Lens power plays an important role in the determination of refractive status. Most children are born hyperopic. During the early childhood development period, the lens loses power from infancy to school age at a rapid rate that slowly but continually decreases from ages 10 to 14.\(^ {3,4,11}\) In adulthood, the lens power exhibits a monotonous decrease with age with a steeper decline after age 50.\(^ {13,14}\) However, the changes in lens power in adolescents aged 14 to 18 years have not yet been reported. Additionally, the relationship between the change in lens power and axial elongation is controversial. Lens power has been demonstrated to be lower in myopic children than in emmetropic children, which might be a compensatory effect for increased axial elongation.\(^ {3,4,6,11}\) However, because the patterns of change in lens power with age appear to be similar across ethnic groups (white and Asian children),\(^ {3,4,11}\) whose patterns of refractive error, specifically the prevalences of myopia are different,\(^ {10-18}\) it seems that they represent a developmental change that is not regulated in relation to AL or refractive error.

To further elucidate these uncertain issues, we included a large sample of Chinese school children and adolescents aged 6 to 18 years with a wider range of refractive errors in this cross-sectional study. The crystalline lens power was calculated using Bennett’s formula and then compared among the children of different age groups, refractive statuses, and AL categories. The association of lens power and AL was analyzed using multiple regression.

**Purpose.** To investigate the relationship between lens power and age as well as the relationship between lens power and axial length (AL) in Chinese children and adolescents.

**Methods.** The participants underwent a comprehensive ophthalmic examination that included AL, cycloplegic refraction, and Pentacam measurements. The crystalline lens power was calculated using Bennett’s formula and then compared among the children of different age groups, refractive statuses, and AL categories. The association of lens power and AL was analyzed using multiple regression.

**Results.** A total of 1992 children and adolescents aged 6- to 18-years old were included. The difference in lens power was greater before 10-years old, followed by a relatively smaller difference in children aged 10 to 14 years and the difference in lens power came to a near plateau in adolescents after 14-years old. The negative association between lens power and AL was found to be more evident in nonmyopes than in myopes irrespective of age (younger than 10 years: nonmyopes: \(\beta = -1.499\), myopes: \(\beta = -0.872\); older than 10 years: nonmyopes: \(\beta = -1.288\), myopes: \(\beta = -0.590\), all \(P < 0.001\)).

**Conclusions.** The lens power in children and adolescents aged 6 to 18 years exhibited three stages. The association between lens power and AL differed between the nonmyopes and myopes. These findings suggested that less reduction in lens power might be associated with both growing age and increasing AL in myopes.

**Keywords:** lens power, myopia, refractive error
Bennett’s formula, compared between ages and different refractive statuses, and analyzed in relation to AL.

**METHODS**

**Setting and Participants**

This cross-sectional study is a part of the Shanghai Children Eye Study (SCES), which is a school-based survey of eye health in a large sample of children in Shanghai, China. The SCES aims to provide scientific evidence for the prevention and control of eye disease in children and adolescents.19-22 The SCES was approved by the institutional review boards of Shanghai General Hospital and Shanghai Jiao Tong University and was conducted according to the tenets of the Declaration of Helsinki. This study was conducted within the schools in the period from October 2013 to January 2016.

A total of 2766 children and adolescents aged 6 to 19-years old from 11 primary and middle schools (including junior and senior high school) in the Jiading District in Shanghai were enrolled in this study, which was randomly selected from those agreed with and being suitable for cycloplegia in SCES.19 Jiading District is located in the Northwest suburban area of Shanghai, with an area of 463.55 km² and a population of 59,8100 at the end of 2016. According to Shanghai Statistical Year Book, in 2016, the average income of urban and rural residents in Jiading was 44,453 Chinese Yuan (CNY) and 26,474 CNY, respectively, which was similar to Shanghai overall where the average income of urban and rural residents was 52,962 CNY and 23,205 CNY, respectively.22 Children with a history of eye disorders, such as cataract or glaucoma, and/or any abnormal findings in examination were excluded from final analysis. All of the children who participated understood the study protocol, and their parents or legal guardians provided written informed consent.

**Measurements and Calculations**

A trained team consisting of an ophthalmologist, five optometrists, five ophthalmic assistants, and a study coordinator conducted ocular examinations. Axial length was measured with an IOL Master (version 5.02; Carl Zeiss, Jena, Germany), and slit-lamp (Y25X; 66 Vision Tech, Suzhou, China) examinations were performed by an ophthalmologist. Intraocular pressure (IOP) was measured with noncontact tonometry (NF-1000; Nidek, Tokyo, Japan). Cycloplegia procedures were performed in children with peripheral anterior chamber depths (ACDs) of greater than one-half the thickness of the cornea, IOPs less than or equal to 25 mm Hg with parental consent for the cycloplegia procedures. The cycloplegia procedures were performed in each eye via the administration of one drop of topical 0.5% proparacaine hydrochloride (Alcaine; Alcon, Fort Worth, TX, USA) followed 5 minutes later by two drops of 1% cyclopentolate (Cyclogyl; Alcon) in each eye. The pupil size and light reflex were examined 30 minutes after the administration of the last drop of cyclopentolate, and cycloplegia was deemed adequate if the pupil size was greater than or equal to 6 mm and the pupillary light reflex was absent. Refraction was examined using a desk-mounted auto-refractor (model KR-8900; Topcon, Tokyo, Japan). Other biometric parameters, including anterior chamber depth, lens thickness, central corneal thickness, the anterior and posterior corneal radii of curvature, were measured using a Pentacam (Oculus, Wetzlar, Germany).

The spherical equivalent (SE) was used to classify the refractive status and was obtained as follows: SE = sphere power + cylinder power/2. Myopia, emmetropia and hyperopia were defined as SE less than or equal to −0.5 dipters (D), −0.5 D less than SE less than or equal to +0.5 D, and SE greater than +0.5 D, respectively.19,22 Myopia was further categorized into high myopia, moderate myopia, and mild myopia, which were defined as SE less than or equal to −5.0 D, −5.0 D less than SE less than or equal to −3.0 D, and −3.0 D less than SE less than or equal to −0.5 D, respectively.

The crystalline lens power (P_L) was calculated using Bennett’s formula,9,24 that is,

\[ P_L = \frac{-1000 t (S_{CV} + K)}{1000 t (ACD + C_1 T) (S_{CV} + K)} + \frac{1000 n}{c_2 T + V}, \]

in which \( T \) is the lens thickness, \( V \) is the vitreous depth, \( n = 4/3 \) of the aqueous and vitreous indices, \( c_1 = 0.596 \), and \( c_2 = -0.358 \) as estimated using the Gullstrand-Emsley eye model. The spherical equivalent refraction was defined as \( S_E = SE/(1 - 0.014 \times SE) \). The effective ACD included the central corneal thickness and the ACD as given by the Pentacam. Accounting for the posterior corneal, the corneal power was calculated as follows (Manns E. IOVS 2014;55:ARVO E-Abstract 3785)25,26.

\[ K_{m,a} = \left( n_c - 1 \right) / R_{m,a} \]

\[ K_{m,p} = \left( n - n_c \right) / R_{m,p} \]

\[ K = K_{m,a} + K_{m,p} = K_{m,a} \times K_{m,p} \times CCT / n_c \]

where \( K_{m,a} \) and \( K_{m,p} \) are the mean anterior and posterior keratometric measurements, respectively, \( R_{m,a} \) and \( R_{m,p} \) are the anterior and posterior corneal radii of curvature, respectively; \( CCT \) is the central corneal thickness; and \( n_c = 1.376 \) is the corneal refractive index.

**Statistical Analyses**

A database was created using Epidata 3.1 (EpiData Association, Odense, Denmark). All data were independently double entered by two trained staff members, and all discrepancies were adjudicated. The statistical analyses were conducted using IBM SPSS statistics version 24.0 (IBM Co., Armonk, NY, USA). Because the biometry data and refractive errors of the two eyes were strongly correlated (the Pearson’s correlation coefficients ranged from 0.843–0.973), only the data from the participants’ right eyes were included in the statistical analyses. The parameters were presented as the means ± SDs for the continuous variables and as the rates (proportions) for the categoric data. Intergroup differences were tested with Student’s t-tests (between sexes) or with ANOVA for the refractive groups and AL categories. Correlations of the ocular biometric parameters were analyzed with Pearson correlation coefficients. Multiple regression analysis was performed to explore the association between lens power and AL after adjusting for the other factors of nonmyopes and myopes both before and after 10-years old. Statistical significance was set at \( P \) less than 0.05 (2-tailed).

**RESULTS**

**General Characteristics**

Out of the 2883 children and adolescents who underwent the examination, 891 lacked data of lens thickness when captured by Pentacam, so 1992 (69.1%) children were included in final analysis. Participants included in the study had longer AL (23.67 ± 1.18 vs. 23.49 ± 1.18, \( P < 0.001 \)), stronger corneal power (41.70 ± 1.35 vs. 41.45 ± 1.44, \( P < 0.001 \)), and deeper
The Relationship Between Lens Power and Age, AL

Table 1. General Characteristics of the 1992 Participants and Comparison Between Boys and Girls

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Total, N = 1992</th>
<th>Boys, N = 1037</th>
<th>Girls, N = 955</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>10.2 ± 3.1</td>
<td>10.2 ± 3.1</td>
<td>10.2 ± 3.1</td>
<td>0.939*</td>
</tr>
<tr>
<td>Lens power, D</td>
<td>25.28 ± 1.93</td>
<td>24.76 ± 1.87</td>
<td>25.84 ± 1.83</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Lens thickness, mm</td>
<td>3.42 ± 0.17</td>
<td>3.41 ± 0.17</td>
<td>3.44 ± 0.16</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Corneal power, D</td>
<td>41.70 ± 1.33</td>
<td>41.37 ± 1.26</td>
<td>42.05 ± 1.32</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>ACD, mm</td>
<td>3.22 ± 0.23</td>
<td>3.27 ± 0.23</td>
<td>3.18 ± 0.22</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>AL, mm</td>
<td>23.67 ± 1.18</td>
<td>23.91 ± 1.15</td>
<td>23.42 ± 1.17</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>SE, D</td>
<td>−0.39 ± 2.08</td>
<td>−0.34 ± 2.02</td>
<td>−0.44 ± 2.16</td>
<td>0.298*</td>
</tr>
</tbody>
</table>

* Statistical significance was tested using Student’s t-test.

ACD (3.22 ± 0.23 vs. 3.15 ± 0.26, P < 0.001), while no significant difference in age, sex, and SE between those included and those excluded was observed (P = 0.272, 0.184, and 0.587, respectively). Table 1 presents the general characteristics of the 1992 participants split by sex. The mean age was 10.2 ± 3.1 years (range, 6–18 years), and 47.9% were girls. The mean AL, SE, and lens power were 23.67 ± 1.18 mm (range, 19.36–29.30 mm), −0.39 ± 2.08 D (range, −11.38 D to +9.18 D), and 25.28 ± 1.93 D (range, 16.53–33.65 D), respectively. The distribution of lens power exhibited a broad, Gaussian shape as demonstrated in Figure 1. The girls exhibited significantly higher lens and corneal powers, thicker lens, shallower anterior chambers, and shorter eyes (all P < 0.001). There was no significant difference in SE between the boys and girls (P = 0.298).

Influence of Age

There was a negative correlation between lens power and age as analyzed with the Pearson’s correlation coefficient (r = −0.391, P < 0.001) and ANOVA (P < 0.001, Table 2). The difference in lens power appeared to be greater in early childhood over the age of 6 to 10 years (mean difference of ~1.93 D), followed by a relatively smaller difference in children aged 10 to 14 years (mean difference of ~0.95 D); subsequently, the difference in lens power came to a near plateau in older childhood aged 14 to 18 (0.15 D difference; Table 2, Fig. 2). When stratified by sex, greater difference of lens power from 6 to 10 years was observed in both sexes (boys: 1.72 D; girls: 2.17 D). However, the boys exhibited smaller difference from 10 to 14 years (mean difference of 1.00 D) and a plateau from ages 14 to 18 years (mean difference of 0.20 D), whereas the girls exhibited a similar difference from ages 10 to 18 years (differences of 0.45 D from ages 10–14 years and 0.46 D from age 14–18 years, respectively; Table 2, Fig. 2). Figure 2 also indicates that the girls exhibited greater lens powers across all age groups (all P < 0.001).

Influence of Refraction

There was a positive correlation between lens power and SE (r = 0.332, P < 0.001). The polynomial curve showed that the positive correlation only existed when SE greater than −5.00 D, while a negative correlation was observed when SE less than −5.00 D (Fig. 3A). The distributions of lens power across the different refractive statuses were further investigated with ANOVA. The results revealed a significant difference between the refraction groups (P < 0.001) in which the values in the hyperopes were markedly greater on average than those of the emmetropes, which were greater than those in the mild myopes (P < 0.001; Table 3). However, there were no significant differences between the mild and moderate myopes or between the moderate and high myopes (P = 0.687 for the moderate versus mild myopes and P = 0.124 for the high versus moderate myopes; Table 3). Similar pattern of differences was observed in the boys and girls (all P < 0.001; Table 3).

Association with AL

There was a negative correlation between lens power and AL (r = −0.666, P < 0.001). The polynomial curve showed that the negative correlation was observed only when AL was less than 25 mm, while there was no significant association between lens power and AL when AL was greater than 25 mm (Fig. 3B). When the eyes were divided into 1-mm bins according to AL, an ANOVA also demonstrated a negative correlation between lens power and AL, and the difference in lens power was greater in the shorter eyes (AL ≤ 25 mm) while smaller in the longer eyes (AL > 25 mm, Table 4). A similar pattern of differences was observed in the boys and girls (all P < 0.001; Table 4). A significant difference in lens thickness was observed in the shorter eyes (AL ≤ 25 mm), and the differences decreased in the longer eyes (AL < 22 mm: 3.56 ± 0.17 mm; AL 22–25 mm: 3.49 ± 0.16 mm; AL 25–29 mm: 3.42 ± 0.15 mm; AL 29–34 mm: 3.37 ± 0.14 mm; AL 34–45 mm: 3.35 ± 0.15 mm; and AL > 66 mm: 3.32 ± 0.17 mm).
After adjusting for age, sex, and lens thickness, lens power was found to be negatively associated with AL. This association was more evident in nonmyopes than in myopes both before and after age 10 (nonmyopes younger than 10 years: \( \beta = -1.499 \); myopes younger than 10 years: \( \beta = -0.872 \); nonmyopes older than 10 years: \( \beta = -1.288 \); and myopes older than 10 years: \( \beta = -0.390 \); all \( P < 0.001 \), Table 5). In nonmyopes, the listed factors explained more compared with those in myopes \( R^2 \): nonmyopes younger than 10 years: 0.815; myopes younger than 10 years: 0.664; nonmyopes older than 10 years: 0.844; myopes older than 10 years: 0.635, Table 5).

**DISCUSSION**

To our knowledge, the present study is the first to investigate the characteristic of lens power and the factors that associate this characteristic in children and adolescents aged 6 to 18 years in a single population with a wide refraction range (−11.38 to 9.13 D). The results revealed that there was a greater difference in lens power in early childhood over the age of 6 to 10 years, followed by a relatively smaller difference in children aged 10 to 14 years, while the difference in lens power came to a near plateau in older childhood aged 14 to 18. Additionally, the results implied that lens power differences were also associated with AL. More evident associations of lens power with AL were observed in the nonmyopes than in the myopes irrespective of age and sex.

Bennett’s formula was used to calculate lens power in the present study. This formula is widely used and allows for the accurate calculation of the lens power without the use of commercially unavailable devices.\(^{10,24}\) To account for the influence of the posterior cornea on the lens power calculation, the total corneal power was calculated from the anterior and posterior radii using a refractive index of 1.376.\(^{14,26}\) The calculated lens powers were in relatively close agreement with the values obtained by Iribarren\(^4\) (mean lens power of boys: 24.22 D, mean lens power of girls: 25.39 D),

![Figure 2](https://example.com/figure2.png)

**Figure 2.** The mean lens power stratified by age for both sexes.

![Figure 3](https://example.com/figure3.png)

**Figure 3.** (A) Relationship between SE and lens power (polynomial fitting). (B) Relationship between AL and lens power (polynomial fitting).
who calculated corneal power from the anterior corneal radius using a refractive index of 1.3515, but found to be greater than that of another study that used the anterior corneal radius and a refractive index of 1.328 (lens power of 23.08 D on average). This difference might be due to the older age (~14-years old) and higher prevalence of myopia (mean SE of ~2.10 D) used in the latter (Li et al.15) sample.

We found that the lens power in children and adolescents aged 6 to 18 years exhibited three stages. During early childhood (ages 6–10 years), the pattern of difference in lens power appeared to be greater (a mean difference of ~1.93 D). After the age of 10 years, lens power difference was relatively smaller (mean reduction of 0.95 D). These phenomena were consistent with those found in previous studies. However, because most previous studies only investigated changes and/or differences in lens power to the age of 14 years, the lens power changes and/or differences from 14 to 18 years remain unknown. The data from the current study indicated that difference in lens power came to a near plateau during this period (decrease of only 0.15 D). This reduction rate was consistent with those found in previous studies. However, because most previous studies only investigated changes and/or differences in lens power to the age of 14 years, the lens power changes and/or differences from 14 to 18 years remain unknown.

The relationships between AL and lens power across different refractive statuses remain controversial, especially around the onset of myopia. Previous longitudinal studies have indicated similar rates of reduction in lens power in myopes and nonmyopes, although an increased rate of lens power loss has been observed at the onset of myopia. However, the results of the current study indicated that lens power exhibited a stronger association with AL in nonmyopes but a relatively weaker association in myopes. These results were consistent with those of a longitudinal study by Mutti et al., who observed a stop in power loss after the onset of myopia, and those of a cross-sectional study of 14-year-old Chinese children conducted by Li et al. who found a similar pattern of change in girls but not in boys. Because the crystalline lens also undergoes a reduced rate of power loss after the age of 10, the finding of changes in lens power in myopes and longer eyes could be an age effect because more myopic and longer eyes are usually found in older children. However, our results further revealed a more evident association of lens power with AL in nonmyopes than in myopes after adjusting for age (split at the age of 10), sex, and lens thickness, which indicated that the compensatory ability of lens power became smaller not only with increasing age for its natural development but also in myopes as axial elongating.

There might be some internal mechanisms, which can explain the difference in lens power changes between myopes and nonmyopes. Before the onset of myopia, lens power reduces in the compensation of AL elongation to maintain emmetropia, which is a co-effect of changes in both the shape and the gradient refractive index of the lens. However, lens power loss might be limited when the shape of the gradient refractive index profile approaches a relatively maximal rate of increase. In contrast, axial growth, which is mainly regulated by environmental factors, such as time spent outdoors during the school years, might have no endpoint.

### Table 3. Distribution of Lens Power Stratified by Refractive Status for Both Sexes (Mean ± SD)

<table>
<thead>
<tr>
<th>Refractive Status</th>
<th>Hyperopes</th>
<th>Emmetropes</th>
<th>Mild Myopes</th>
<th>Moderate Myopes</th>
<th>High Myopes</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (% of Boys)</td>
<td>780 (52.3)</td>
<td>495 (52.1)</td>
<td>411 (53.5)</td>
<td>228 (53.5)</td>
<td>78 (39.7)</td>
</tr>
<tr>
<td>Lens power, D</td>
<td>26.45 ± 1.82</td>
<td>25.49 ± 1.82*</td>
<td>24.72 ± 1.68*</td>
<td>24.51 ± 1.84</td>
<td>25.05 ± 1.86</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.001†</td>
<td>&lt;0.001†</td>
<td>&lt;0.001†</td>
<td>&lt;0.001†</td>
<td>0.047‡</td>
</tr>
</tbody>
</table>

† Statistical significance was tested using Student’s t test.

### Table 4. Distribution of Lens Power by Axial Length for Both Sexes (Mean ± SD)

<table>
<thead>
<tr>
<th>AL, mm</th>
<th>≤22</th>
<th>22 &lt; AL ≤23</th>
<th>23 &lt; AL ≤24</th>
<th>24 &lt; A ≤25</th>
<th>25 &lt; AL ≤26</th>
<th>≥26</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proportions with myopia, %</td>
<td>0.0</td>
<td>4.1</td>
<td>24.1</td>
<td>66.3</td>
<td>94.1</td>
<td>98.9</td>
</tr>
<tr>
<td>N (% of Boys)</td>
<td>88 (20.5)</td>
<td>516 (59.5)</td>
<td>713 (55.0)</td>
<td>415 (60.5)</td>
<td>170 (68.8)</td>
<td>90 (61.1)</td>
</tr>
<tr>
<td>Lens power, D</td>
<td>28.63 ± 1.64</td>
<td>26.67 ± 1.33†</td>
<td>25.21 ± 1.24*</td>
<td>24.11 ± 1.49*</td>
<td>23.53 ± 1.55*</td>
<td>23.28 ± 2.11</td>
</tr>
<tr>
<td>P value</td>
<td>0.615†</td>
<td>0.040†</td>
<td>&lt; 0.001†</td>
<td>&lt; 0.001†</td>
<td>&lt; 0.001†</td>
<td>0.016†</td>
</tr>
</tbody>
</table>

† Statistical significance was tested using Student’s t test.
The Relationship Between Lens Power and Age, AL

TABLE 5. Multivariate Regression Analysis of Associations With Lens Power for Nonmyopes and Myopes Before and After the Age of 10

<table>
<thead>
<tr>
<th>Variables</th>
<th>Nonmyopes, N = 921</th>
<th>Myopes, N = 354</th>
<th>Age &gt; 10 y</th>
<th>Age ≤ 10 y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimate, 95% CI</td>
<td>Estimate, 95% CI</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Age, D/year</td>
<td>0.065 (-0.120 to 0.250)</td>
<td>0.094 (0.036 to 0.152)</td>
<td>0.009</td>
<td>0.008</td>
</tr>
<tr>
<td>Sex, boys vs. girls</td>
<td>0.036 (-0.033 to 0.105)</td>
<td>0.211 (-0.987 to 1.408)</td>
<td>0.174</td>
<td>0.010</td>
</tr>
<tr>
<td>AL, D/mm</td>
<td>1.499 (1.351 to 1.647)</td>
<td>1.288 (1.125 to 1.451)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Lens thickness, D/mm</td>
<td>5.777 (5.184 to 6.370)</td>
<td>4.678 (4.064 to 5.291)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Adjusted for all variables listed, r² for nonmyopes younger than 10 y: 0.464, r² for myopes younger than 10 y: 0.459, r² for myopes older than 10 y: 0.450, 1 - r² for nonmyopes older than 10 y: 0.536, 1 - r² for myopes older than 10 y: 0.550.

References