little effect on macular thickness and volume in the present study population. These data may be valuable when interpreting macular parameters for diagnosis and monitoring of disease severity or progression in Chinese children and may be of help when evaluating differences in macular measurements between the different races.

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