Retinal Nerve Fiber Layer Thickness in Normal Chinese Students Aged 6 to 17 Years

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Purpose. We obtained retinal nerve fiber layer (RNFL) thickness measurements in normal Chinese students aged 6 to 17 years, and investigated the relationship between RNFL thickness and sex, eye laterality, age, axial length, and refractive error.

Methods. A total of 4648 eyes in 2324 normal, randomly-selected Chinese students aged 6 to 17 years was examined in this study. The RNFL thickness was measured by optical coherence tomography. The effects of sex, eye laterality (left or right), age, refractive error, and axial length on RNFL thickness were assessed.

Results. The average age of the subjects was 12.82 ± 3.11 years. The global average RNFL thickness (±SD) was 106.89 ± 12.84 μm. The thickest RNFL measurements were found at the superior (133.22 ± 19.48 μm) and inferior (129.23 ± 20.30 μm) quadrants of the retina, followed by the temporal (93.58 ± 29.15 μm) and nasal (77.10 ± 14.89 μm) quadrants. In the 1529 participants aged 12 to 17, there were no significant differences in RNFL thickness values between the right and left eyes ($P > 0.05$); significant differences in RNFL were found only in the inferior and temporal quadrants of the retina in different sex groups ($P < 0.05$). Linear regression analysis revealed that the RNFL thickness values were correlated independently with axial length and refractive error ($P < 0.05$).

Conclusions. For clinical assessment of RNFL thickness, the influence of refractive error and axial length should be taken into account.

Keywords: retinal nerve fiber layer, thickness, Chinese, children

Glaucoma is a syndrome with manifestations of high intraocular tension, damaged visual function and damage to the optic nerve, leading to blindness.[1] According to a recent epidemiologic study, the prevalence of glaucoma in China is approximately 0.21% to 1.64%.[2] Early diagnosis and prevention of glaucoma is important, because damage to the visual field is irreversible. Studies confirm that before the occurrence of clinical visual field defects in glaucoma patients, approximately 40% to 50% of the retinal nerve fibers already have been lost.[3] Therefore, recognition of changes in retinal nerve fibers is extremely important in the early diagnosis and follow-up control of glaucoma.

Optical coherence tomography (OCT) is a technology that uses near-infrared light to create high-resolution images. It is noninvasive, rapid, and easy to perform, and does not involve contact. The OCT has been used widely for the observation and follow-up of changes in retinal nerve fibers, with good repeatability and high reliability. Early diagnosis and precise monitoring of retinal nerve fiber layer (RNFL) thickness alterations is possible only if an accurate database of living healthy human RNFL thickness is available. Several studies have obtained data for RNFL thickness using OCT in Chinese children.[4–7] Nevertheless, none of these studies involved more than 200 healthy children, and few of them reported retinal thickness in different age or sex groups. Thus, data for Chinese teenagers under 18 years of age are lacking. Such data would be useful in the auxiliary diagnosis of early glaucoma and to follow suspected glaucoma patients longitudinally; such data also would provide information on whether RNFL thickness increases or decreases in normal eyes during childhood. In our study, we reported in vivo measurement of RNFL thickness in 4648 healthy eyes of 2324 healthy Chinese teenagers aged 6 to 17 years using OCT, and explore factors related to our observations.

Methods

We first randomly selected the Luwan, Huangpu, and Jiading districts from 18 Shanghai administrative districts. These three districts represent the city, rural-urban fringe, and countryside. Five primary schools and seven middle schools in these three districts were selected randomly as survey sites, and the students with odd student code numbers were chosen for participation. The inclusion criteria were: Chinese nationality; age between 6 and 17 years; best-corrected visual acuity of 12/20 or better; no history of eye disorders, such as cataract or glaucoma, and no abnormal findings in examinations. Those who could not cooperate with the examination and those who did not sign the informed consent form were excluded from the study. This study was conducted according to the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board at the Shanghai First People's Hospital, Shanghai Jiao Tong University.

Table 1. Parameter Locations and Abbreviations Used in the Analysis

Location	Abbreviation Term Used in Analysis	Right Eye	Left Eye
Superior nasal	SN	00:00–01:30	10:30–00:00
Nasal upper	NU	01:30–03:00	09:00–10:30
Nasal lower	NL	03:00–04:30	07:30–09:00
Inferior nasal	IN	04:30–06:00	06:00–07:30
Inferior temporal	IT	06:00–07:30	04:30–06:00
Temporal lower	TL	07:30–09:00	03:00–04:30
Temporal upper	TU	09:00–10:30	01:30–03:00
Superior temporal	ST	10:30–00:00	00:00–01:30
Superior	S	10:30–12:00–01:30	10:30–12:00–01:30
Nasal	N	01:30–03:00–04:30	07:30–09:00–10:30
Inferior	I	04:30–06:00–07:30	04:30–06:00–07:30
Temporal	T	07:30–09:00–10:30	01:30–03:00–04:30
Total quadrants	Avg	00:00–06:00–12:00	00:00–06:00–12:00

Field investigations took place from October 2011 to June 2013. The investigative team included three trained ophthalmologists who conducted OCT examinations and seven experienced doctors who assisted with the investigations. The three ophthalmologists received training in the study methodology and conducted pilot OCT examinations on volunteers 1 month before the investigations.

Before field examination, the purpose and methods of this study were explained to the participants' parents, and written informed consent was obtained. We collected data, including age, sex, best-corrected visual acuity, refraction, and axial length (AL). An autorefractor (model KR-8800; Topcon, Tokyo, Japan) provided a median value of three reliable measurements of refractive status if individual measurements varied by no more than 0.5 diopters (D). An IOL-Master (Carl Zeiss Meditec, Oberkochen, Germany) provided a median value of five reliable measurements of AL if individual measurements varied by no more than 0.02 mm. OCT (OCT-iVue100, version 1.5; Optovue, Inc., Fremont, CA) was performed without pupillary dilation. The position of the aiming circle was adjusted by the operator to match the optic nerve head so that the nerve head scan, covering a set diameter (3.45 mm) around the center of the optic disc, would acquire an OCT image that was equidistant from the disc margins in all directions. The operator was to ensure the centration of the measurement circle before OCT image acquisition. The RNFL thickness was evaluated as a global average in various quadrants and at 45° intervals, and 13 RNFL parameters representing the average RNFL thickness of 13 different locations were displayed by means of a color-coded map. The locations and abbreviation terms corresponding to these 13 parameters are presented in Table 1. Any questions raised during the study were discussed by the staff and resolved in a timely fashion. An engineer from Optovue, Inc. (Shanghai, China) frequently helped us ensure that the OCT-iVue100 device (Optovue, Inc.) was working properly.

The data were recorded on Excel spreadsheets by two persons independently. The spherical equivalent was calculated as the spherical degree plus half of the cylindrical degree. Statistical analyses were performed using an SPSS software

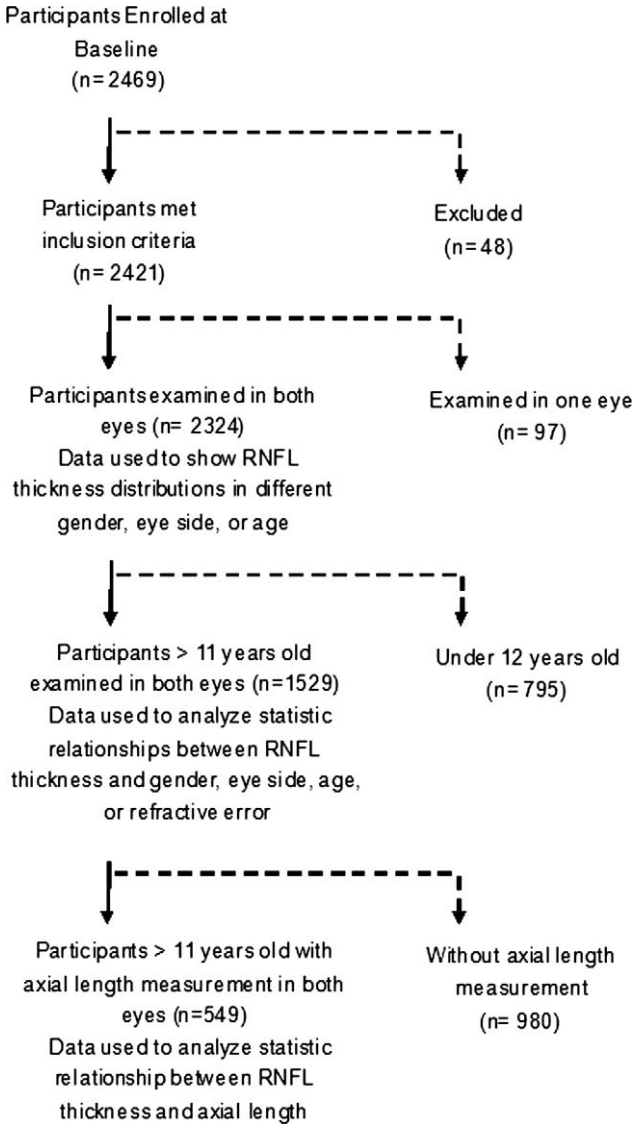

Figure. Participation flowchart for assessing RNFL thickness distribution and related factors in our study.

Table 2. Demographic Characteristics of 2324 Normal Chinese Students Aged 6 to 17 Years

Age, y	Total *N*	Male *N*	Female *N*	Spherical Equivalent Mean (SD)	
				Right Eye	Left Eye
6	92	55	37	NA	NA
7	89	41	48	NA	NA
8	86	43	43	NA	NA
9	94	59	35	NA	NA
10	118	61	57	NA	NA
11	316	148	168	NA	NA
12	242	135	107	−1.61 (2.88)	−1.66 (2.63)
13	218	120	98	−2.11 (2.81)	−2.13 (2.75)
14	232	125	107	−2.52 (4.09)	−2.59 (2.52)
15	258	137	121	−2.74 (3.86)	−2.84 (3.55)
16	275	129	146	−3.44 (4.76)	−3.37 (4.55)
17	304	144	160	−3.67 (5.19)	−3.61 (5.10)
Total	2324	1197	1127	NA	NA

NA, not available.

Table 3. RNFL Thickness Measurement Results in Different Eye Side Groups of Normal Chinese Students

	Total 2324 Participants Aged 6–17		1529 Participants Aged 12–17			
	Right Eye	Left Eye	Right Eye	Left Eye	Z*	P
SN						
Range	65–241	43–276	74–209	57–208	1.95	0.05
Mean ± SD	122.85 ± 25.23	121.66 ± 22.94	122.72 ± 26.84	117.58 ± 21.24		
NU						
Range	33–243	33–248	33–168	33–248	3.80	<0.01
Mean ± SD	83.63 ± 16.64	87.16 ± 32.37	80.94 ± 14.58	90.57 ± 37.28		
NL						
Range	23–251	21–246	23–146	21–246	1.10	0.27
Mean ± SD	70.55 ± 14.83	72.60 ± 24.49	68.00 ± 11.93	73.28 ± 27.45		
IN						
Range	53–231	57–267	58–224	57–220	1.63	0.10
Mean ± SD	108.95 ± 25.47	110.20 ± 27.96	105.45 ± 24.46	108.95 ± 29.72		
IT						
Range	57–248	73–260	57–226	73–246	1.56	0.19
Mean ± SD	149.48 ± 23.73	147.93 ± 25.88	148.45 ± 24.46	144.37 ± 26.25		
TL						
Range	42–254	45–210	54–254	45–159	1.62	0.11
Mean ± SD	92.12 ± 33.58	83.97 ± 15.80	97.65 ± 39.28	96.93 ± 16.53		
TU						
Range	35–204	37–185	46–203	37–166	1.77	0.08
Mean ± SD	95.03 ± 28.57	89.53 ± 17.39	99.35 ± 32.62	99.05 ± 17.96		
ST						
Range	73–260	72–249	78–220	72–239	1.12	0.26
Mean ± SD	143.56 ± 19.99	143.01 ± 21.38	142.04 ± 19.84	141.20 ± 21.41		
S						
Range	72–251	69–257	79–205	69–216	1.09	0.28
Mean ± SD	133.22 ± 19.48	132.31 ± 19.12	132.38 ± 19.97	129.39 ± 18.58		
N						
Range	28–247	31–203	28–151	33–203	3.38	<0.01
Mean ± SD	77.10 ± 14.89	79.89 ± 24.43	74.47 ± 12.37	81.92 ± 30.13		
I						
Range	67–234	71–249	67–189	71–210	0.03	0.90
Mean ± SD	129.23 ± 20.30	129.10 ± 20.07	127.03 ± 20.47	126.66 ± 19.69		
T						
Range	45–220	48–197	56–220	48–163	0.77	0.40
Mean ± SD	93.58 ± 29.15	86.76 ± 14.63	98.50 ± 33.87	97.99 ± 15.36		
Avg						
Range	70–167	67–222	72–151	72–153	1.96	0.05
Mean ± SD	108.28 ± 13.97	107.01 ± 11.41	108.09 ± 15.13	108.99 ± 11.17		

* Wilcoxon signed rank test.

program (SPSS16.0; SPSS Institute, Inc., Chicago, IL). Normalcy of distribution of the 13 RNFL thickness parameter values was evaluated using the 1-sample Kolmogorov-Smirnov *Z* test. If the values did not follow a Gaussian distribution, the Wilcoxon signed-rank or Mann-Whitney *U* nonparameter test was used to determine significant difference. A 2-tailed Pearson bivariate correlation analysis was used to determine the interaction between RNFL thickness and age, refractive error, and axial length. Multiple linear regression analysis was used to determine the effects of sex, eye laterality, age, and refractive error on RNFL measurements. *P* values <0.05 were considered statistically significant.

Results

There were 2469 participants enrolled at baseline, and 2421 children who met the inclusion criteria were examined by OCT. Data for only one eye were obtained for 97 of the 2421 healthy participants, because they could not cooperate fully with the OCT examination. To minimize possible bias from poor cooperation, the data on 4648 eyes of 2324 participants who underwent examination in both eyes were used for RNFL thickness distribution analysis in different sex, eye side, or age. Participants under 12 years of age were not given cycloplegia. Therefore, the group comparisons and regression analysis

Table 4. RNFL Thickness Measurement Results for the Right Eye in Normal Chinese Students Aged 6 to 11 Years

	Age 6	Age 7	Age 8	Age 9	Age 10	Age 11
SN						
Range	80–171	80–229	84–188	65–191	75–239	71–241
Mean ± SD	123.00 ± 20.88	121.34 ± 25.02	120.86 ± 18.18	121.83 ± 20.86	124.09 ± 23.36	124.22 ± 22.58
NU						
Range	46–122	36–230	66–234	43–222	38–243	42–223
Mean ± SD	87.17 ± 14.70	87.90 ± 19.76	91.02 ± 21.90	86.99 ± 22.68	90.64 ± 26.17	88.80 ± 17.33
NL						
Range	44–111	44–177	50–210	39–205	46–251	40–238
Mean ± SD	74.45 ± 12.44	74.27 ± 15.35	77.78 ± 21.48	72.26 ± 20.90	76.54 ± 24.98	76.00 ± 18.18
IN						
Range	53–174	73–164	78–224	74–231	75–190	66–225
Mean ± SD	116.42 ± 22.70	114.30 ± 22.10	121.26 ± 27.66	115.76 ± 26.17	113.81 ± 23.47	114.28 ± 24.59
IT						
Range	79–225	77–204	110–205	92–198	97–239	71–248
Mean ± SD	152.33 ± 23.46	152.80 ± 21.90	153.21 ± 19.47	149.63 ± 20.93	153.16 ± 22.64	150.26 ± 22.71
TL						
Range	56–116	60–140	56–109	54–116	42–146	54–135
Mean ± SD	81.15 ± 11.18	84.17 ± 14.70	79.27 ± 10.96	80.17 ± 11.30	84.00 ± 13.62	80.91 ± 12.53
TU						
Range	54–146	59–182	58–116	35–123	59–146	56–204
Mean ± SD	85.27 ± 15.05	89.00 ± 16.90	85.29 ± 12.45	84.09 ± 15.13	87.05 ± 14.34	87.57 ± 16.04
ST						
Range	86–207	84–184	105–217	73–184	83–194	97–260
Mean ± SD	144.14 ± 19.32	147.03 ± 19.22	147.30 ± 20.40	145.05 ± 20.00	147.13 ± 19.95	146.98 ± 20.33
S						
Range	85–188	93–203	104–189	72–185	92–216	93–251
Mean ± SD	133.61 ± 18.18	134.19 ± 19.07	134.14 ± 16.11	133.49 ± 17.89	135.64 ± 18.61	135.66 ± 18.99
N						
Range	53–108	51–204	58–222	45–117	47–247	46–212
Mean ± SD	80.82 ± 12.05	81.06 ± 16.78	84.47 ± 21.19	79.70 ± 10.99	85.58 ± 24.69	82.46 ± 16.94
I						
Range	81–185	82–175	97–184	83–207	93–213	83–234
Mean ± SD	134.42 ± 18.96	133.54 ± 18.07	137.23 ± 18.89	132.70 ± 20.28	133.49 ± 18.75	132.29 ± 19.69
T						
Range	60–131	62–151	66–111	45–113	53–127	64–169
Mean ± SD	83.24 ± 10.84	86.54 ± 13.99	82.30 ± 9.73	82.20 ± 11.05	85.50 ± 12.07	84.26 ± 12.34
Avg						
Range	79–131	84–150	87–154	70–149	81–159	82–167
Mean ± SD	108.02 ± 10.35	108.83 ± 10.65	109.53 ± 11.06	107.02 ± 11.20	109.55 ± 12.15	108.69 ± 11.84

between RNFL thickness and sex, eye laterality, age, and refractive error were conducted using only the data from the 1529 participants aged 12 to 17, because their refractive error data could be included in the analysis. Of the 1529 participants in this age group, IOL-Master examinations were well-conducted in 549 subjects, and the data obtained from these 549 subjects were used to evaluate the relationship statistically between RNFL thickness and AL. The participation flowchart for assessment used in the study is shown in the Figure.

The demographic characteristics of the 2324 participants are shown in Table 2. The mean (SD) age of the participants was 12.82 (3.11) years. A significant correlation was found between spherical equivalent and age, regardless of eye laterality (2-tailed Pearson bivariate correlation coefficients of 0.35 and 0.34, both $P < 0.01$).

The 13 RNFL thickness parameter values of the participants' right and left eyes are shown in Table 3. Considering the correlation between the two eyes, we used data of the 2324 right eyes to evaluate RNFL thickness distribution in different age and sex groups. For these eyes, the mean (SD) RNFL thickness of the superior, inferior, temporal, nasal, and total quadrants was 133.22 (19.48), 129.23 (20.30), 93.58 (29.15), 77.10 (14.89), and 106.89 (12.84) μm, respectively. The detailed distributions of the 13 RNFL thickness parameter values in different age groups are shown in Tables 4 and 5. In almost all age groups, the thickest RNFL was located in the superior quadrant, with the inferior quadrant following. The temporal quadrant was thinner, and the nasal quadrant was thinnest. The distributions of the 13 RNFL thickness parameter values in the two sex groups are shown in Table 6.

Table 5. RNFL Thickness Measurement Results for the Right Eye in Normal Chinese Students Aged 12 to 17 Years

	Age 12	Age 13	Age 14	Age 15	Age 16	Age 17	CC	*P*
SN								
Range	78–188	80–187	85–187	78–209	74–205	74–191	−0.25	<0.01
Mean ± SD	125.11 ± 23.88	127.33 ± 28.06	123.88 ± 30.20	121.49 ± 26.50	111.99 ± 20.18	112.11 ± 19.35		
NU								
Range	43–130	42–142	52–120	42–155	34–168	33–159	−0.12	<0.01
Mean ± SD	85.29 ± 13.68	83.21 ± 14.13	78.01 ± 13.28	80.49 ± 14.17	79.95 ± 15.60	79.37 ± 15.07		
NL								
Range	46–218	28–208	42–206	33–246	35–227	23–241	−0.17	<0.01
Mean ± SD	72.15 ± 20.90	69.59 ± 20.30	67.74 ± 20.25	67.19 ± 22.23	66.08 ± 22.11	66.16 ± 23.60		
IN								
Range	68–224	62–197	62–176	59–183	62–168	58–210	−0.19	<0.01
Mean ± SD	112.12 ± 24.02	108.94 ± 26.86	110.06 ± 28.89	106.05 ± 23.33	99.66 ± 20.93	99.63 ± 25.13		
IT								
Range	57–225	60–215	67–221	68–218	77–214	62–226	−0.13	<0.01
Mean ± SD	152.52 ± 23.79	149.10 ± 23.35	153.50 ± 28.72	149.50 ± 21.89	144.80 ± 22.46	143.28 ± 24.73		
TL								
Range	56–230	55–254	56–245	54–194	55–193	56–192	−0.18	<0.01
Mean ± SD	92.44 ± 34.98	100.97 ± 34.25	97.05 ± 24.67	95.76 ± 34.47	82.49 ± 15.94	84.65 ± 16.83		
TU								
Range	60–187	54–197	56–203	57–198	46–187	47–175	−0.12	<0.01
Mean ± SD	95.06 ± 28.65	98.68 ± 34.52	105.21 ± 47.90	101.03 ± 31.72	90.62 ± 17.75	89.96 ± 16.91		
ST								
Range	86–217	78–208	94–213	92–217	88–206	84–220	−0.12	<0.01
Mean ± SD	145.78 ± 19.31	144.11 ± 18.86	143.33 ± 19.03	142.08 ± 20.59	138.49 ± 19.05	139.78 ± 20.93		
S								
Range	85–191	79–188	92–195	87–197	85–187	84–205	−0.23	<0.01
Mean ± SD	135.44 ± 17.84	135.72 ± 19.76	133.61 ± 19.79	131.78 ± 20.38	125.24 ± 17.91	125.95 ± 18.36		
N								
Range	45–124	37–125	47–101	38–151	36–148	28–138	−0.15	<0.01
Mean ± SD	78.72 ± 11.35	76.40 ± 11.30	72.88 ± 10.67	73.84 ± 12.37	73.01 ± 13.12	72.77 ± 13.45		
I								
Range	77–185	76–184	71–183	74–175	72–176	67–189	−0.19	<0.01
Mean ± SD	132.32 ± 18.68	129.02 ± 20.40	131.78 ± 21.45	127.77 ± 19.26	122.23 ± 18.91	121.45 ± 21.29		
T								
Range	66–208	63–220	66–212	62–193	65–190	56–183	−0.17	<0.01
Mean ± SD	93.75 ± 29.83	99.82 ± 37.11	101.13 ± 48.35	98.39 ± 31.07	86.56 ± 14.56	87.31 ± 14.39		
Avg								
Range	79–149	77–150	82–151	79–145	72–142	74–144	−0.18	<0.01
Mean ± SD	110.06 ± 13.14	110.24 ± 14.99	109.85 ± 18.04	107.95 ± 14.37	101.76 ± 11.10	101.87 ± 11.56		

CC, 2-tailed Pearson bivariate correlation coefficient.

Among the 1529 participants who were at least 12 years of age, none of the 13 RNFL thickness parameter values, and neither the right nor the left eye spherical equivalent followed a Gaussian distribution (1-sample Kolmogorov Smirnov Z ranged from 1.347–9.177, all $P < 0.05$). The mean spherical equivalent of the 1529 right eyes was −2.74 (SD 2.07), a value that was not statistically significantly different from that of the 1529 left eyes (mean −2.76, SD 2.02, Wilcoxon signed rank test $Z = 1.91$, $P = 0.06$). The Wilcoxon signed rank test was used to compare RFNL thickness in the right and left eyes of the 1529 subjects. Significant differences were found in only 2 of the 13 parameters, the nasal upper quadrant and the nasal part (Table 3). Therefore, we considered that there were no significant differences in RNFL thickness parameter values between the right and left eyes. Between male and female sex groups, no statistically significant difference was found in spherical equivalent, regardless of eye laterality (Wilcoxon signed rank test $Z = 1.00$ or 1.44, $P = 0.32$ or 0.15), while significant differences in RNFL thickness were found in the inferior and temporal parts in the two sex groups (Table 6).

Of the 1529 subjects older than 11 years, almost all of the 13 parameters decreased significantly with age (Table 5). Significant correlation was found between spherical equivalent and all of the 13 parameters, regardless of eye laterality (2-tailed Pearson bivariate correlation coefficient between 0.10 and 0.44, all $P < 0.05$). Linear regression analyses were performed in the 1529 subjects, keeping the RNFL thickness parameters as the dependent variables, and designating age, sex, and spherical equivalent as the independent variables. For 5 of the 13 RNFL thickness parameters, spherical equivalent

Table 6. RNFL Thickness Measurement Results for the Right Eye in Different Sex Groups of Normal Chinese Students

	Total 2324 Participants Aged 6–17		1529 Participants Aged 12–17			
	Male	Female	Male	Female	*Z**	*P*
SN						
Range	65–241	74–239	74–205	74–209	−0.80	0.43
Mean ± SD	122.74 ± 24.90	122.96 ± 25.78	121.99 ± 26.29	123.49 ± 27.40		
NU						
Range	34–243	33–223	34–159	33–168	−1.74	0.08
Mean ± SD	84.25 ± 17.33	82.98 ± 15.85	81.49 ± 13.95	80.36 ± 15.20		
NL						
Range	28–251	23–200	28–116	23–146	−1.05	0.29
Mean ± SD	70.83 ± 15.50	70.24 ± 14.08	68.20 ± 11.39	67.78 ± 12.48		
IN						
Range	58–224	53–231	58–183	59–224	−1.12	0.26
Mean ± SD	107.96 ± 24.73	110.00 ± 26.20	104.71 ± 24.61	106.54 ± 26.00		
IT						
Range	60–248	57–242	60–225	57–226	−7.09	<0.01
Mean ± SD	146.55 ± 22.81	152.59 ± 24.30	144.31 ± 23.08	152.77 ± 25.12		
TL						
Range	42–254	54–233	54–254	56–233	−3.87	<0.01
Mean ± SD	90.46 ± 32.84	93.89 ± 34.27	94.98 ± 38.17	100.43 ± 40.24		
TU						
Range	35–204	56–198	46–203	56–198	−6.19	<0.01
Mean ± SD	92.91 ± 28.50	97.28 ± 28.49	96.04 ± 32.08	102.79 ± 32.85		
ST						
Range	73–260	84–222	78–220	84–217	−0.59	0.56
Mean ± SD	143.22 ± 19.58	143.93 ± 20.43	141.63 ± 19.43	142.27 ± 20.27		
S						
Range	72–251	84–216	79–205	84–197	−1.05	0.29
Mean ± SD	132.98 ± 18.95	133.47 ± 20.03	131.81 ± 19.60	132.98 ± 20.35		
N						
Range	36–247	28–212	36–138	28–151	−1.59	0.11
Mean ± SD	77.55 ± 15.67	76.63 ± 14.01	74.85 ± 11.83	74.07 ± 12.90		
I						
Range	68–213	67–234	68–185	67–189	−4.90	<0.01
Mean ± SD	127.30 ± 19.89	131.28 ± 20.54	123.51 ± 20.09	129.66 ± 20.55		
T						
Range	45–220	58–210	56–220	58–210	−5.72	<0.01
Mean ± SD	91.69 ± 28.78	95.59 ± 29.42	95.51 ± 33.15	101.61 ± 34.35		
Avg						
Range	70–163	75–167	72–151	75–151	−4.52	<0.01
Mean ± SD	104.67 ± 11.04	109.24 ± 14.13	106.67 ± 14.86	109.58 ± 15.28		

* Mann-Whitney *U* test.

was found to be the only independent relative factor in linear regression analysis. For the remaining eight parameters, which included temporal, inferior, and nasal parts, spherical equivalent and age were the independent relative factors, as shown in Table 7.

Using IOL-Master, AL measurement results were acquired in 267 boys and 282 girls, including 138 subjects aged 12, 113 subjects aged 13, 170 subjects aged 14, 51 subjects aged 15, 36 subjects aged 16, and 41 subjects aged 17 years. Significant correlation was found between AL and all of the 13 parameters, regardless of eye laterality (2-tailed Pearson bivariate correlation coefficient between 0.09 and 0.49, all $P < 0.05$). Linear regression analyses then were performed in the 549 subjects, keeping the RNFL thickness parameters as the dependent variables, and designating age, sex, spherical equivalent, and AL as the independent variables. The AL and spherical equivalent were found as the independent relative factors of almost all of the 13 RNFL thickness parameters in linear regression analysis, as shown in Table 8.

Discussion

Reliable visual field results are difficult to obtain in children, making the use of conventional methods for diagnosis and management of childhood glaucoma difficult.[8] In contrast,

Table 7. Multiple Linear Regression Analysis of the Relationship of RNFL Thickness Parameters to Independent Variables in 1529 Chinese Students Aged 12 to 17

Dependent Variable	Independent Variables Included in Equation	Accumulative Adjusted R^2	Standardized β Coefficients	P
SN	Spherical equivalent	0.10	0.25	<0.01
	Age	0.12	0.17	<0.01
NU	Spherical equivalent	0.11	0.33	<0.01
NL	Spherical equivalent	0.18	0.42	<0.01
IN	Spherical equivalent	0.20	0.44	<0.01
IT	Spherical equivalent	0.06	0.25	<0.01
	Age	0.09	0.18	<0.01
TL	Spherical equivalent	0.03	0.19	<0.01
	Age	0.04	0.08	<0.01
TU	Spherical equivalent	0.02	0.13	<0.01
	Age	0.03	0.11	<0.01
ST	Spherical equivalent	0.06	0.24	<0.01
S	Spherical equivalent	0.11	0.28	<0.01
	Age	0.12	0.13	<0.01
N	Spherical equivalent	0.16	0.39	<0.01
I	Spherical equivalent	0.18	0.42	<0.01
	Age	0.19	0.13	<0.01
T	Spherical equivalent	0.03	0.17	<0.01
	Age	0.04	0.10	<0.01
Avg	Spherical equivalent	0.15	0.34	<0.01
	Age	0.17	0.15	<0.01

Using data from the right eye, the following independent variables were put into the regression equation for analysis: age, sex, and spherical equivalent.

Table 8. Multiple Linear Regression Analysis of the Relationship of RNFL Thickness Parameters to Independent Variables in 549 Chinese Students Aged 12 to 17

Dependent Variable	Independent Variables Included in Equation	Accumulative Adjusted R^2	Standardized β Coefficients	P
SN	Spherical equivalent	0.02	0.30	<0.01
	Axial length	0.06	0.28	<0.01
	Age	0.07	0.09	<0.01
NU	Axial length	0.22	0.47	<0.01
NL	Spherical equivalent	0.20	0.30	<0.01
	Axial length	0.25	0.26	<0.01
IN	Axial length	0.18	0.34	<0.01
	Spherical equivalent	0.20	0.16	<0.01
IT	Axial length	0.03	0.18	<0.01
	Spherical equivalent	0.04	0.09	<0.01
TL	Axial length	0.08	0.42	<0.01
	Spherical equivalent	0.12	0.24	<0.01
TU	Axial length	0.04	0.30	<0.01
	Spherical equivalent	0.06	0.16	<0.01
ST	Spherical equivalent	0.02	0.14	<0.01
	Axial length	0.03	0.09	<0.01
S	Spherical equivalent	0.03	0.28	<0.01
	Axial length	0.05	0.18	<0.01
N	Axial length	0.24	0.39	<0.01
	Spherical equivalent	0.27	0.19	<0.01
I	Axial length	0.12	0.25	<0.01
	Spherical equivalent	0.13	0.16	<0.01
T	Axial length	0.07	0.39	<0.01
	Spherical equivalent	0.10	0.22	<0.01
Avg	Spherical equivalent	0.04	0.30	<0.01
	Axial length	0.06	0.18	<0.01

Using data from the right eye, the following independent variables were put into the regression equation for analysis: age, sex, spherical equivalent, and axial length.

OCT is suitable for children due to its quick and easy methodology. In this study of RNFL thickness in Shanghai children and teenagers, we found that RNFL thickness showed a "double hump" curve, as was reported in some previous studies[9,10]: the RNFL is thickest in its superior and inferior parts, followed by the temporal part, and it is thinnest in the nasal part. The average RNFL thickness measured in 2324 subjects in our study was similar to the measurements obtained in two small-sample Asian studies: 107.3 ± 10.2 μm in 18 nonglaucomatous individuals aged <18 years[5] and 112.36 ± 9.21 μm in 199 healthy individuals aged 5 to 18 years.[4]

The average measured RNFL thickness in the right and left eyes of children differed in previous studies. Qian et al.[4] found that the RNFL was thicker in the left eye. However, Mwanza et al.[11] considered that the superior quadrant RNFL was thicker in the left eye, while the RNFL in the other three quadrants was thicker in the right eye. Data from Huynh et al.[12] showed no statistically significant differences between right and left eyes. We considered that differences in refractive error may bias comparison of RNFL thickness. In the 1529 participants aged over 11 in our study, we found no significant differences in RNFL thickness in the symmetric parts between the two eyes, which were almost equal to each other in refractive error.

Several previous reports suggest that sex is not a relevant factor affecting RNFL thickness.[5,6,13] In our study, most of the RNFL thickness parameter values did not differ between the two sex groups; however, the RNFL thickness in the inferior and temporal quadrants was greater in girls than in boys, in agreement with results reported in two previous studies.[4,13] However, Huynh et al.[14] found the opposite result in a population of 6-year-old children in which the inferior quadrant RNFL was thicker in the eyes of boys than girls. We considered that differences in study design may have led to these different conclusions.

Bivariate tests revealed a negative correlation between all RNFL thickness parameter values and age, and further regression analysis indicated that age was an independent variable associated with several parameter values. Nevertheless, we considered age to have less influence on RNFL than refractive error or AL, as shown in Tables 7 and 8. A strong influence of refractive error and AL on RNFL thickness also has been found in other studies,[14–16] and is plausible based on the viewpoint expressed by Lam et al.[17]: in Asian children, refractive status always changes from hypermetropia to myopia and AL gradually increases with age,[18,19] resulting in expansion of the ocular wall and the creation of more space in the retina.

Some inherent weaknesses of our study should not be neglected. First, the applicability of our results to non-Chinese racial groups or to adults is not known. Second, because the Institutional Review Board did not approve the use of cycloplegia in this large-scale population-based study, the refractive error data of participants under 12 years of age was not taken into consideration. Future studies may shed further light on the relationship of refractive error status and RNFL thickness in young children.

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