· Investigation ·

Age-specific distribution of oculometric parameters and myopia in children aged 8-12y

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Abstract

● **AIM:** To describe the distribution of ocular biometrics and to evaluate its associations with refractive error and to assess the contribution from ocular parameters to refractive error among Chinese myopic children.

● **METHODS:** This cross-sectional study evaluated subjects aged 8-12y. Keratometry, ocular biometry, and cycloplegic autorefraction were performed on each subject. Spherical equivalent refraction (SER) and ocular biometrics were assessed as a function of age and gender. The Pearson correlation analysis between SER and ocular biometrics was carried out. Multiple linear regression was performed to analyze the association between SER and ocular parameters.

● **RESULTS:** A total of 689 out of 735 participants (321 boys, 48.1%) were analyzed, with a mean SER of -2.98±1.47 diopter (D). Axial length (AL), anterior chamber depth (ACD), corneal radius of curvature (CR), horizontal visible iris diameter (HVID), central corneal thickness (CCT) and lens power (LP) showed normal distribution. The AL, AL/CR ratio, ACD and CR increased from 8 to 12y of age, while SER and LP decreased, HVID and CCT remained stable. There was no difference in gender. SER decreased by 0.929 D for every 1 mm increase in AL and decreased by 1.144 D for every 0.1 increase in AL/CR ratio. The Pearson correlation coefficient between SER and AL was -0.538 (*P*<0.01) and -0.747 (*P*<0.01) between SER and AL/CR ratio. For the SER variance, AL explained 29.0%, AL/CR ratio explained 55.7%, while AL, CR, ACD and LP explained 99.3% after adjusting for age and gender.

● **CONCLUSION:** The AL, CR, ACD and LP are the most important determinants of myopic refractive error during myopia progression.

● **KEYWORDS:** myopia; ocular biometry; refractive error; population-based study

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INTRODUCTION

Myopia, a common eye disorder, has become a global health problem as documented by population-based prevalence studies world-wide[1-3]. It is predicted that, by 2050, 49.8% of the global population (4758 million people) will have myopia and 19.7% (938 million people) will have high myopia[4]. In China, the prevalence of myopia was 36.7%-63.1% in children[3,5-6]. Therefore, routine vision screening of children is recommended as an integral part of preventive healthcare, which has utility for early detection of myopia and leads to timely interventions.

Plenty of studies have reported the correlation between ocular biometrics and refraction[7-9]. It is commonly acknowledged that axial elongation is the cause of the age-related myopic shift in refraction in school-age children[10-12]. The development of refraction may also be impacted by changes in several ocular parameters. A study done by Mutti *et al*[13] showed that in 222 normal-birthweight human infants between 3 and 9mo of age, axial length (AL), corneal radius of curvature (CR) and lens power (LP) have the strongest correlation with refraction in emmetropization, and the ocular components change was characterized by increases in AL and decreases in LP and CR. Guo *et al*[14] reported that 80% variance of spherical equivalent refraction (SER) could be explained by AL, CR and LP, which affect the final ocular refractive status among 1127 Chinese preschoolers aged 3 to 6y. Chamberlain *et al*[11] indicated that a greater correlation of refraction with AL, anterior chamber depth (ACD) and LP in East Asian than European Caucasian children aged 12y. In a rural Burmese population aged 40 to 60+ years, nuclear opalescence (NO) is the mainly determinant of myopia[15]. As mentioned above, the ocular parameters that determine refractive state of the eyes may be different for subjects with different age, refractive error and even ethnic groups. Thus, for children with myopia, how the relationship between refractive error and ocular components changes with age, and ultimately determine the refractive status of the eyes? More studies are still needed to conduct.

Children aged 8 to 12y in China are prone to suffer myopia due to the pressure of heavy school work. Studying this sample may allow a better analysis of the correlation between ocular biometrics and refractive error. Detailed documentation of these ocular parameters, including AL, CR, ACD, LP, central corneal thickness (CCT), horizontal visible iris diameter (HVID) in large population will be favorable for us to understand the myopia-related changes in these ocular components during myopia progression. Therefore, the purposes of this study are to report the distributions of SER and other ocular biometrics and to evaluate associations between refractive error and ocular parameters. We also assess the contribution from ocular parameters to refractive error, with an insight to know the age-specific cause of refractive error in Chinese myopic children aged 8 to 12y.

SUBJECTS AND METHODS

Ethical Approval This study was approved by the institutional research ethics committee of Peking University People's Hospital (2021PHB322-001). This study was performed in accordance with the Declaration of Helsinki. The purposes and procedures of this study were explained to the parents or legal guardians in detail, and they signed written informed consent forms for data storage and data usage for clinical/research purposes before the study.

Study Population A cross-sectional study consisted of participants who visited Peking University People's Hospital optometry center due to myopia, was conducted to investigate ocular biometrics, refractive error and to evaluate the association in different age groups.

Each subject received a comprehensive eye examination and fulfilled the inclusion criteria, which required a suitable age from 8 to 12 years old, SER of -0.50 diopter (D) or less, the absence of any ocular diseases (such as cataract, glaucoma, strabismus), and newly developed myopic eyes. Data from 734 patients were collected, and 689 patients' data were ultimately analyzed in the study after 45 patients were excluded due to out of age range (14/45, less than 8 years old or more than 12 years old) or missing value (31/45).

Biometric Measurements Ocular biometry such as AL was measured with noncontact partial-coherence laser interferometry (IOL Master; Carl Zeiss Meditec, Oberkochen, Germany). Five consistent and good-quality scans were obtained and recorded. The measurement of AL was the distance from the tear film to the retinal pigment epithelium (RPE). A corneal topography system (the Sirius, Italy) was used to obtain the mean K reading (K_{mean}), ACD, CCT, and HVID. Five consistent keratometry readings were taken and used in analysis. The measurements were performed by the same experienced ophthalmologist. CR was measured in two meridians, including the deepest CR (CR1) and the flattest CR (CR2). The measurement of ACD was the distance from the anterior corneal surface to the anterior lens surface.

After the ocular biometric measurements, all participants underwent non-cycloplegic refraction with an autorefractometer (KP8800; Topcon Corp., Tokyo, Japan). Five reliable readings of refraction in both eyes and the average reading were used for analysis. Then, cycloplegic refraction was performed for each subject with 0.5% compound tropicamide eye drops (Santen Pharmaceutical Co. Ltd., Japan, 0.5% tropicamide combined with 0.5% phenylephrine), three cycles of 0.5% compound tropicamide eye drops instilled 5min apart. The autorefractometer (KP8800; Topcon Corp., Tokyo, Japan) was performed 25min after administration of eye drops. Cycloplegia was considered complete if pupil dilated to 6 mm or more and there was no pupillary reflex. The average value of five valid readings automatically performed by the autorefractor was used for analysis.

Definitions Refractive error was defined as SER (SER= spherical power+$^1/_2$cylinder power). Low myopia was defined as -3.00 D ≤SER<-0.50 D, -3.00 D to -6.00 D was labeled as moderate myopia, and if it was SER<-6.00 D it was categorized as high myopia. Mean K reading [K_{mean}=$^1/_2$(flat K reading + steep K reading)] was the average of the steepest and flattest meridians. CR was converted from the K_{mean} data using the formula CR=0.3375/K_{mean}×1000. Axial length-corneal radius ratio (AL/CR ratio) was defined as the AL divided by the mean CR. LP was calculated using the Bennett-Rabbetts method[16-17] with unknown lens thickness, using measured values for SER, ACD, CR and AL.

Statistical Analysis Statistical analysis was performed using the SPSS statistical software package (Version 22.0, IBM Corp., USA). Descriptive statistics were calculated.

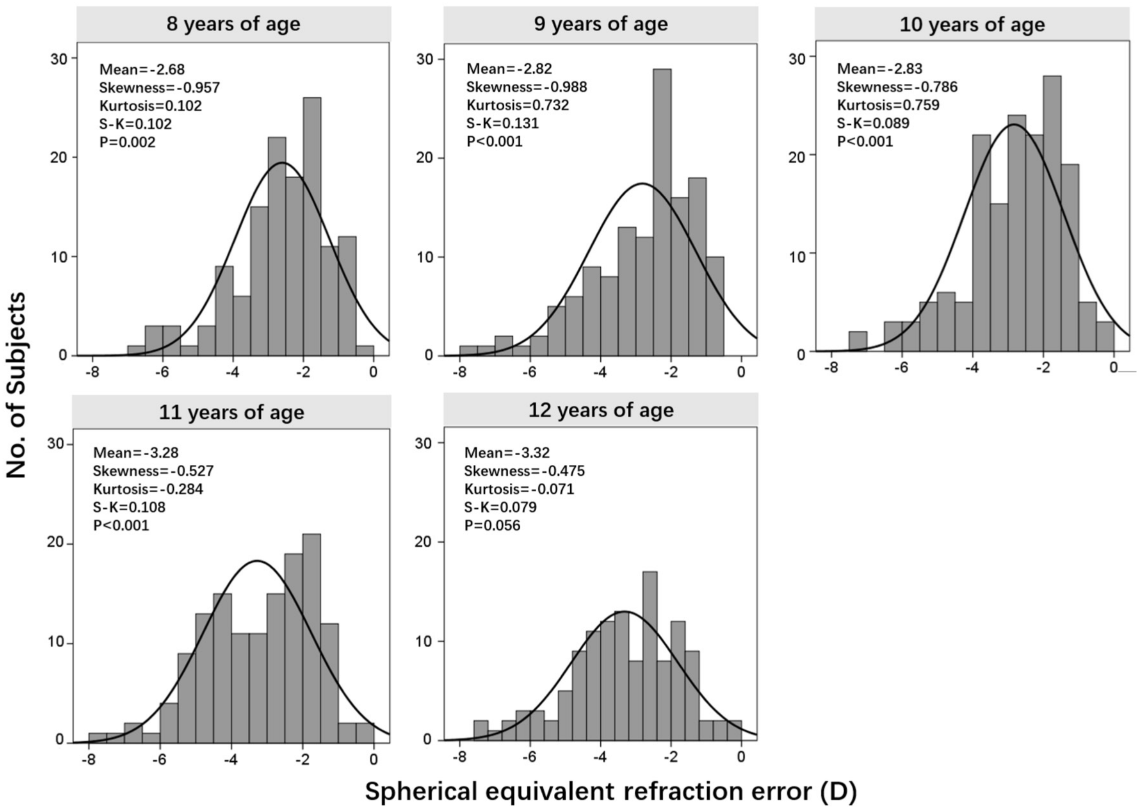

Figure 1 Histograms showing age-specific distributions of spherical equivalent refraction (SER) in the right eyes D: Diopters.

Continuous data were expressed as mean±standard deviation (SD). Correlation between right and left eye was analyzed with Pearson correlation. As biometric data for the right and left eyes were highly correlated, analyses were performed using data of the right eye only. The overall distributions of changes in refractive error and ocular component values were assessed for skew and kurtosis. The Kolmogorov-Smirnov test for normality was used. Kurtosis is a measure of how data points are concentrated around the mean of a distribution; higher kurtosis values indicate a sharper peak than the normal distribution. The normally distributed continuous variables between the boys and girls were compared using Student's *t*-test (unpaired samples). The non-normally distributed continuous variables between the boys and girls were compared using the Mann-Whitney *U* test. Groups of continuous variables were compared using one-way analysis of variance (ANOVA, *P* for trends). Pearson's correlation coefficient (*r*) and scatterplots were used for univariate associations among age, SER and biometric parameters. Multiple regression analysis was performed to assess the association between SER and ocular biometric parameters using different models. All *P* values were two sided, and a *P*<0.05 was considered statistically significant.

RESULTS

Of 735 subjects were eligible, 46 were out of the range of age or had missing values of ocular parameters, 689 children (93.7%) aged 8 to12y were included in this research. Totally 321 (48.1%) of whom were boys and 368 (51.9%) were girls. There were 132 children aged 8y, 133 children aged 9y, 163 children aged 10y, 139 children aged 11y, and 123 children aged 12y. The mean age of all included participants was 9.98±1.37y, with no significant difference in gender (*P*=0.947). For each age group, the gender distributions were comparable (*P*=0.524). As a high correlation between right and left eye of SER (*r*=0.92), the data of right eyes were used to analyze in the study.

Table 1 showed the distributions of SER, ocular biometric parameters and AL/CR ratio by age and gender. The mean SER of all subjects was -2.98±1.47 D, and higher myopic refraction error was found in older age groups. In different age groups, there were no statistically significant differences in SER between boys and girls (all *P*>0.05). From 8 to 12y of age, both boys and girls showed a decreasing trend in mean SER. Figure 1 described the distributions of myopic refractive error in different age groups. SER was not normally distributed for all age groups except for the 12-year-old group. Age groups 8, 9, 10, 11 and 12y displayed significant trends of decreasing mean SER (-2.68, -2.81, -2.83, -3.28 and -3.32 D, respectively, *P* for trend<0.001), mean LP (22.92, 22.65, 22.46, 22.25 and 22.10 D, respectively, *P* for trend<0.001), but significant trends of increasing mean AL (24.44, 24.45, 24.65, 24.93 and 25.07 mm, respectively, *P* for trend<0.001), mean AL/CR ratio (3.14, 3.15, 3.17, 3.20 and 3.20, respectively, *P* for trend<0.001), mean ACD (3.25, 3.31, 3.32, 3.32 and 3.33 mm, respectively, *P* for trend=0.01) and

Table 1 Age-specific distributions of spherical equivalent refraction, ocular biometric parameters and axial length to corneal radius ratio for boys and girls

Characteristics	Age (y)					P^c
	8	9	10	11	12	
SER (D)						
Total	-2.68±1.32	-2.81±1.52	-2.83±1.41	-3.28±1.51	-3.32±1.51	<0.001
Girls	-2.75±1.35	-2.86±1.55	-3.00±1.30	-3.16±1.47	-3.26±1.47	0.022
Boys	-2.61±1.30	-2.76±1.49	-2.64±1.51	-3.43±1.56	-3.38±1.55	<0.001
P^a	0.537	0.712	0.099	0.305	0.659	
Skewness	-0.957	-0.988	-0.786	-0.527	-0.475	
Kurtosis	+0.804	+0.732	+0.759	-0.284	-0.071	
S-K	0.102	0.131	0.089	0.108	0.079	
P^b	0.002	<0.001	0.003	<0.001	0.056	
AL (mm)						
Total	24.44±0.77	24.45±0.81	24.65±0.75	24.93±0.89	25.07±0.86	<0.001
Girls	24.47±0.75	24.50±0.83	24.68±0.78	24.87±0.83	25.06±0.79	<0.001
Boys	24.42±0.79	24.41±0.80	24.62±0.72	24.97±0.97	25.09±0.92	<0.001
P^a	0.716	0.530	0.590	0.550	0.872	
Skewness	-0.234	+0.111	+0.183	+0.299	+0.012	
Kurtosis	+0.661	-0.569	+0.195	-0.184	-0.242	
S-K	0.049	0.053	0.053	0.053	0.039	
P^b	0.200	0.200	0.200	0.200	0.200	
CR (mm)						
Total	7.76±0.27	7.75±0.27	7.77±0.24	7.79±0.26	7.84±0.25	0.016
Girls	7.77±0.25	7.76±0.29	7.78±0.25	7.81±0.25	7.85±0.25	0.015
Boys	7.75±0.28	7.74±0.24	7.76±0.24	7.77±0.27	7.82±0.25	0.012
P^a	0.587	0.560	0.144	0.386	0.593	
Skewness	-0.276	-0.038	0.267	0.136	0.458	
Kurtosis	0.578	-0.126	0.129	0.025	1.155	
S-K	0.059	0.039	0.060	0.054	0.043	
P^b	0.200	0.200	0.200	0.200	0.200	
AL/CR ratio						
Total	3.14±0.09	3.15±0.09	3.17±0.09	3.20±0.10	3.20±0.10	<0.001
Girls	3.14±0.10	3.16±0.09	3.18±0.10	3.19±0.10	3.20±0.09	<0.001
Boys	3.15±0.18	3.15±0.08	3.17±0.08	3.20±0.10	3.20±0.11	<0.001
P^a	0.791	0.934	0.517	0.822	0.718	
Skewness	0.525	0.248	0.095	0.370	0.156	
Kurtosis	0.452	-0.307	-0.345	-0.120	-0.049	
S-K	0.060	0.044	0.061	0.064	0.056	
P^b	0.200	0.200	0.200	0.200	0.200	
ACD (mm)						
Total	3.25±0.20	3.31±0.22	3.32±0.22	3.32±0.21	3.33±0.23	0.010
Girls	3.24±0.20	3.33±0.25	3.33±0.22	3.32±0.21	3.32±0.25	0.156
Boys	3.28±0.21	3.30±0.19	3.32±0.22	3.33±0.22	3.34±0.21	0.068
P^a	0.320	0.561	0.286	0.847	0.596	
Skewness	-0.463	0.482	-0.020	0.042	-0.183	
Kurtosis	0.081	1.552	0.354	0.049	-0.647	
S-K	0.074	0.068	0.069	0.056	0.059	
P^b	0.077	0.200	0.057	0.200	0.200	

Table 1 Age-specific distributions of spherical equivalent refraction, ocular biometric parameters and axial length to corneal radius ratio for boys and girls (continued)

Characteristics	Age (y)					P^c
	8	9	10	11	12	
HVID (mm)						
Total	11.99±0.38	11.95±0.52	11.97±0.43	11.96±0.47	11.97±0.41	0.854
Girls	11.96±0.36	11.98±0.51	11.95±0.42	11.97±0.52	11.96±0.41	0.957
Boys	12.02±0.40	11.91±0.53	12.00±0.44	11.95±0.41	11.98±0.42	0.850
P^a	0.362	0.417	0.494	0.738	0.726	
Skewness	0.039	0.472	0.859	0.905	0.094	
Kurtosis	-0.332	3.101	3.510	1.643	0.123	
S-K	0.052	0.072	0.088	0.090	0.075	
P^b	0.200	0.190	0.078	0.095	0.084	
CCT (μm)						
Total	552.60±31.02	549.07±33.27	552.75±30.19	552.83±33.09	553.20±30.71	0.575
Girls	553.53±28.65	546.83±32.56	550.16±30.71	552.62±35.48	553.54±29.06	0.643
Boys	551.72±33.33	551.72±34.182	555.56±29.55	553.10±30.051	552.89±32.39	0.767
P^a	0.739	0.401	0.255	0.932	0.907	
Skewness	-0.076	0.235	-0.129	0.410	-0.281	
Kurtosis	0.107	0.682	-0.311	1.192	-0.450	
S-K	0.059	0.048	0.065	0.060	0.062	
P^b	0.200	0.200	0.200	0.200	0.200	
LP^d (D)						
Total	22.92±1.34	22.65±1.43	22.46±1.55	22.25±1.52	22.10±1.42	<0.001
Girls	22.98±1.31	22.69±1.55	22.43±1.43	22.07±1.48	22.02±1.22	<0.001
Boys	22.87±1.37	22.61±1.46	22.54±1.44	22.47±1.56	22.18±1.59	<0.001
P^a	0.664	0.880	0.615	0.122	0.556	
Skewness	-0.017	-0.166	0.019	-0.222	0.982	
Kurtosis	-0.553	-0.295	-0.376	1.159	2.686	
S-K	0.072	0.052	0.039	0.083	0.070	
P^b	0.096	0.200	0.200	0.083	0.200	

K-S: Kolmogorov-Smirnov test for normality; if P>0.05, the data deviate significantly from a normal distribution. P-value are 2-tailed; ^aP, ^bP calculated using student's t-test (unpaired samples), comparison between boys and girls in single age group adjusted by gender; ^cP calculated using analysis of variance (ANOVA; P for trend). ^{d}Lens power calculated according to Bennett's formula. Statistical significance was considered at the 0.05 level. SER: Spherical equivalent refraction; AL: Axial length; CR: Corneal radius; AL/CR ratio: Axial length to corneal radius ratio; ACD: Anterior chamber depth; CCT: Central corneal thickness; HVID: Horizontal visible iris diameter; LP: Calculated lens power; D: Diopters.

mean CR (7.76, 7.75, 7.77, 7.79 and 7.84 mm, respectively, P for trend=0.016), whereas HVID and CCT remained stable (both P for trend>0.05). There was no significant difference in gender (Figure 2). Besides, the increasing trend in ACD was observed in the total population, not found in either girls or boys. All ocular parameters were normally distributed for all age groups.

Figure 3 described the distributions of the prevalence of myopia categories in different age groups. In general, low myopia was the most common refractive status in 8- to 10-year-old age groups, while in 11- and 12-year-old age groups, more than a half of the children were moderate and high myopia (51.1% and 53.7%, respectively). The overall prevalence of high myopia was 4.2% (29/689), and the prevalence of high myopia of boys is higher than that in girls (5.3% *vs* 3.3%). The portions of children with moderate or high myopia from 8 to 12y of age showed a significantly increasing trend (P_{trend}<0.001), and boys and girls had no statistically significant differences (P=0.45).

The distribution of AL was normal in all age groups, and normal distribution for AL were observed in both of boys and girls. The mean AL of all the children was 24.70±0.84 mm, and there was no significant difference in sex (24.68 mm in the boys; 24.72 mm in the girls; P=0.49). The AL elongated at a rate of 0.18 mm/y in girls and 0.16 mm/y in boys when the data was analyzed as longitudinal change. The AL was positively correlated with age (r=0.279, P<0.0001) and negatively correlated with SER (r=-0.534, P<0.0001).

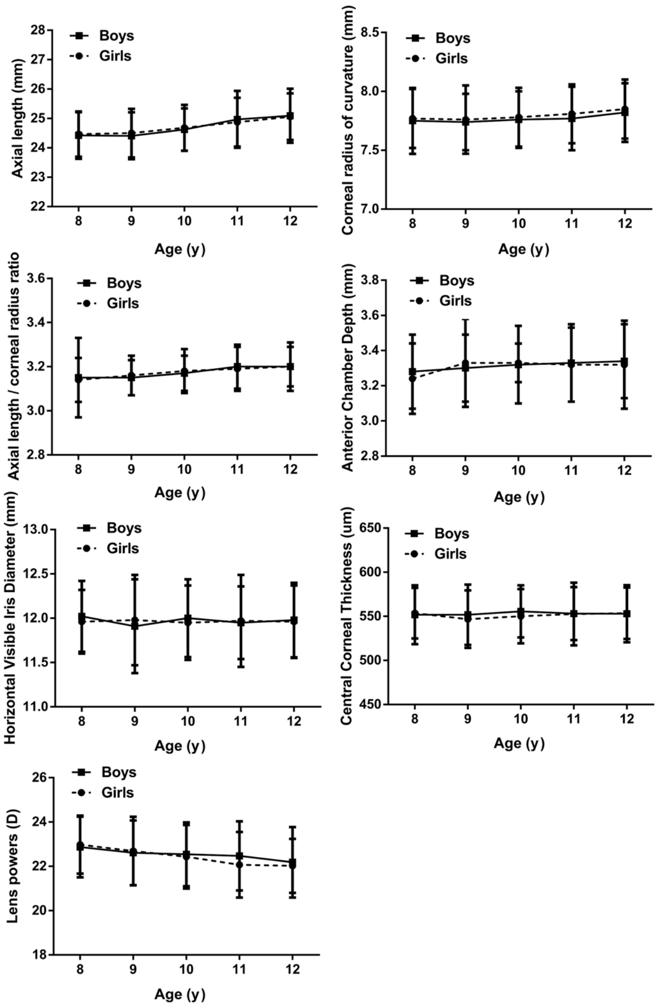

Figure 2 The changes of axial length, corneal radius of curvature, axial length to corneal radius ratio, anterior chamber depth, horizontal visible iris diameter, central corneal thickness, calculated lens power with age for boys and girls D: Diopters.

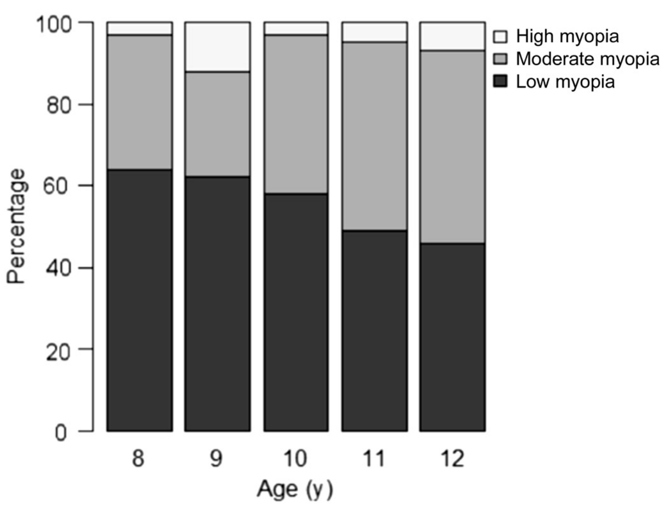

Figure 3 Stacked histogram showing age-specific distribution of the prevalence of myopic refractive error in the right eyes Low myopia, -3.00 D ≤SER<-0.50 D; moderate myopia, -6.00 D ≤SER<-3.00 D; high myopia, SER<-6.00 D. SER: Spherical equivalent refraction; D: Diopters.

From 8 to 12y of age, the CR was distributed normally in all age groups as well, and normal distribution for AL were found in both of boys and girls. The mean CR was 7.78±0.26 mm, with a slight increase of 0.07 mm, roughly 0.50 D corneal flattening. Boys and girls have the same CR (7.78 mm in the boys; 7.78 mm in the girls; *P*=0.90). Positive correlations were found between CR and SER (*r*=0.124, *P*=0.001) and between CR and age (*r*=0.091, *P*=0.017).

All age groups had a normal distribution of ACD, with a mean of 3.32±0.22 mm, with a slight deepening of 0.02 mm from 8 to 12y of age. There was no significant difference in gender (3.31 mm in the boys; 3.32 mm in the girls; *P*=0.76). The ACD was positively correlated with age (*r*=0.099, *P*=0.010) and negatively correlated with SER (*r*=-0.093, *P*=0.015).

Unlike AL, ACD and CR, the CCT and HVID tended to stabilize from 8- to 12-years old, with a mean CCT of 552.11±31.59 μm and mean HVID of 11.97±0.44 mm, respectively. Boys and girls have the same CCT (553.11 μm in the boys; 551.19 mm in the girls; *P*=0.426) and HVID (11.97 mm in the boys; 11.96 mm in the girls; *P*=0.80). No correlations were found between age and CCT and HVID, and no correlations were observed between SER and CCT and HVID in this population.

The AL/CR ratio was normally distributed in all age groups. The AL/CR ratio increased from 3.14 at 8 years of age to 3.20 at 12 years of age, with a mean of 3.17±0.10. No significant difference was found between boys and girls (3.17 *vs* 3.18, *P*=0.34). The AL/CR ratio was positively correlated with age (*r*=0.216, *P*<0.0001) and negatively correlated with SER (*r*=-0.747, *P*<0.0001).

The calculated LP distributed normally in all age groups, with a mean LP of 22.56±1.48 D, and indicated a downward trend, from 22.92±0.134 D at 8 years old to 22.10±1.42 D at 12 years of age, with a slight decrease of 0.82 D. There was no significant difference between boys and girls (22.62 D *vs* 22.51 D, *P*=0.36). The calculated LP was negatively correlated with age (*r*=-0.227, *P*<0.0001) and was not correlated with SER (*P*=0.645; Figure 4) in this study.

Multiple linear regression models were used to evaluate the correlations between SER and ocular biometrics parameters after adjusting for age and gender (Table 2). When only AL was included in the model 1 analysis, 29% of the variance in SER was explained, with a 1-mm increase in AL was associated with a -0.929 D change in SER. When both AL and CR were included analysis, the model 2 was able to explain 59.9% of the variance in SER. The AL was found to be negatively correlated with SER (*β*=-1.681; *P*<0.001), while the CR was observed to be positively related to SER (*β*=3.991; *P*<0.001). The model 3 assessed the correlation between SER and AL/CR ratio, and found that it explained 55.7% of the variance in SER. An increase of 0.1 unit in the AL/CR ratio was associated with a 1.144 D change in SER. Model 4 included LP, AL and CR,

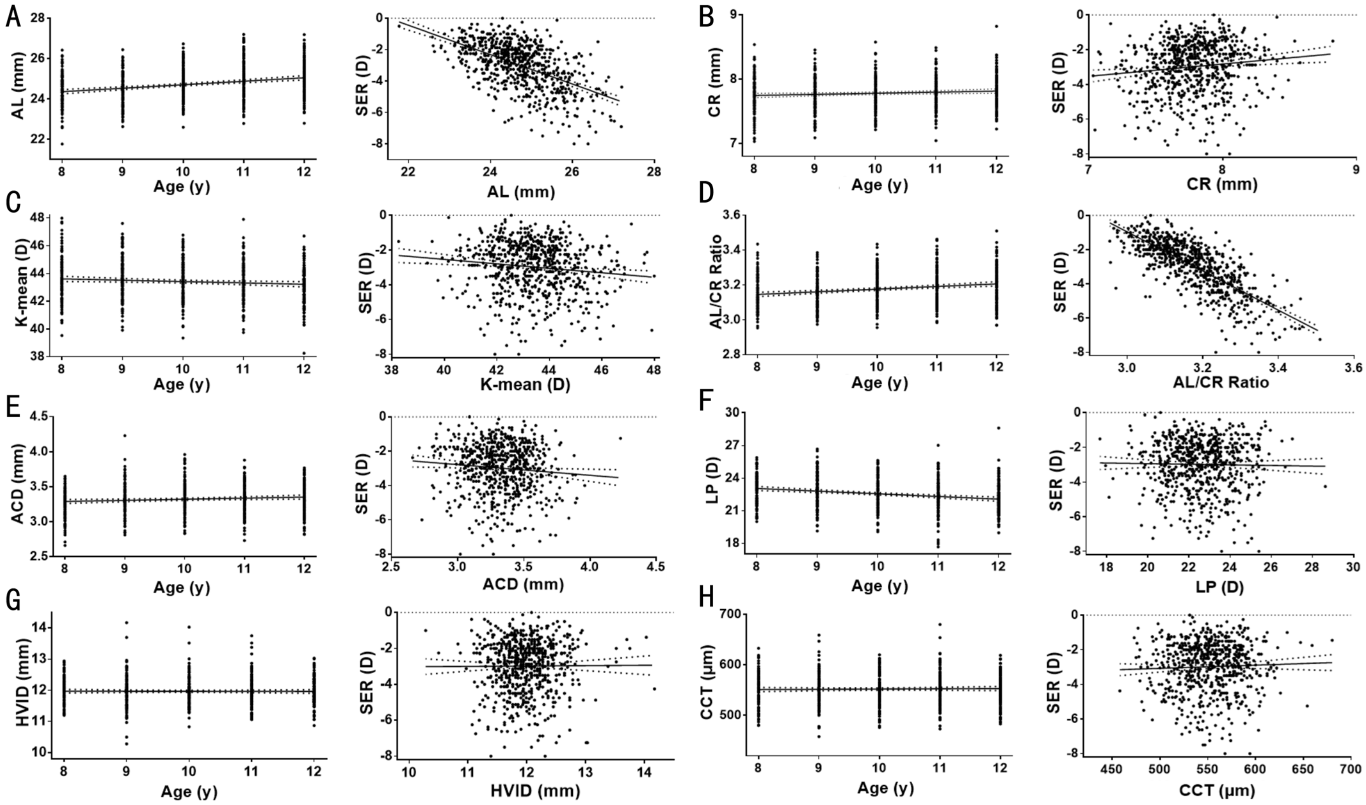

Figure 4 Scatterplot showing correlation of age with ocular biometric parameters and correlation of spherical equivalent refraction with ocular biometric parameters A: Axial length; B: Corneal radius of curvature; C: K_{mean}; D: Axial length to corneal radius ratio; E: Anterior chamber depth; F: Calculated lens power; G: Horizontal visible iris diameter; H: Central corneal thickness. SER: Spherical equivalent refraction; AL: Axial length; CR: Corneal radius; AL/CR ratio: Axial length to corneal radius ratio; ACD: Anterior chamber depth; CCT: Central corneal thickness; HVID: Horizontal visible iris diameter; LP: Calculated lens power; D: Diopters.

Table 2 Linear regression models for spherical equivalent refraction with age, gender, and ocular biometric parameters

Variables	Model 1		Model 2		Model 3		Model 4		Model 5	
	β^a	P	β	P	β	P	β	P	β	P
Age (y)	-0.014	0.704	0.048	0.078	-0.001	0.985	0.002	0.037	0.007	0.072
Gender	0.021	0.824	-0.021	0.766	-0.017	0.820	0.010	0.716	0.007	0.462
AL (mm)	-0.929	<0.001	-1.681	<0.001			-2.611	<0.001	-2.827	<0.001
CR (mm)			3.991	<0.001			5.570	<0.001	6.039	<0.001
AL/CR					-11.444	<0.001				
ACD									1.700	<0.001
LP (D)							-0.729	<0.001	-0.720	<0.001

The model R^2 shows the variation in SER explained by multivariate models that include age, gender and ocular biometric parameter as explanatory variables. [a]In regression models, SER was the dependent variable with each biometric variable as an independent variable. AL: Axial length; CR: Corneal radius of curvature; ACD: Anterior chamber depth; LP: Calculated lens power; D: Diopters. Adjusted for age, gender, and AL (R^2=0.29; P<0.001). Adjusted for age, gender, AL, and CR (R^2= 0.599; P<0.001). Adjusted for age, gender, and AL/CR (R^2= 0.557; P<0.001). Adjusted for age, gender, AL, CR, and LP (R^2= 0.94; P<0.001). Adjusted for age, gender, AL, CR, ACD and LP (R^2=0.993; P<0.001).

which can explain 94% of the variance in SER. When model 5 incorporates more ocular biometrics, including AL, CR, LP and ACD, it can explain 99.3% of the variance in SER, which was found to be negatively associated with AL (β=-2.827; P<0.001) and LP (β=-0.72; P<0.001), but positively associated with CR (β=6.039; P<0.001) and ACD (β=1.7; P<0.001).

Table 3 showed the correlation between SER and ocular biometric variables. The SER showed a better correlation with AL/CR ratio (r=-0.747) compared to either AL (r=-0.538) or CR (r=0.124) alone in this population. Significant correlations were observed between AL and ACD, CR, HVID and LP, but not in CCT. The CR was strongly correlated with AL, CCT and HVID, excepting for LP. More detailed Pearson correlation coefficient (r) of ocular biometrics was shown in Table 3.

DISCUSSION

This study documented the distribution of myopic refraction

Table 3 Correlation of spherical equivalent refraction with ocular biometric parameters

Parameters	Pearson correlation coefficient							
	SER	AL	ACD	CR	AL/CR	CCT	HVID	LP
SER	-	-0.538[b]	-0.093[a]	0.124[b]	-0.747[b]	0.040	0.006	-0.018
AL		-	0.313[b]	0.597[b]	0.481[b]	0.054	0.358[b]	-0.520[b]
ACD			-	-0.029	0.388[b]	-0.131[b]	0.467[b]	-0.267[b]
CR				-	-0.415[b]	0.117[b]	0.301[b]	-0.064
AL/CR					-	-0.068	0.078[a]	-0.519[b]
CCT						-	-0.056	-0.048
HVID							-	-0.210[b]
LP								-

The numbers represent Pearson correlation coefficient (*r*). D: Diopters; SER: Spherical equivalent refraction; AL: Axial length; CR: Corneal radius; AL/CR: Axial length to corneal radius ratio; ACD: Anterior chamber depth; CCT: Central corneal thickness; HVID: Horizontal visible iris diameter; LP: Calculated lens power. [a]$P<0.05$, [b]$P<0.01$.

error and ocular biometric parameters, and determined age-related changes in myopic refractive error and ocular parameters in a population-based sample of Chinese schoolchildren aged 8 to 12y.

Central Corneal Thickness and Horizontal Visible Iris Diameter In our analysis of the relationship between CCT and age, no significant variation in CCT was found with increasing age, which was similar to studies done by Chebil *et al*[18] and Zhou *et al*[19]. In contrast, however, several studies have reported the CCT undergo age-related changes[20-22]. Some studies have also found a correlation between CCT and refraction. Laiquzzaman *et al*[23] revealed that CCT correlates with refractive error and myopes have the thinnest CCT (449.65±39.27 μm), followed by emmetropes (542.66±46.35 μm) and hyperopes (557.67±41.83 μm). Chang *et al*[24] also reported that the corneas were thinner in more myopic eyes. However, Fam *et al*[25] found that CCT was not correlated with the degree of myopia in 714 Singaporean Chinese with an averaged refractive error of -5.3 D. In our study with a myopic population, we found no correlation between CCT and refractive error. Differences in age, race, the measurement methods and techniques may account for the discrepancy in the various studies.

Some studies reported that HVID is associated with age[26-29]. A study based on 39 986 eyes from 23 627 Chinese patients showed that a significant negative correlation between HVID and age[26]. However, Hashemi *et al*[30] and Gharaee *et al*[27] reported no significant correlation between HVID and age. In agreement with previous studies, we found no increase in HVID from 8 to 12y[28-31]. In our study, no correlation was observed between HVID and refractive error. However, Xu *et al*[28] investigated 7893 patients with the mean SER of -4.87±1.66 D and found that patients with higher myopic refractive error have a smaller HVID. Zha *et al*[32] also reported that myopia with degrees higher than 3.0 D have smaller HVID. Xu *et al*[28] speculated that the decrease of HVID with higher myopia was duo to posterior traction of the limbus caused by elongation of the eyeball. Therefore, based on the results in the population, the severity of myopia may have an impact on the size of the corneal diameter. But our findings confirmed that CCT and HVID are independent ocular biometrics unrelated to refractive error and age, playing insignificant roles in changing refractive error among myopic school-age children.

Axial Length, Anterior Chamber Depth and Lens Power Correlation analysis revealed that ACD was negatively correlated with SER, while LP had no correlation with SER. But in multivariate regression analysis, both ACD and LP appeared to influence SER. Our results showed that longer eyes correlated with a deeper ACD and lower LP. Since part of the lens is in the ACD, thinning of the lens may be one of the reasons for the increased ACD. Numerous studies have also demonstrated these results[14,33-35]. A study analyzed the data of 1133 preschoolers showed that children with an averaged SER of +1.37±0.63 D had a long AL and ACD and a less powerful lenses from 3 to 6y[14]. Another study also found the same results in 6-17-year-old population with a preponderance of hyperopia[36]. Therefore, above findings confirmed that whether hyperopic or myopic eyes, increasing in myopic refractive error was compensated by the elongation of AL, a deepening ACD and a smaller LP, which was consistent with studies done by Saw *et al*[37] and Zadnik *et al*[38] as well. In addition, these developmental patterns of ocular biometrics were similar observed in both boys and girls in this study. These findings followed the developmental pattern previously reported in school-age children, with axial elongation, an increase in ACD and a decrease in LP[39-40]. It is possible that a smaller LP and a deepening ACD may represent more active compensatory to counter the optical effect of axial elongation during myopia progression.

Corneal Curvature The corneal curvature is an important component for ocular dioptric power. Slightly change in this parameter can be related to a large change in refraction. Previous studies reported that the CR remains stable with age and it changes little from 5 to 14 years of age[9-10,37-38]. However, a multicenter study evaluating 30 618 healthy Chinese subjects revealed that the anterior and posterior corneal curvatures increased with age[20]. In a longitudinal study of 40 to 60 years old, 5-year changes in the K_{max} and K_{min} increased by 0.38±1.95 D and 0.46±1.97 D, respectively[41]. In contrast, Scheiman *et al*[42] found that the CR slightly but significantly flattens over 14 years of age. In this study, we observed that older children have flatter CR. The 0.08-mm change in the CR from 8 to 12 years of age caused approximately 0.50 D refractive error. A possible explanation for these conflicting results were that different age population were examined in various studies. The age factor might affect the corneal curvature to some extent. Furthermore, different keratometry devices used to measure corneal curvature may impact results, which may be related to the built-in devices and algorithms of different keratometry devices.

The cornea seems to change its shape to regulate refraction of the eyes. A flatter cornea was associated with higher myopic refractive error and longer AL in this sample. In agreement with previous studies, Long *et al*[43] found that the cornea of the myopic eyes is steeper than that of the hyperopic eyes at 4 to 6 years of age. Friedman *et al*[44] analyzed the data of 788 children aged 6y and 14y and concluded that the AL increases and the CR continues to flatten. Chen *et al*[45] reported that longer AL tends to have flatter cornea. This finding suggests that an excessive elongation in AL could lead to a reduction in CR. It is speculated that the CR may be actively modulated to regulate the refractive error, and myopia results from a failure of corneal compensation for axial elongation. Therefore, in addition to changes in LP and AL, corneal change was necessary to be considered in the assessment of refractive error in schoolchildren. The progressive flattening of corneal curvature may be a potential indicator of myopia progression. In view of this, for myopic children, it is necessary to pay attention to change in corneal curvature.

Axial Length to Corneal Radius Ratio In our study, the SER was strongly correlated with AL/CR ratio than AL alone. This result is similar to those of Guo *et al*[14] and Scheiman *et al*[42]. This finding indicates that the AL/CR ratio may be useful in monitoring myopia progression in this age range of children. The results of the multiple linear regression showed that among the variables that entered into the model, AL had the greatest effect on the SER. AL alone contributed 29% of the variance in SER, whereas AL/CR ratio accounted for 55.7%. He *et al*[46] reported that AL/CR ratio alone explained 66.4% of the variance in SER in a group of Chinese children 6 to 12y. Another study also found that AL explained up to 68% of the variance in East Asians 12y[11]. However, in Guo *et al*'s[14] study, they found AL alone contributed 18.6% of the variance in SER, whereas AL/CR ratio accounted for 39.8%, while AL, CR and LP explained 80.0% after adjusting for age and gender in the study population of preschoolers aged 3-6y. Differences in age and refractive state may account for these various results. Our study revealed that 99.3% of the variance in SER in myopic children can be explained by AL, LP, CR and ACD. Therefore, during myopia progression, AL, LP, CR and ACD are the most important determinants of myopic refractive error. The changes in LP, CR and ACD are not sufficient to compensate for the myopic drift in refraction caused by excessive elongation of AL, resulting in myopia progression.

Our study also has some limitations. The data of Beijing may be not representative for the rural areas and other regions in China. Another limitation of this study is that the analysis was cross-sectional design rather than longitudinal study. Although data from a cross-sectional sample of children are not longitudinal results, our age-specific data provide some insight into changing patterns of ocular biometrics with age. Admittedly, longitudinal studies would be needed to conduct to evaluate intraindividual discrepancy. Last, we only included myopic patients aged 8-12y in the study. Because the distribution pattern of refractive error and ocular biometry in children with different refractive states and age groups may be different, distributions of SER and ocular parameters in emmetropic and hyperopic children and other age groups children needs to be investigated in future studies.

In conclusion, our sample of 8-12-year-old myopic children showed significant trends towards lower SER, increased ACD, CR and AL, and decreased LP with increasing age. There were no significant changes in HVID or CCT. Boys and girls have similar developmental patterns of ocular parameters. The AL, CR, LP and ACD are the most important determinants of myopic refractive error during myopia progression. The progressive flattening of CR and decreasing LP may be potential indicators of myopia progression.

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REFERENCES

1 Baird PN, Saw SM, Lanca C, Guggenheim JA, Smith Iii EL, Zhou X, Matsui KO, Wu PC, Sankaridurg P, Chia A, Rosman M, Lamoureux EL, Man R, He M. Myopia. *Nat Rev Dis Primers* 2020;6(1):99.

2 Lee SS, MacKey DA. Prevalence and risk factors of myopia in young adults: review of findings from the raine study. *Front Public Health* 2022;10:861044.

3 Wang HX, Li YC, Qiu KL, Zhang RP, Lu XH, Luo L, Lin JW, Lu YL, Zhang D, Guo PT, Yang Y, Jing L, Huang YZ, Ma Q, Zhou RQ, Ou YX, Chen QW, Zhou YM, Deng DD, Li C, Yam JC, Chen LJ, Pang CP, Zhang MZ. Prevalence of myopia and uncorrected myopia among 721 032 schoolchildren in a city-wide vision screening in Southern China: the Shantou Myopia Study. *Br J Ophthalmol* 2023;107(12):1798-1805.

4 Holden BA, Fricke TR, Wilson DA, Jong M, Naidoo KS, Sankaridurg P, Wong TY, Naduvilath TJ, Resnikoff S. Global prevalence of myopia and high myopia and temporal trends from 2000 through 2050. *Ophthalmology* 2016;123(5):1036-1042.

5 Wang JY, Ying GS, Fu XJ, Zhang RH, Meng J, Gu F, Li JJ. Prevalence of myopia and vision impairment in school students in Eastern China. *BMC Ophthalmol* 2020;20(1):2.

6 Wang JL, Liu JN, Ma W, Zhang Q, Li R, He X, Liu LQ. Prevalence of myopia in 3-14-year-old Chinese children: a school-based cross-sectional study in Chengdu. *BMC Ophthalmol* 2021;21(1):318.

7 Yum HR, Park SH, Shin SY. Longitudinal analysis of refraction and ocular biometrics in preschool children with early-onset high myopia. *Sci Rep* 2023;13(1):22474.

8 Momeni-Moghaddam H, Hashemi H, Zarei-Ghanavati S, Ostadimoghaddam H, Yekta A, Khabazkhoob M. Four-year change in ocular biometric components and refraction in schoolchildren: a cohort study. *J Curr Ophthalmol* 2019;31(2):206-213.

9 Hashemi H, Pakzad R, Khabazkhoob M, Yekta A, Emamian MH, Fotouhi A. Ocular biometrics as a function of age, gender, height, weight, and its association with spherical equivalent in children. *Eur J Ophthalmol* 2021;31(2):688-697.

10 Lawrenson JG, Shah R, Huntjens B, Downie LE, Virgili G, Dhakal R, Verkicharla PK, Li DF, Mavi S, Kernohan A, Li TJ, Walline JJ. Interventions for myopia control in children: a living systematic review and network meta-analysis. *Cochrane Database Syst Rev* 2023;2(2):CD014758.

11 Chamberlain P, Lazon de la Jara P, Arumugam B, Bullimore MA. Axial length targets for myopia control. *Ophthalmic Physiol Opt* 2021;41(3):523-531.

12 Jakobsen TM, Hansen NC, Hvid-Hansen A, Møller F, Kessel L. Myopia in children and adolescents. *Ugeskr Laeger* 2023;185(48):V04230251.

13 Mutti DO, Mitchell GL, Jones LA, Friedman NE, Frane SL, Lin WK, Moeschberger ML, Zadnik K. Axial growth and changes in lenticular and corneal power during emmetropization in infants. *Invest Ophthalmol Vis Sci* 2005;46(9):3074-3080.

14 Guo XX, Fu M, Ding XH, Morgan IG, Zeng YF, He MG. Significant axial elongation with minimal change in refraction in 3- to 6-year-old Chinese preschoolers: the Shenzhen kindergarten eye study. *Ophthalmology* 2017;124(12):1826-1838.

15 Warrier S, Wu HM, Newland HS, Muecke J, Selva D, Aung T, Casson RJ. Ocular biometry and determinants of refractive error in rural Myanmar: the Meiktila Eye Study. *Br J Ophthalmol* 2008;92(12):1591-1594.

16 Bennett AG. A method of determining the equivalent powers of the eye and its crystalline lens without resort to phakometry. *Ophthalmic Physiol Opt* 1988;8(1):53-59.

17 Dunne MC, Barnes DA, Royston JM. An evaluation of Bennett's method for determining the equivalent powers of the eye and its crystalline lens without resort to phakometry. *Ophthalmic Physiol Opt* 1989;9(1):69-71.

18 Chebil A, Choura R, Falfoul Y, Fekih O, El Matri L. Central corneal thickness in a healthy Tunisian population. *Tunis Med* 2021;99(2):221-224.

19 Zhou Q, Gao TY, Fan SJ, Peng Y, Li L, Lin Z, Han W, Lin HS, Wang NL, Liang YB. Intraocular pressure, age, and central corneal thickness in a healthy Chinese children population: the Handan offspring myopia study. *Ophthalmic Epidemiol* 2022;29(5):499-506.

20 Ma RJ, Liu YY, Zhang L, Ma JN, Cui T, Lei YL, Hou J, Shen ZW, Yi XL, Liang G, Wang Y. Changes in corneal morphology with age in Asian population: a multicenter study of 30, 618 cases. *Adv Ther* 2021;38(12):5763-5776.

21 du Toit R, Vega JA, Fonn D, Simpson T. Diurnal variation of corneal sensitivity and thickness. *Cornea* 2003;22(3):205-209.

22 Almazrou AA, Abualnaja WA, Abualnaja AA, Alkhars AZ. Central corneal thickness of a Saudi population in relation to age, gender, refractive errors, and corneal curvature. *Cureus* 2022;14(10):e30441.

23 Laiquzzaman M, Tambe K, Shah S. Comparison of biomechanical parameters in penetrating keratoplasty and normal eyes using the Ocular Response Analyser. *Clin Exp Ophthalmol* 2010;38(8):758-763.

24 Chang SW, Tsai IL, Hu FR, Lin LL, Shih YF. The cornea in young myopic adults. *Br J Ophthalmol* 2001;85(8):916-920.

25 Fam HB, How AC, Baskaran M, Lim KL, Chan YH, Aung T. Central corneal thickness and its relationship to myopia in Chinese adults. *Br J Ophthalmol* 2006;90(12):1451-1453.

26 Wei L, He WW, Meng JQ, Qian DJ, Lu Y, Zhu XJ. Evaluation of the white-to-white distance in 39, 986 Chinese cataractous eyes. *Invest Ophthalmol Vis Sci* 2021;62(1):7.

27 Gharaee H, Abrishami M, Shafiee M, Ehsaei A. White-to-white corneal diameter: normal values in healthy Iranian population obtained with the Orbscan II. *Int J Ophthalmol* 2014;7(2):309-312.

28 Xu GH, Wu GR, Du ZJ, Zhu SQ, Guo YX, Yu HH, Hu YJ. Distribution of white-to-white corneal diameter and anterior chamber depth in Chinese myopic patients. *Front Med* 2021;8:732719.

29 Lee DW, Kim JM, Choi CY, Shin D, Park KH, Cho JG. Age-related changes of ocular parameters in Korean subjects. *Clin Ophthalmol* 2010;4:725-730.

30 Hashemi H, KhabazKhoob M, Yazdani K, Mehravaran S, Mohammad K, Fotouhi A. White-to-white corneal diameter in the Tehran Eye Study. *Cornea* 2010;29(1):9-12.

31 Jonuscheit S, Doughty MJ. Evidence for a relative thinning of the peripheral cornea with age in white European subjects. *Invest Ophthalmol Vis Sci* 2009;50(9):4121-4128.

32 Zha Y, Feng WQ, Han XH, Cai JQ. Evaluation of myopic corneal diameter with the Orbscan II Topography System. *Graefes Arch Clin Exp Ophthalmol* 2013;251(2):537-541.

33 Liu LJ, Jiang DD, Li CC, Lin YY, Zhou WZ, Xiao HS, Chen YY. Relationship between myopia progression and school entrance age: a 2.5-year longitudinal study. *J Ophthalmol* 2021;2021:7430576.

34 Iribarren R, Morgan IG, Nangia V, Jonas JB. Crystalline lens power and refractive error. *Invest Ophthalmol Vis Sci* 2012;53(2):543-550.

35 Zong Y, Li QC, Xu H, Yu J, Jiang CH, Sun XH. Measurement of the depths at different regions of the anterior chamber in healthy Chinese adults. *Int J Ophthalmol* 2020;13(1):135-140.

36 Lira RP, Arieta CE, Passos TH, Maziero D, Astur GL, do Espírito Santo ÍF, Bertolani AC, Pozzi LF, de Castro RS, Ferraz ÁA. Distribution of ocular component measures and refraction in Brazilian school children. *Ophthalmic Epidemiol* 2017;24(1):29-35.

37 Saw SM, Carkeet A, Chia KS, Stone RA, Tan DT. Component dependent risk factors for ocular parameters in Singapore Chinese children. *Ophthalmology* 2002;109(11):2065-2071.

38 Zadnik K, Manny RE, Yu JA, Mitchell GL, Cotter SA, Quiralte JC, Shipp M, Friedman NE, Kleinstein R, Walker TW, Jones LA, Moeschberger ML, Mutti DO; Collaborative Longitudinal Evaluation of Ethnicity and Refractive Error (CLEERE) Study Group. Ocular component data in schoolchildren as a function of age and gender. *Optom Vis Sci* 2003;80(3):226-236.

39 Zadnik K, Mutti DO, Mitchell GL, Jones LA, Burr D, Moeschberger ML. Normal eye growth in emmetropic schoolchildren. *Optom Vis Sci* 2004;81(11):819-828.

40 Twelker JD, Mitchell GL, Messer DH, Bhakta R, Jones LA, Mutti DO, Cotter SA, Klenstein RN, Manny RE, Zadnik K, CLEERE Study Group. Children's ocular components and age, gender, and ethnicity. *Optom Vis Sci* 2009;86(8):918-935.

41 Hashemi H, Asgari S, Emamian MH, Mehravaran S, Fotouhi A. Age-related changes in corneal curvature and shape: the shahroud eye cohort study. *Cornea* 2015;34(11):1456-1458.

42 Scheiman M, Gwiazda J, Zhang QH, Deng L, Fern K, Manny RE, Weissberg E, Hyman L, COMET Group. Longitudinal changes in corneal curvature and its relationship to axial length in the Correction of Myopia Evaluation Trial (COMET) cohort. *J Optom* 2016;9(1):13-21.

43 Long W, Zhao YM, Hu Y, Li ZY, Zhang XX, Zhao WC, Yang X, Cui DM, Trier K. Characteristics of corneal biomechanics in Chinese preschool children with different refractive status. *Cornea* 2019;38(11):1395-1399.

44 Friedman NE, Mutti DO, Zadnik K. Corneal changes in schoolchildren. *Optom Vis Sci* 1996;73(8):552-557.

45 Chen MJ, Liu YT, Tsai CC, Chen YC, Chou CK, Lee SM. Relationship between central corneal thickness, refractive error, corneal curvature, anterior chamber depth and axial length. *J Chin Med Assoc* 2009;72(3):133-137.

46 He XG, Zou HD, Lu LN, Zhao R, Zhao HJ, Li QQ, Zhu JF. Axial length/corneal radius ratio: association with refractive state and role on myopia detection combined with visual acuity in Chinese schoolchildren. *PLoS One* 2015;10(2):e0111766.