Crystalline Lens Power and Associated Factors in Highly Myopic Children and Adolescents Aged 4 to 19 Years

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- **PURPOSE:** To investigate the distribution characteristics of lens power in highly myopic Chinese children and adolescents and its association with age, axial length (AL), and spherical equivalent (SE).
- **DESIGN:** Cross-sectional study.
- **METHODS:** A total of 459 highly myopic (SE ≤ -5 diopter [D]) children and adolescents aged 4-19 years were included in the study. Participants underwent a series of ophthalmic examinations, which included AL, cycloplegic refraction, and Pentacam measurements. Lens power was calculated using Bennett's formula with its distribution described by age, AL, and SE. Multiple regression was conducted to analyze the associated factors of lens power.
- **RESULTS:** Greater lens power was independently associated with younger age, girls, shorter AL, and thicker lens thickness (standardized $\beta = -0.203$, 0.214, -0.379 and 0.492, respectively; all $P < .001$). However, a significant difference in lens power with age was only found in participants younger than 9 years, after which it reached a plateau (mean difference of 1.23 and 0.084 D per age group, respectively). Lens power was negatively associated with AL only in participants with AL <27 mm. No correlation was observed between lens power and SE.
- **CONCLUSION:** Among highly myopic children and adolescents, differences in lens power with age declined significantly after 9 years of age, which was 1 year earlier than non-high myopic patients in previous studies, which implied differences in pathophysiological process between non-high myopia and high myopia. The decoupling of lens power and AL in eyes >27 mm might represent the limited influence of AL on lens power. (Am J Ophthalmol 2021;223:169–177. © 2021 The Authors. Published by Elsevier Inc. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).)

MYOPIA, AS THE MOST COMMON REFRACTIVE ERror, affects >80% of young adults in East and Southeast Asia.[1] The concomitant prevalence of high myopia is also increasing, with predictions suggesting that the global prevalence will increase to 10% by 2050.[2] High myopia is associated with complications, such as myopic maculopathy, glaucoma, cataracts, and retinal detachment, which could result in irreversible vision loss and heavy financial burdens.[3,4] To date, the etiology and pathogenesis of myopia and high myopia are not entirely clear, although both genetic and environmental factors contribute to changes in ocular structures that essentially disrupt the balanced refractive status.

Crystalline lens power, as well as corneal power and axial length (AL), are the main ocular components of refractive status.[5] Studies have reported a stabilization of corneal power within 1-2 years after birth.[6,7] However, lens power loss could last for the whole lifespan, with its speed changing during different stages,[6,8] which is the critical component against myopic progression driven by the fast increasing of AL. During ocular growth, the onset and development of myopia among children and adolescents is mainly due to the imbalance between AL elongation and lens power reduction.[9,10] AL was reported to be negatively correlated with lens power in emmetropic and myopic individuals, whereas other studies demonstrated that lens power declined rapidly during childhood and stabilized at 10 years of age, with lens power changing faster in emmetropic individuals than that of myopic individuals. There is also a sudden loss of lens power before myopia onset.[11–13] However, the association of lens power with the development of high myopia in children and adolescents is still unclear, because refraction progression characteristics in non-high myopic and high myopic individuals are different.

Therefore, this cross-sectional study was conducted to explore the characteristics of lens power in highly myopic

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children and adolescents and to identify the associated factors of lens power to elucidate its potential role in high myopia.

METHODS

• **PARTICIPANTS:** A total of 585 children and adolescents with high myopia (spherical equivalent [SE] ≤−5 D) age 4-19 years old were enrolled in this study. Participants with organic eye diseases, including amblyopia, strabismus, moderate to severe ptosis, congenital cataract, and glaucoma, were excluded, and those who were unable to complete all examinations were not included in the final analysis. All participants and their guardians were informed of the study purpose and protocol. For participants older than 12 years, written informed consent was obtained from themselves and their guardians. For participants younger than 12 years, written informed consent was only obtained from their guardians, whereas oral consent was given by themselves before the examination. This study, which was approved by the Shanghai General Hospital Ethics Committee, adhered to the tenets of the Declaration of Helsinki.

• **MEASUREMENTS AND CALCULATIONS:** All participants underwent a series of ocular examinations administered by a trained team that consisted of an ophthalmologist, optometrists, coordinators, and nurses. In addition to the basic examination, which included height, weight, and visual acuity (uncorrected and corrected visual acuity), the AL was measured with an IOL Master 700 (Carl Zeiss Meditec, Germany); a signal-to-noise ratio >2 was considered eligible for study. If the difference in 2 consecutive AL readings was >0.02 mm, the procedure was repeated. The intraocular pressure (IOP) was measured with a noncontact tonometer (NT-510, Nidek, Japan). Thereafter, participants underwent a slit-lamp examination, which was performed by an ophthalmologist to guarantee the safety of cycloplegia. Participants with a peripheral anterior chamber depth (ACD) of less than one-half of the corneal thickness, with acute anterior segment inflammation, or with an IOP >24 mm Hg were excluded from the cycloplegia procedure. Cycloplegia was induced by 1 drop of 0.5% proparacaine (Alcaine, Alcon, USA) in each eye, followed by 2 drops of 1% cyclopentolate (Cyclogyl, Alcon, USA), with the drops administered 5 minutes apart. Approximately 30 minutes after the last drop of cyclopentalate was administered, an absence of light reflection and a pupil diameter >6 mm were considered to be successful cycloplegia. Thereafter, refractive status was measured with an autorefractor (KR-8900, Topcon, Tokyo, Japan) with 3 consecutive readings per eye. If any 2 measurements varied by >0.50 diopters (D), another 3 consecutive measurements were obtained and repeated until the variation between each 2 measurements within a set was <0.50 D. A Pentacam (Oculus Optikgeräte GmbH, Wetzlar, Germany) was used to obtain the biometric parameters of the ocular anterior segment, including the central corneal thickness (CCT), anterior and posterior corneal radii of curvature, ACD, and lens thickness (LT). All the examinations were performed from 10 AM to 3 PM each day to minimize the influence of circadian rhythms.

SE was calculated as follows: SE = spherical power + 0.5 × cylindrical power. High myopia was defined as an SE ≤−5 D of the more myopic eye, and participants who did not meet this criterion were excluded from the study. The corneal power (K, in D) was calculated from the CCT, anterior and posterior corneal radii curvature ($R_{m,a}$ and $R_{m,p}$), and the corneal refractive index ($n_c = 1.376$), as well as the refractive index of aqueous and vitreous humors ($n = 4/3$).[11,14–16]

$$K_{m,a} = \frac{n_c - 1}{R_{m,a}} \quad K_{m,p} = \frac{n - n_c}{R_{m,p}}$$

$$K = K_{m,a} + K_{m,p} - K_{m,a} \times K_{m,p} \times CCT / n_c$$

The calculation of crystalline lens power (P_L) was based on Bennett's formula, which was valid even in highly myopic eyes,[16] using measurements of ACD, LT, CCT, and AL; the calculation of SE, corneal power, and vitreous depth (V), as well as $c_1 = 0.596$ and $c_2 = -0.358$ were the estimated parameters by the Gullstrand-Emsley eye model. S_{cv} was the spherical refraction at the corneal vertex. In addition, the ACD in this formula contained the CCT, which was the same with that measured by Pentacam:

$$P_L = \frac{-1,000n(S_{cv} + K)}{1,000n - (ACD + c_1 LT)(S_{cv} + K)} + \frac{1000n}{-c_2 LT + V}$$

$$S_{cv} = \frac{SE}{1 - 0.014 \times SE}$$

$$V = AL - ACD - LT$$

• **STATISTICAL ANALYSES:** All participants' data were compiled using a self-designed comprehensive database system (Gaussinfomad, Beijing, China) with in-built logic to import data from the auto-refractor, IOL-Master and Pentacam. We randomly used the cleaned data of the right eye for analysis, and analyses were performed with SPSS (version 25.0; IBM, Armonk, New York, USA). Descriptive analysis of continuous variables, such as SE or AL, were described as mean ± SD, whereas discrete variables were described as counts (proportions). There were 4 main parts of our analysis. First, distribution of lens power was examined using the Kolmogorov-Smirnov test. Student's *t*-test was used for comparing the differences between

TABLE 1. Characteristics of Participants Included and Excluded (Mean ± SD)

Variables	Included, N = 459	Excluded, N = 126	*P* Value
Age, year[a]	13.10 ± 2.93	11.92 ± 3.86	.002[c]
Gender—boys, N (%)[b]	219 (47.7)	59 (46.8)	.860
Axial length, mm[a]	26.71 ± 1.09	26.39 ± 1.33	.006[c]
Spherical equivalent, D[a]	−8.34 ± 1.99	−8.58 ± 2.84	.382
Anterior chamber depth, mm[a]	3.34 ± 0.22	3.31 ± 0.32	.361
Corneal power, D[a]	41.82 ± 1.37	42.28 ± 2.81	.102
Height, cm[a]	160.1 ± 14.9	151.1 ± 20.3	<.001[c]

[a] Statistical significance was tested by Student's t-test.
[b] Statistical significance was tested by Person chi-square test.
[c] $P < .05$.

TABLE 2. Characteristics of Included Highly Myopic Participants by Gender

Variables (Mean ± SD)	Total, N = 459	Boys, N = 219	Girls, N = 240	*P* Value[a]
Age, years	13.10 ± 2.93	13.26 ± 2.80	12.94 ± 3.04	.238
Axial length, mm	26.71 ± 1.09	26.98 ± 1.05	26.45 ± 1.06	<.001[b]
Spherical equivalent, D	−8.34 ± 1.99	−8.26 ± 1.87	−8.42 ± 2.09	.369
Lens power, D	24.17 ± 1.58	23.61 ± 1.51	24.67 ± 1.48	<.001[b]
Lens thickness, mm	3.38 ± 0.16	3.38 ± 0.16	3.39 ± 0.15	.458
Corneal power, D	41.82 ± 1.37	41.60 ± 1.39	42.01 ± 1.33	.001[b]
Central corneal thickness, μm	550.79 ± 40.96	555.22 ± 32.64	546.75 ± 46.99	.027[b]
Anterior chamber depth, mm	3.34 ± 0.22	3.39 ± 0.22	3.29 ± 0.21	<.001[b]
Height, cm	160.1 ± 14.9	164.8 ± 15.4	155.8 ± 13.1	<.001[b]

[a] Statistical significance was tested by Student's t-test.
[b] $P < .05$.

sexes. Second, analysis of variance (ANOVA) was performed for the distribution of crystalline lens power with age and AL, and the Student-Newman-Keuls method was used for *post hoc* tests. Third, correlations between lens power, age, sex, AL, SE, LT, and corneal power were checked. Last, a multiple linear regression model was used to observe the lens power—associated factors. Subgroup analysis of multiple regression was also conducted by age and AL group. Statistical significance was defined as $P < .05$ (2-tailed).

RESULTS

- **PARTICIPANTS' CHARACTERISTICS:** A total of 459 (78.5%) participants were included in the final analysis, with 129 subjects excluded for non-cooperation during the examinations. The included subjects were older (13.10 ± 2.93 years vs 11.92 ± 3.86 years; $P = .002$), and taller (160.1 ± 14.9 cm vs 151.1 ± 20.3 cm; $P < .001$), and had longer AL (26.71 ± 1.09 mm vs 26.39 ± 1.33 mm; $P = .006$) than the excluded subjects (Table 1). No statistical differences were observed in the sexes, SE, ACD, and corneal power ($P = .860$, .382, .361, and .102, respectively) between the included and excluded subjects.

The general characteristics of these 459 participants are listed in Table 2. The mean age of these highly myopic children and adolescents was 13.10 ± 2.93 years; 219 (47.7%) were boys. The mean lens power was 24.17 ± 1.58 D, and its frequency distribution graph had an approximate Gaussian shape (Figure 1). Boys were taller, with a relatively deeper ACD and longer AL than those in girls (all $P < .001$), whereas there were no statistical differences in age and SE ($P = .238$ and .369, respectively). In addition, lens power (23.61 ± 1.51 D vs 24.67 ± 1.48 D; $P < .001$) and corneal power (41.60 ± 1.39 D vs 42.01 ± 1.33 D; $P = .001$) were significantly lower in boys than those in girls.

- **IMPACT OF AGE:** Lens power was negatively correlated with age in participants with high myopia when performing both Pearson's correlation analysis ($r = -0.379$; $P < .001$)

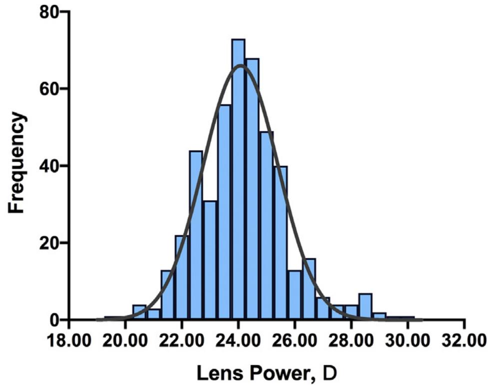
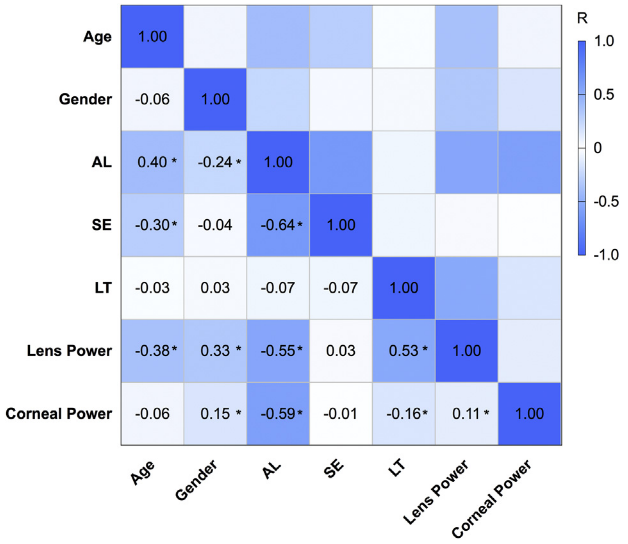


FIGURE 1. The distribution of lens power for all of the included participants (N = 459). Its frequency distribution graph had an approximate Gaussian shape. D = diopter.

(Figure 2) and one-way ANOVA (*P* < 0001; *P*-trend <.001) (Table 3). Differences in lens power between age groups were greater in participants younger than 9 years old, with a mean decreased power of 1.23 D per age, after which these differences became much smaller (mean deceased power of 0.084 D per age) (Figure 3, A). *Post hoc* analysis with the Student-Newman-Keuls method also indicated that there were negligible changes in lens power after 9 years of age (because they were all in the same subset). Concomitantly, LT and AL differed significantly before and after the age of 9 years (Figure 3, B and C). The distribution of LT with age displayed as an approximate U-type, and LT fell to the trough after the age of 9 years. Similarly, differences in AL between age groups also became smaller after the age of 9 years (0.597 mm vs 0.053 mm per age before and after 9 years old) (Table 3).

- **IMPACT OF AL AND SE:** In participants with high myopia, lens power showed a declining trend with a longer AL by ANOVA (*P* < .001, *P*-trend < .001) (Table 4). There was a negative correlation between lens power and AL (r = −0.546; *P* < .001) (Figure 2), as well as with age and sex-adjusted characteristics (r = −0.421; *P* < .001). However, AL was no longer significantly correlated with lens power when the AL was >27 mm (for group AL <26 mm: r = −0.454, *P* < .001; for group 26 mm ≤ AL <27 mm: r = −0.200, *P* = .009; for group 27 mm ≤ AL <28 mm: r = −0.044; *P* = .626; for group AL >28 mm: r = −0.103; *P* = .496) after adjusting for age and sex. As shown in the scatterplot (Figure 4), the slope of the fitting curve became smaller and smaller, which represented that differences in lens power had a decreasing tendency with AL elongation. However, different from AL, no significant correlation was shown between lens power and SE among highly myopic subjects (r = 0.033; *P* = .481) (Figure 2).

- **ASSOCIATION WITH AGE AND AL:** As shown in Table 5, when performing multiple regression analysis, greater lens power was independently associated with younger age (standardized β = −0.203; *P* < .001), girls (standardized β = 0.214; *P* < .001), shorter AL (standardized β = −0.379; *P* < .001) and thicker LT (standardized β = 0.492; *P* < .001) in high myopic subjects. After adjusting for other factors, the negative association between lens power and age was more evident among participants younger than 9 years old (β = −0.519 and −0.070 in the younger than 9-year-old group and the 9-year-old or older group; *P* < .001 and *P* = .001, respectively). Age had the least impact on the lens power in the 9-year-old or older group than the other factors (standardized β of age = −0.115; *P* = .001). In contrast, LT revealed an independent positive correlation with lens power only in the 9-year-old or older group (β = 1.587 and 4.877 in the younger than 9-year-old group and 9-year-old or older group; *P* = .274 and *P* < .001, respectively). The correlation between the lens power and AL was similar between these 2 age groups (β = −0.680 and −0.524, respectively; *P* < .001). However, the correlation between the lens power and AL disappeared when the AL was >27 mm with age, sex and LT controlled (for group AL <26 mm: β = −0.837, *P* < .001; for group 26 mm ≤ AL <27 mm: β = −0.814, *P* = .001; for group 27 mm ≤ AL <28 mm: β = −0.400, *P* = .250; for group AL >28 mm: β = −0.283, *P* = .223) (Table 6).



	Age	Gender	AL	SE	LT	Lens Power	Corneal Power
Age	1.00						
Gender	-0.06	1.00					
AL	0.40 *	-0.24 *	1.00				
SE	-0.30*	-0.04	-0.64 *	1.00			
LT	-0.03	0.03	-0.07	-0.07	1.00		
Lens Power	-0.38*	0.33 *	-0.55 *	0.03	0.53 *	1.00	
Corneal Power	-0.06	0.15 *	-0.59*	-0.01	-0.16*	0.11 *	1.00

FIGURE 2. The correlation between lens power and other associated factors. The numbers represent correlation coefficient (R). Significant differences are masked by asterisks. AL = axial length; LT = lens thickness; SE = spherical equivalent.

DISCUSSION

TO OUR KNOWLEDGE, THIS STUDY WAS THE FIRST TO INVESTIGATE the characteristics of crystalline lens power and its associated factors in a population of highly myopic children

TABLE 3. Distribution of Lens Power and Other Refractive Parameters by Age (Mean ± SD)

Age, Year	N	Lens Power, D	Subsets[b]	AL, mm	SE, D	LT, mm
≤6[a]	10	28.15 ± 1.41	1	24.53 ± 1.31	−6.41 ± 2.68	3.52 ± 0.13
7	10	25.78 ± 0.85	2	25.89 ± 1.05	−6.80 ± 2.53	3.44 ± 0.13
8	17	25.70 ± 1.34	2	25.57 ± 0.94	−7.19 ± 1.89	3.45 ± 0.11
9	19	24.46 ± 1.44	3	26.32 ± 1.05	−7.76 ± 2.68	3.36 ± 0.17
10	20	23.71 ± 1.56	3	26.42 ± 1.17	-6.70 ± 1.85	3.35 ± 0.17
11	46	24.67 ± 1.43	3	26.24 ± 0.86	−7.76 ± 1.85	3.35 ± 0.16
12	44	24.44 ± 1.40	3	26.73 ± 0.91	−8.62 ± 1.72	3.38 ± 0.15
13	74	23.62 ± 1.41	3	26.90 ± 1.00	−8.49 ± 1.82	3.34 ± 0.17
14	72	23.89 ± 1.61	3	26.98 ± 0.91	−8.61 ± 1.69	3.38 ± 0.15
15	48	23.95 ± 1.33	3	27.08 ± 1.11	−9.01 ± 2.26	3.40 ± 0.13
16	44	23.59 ± 1.13	3	27.05 ± 1.02	−8.90 ± 1.70	3.40 ± 0.16
17	35	23.92 ± 1.25	3	27.11 ± 0.76	−9.09 ± 1.69	3.38 ± 0.20
≥18[a]	20	23.70 ± 1.02	3	26.80 ± 1.09	−8.34 ± 1.99	3.43 ± 0.10

AL, axial length; SE, spherical equivalent; LT, lens thickness.

[a] The age group ≤6 contains four 4-year-old and four 5-year-old subjects; the age group ≥18 contains three 19-year-old subjects.

[b] Homogeneous subsets was divided using Student-Newman-Keuls (SNK) method.

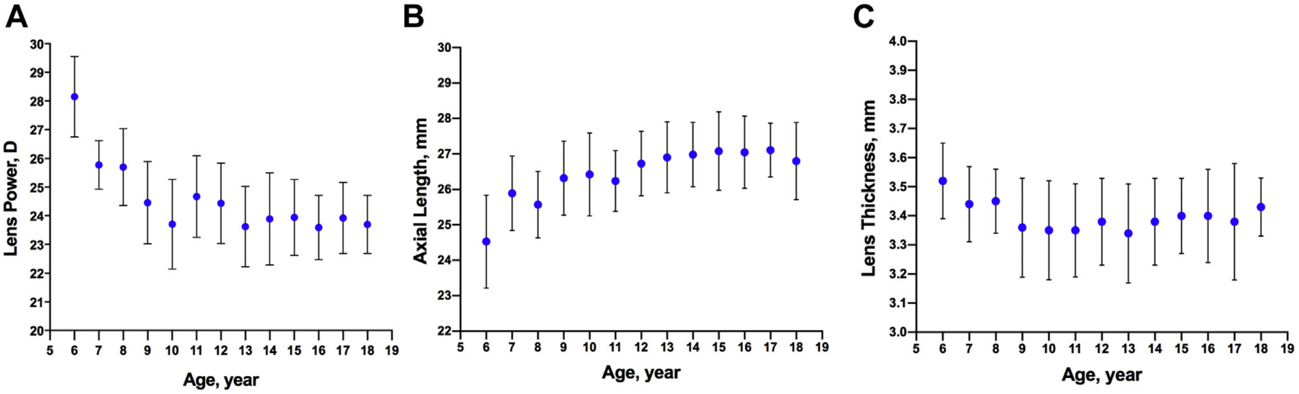


FIGURE 3. Differences of lens power, lens thickness and axial length by age. (A) The mean lens power (diopters [D]) stratified by age. (B) The mean lens thickness (mm) stratified by age. (C) The mean axial length (mm) stratified by age. The 6-year-old group contains four 4-year-old and four 5-year-old subjects; the 18-year-old group contains three 19-year-old subjects.

and adolescents. The results revealed that lens power showed an obvious decreasing trend with age in those with high myopia who were younger than 9 years old, after which it came to a near plateau. In addition, lens power was negatively correlated with AL only when AL was not >27 mm, whereas no significant association was observed between lens power and SE.

Our results indicated that lens power exhibited 2 stages among highly myopic children and adolescents (stage I: 4-9 years old, stage II: 9-19 years old), which was similar with the results of previous studies in non-high myopic individuals.[11,17] Differences in lens power at stage I (mean difference of 1.23 D per age) were much greater than those at stage II (mean difference of 0.084 D per age). In addition, the impact of age on lens power was much smaller at stage II with other confounding factors controlled. These changes of lens power with age seemed to be an inherent and passive process during lens growth, accompanying the changes of LT. At stage I, LT also decreased significantly with age. Because the lens fibers started to differentiate and compact since early life,[18] the lens gradually thinned as the compaction rate of the lens nucleus outpaced the synthesis speed of the fibers in the cortex.[19,20] Furthermore, because the equatorial diameter growth was achieved at approximately 90% before the age of 3 years, the lens gradually flattened from its rounded ellipsoidal shape with a relative stable equatorial diameter.[21,22] On one hand, as a consequence of lens thinning, the lens lost its surface power as its anterior and posterior curvatures became flatter[23]; on the other hand, the lens lost its internal power because there was

TABLE 4. Distribution of Lens Power and Other Refractive Parameters by AL

AL, mm	AL ≤ 26	26 < AL ≤ 27	27 < AL ≤ 28	AL > 28	*P* [a]	*P-Trend* [a]
N	109	174	128	48	/	/
AL, mm	25.31 ± 0.73	26.54 ± 0.29	27.45 ± 0.28	28.51 ± 0.53	<.001[b]	<.001[b]
Lens power, D	25.29 ± 1.63	24.25 ± 1.27	23.57 ± 1.41	22.92 ± 1.22	<.001[b]	<.001[b]
LT, mm	3.41 ± 0.15	3.37 ± 0.15	3.37 ± 0.16	3.39 ± 0.16	.277	.550
Corneal power, D	42.90 ± 1.36	41.96 ± .111	41.29 ± 0.97	40.26 ± 1.01	<.001[b]	<.001[b]
SE, D	−6.69 ± 1.73	−8.22 ± 1.51	−9.24 ± 1.64	−10.14 ± 2.03	<.001[b]	<.001[b]
ACD, mm	3.29 ± 0.23	3.34 ± 0.21	3.38 ± 0.23	3.33 ± 0.21	.042[b]	.232

AL, axial length; LT, lens thickness; SE, spherical equivalent; ACD, anterior chamber depth.

[a] Statistical significance was tested by one-way ANOVA.

[b] $P < .05$.

more climbing gradient of the refractive index from the surface to the higher peak in the center in the thinner lens.[6,24,25] At stage II, LT started to increase due to the enhanced synthesis of fibers in the newly developed cortex and the reduced maturation and compaction of fibers in the nucleus.[19] Although the surface power of the lens increased as its curvature became steeper, total lens power still decreased because the continuously compacting nucleus rendered the gradient of the refractive index more abrupt. Therefore, differences in the lens power with age were much smaller during this stage because the increasing surface power partially offset the decline of the internal power.

The cutoff point for the 2 previously mentioned stages in this young highly myopic population may be 1 year earlier than that reported in previous studies with non-high myopic subjects. We previously found this turning point to be 10 years old in a cohort of Chinese children and adolescents with a mean SE of 0.39 ± 2.08 D.[11] Several longitudinal studies indicated that the rate of lens power loss significantly slowed down after the age of 10 years.[12,17] However, all these studies focused on the changes in lens power around the time of myopia onset, rather than its role among young high myopic individuals. We hypothesized that, for highly myopic children and adolescents with longer AL, this earlier deceleration of lens power loss might reflect different pathophysiological processes between myopia and high myopia, which were influenced by both genetic and environmental factors. The ocular growth began earlier in high myopic individuals than non-high myopic individuals. Meanwhile, lens power loss, as the compensation mechanism for AL elongation, might be induced earlier as well. The rate of fiber synthesis in the newly developed cortex might catch up with the maturation and compaction of the nucleus at a younger age. Therefore, the lens power arrived at a plateau earlier after the LT reached its lowest point.

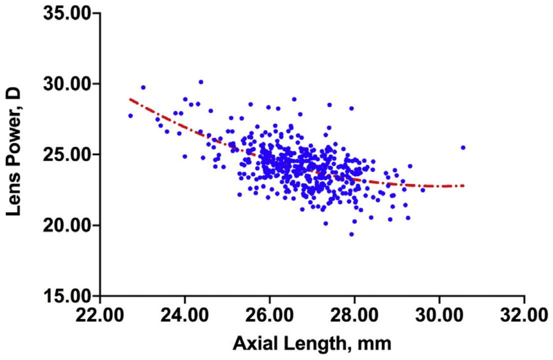


FIGURE 4. The relationship between lens power and axial length (polynomial fitting). Lens power demonstrated a negative corelation with axial length. D = diopter.

We also identified a negative correlation of the lens power with AL, which decreased gradually with AL elongation. In addition no significant association between lens power and AL was observed for eyes >27 mm. This finding indicated that the compensatory ability of the lens power might be limited and became less effective in longer eyes. Although no data has revealed this phenomenon among highly myopic children and adolescents before, there is some evidence to support this study. We previously reported that the lens power had a stronger association with AL in non-myopic subjects than that in myopic subjects after adjusting for age, sex, and LT, which might have been due to the fact that myopic subjects had a longer AL.[11] Several longitudinal studies also reported a sudden lost of lens power at myopia onset, after which the lens power loss became slower.[12,26]

Therefore, we speculated that, in addition to the natural reduction with age, the lens could actively reduce its power in adaption for AL elongation, but this kind of compensatory mechanism became weaker with increase of AL. No significant association between lens power and AL existed when the AL was beyond the compensation range of lens

TABLE 5. Multiple Regression of Lens Power among Different Age Groups

Variables	Total, N = 459 (R^2 = 0.613)				Age < 9, N = 37 (R^2 = 0.663)				Age ≥ 9, N = 422 (R^2 = 0.541)			
	β	95% CI	Standardized β	P [a]	β	95% CI	Standardized β	P [a]	β	95% CI	Standardized β	P [a]
Age, year	−0.110	(−0.144,−0.076)	−0.203	<.001[b]	−0.519	(−0.764,−0.274)	−0.444	<.001[b]	−0.070	(−0.111,−0.029)	−0.115	.001[b]
AL, mm	−0.554	(−0.648,−0.460)	−0.379	<.001[b]	−0.680	(−1.001,−0.359)	−0.490	<.001[b]	−0.524	(−0.622,−0.426)	−0.366	<.001[b]
LT, mm	4.950	(4.373,5.526)	0.492	<.001[b]	1.587	(−1.318,4.493)	0.120	.274	4.877	(4.287,5.468)	0.540	<.001[b]
Gender	0.679	(0.492,0.866)	0.214	<.001[b]	0.315	(−0.370,1.000)	0.093	.356	0.697	(0.506,0.887)	0.244	<.001[b]

AL, axial length; LT, lens thickness.

[a] Statistical significance was tested by multiple linear regression.

[b] $P < .05$.

power, possibly due to the restricted equatorial growth of the lens.[11] This phenomenon might be the reason of the close correlation between SE and AL among high myopic individuals. Because corneal power was reported to be stabilized in a few years after birth, AL and lens power were the major determinant factors of SE. However, among high myopic individuals with longer AL, changes in SE might be fully explained by changes in AL when it is beyond the compensatory limit of lens power loss. Especially for highly myopic children and adolescents who are still undergoing the rapid stage of ocular development, significant myopic progression in SE might happen with AL elongation compared with the limited compensatory effect of lens power loss. Longitudinal data are still being collected for further investigation of lens power changing in young high myopic children.

Logically, there was no correlation between lens power and SE in high myopic children, which might have been associated with the significant imbalance between lens power and AL. Lens power loss represented a compensatory mechanism against myopic progression, which might be driven by AL elongation. However, in highly myopic children and adolescents, lens power loss could not catch up with AL elongation, thereby causing the SE to become more myopic. We previously reported a significant positive correlation between lens power and SE only in non-high myopic participants (SE > −5 D). No significant difference of lens power was observed between moderate and high myopic individuals, which was in agreement with our present results.[11] In addition, no difference was revealed between lens power and SE in adults of all refractive groups as reported by Sien and colleagues.[27]

There were several limitations in our study. First, the lens power was calculated using Bennett's formula in the absence of direct measurements of anterior and posterior radii of the lens by phakometry, and there were errors in approximately 5% of cases. However, a study reported good agreement between lens power calculated using Bennett's formula and that measured by phakometry.[17] Second, lens power failed to be associated with AL based on the Bennett's formula, by which it was calculated with AL measurements. However, population-based studies are still needed to make comparisons of this correlation by age or AL groups to investigate its potential rules. Third, the age distribution was asymmetric, with a small number of younger participants (56 participants younger than 9 years of age, accounting for 12.2%), because young children with high myopia are relatively uncommon. Also, several young patients were unable to cooperate during the Pantacam examination. Young participants with high myopia were continuously screened for possible inclusion in this study. Fourth, results about the decoupling of lens power and AL were based on the *post hoc* subgroup analysis, which might result in some false positive errors. We would enroll more subjects for further verification in the future. Finally, this was a cross-sectional study. Therefore, only

TABLE 6. Multiple Regression of Lens Power among AL Groups

Variables	β	95% CI	Standardized β	P [a]
AL ≤ 26, N=109 ($R^2 = 0.614$)				
Age, year	−0.138	(−0.200, −0.076)	−0.296	<.001[b]
AL, mm	−0.837	(−1.134, −0.539)	−0.373	<.001[b]
LT, mm	4.515	(3.170, 5.860)	0.411	<.001[b]
Gender	0.574	(0.155,0.993)	0.163	.008[b]
26 < AL ≤ 27, N = 174 ($R^2 = 0.523$)				
Age, year	−0.092	(−0.140, −0.043)	−0.200	<.001[b]
AL, mm	−0.814	(−1.280, −0.348)	−0.183	.001[b]
LT, mm	4.995	(4.130, 5.860)	0.599	<.001[b]
Gender	0.747	(0.480, 1.013)	0.293	<.001[b]
27 < AL ≤ 28, N = 128 ($R^2 = 0.395$)				
Age, year	−0.106	(−0.196, −0.016)	-0.165	.022[b]
AL, mm	−0.400	(−1.086, 0.286)	−0.080	.250
LT, mm	5.450	(4.231, 6.668)	0.627	<.001[b]
Gender	0.403	(0.012, 0.793)	0.142	.043[b]
AL > 28, N = 48 ($R^2 = 0.557$)				
Age, year	0.007	(−0.120, 0.135)	0.012	.907
AL, mm	−0.283	(−0.746, 0.179)	−0.123	.223
LT, mm	3.595	(2.211, 4.980)	0.527	<.001[b]
Gender	1.671	(1.099, 2.243)	0.581	<.001[b]

AL, axial length; LT, lens thickness.

[a] Statistical significance was tested by multiple linear regression.

[b] $P < .05$.

the distribution, rather than changes in the lens power with increasing age and AL elongation, could be obtained. A follow-up study of this population with longitudinal results is being conducted.

CONCLUSIONS

IN CONCLUSION, IN THIS YOUNG POPULATION WITH HIGH myopia, difference in lens power with age decreased significantly after age 9 years, which was 1 year earlier than that reported in previous studies with a non-highly myopic population. It might reflect differences in the pathophysiological process between non-high myopia and high myopia. Furthermore, decoupling of lens power and AL was observed in eyes >27 mm, whereas no correlation was shown between lens power and SE, which might imply that influence of refraction and AL on lens power was limited in high myopic children.

CRediT AUTHORSHIP CONTRIBUTION STATEMENT

TIANYU CHENG: WRITING - ORIGINAL DRAFT, WRITING - review & editing, Formal analysis, Methodology, Investigation. **Junjie Deng:** Writing - review & editing, Methodology, Investigation. **Shuyu Xiong:** Writing - review & editing, Methodology. **Suqin Yu:** Writing - review & editing, Methodology. **Bo Zhang:** Methodology, Investigation. **Jingjing Wang:** Writing - review & editing, Formal analysis. **Wei Gong:** Writing - review & editing, Investigation. **Huijuan Zhao:** Methodology, Investigation. **Mengli Luan:** Methodology, Investigation. **Mengjun Zhu:** Methodology, Investigation. **Jianfeng Zhu:** Methodology. **Haidong Zou:** Methodology. **Xian Xu:** Writing - review & editing, Methodology, Investigation. **Xiangui He:** Writing - review & editing, Formal analysis, Methodology, Investigation. **Xun Xu:** Writing - review & editing, Formal analysis, Methodology, Investigation.

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