Original Article

An analysis of macular ganglion cell complex in 7-year-old children in China: the Anyang Childhood Eye Study

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Background: This study used spectral-domain optical coherence tomography (SD-OCT) imaging to describe the distribution of macular ganglion cell complex (GCC) thickness and its association with ocular and systemic parameters in 7-year-old children in China.

Methods: The study involved a school-based, cross-sectional analysis of the Anyang Childhood Eye Study (ACES) and included 2,505 first-grade students from urban areas in Anyang, Henan Province, Central China. All participants underwent systemic and ocular examinations. Both GCC and retinal nerve fiber layer (RNFL) thickness were measured using the iVue-100 OCT (Optovue, Fremont, CA, USA). Intraocular pressure (IOP) was recorded with noncontact tonometer (Huvitz, HNT-7000). Axial length (AL) was measured using optical biometry (Lenstar LS 900, Haag-Streit Diagnostics, Koniz, Switzerland).

Results: The mean GCC thickness was 95.31±7.67 μm. GCC thickness had negative associations with AL (r=–0.124, P<0.001), cup-to-disc (C-D) area ratio (r=–0.068, P=0.0033), horizontal C-D (H C-D) ratio (r=–0.048, P=0.0384), and vertical C-D (V C-D) ratio (r=–0.074, P=0.0013). Positive correlations were found with spherical equivalent (SE) (r=0.080, P=0.0001), RNFL thickness (r=0.363, P<0.001), height (r=0.059, P=0.0036), fovea parameters, disc area (r=0.078, P=0.0007), rim area (r=0.115, P<0.001), rim volume (r=0.119, P<0.001), and optic nerve head volume (r=0.097, P<0.001). GCC thickness had no significant association with IOP, age, sex, or weight, waist, or head circumference.

Conclusions: This study provides normative GCC data for 7-year-old healthy children in China. The findings support an association between GCC and AL, SE, RNFL, height, and C-D ratio in children.

Keywords: Macular ganglion cell complex (macular GCC); retinal nerve fiber layer (RNFL); intraocular pressure (IOP); axial length (AL)

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Introduction

Glaucoma, an irreversible condition of the eye that can lead to blindness, is characterized by loss of retinal ganglion cells (RGCs), structural changes of the optic nerve head and retinal nerve fiber layer (RNFL), and visual field defects (1,2). The macular ganglion cell complex (GCC), comprising RNFL, ganglion cell layer (GCL), and inner plexiform layer (IPL), can improve the detection of glaucoma (3-5). GCC is superior to RNFL thickness evaluation for early investigation of damage caused by glaucoma, particularly in the diagnosis of very early glaucoma (6).

The gold standard clinical test for glaucoma diagnosis is standard automated perimetry (7), which shows visual field defects when 25% to 40% of RGCs are lost (8). However, this typically reliable and reproducible visual field test is often unsuccessful or difficult to interpret in children because it requires patient cooperation (9).

Optical coherence tomography (OCT) is a noninvasive structural diagnostic device that provides objective measurements and can reveal structural changes in the retina with high-resolution, cross-sectional images. Previous studies have shown that spectral-domain OCT (SD-OCT) can reproducibly measure RNFL thickness in children (10,11). However, the OCT normative databases only include data on adults over 18 and are limited by low representation of Asian subjects (12,13) and lack of child subjects (14). This limits the usefulness of OCT for children as it is inappropriate to compare their results with the adult database (8,9).

In this study, we used SD-OCT imaging to describe macular GCC thickness and its association with systematic and ocular parameters in a cohort of 7-year-old children in China. We present the following article in accordance with the STROBE reporting checklist (available at https://dx.doi.org/10.21037/tp-21-323).

Methods

Study design and population

A cross-sectional study was conducted involving 2,505 students from urban areas in Anyang, Henan Province, Central China. The study has been recognized elsewhere for its detailed methodology (15). The Anyang Childhood Eye Study (ACES) was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of Beijing Tongren Hospital, Capital Medical University, Beijing, China (No. TRECKY2018-030). Each student provided verbal consent and informed written consent was obtained from at least one parent.

Standardized examinations

The height and weight of the participants were measured using professional, automated, and integrated equipment (UAL6X, UOSIM Co., Ltd., Dalian, China).

All subjects underwent examination of visual acuity using LogMAR chart (Precision Vision, Woodstock, IL, USA) to assess distant vision and HOTV eye chart (Precision Vision) for near vision.

Optical biometry measurements were recorded and then cycloplegic autorefraction was performed 30 minutes after 2 drops of 1% cyclopentolate (Alcaine; Alcon, Fort Worth, TX, USA) and 1 drop of 0.5% tropicamide (Mydrin-P; Santen Pharmaceutical Co., Ltd., Osaka, Japan). Refraction was defined as spherical equivalent (SE, sphere power + cylinder power/2) in diopters (D). Myopia was defined as SE <–0.5 D, hyperopia as SE >+0.5 D and emmetropia as –0.5 D ≤ SE ≤ +0.5 D.

Intraocular pressure (IOP) in both eyes was measured 3 times by the same observer using a noncontact tonometer (Huvitz, HNT-7000). The mean value was calculated and taken as the final value for analysis.

Axial length (AL) was measured using optical biometry (Lenstar LS 900, Haag-Streit Diagnostics, Koniz, Switzerland) and the mean of five repeated measurements was recorded.

The iVue-100 SD-OCT (Optovue, Fremont, CA, USA) was used to measure the right eye of each subject. Images of ocular microstructures were obtained using a scanning laser diode emitting an 840 nm wavelength beam at a speed of 26,000 A-scans per second (16,17). The total scan time was 0.37 seconds per eye.

The protocol for the optic nerve head SD-OCT (iVue-100, Optovue) consisted of 12 radial scans (3.4 mm in length, 459 A-scans each) and 13 concentric ring scans (ranging from 1.3 to 4.9 mm, 429–969 A-scans each) centered on the optic disc (16,17). The areas between the A-scans were interpolated and various parameters were generated to describe the RNFL along a fixed 3.45-mm diameter ring centered on the optic disc. The RNFL values included: (I) average RNFL thickness; (II) temporal, superior, nasal, and inferior average RNFL thickness; (III) 16 sections (22.5° each) of the measurement circle around

the optic nerve head (*Figure 1*); (IV) optic disc parameters including disc, cup, and rim area, cup/disc ratio, rim volume, nerve head volume, and cup volume.

The GCC scan measured from the internal limiting membrane to the posterior boundary of the IPL and included: (I) average GCC—the average GCC thickness of the total measured area (*Figure 2*); (II) superior GCC—the average GCC thickness above the horizontal meridian; (III) inferior GCC—the average GCC thickness below the horizontal meridian; (IV) superior-inferior GCC (S-I GCC)—superior and inferior hemispheric difference of GCC thickness; (V) focal loss volume (FLV)—the average amount of focal loss over the whole GCC field; (VI) global loss volume (GLV)—the average amount of GCC loss over the whole GCC field.

Image quality and integrity assessed with a signal strength index (SSI) higher than 45 (as recommended by the manufacturer) were labeled as good.

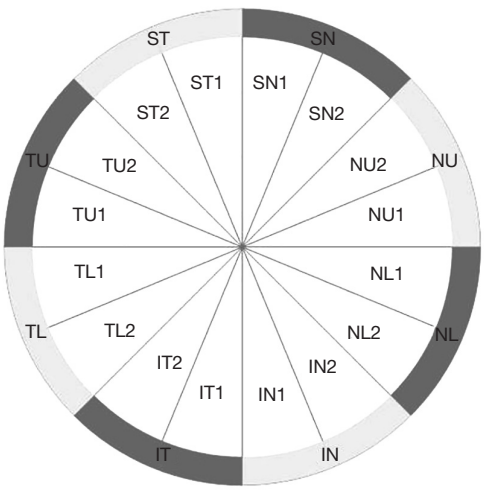

Figure 1 Sixteen sections of the measurement circle around the optic nerve head. S, superior; N, nasal; U, upper; L, lower; I, inferior; T, temporal.

Statistical analysis

Statistical analysis was performed with Statistical Analysis System software (SAS 9.2; SAS Institute Inc., Cary, NC, USA). Only the data collected on the subjects' right eyes were used for analysis. Continuous variables were compared using *t*-test and categorical variables were compared using Chi-squared test. Pearson's correlation was used to evaluate the association of GCC with RNFL, AL, and SE. Statistical significance was considered as $P<0.05$.

Results

Demographics

In total, 2,954 students underwent eye examinations, with 370 subjects excluded due to an SSI score below 45 and 79 subjects excluded because of a clinical diagnosis of amblyopia. A total of 2,505 subjects were enrolled in the study, including 1,452 boys (58.0%) and 1,053 girls (42.0%). The mean age was 7.10±0.41 (boys 7.12±0.41 *vs.* girls 7.07±0.40, P=0.0025). The data included age, IOP, height, weight, waist, head circumference, AL, and SE. The characteristics of the participants are summarized in *Table 1*.

Distribution of GCC

The mean GCC thickness was 95.31±7.67 μm (*Figure 3*). The superior GCC thickness (95.36±8.07 μm) was thicker than inferior GCC thickness (95.27±7.96 μm), although the difference was less than 1μm. The S-I GCC thickness was 0.10±4.59 μm, the GLV was 2.03%±2.41%, and the FLV was 1.24%±1.47%. The macular GCC parameters are presented in *Table 2*.

The average GCC thickness was 95.46±8.25 μm in boys and 95.11±6.80 μm in girls (P=0.2738). The parameters

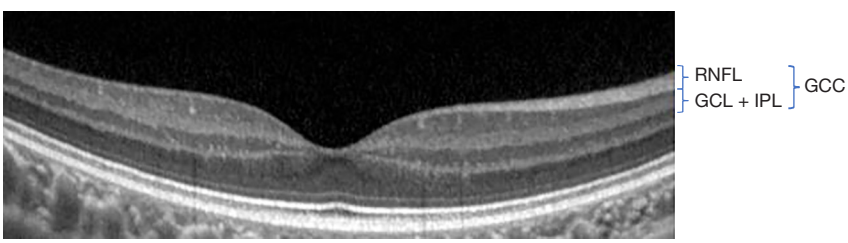

Figure 2 Thickness measurement map of the macula. GCC is the sum of RNFL, GCL, and IPL. GCC, ganglion cell complex; RNFL, retinal nerve fiber layer; GCL, ganglion cell layer; IPL, inner plexiform layer.

Table 1 Systemic and ocular characteristics of the study participants

Characteristics	Mean	Boys	Girls	t	P
Age (y)	7.10±0.41	7.12±0.41	7.07±0.40	3.03	0.0025
IOP (mmHg)	13.53±3.04	13.31±2.94	13.83±3.15	−4.11	<0.001
Height (cm)	123.45±5.51	124.11±5.55	122.52±5.34	7.11	<0.001
Weight (kg)	24.56±4.83	25.09±4.84	23.82±4.73	6.47	<0.001
Waist (cm)	55.63±5.94	56.28±5.98	54.73±5.78	6.39	<0.001
Head circumference (cm)	51.51±1.98	51.79±1.83	51.12±2.12	8.31	<0.001
AL (mm)	22.71±0.73	22.94±0.68	22.38±0.67	20.1	<0.001
SE (D)	0.88±0.90	0.84±0.88	0.93±0.92	−2.32	0.0206
LogMAR	0.00±0.01	0.00±0.01	0.00±0.02	−0.78	0.4335

IOP, intraocular pressure; AL, axial length; SE, spherical equivalent; D, diopters.

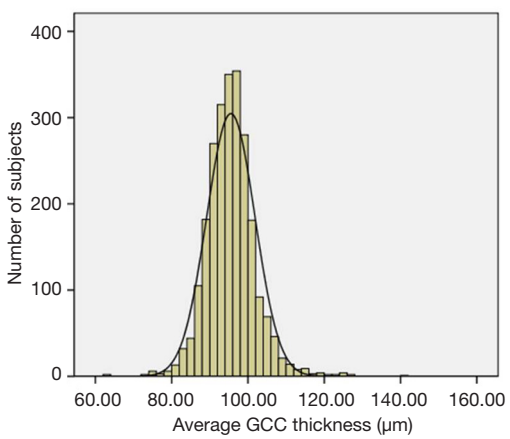

Figure 3 Normal distribution of average GCC thickness in children in China. GCC, ganglion cell complex; mGCC, macular GCC.

Table 2 Distribution of GCC parameters in eyes of 7-year-old children

GCC parameters	Mean ± SD	95% confidence interval	
		Lower bound	Upper bound
Average GCC (μm)	95.31±7.67	95.01	95.62
Superior GCC (μm)	95.36±8.07	95.04	95.69
Inferior GCC (μm)	95.27±7.96	94.95	95.59
S-I GCC (μm)	0.10±4.59	−0.09	0.28
GLV (%)	2.03±2.41	1.94	2.13
FLV (%)	1.24±1.47	1.18	1.30

GCC, ganglion cell complex; S-I, superior-inferior; GLV, global loss volume; FLV, focal loss volume.

FLV, IT, TU2, ST1, SN1, IT1, IT2, and TL1 showed significant difference between boys and girls (*Table 3*).

GCC thickness in the myopia, emmetropia, and hyperopia groups are shown in *Table 4*. Compared with myopic children, children with hyperopia had significantly thicker average GCC (95.69±7.45 *vs.* 93.33±9.83 μm), superior GCC (95.76±7.86 *vs.* 93.38±9.84 μm), and inferior GCC (95.61±7.67 *vs.* 93.35±10.35 μm). A difference in GLV was found between the hyperopia and emmetropia groups (1.95% *vs.* 2.31%, P=0.0075). There was no significant effect of refraction error on S-I GCC (P=0.5618), or FLV (P=0.5945).

Associations of GCC with ocular and systemic parameters

The relationships between GCC thickness and ocular and systemic parameters are shown in *Table 5*. Height, SE, RNFL parameters, fovea parameters, disc area, rim area, rim volume, and nerve head volume were found to have significant positive association with average GCC thickness, superior GCC thickness, and inferior GCC thickness. AL, area cup-to-disc (C-D) ratio, horizontal C-D (H C-D) ratio, and vertical C-D (V C-D) ratio were negatively correlated with average GCC thickness, superior GCC thickness, and inferior GCC thickness. Superior GCC thickness was associated with weight (P=0.0464). GCC thickness was not significantly associated with age, IOP, waist, head circumference, best corrected visual acuity (BCVA), cup area, or cup volume. *Figure 4A*,*4B* shows the positive relationships between RNFL thickness, SE, and average GCC thickness. *Figure 4C* shows the negative relationship between average GCC thickness and AL.

Table 3 Differences in GCC and RNFL parameters between boys and girls

Variables	Mean ± SD	Boys (n=1,452)	Girls (n=1,053)	t	P
Average GCC (μm)	95.31±7.67	95.46±8.25	95.11±6.80	1.09	0.2738
Superior GCC (μm)	95.36±8.07	95.47±8.59	95.22±7.31	0.74	0.4569
Inferior GCC (μm)	95.27±7.96	95.43±8.59	95.05±7.01	1.13	0.2569
S-I GCC (μm)	0.10±4.59	0.04±4.87	0.17±4.18	–0.66	0.5103
GLV (%)	2.03±2.41	1.98±2.43	2.11±2.39	–1.35	0.1762
FLV (%)	1.24±1.47	1.16±1.42	1.36±1.54	–3.40	0.0007
Average RNFL	102.04±8.26	102.07±8.57	102.00±7.85	0.20	0.8442
Superior half	104.34±9.41	104.59±9.66	104.02±9.06	1.31	0.1903
Inferior half	99.74±9.33	99.55±9.70	99.97±8.82	–0.97	0.3321
Temporal quadrant	301.97±153.03	302.48±156.47	301.27±148.26	0.19	0.8470
Superior quadrant	300.79±152.86	301.21±156.34	300.20±148.01	0.16	0.8713
Nasal quadrant	289.41±153.35	290.16±156.92	288.39±148.39	0.28	0.7789
TU	86.08±12.30	85.80±13.01	86.44±11.33	–1.12	0.2649
ST	140.33±17.48	140.85±17.75	139.67±17.11	1.45	0.1463
SN	109.73±15.80	110.20±16.28	109.14±15.15	1.45	0.1478
NU	81.20±14.80	81.49±15.09	80.83±14.41	0.97	0.3329
NL	70.93±15.02	71.21±15.59	70.58±14.25	0.90	0.3688
IN	113.35±18.39	113.02±18.60	113.78±18.13	–0.89	0.3722
IT	140.22±18.52	139.24±19.01	141.48±17.82	–2.61	0.0092
TL	74.43±11.17	74.73±11.90	74.05±10.15	1.32	0.1883
TU1	70.97±10.37	71.12±11.18	70.78±9.22	0.70	0.4852
TU2	101.18±16.05	100.47±16.65	102.08±15.21	–2.16	0.0308
ST1	141.77±21.12	143.36±21.31	139.73±20.70	3.71	0.0002
ST2	138.89±21.35	138.34±21.99	139.61±20.50	–1.28	0.2006
SN1	113.10±19.18	113.95±19.59	112.01±18.59	2.18	0.0297
SN2	106.37±15.46	106.45±16.00	106.26±14.74	0.26	0.7936
NU1	71.89±16.00	72.34±16.51	71.31±15.30	1.38	0.1665
NU2	90.51±15.52	90.64±15.89	90.34±15.04	0.42	0.6740
NL1	64.78±15.77	65.13±16.55	64.32±14.70	1.11	0.2662
NL2	77.09±16.30	77.28±17.03	76.84±15.32	0.58	0.5619
IN1	124.09±22.66	123.48±22.90	124.86±22.35	–1.31	0.1918
IN2	102.62±17.07	102.55±17.65	102.70±16.30	–0.19	0.8489
IT1	146.61±21.88	145.65±22.63	147.85±20.83	–2.17	0.0305
IT2	133.82±21.28	132.83±21.33	135.11±21.16	–2.31	0.0210
TL1	62.65±9.72	63.09±10.75	62.08±8.17	2.24	0.0253
TL2	86.21±14.77	86.36±15.12	86.01±14.30	0.52	0.6053

GCC, ganglion cell complex; RNFL, retinal nerve fiber layer; S-I, superior-inferior; GLV, global loss volume; FLV, focal loss volume; S, superior; N, nasal; U, upper; L, lower; I, inferior; T, temporal.

Table 4 GCC parameters in myopia, emmetropia and hyperopia groups

GCC parameters	Myopia (n=149)	Emmetropia (n=500)	Hyperopia (n=1,856)	F	P
Average GCC (μm)	93.33±9.83	94.38±7.61	95.69±7.45*	10.47	<0.0001
Superior GCC (μm)	93.38±9.84	94.36±8.13	95.76±7.86*	10.12	<0.0001
Inferior GCC (μm)	93.35±10.35	94.47±8.11	95.61±7.67*	8.25	0.0003
S-I GCC (μm)	0.04±4.36	−0.11±5.06	0.15±4.49	0.58	0.5618
GLV (%)	2.28±2.46	2.31±3.00	1.95±2.24†	4.9	0.0075
FLV (%)	1.14±1.07	1.29±1.75	1.24±1.43	0.52	0.5945

*, there were statistically significant differences between myopia and hyperopia; †, there were statistically significant differences between emmetropia and hyperopia. GCC, ganglion cell complex; S-I, superior-inferior; GLV, global loss volume; FLV, focal loss volume.

Table 5 Relationship between GCC thickness and ocular and systemic parameters

Variables	Average GCC thickness		Superior GCC thickness		Inferior GCC thickness	
	r	P	r	P	r	P
Age	0.010	0.6384	0.019	0.3464	0.003	0.8932
IOP	−0.003	0.8710	0.003	0.8962	−0.005	0.8176
Height	0.059	0.0036	0.067	0.0010	0.044	0.0309
Weight	0.032	0.1119	0.041	0.0464	0.024	0.2440
Waist	0.007	0.7397	0.011	0.5849	0.003	0.8817
Head circumference	0.036	0.0802	0.036	0.0799	0.035	0.0892
AL	−0.124	<0.001	−0.126	<0.001	−0.113	<0.001
SE	0.080	0.0001	0.082	0.0001	0.064	0.0017
BCVA	0.025	0.2834	0.016	0.4868	0.039	0.0969
RNFL parameters						
Average RNFL	0.363	<0.001	0.356	<0.001	0.329	<0.001
Superior RNFL	0.338	<0.001	0.347	<0.001	0.291	<0.001
Inferior RNFL	0.302	<0.001	0.280	<0.001	0.290	<0.001
Temporal	0.084	<0.001	0.072	0.0004	0.108	<0.001
Superior	0.079	0.0001	0.067	0.0010	0.106	<0.001
Nasal	0.060	0.0030	0.047	0.0200	0.090	<0.001
Inferior	0.085	<0.001	0.074	0.0003	0.110	<0.001
16 sections						
TU	0.205	<0.001	0.232	<0.001	0.149	<0.001
ST	0.284	<0.001	0.279	<0.001	0.259	<0.001
SN	0.193	<0.001	0.185	<0.001	0.181	<0.001
NU	0.148	<0.001	0.162	<0.001	0.116	<0.001
NL	0.144	<0.001	0.149	<0.001	0.125	<0.001
IN	0.182	<0.001	0.178	<0.001	0.164	<0.001
IT	0.186	<0.001	0.162	<0.001	0.188	<0.001

Table 5 (*continued*)

Table 5 (*continued*)

Variables	Average GCC thickness		Superior GCC thickness		Inferior GCC thickness	
	r	P	r	P	r	P
TL	0.210	<0.001	0.176	<0.001	0.225	<0.001
TU1	0.194	<0.001	0.215	<0.001	0.144	<0.001
TU2	0.189	<0.001	0.218	<0.001	0.135	<0.001
ST2	0.225	<0.001	0.239	<0.001	0.185	<0.001
ST1	0.242	<0.001	0.219	<0.001	0.242	<0.001
SN1	0.174	<0.001	0.156	<0.001	0.177	<0.001
SN2	0.178	<0.001	0.186	<0.001	0.152	<0.001
NU2	0.131	<0.001	0.149	<0.001	0.099	<0.001
NU1	0.146	<0.001	0.155	<0.001	0.119	<0.001
NL1	0.118	<0.001	0.125	<0.001	0.097	<0.001
NL2	0.151	<0.001	0.154	<0.001	0.136	<0.001
IN2	0.192	<0.001	0.188	<0.001	0.178	<0.001
IN1	0.150	<0.001	0.148	<0.001	0.132	<0.001
IT1	0.157	<0.001	0.148	<0.001	0.143	<0.001
IT2	0.164	<0.001	0.130	<0.001	0.180	<0.001
TL2	0.178	<0.001	0.136	<0.001	0.205	<0.001
TL1	0.212	<0.001	0.199	<0.001	0.203	<0.001
Fovea parameters						
Full retina fovea thickness	0.058	0.0043	0.043	0.0349	0.088	<0.001
Parafovea	0.081	0.0001	0.069	0.0006	0.107	<0.001
Temporal	0.082	0.0001	0.070	0.0005	0.110	<0.001
Superior	0.088	<0.001	0.074	0.0003	0.114	<0.001
Nasal	0.089	<0.001	0.079	0.0001	0.109	<0.001
Inferior	0.087	<0.001	0.070	0.0006	0.119	<0.001
Perifovea	0.097	<0.001	0.086	<0.001	0.116	<0.001
Optic disc parameters						
Disc area (mm^2)	0.078	0.0007	0.082	0.0004	0.063	0.0065
Cup area (mm^2)	–0.039	0.0914	–0.029	0.2072	–0.042	0.0706
Rim area (mm^2)	0.115	<0.001	0.111	<0.001	0.102	<0.001
Rim volume (mm^3)	0.119	<0.001	0.105	<0.001	0.116	<0.001
Nerve head volume (mm^3)	0.097	<0.001	0.089	0.0001	0.092	0.0001
Cup volume (mm^3)	–0.025	0.2701	–0.020	0.3976	–0.027	0.2497
Area C-D ratio	–0.068	0.0033	–0.057	0.0140	–0.068	0.0030
H C-D ratio	–0.048	0.0384	–0.041	0.0726	–0.046	0.0446
V C-D ratio	–0.074	0.0013	–0.061	0.0087	–0.076	0.0009

GCC, ganglion cell complex; IOP, intraocular pressure; AL, axial length; SE, spherical equivalent; BCVA, best corrected visual acuity; RNFL, retinal nerve fiber layer; S, superior; N, nasal; U, upper; L, lower; I, inferior; T, temporal; C-D, cup-to-disc; H C-D, horizontal C-D; V C-D, vertical C-D.

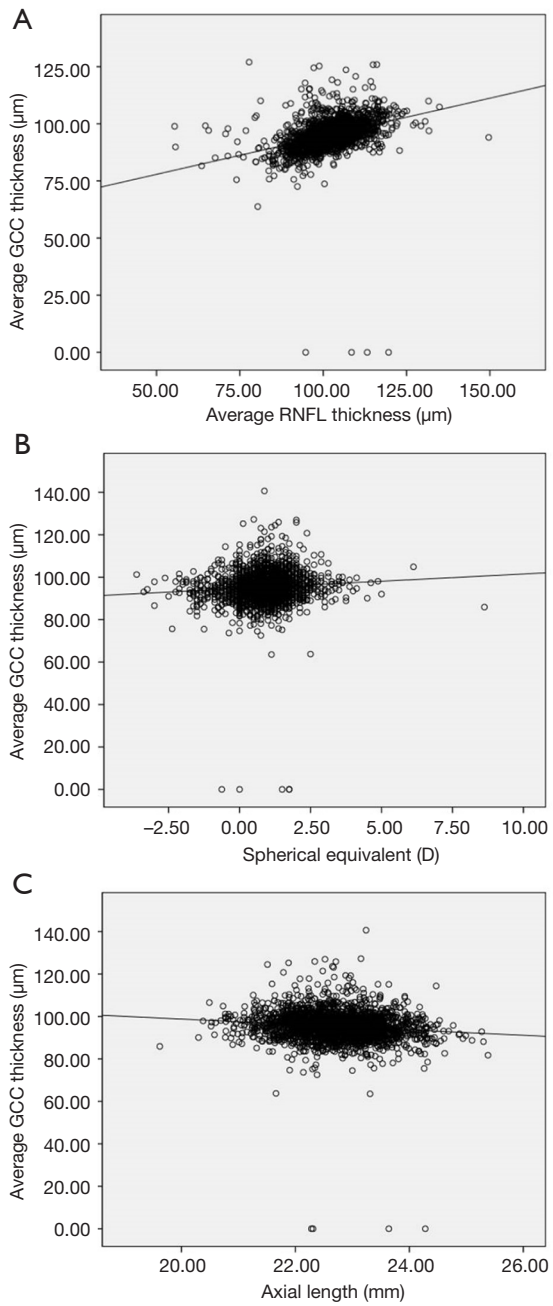

Figure 4 Scatterplot showing the relationship between average GCC thickness and (A) average RNFL thickness (r=0.363, P<0.001); (B) SE (r=0.080, P=0.0001); (C) AL (r=−0.124, P<0.001). GCC, ganglion cell complex; RNFL, retinal nerve fiber layer; SE, spherical equivalent; AL, axial length.

Discussion

Normal values of GCC thickness and the relationship with age, IOP, height, AL, SE, RNFL thickness, fovea, and optic disc were assessed in a large cohort of 7-year-old children in China. We found that the mean average GCC thickness was largely normally distributed, the superior GCC was thicker than the inferior GCC, and that GCC thickness was associated with AL, SE, RNFL thickness, height, fovea parameters, disc area, rim area, rim volume, nerve head volume, area C-D ratio, H C-D ratio, and V C-D ratio.

Consistent with the findings of previous studies (18,19), our study showed GCC thickness had a positive correlation with SE and negative correlation with AL. We also found that hyperopic children had thicker GCC than myopic children (P<0.0001), including superior GCC and inferior GCC (*Table 4*). GLV was lower in the hyperopia group compared to the emmetropia group (*Table 4*). However, in several studies, AL and SE (4) were found to have no correlation with GCC thickness. This might be due to the different age of participants (adults versus children), which may indicate that the results are impacted by age. Previous histopathologic studies have shown that increasing AL and eyeball expansion lead to the development of myopia (20). The elongation of the eyeball might result in mechanical stretching and traction, which may make the retina and sclera thinner in myopic eyes (21,22). The mechanical stretching is located mostly at the posterior pole and influences GCC and peripapillary RNFL (18). In addition, we found that S-I GCC and FLV had no correlation with SE. S-I GCC might be used as a parameter to track glaucoma in children; however, more data is needed to support the diagnostic performance of S-I GCC.

Our study demonstrated that GCC thickness had positive correlations with RNFL thickness, fovea parameters, disc area, and rim area and negative correlations with area C-D ratio, H C-D ratio, and V C-D ratio. RNFL parameters and optic disc parameters are useful for detecting glaucoma. However, optic disc tilting, peripapillary atrophy, and oval configuration in highly myopic eyes (23) may influence disc margin determination (24). The disc margin definition can affect RNFL and optic disc parameters, which are less reliable than GCC in the analysis of highly myopic eyes (25).

GCC can be a marker for a decrease in RGCs, which can happen before visual field defects are apparent (26). Therefore, GCC may be superior to RNFL and optic disc parameters in the early detection of glaucoma progression (27).

We found that taller height was associated with thicker GCC. In a study of 42,044 participants, height was not associated significantly with GCC (P>0.30), which was measured using 3D OCT-1000 Mark II (Topcon Inc., Tokyo, Japan) (19). In a study of 258 children using the iScan OCT (Optovue), Grundy *et al.* found no evidence of a relationship between height or weight with either RNFL or GCC (28). These contradictory findings may be explained by differences in the ethnicity of subjects, sample size, and measurement equipment.

We observed no significant relationship between GCC thickness and IOP, which is consistent with previous studies (20,29). However, Khawaja *et al.* found a negative relationship between GCC thickness and IOP ($P=5.8\times10^{-5}$) (19). IOP above threshold will damage ganglion cells at the lamina cribrosa (30). Furthermore, it is possible that translamina cribrosa pressure difference (TLCPD, IOP minus cerebrospinal fluid pressure), and not IOP, is associated with the pathogenesis of glaucomatous optic neuropathy (31).

Age had no any significant association with GCC thickness, which is consistent with some previous studies (18,32). However, several studies have demonstrated a thinner retinal thickness with older age in adults (19,30), although this inconsistency may be due to our participants being young children. It would be useful to do a longitudinal study of GCC thickness and age in the future.

In our study, no significant differences were observed between girls and boys in average GCC thickness, superior GCC thickness, inferior GCC thickness, S-I GCC, or GLV. Similarly, Bloch *et al.* did not find sex differences in GCC thickness (30). However, women were found to have thicker macular inner retinas in the UK biobank (19) study and thinner superotemporal GC-IPL thickness in the Singapore Chinese Eye Study (SCES) (33). Although these studies found a significant association between inner retinal thickness and sex, their findings are based on a smaller sample size. Additionally, the correlation between GCC thickness and sex may vary among different ethnic groups. We found that BCVA, waist, head circumference, cup area, and cup volume were not correlated with GCC thickness, similar to the results of another report (28).

Our sample size of healthy Chinese children was large and the study was a school-based design, not population-based design. The schools were chosen to broadly represent the region. However, our study has several limitations that should be kept in mind. Our study only included children in the first grade and it would be beneficial to include child participants across a wide age span. By limitation of the ACES methodology, a noncontact tonometer was used to measure IOP rather than the Goldmann tonometer.

Conclusions

In conclusion, our study provides normative GCC thickness data, distribution patterns, and correlated ocular and systemic parameters in a large cohort of healthy 7-year-old children in China. The findings support an association between GCC thickness and AL, SE, height, RNFL, fovea parameters, disc area, rim area, rim volume, nerve head volume, area C-D ratio, H C-D ratio, and V C-D ratio in children. We did not find an association between GCC thickness and IOP, age, or sex. Future studies are planned to follow the cohort for further investigation of these associations.

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Footnote

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interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The Anyang Childhood Eye Study (ACES) was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and was approved by the Ethics Committee of Beijing Tongren Hospital, Capital Medical University, Beijing, China (No. TRECKY2018-030). Each student provided verbal consent and informed written consent was obtained from at least one parent.

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