Preschool Children Exhibit Evident Compensatory Role of Internal Astigmatism in Distribution of Astigmatism: The Nanjing Eye Study

Zijin Wang,1 Dan Huang,1 Xuejuan Chen,1 Hui Zhu,1 Qigang Sun,1 Yue Wang,1 Xiaohan Zhang,1 Yue Wang,2 Leili Zhai,2 Chenyang Wang,2 and Hu Liu1

1Department of Ophthalmology, The First Affiliated Hospital with Nanjing Medical University, Nanjing, China
2The Fourth School of Clinical Medicine of Nanjing Medical University, Nanjing, China

Correspondence: Hu Liu, Department of Ophthalmology, The First Affiliated Hospital with Nanjing Medical University, 300 Guangzhou Road, Nanjing 210029, China; liuhu66@njmu.edu.cn.
ZW, DH, and XC contributed equally to the work presented here and should therefore be regarded as equivalent authors.
Submitted: May 15, 2018
Accepted: November 15, 2018

PURPOSE. To determine the prevalence and associated risk factors for total, corneal, and residual astigmatism and to evaluate the relations between components of astigmatism in Chinese preschool children.

METHODS. In the population-based, cross-sectional Nanjing Eye Study, children were measured for noncycloplegic refractive error using an autorefractor and for biometric parameters using an optical low-coherent reflectometry. Data from right eyes were analyzed to calculate the prevalence of astigmatism using various cutpoints (0.5, 1.0, and 1.5 diopters [D]) and for determining risk factors using logistic regression models. Relations between astigmatism components were assessed using Spearman correlation coefficients (ρ).

RESULTS. Of 1817 children (mean ± SD of age: 54.8 ± 3.5 months, 54.2% male), the median (1st and 3rd quartile) of total, corneal, and residual astigmatism (vectorial difference between total and corneal astigmatism) was −0.25 (−0.50, 0), −1.06 (−1.49, −0.72), and −0.92 (−1.23, −0.62) D and their prevalence rate 1.0 D or more was 14.2%, 56.1%, and 44.2%, respectively. With-the-rule was the most common type in total astigmatism (75.2%) and in corneal astigmatism (88.2%) while against-the-rule was predominant in residual astigmatism (75.6%). A negative correlation was found between corneal J0 and internal J0 (ρ = −0.74, P < 0.001) and between corneal J45 and internal J45 (ρ = −0.87, P < 0.001). Based on compensation factor (CF), defined as the minus ratio of internal astigmatism (vectorial difference between total and anterior corneal astigmatism) and anterior corneal astigmatism, internal J0 compensated for total J0 in varying degrees (CF: 0.1–2) in 91.5% cases, while that percentage for J45 component was 77.2%. In univariate logistic regression model, older age was significantly associated with total astigmatism (odds ratio [OR] = 0.96 for per-month increase, P = 0.03), and larger axial length–corneal radius ratio was significantly associated with higher risk of residual astigmatism (OR = 2.28 for per unit increase, P = 0.03).

CONCLUSIONS. The compensatory role of internal astigmatism on reducing corneal astigmatism was prominent in preschool children. Larger axial length–corneal radius ratio was significantly associated with higher risk of residual astigmatism.

Keywords: astigmatism, prevalence, compensation factor, risk factor

A

stigmatism is the condition that prevents light rays from focusing at a single point in the eye, leading to the blurred vision at near or far distance. Astigmatism, an important type of refractive error, is a clinical and public health problem. Astigmatism, if uncorrected, can lead to continuous blurred vision experienced at all distances; thus, increases the risk of amblyopia. Orientation-dependent visual deficits caused by uncorrected astigmatism cannot be reversed if optical correction is delayed. In addition, some researchers suggest that astigmatism may be associated with myopia progression.

Two components of astigmatism have been independently measured and calculated, total astigmatism (TA) and corneal astigmatism (CA), to describe the characteristics of astigmatism. CA is calculated using an equivalent refractive index of 1.376. Residual astigmatism (RA) is defined as the vectorial difference between TA and CA. Anterior corneal astigmatism (ACA) is defined as astigmatism of anterior corneal surface and calculated using corneal refractive index of 1.376. Internal astigmatism (IA) is defined as the vectorial difference between TA and ACA. Data on the distribution and relationship between these components of astigmatism are very limited, but they are important to help understand the development and progression of astigmatism in relation to corneal, refractive, and cataract surgery.
Compensatory Role of Internal Astigmatism

**METHODS**

**Study Design and Subjects**

The Nanjing Eye Study (NES) is a population-based cohort study, designed to longitudinally observe the onset and progression of childhood ocular diseases in eastern China. The study was approved by the institutional review board in The First Affiliated Hospital with Nanjing Medical University and was conducted in accordance with the tenets of the Declaration of Helsinki. Written consent was obtained from the parents or guardians of all children.

The study population for the present study consisted of 48- to 60-month-old children enrolled in kindergarten in the Yuhuatai District and born between September 2011 and August 2012. Eye examination results were presented from September to November of 2016.

**Eye Examination**

Two ophthalmologists and two optometrists specialized in pediatric eye care performed comprehensive eye examinations following the similar standardized study protocols described in the multiethnic pediatric eye disease study (MEPDS).

The noncycloplegic refractive status of both eyes of each participant was measured using an autorefractor (Cannon R-F10; Canon, Tokyo, Japan). The optic low-coherent reflectometer (LenStar LS-900; Haag-Streit AG, Koeniz, Switzerland) obtained biometric parameters, including central corneal thickness, corneal curvatures, anterior chamber depth, white-to-white corneal diameter, and axial length. Three consecutive scans were performed by the same experienced examiner. Scans were operated without pupil dilation, in a dimly lit room according to the manufacturers’ guidelines. Children first got seated, placed their chin on the chin rest with their forehead adhered to the headrest of the device. They were asked to stare into the central fixation dot in front of them and not to blink during the measurement. If the signal-to-noise ratio (SNR) was less than 2.1, another measurement was taken until reliable readings were achieved from each eye.

**Definition**

Astigmatism was defined as a cylinder magnitude worse than or equal to 0.5, 1.0, and 1.5 diopters (D), expressed as a negative cylinder form. ACA was calculated as the difference between the flattest and steepest corneal meridians of the anterior corneal surface with the cylindrical axis equal to the flattest meridian. The anterior corneal surface power was calculated by $(1.376 - 1)/r$, where $r$ is the anterior curvature of the central radius and 1.376 is the refractive index of the cornea. Corneal refractive error was calculated by $(1.3375 - 1)/r$. This equivalent refractive index value 1.3375 takes the negative refractive power of the posterior corneal surface into account. RA was the vectorial difference between TA and CA. IA was the vectorial difference between TA and ACA. ATR astigmatism, respectively.12

The compensation factor (CF) was defined as the minus ratio of RA and ACA. The compensation factors were classified as following based on the calculated CF:

1. $0.1$: same axis augmentation; (2) $0.1$ to $0.1$: no compensation; (3) $0.1$ to $0.9$: under-compensation; (4) $0.9$ to $1.1$: full compensation; (5) $1.1$ to $2$: overcompensation; and (6) greater than $2$: opposite axis augmentation.

**Statistical Analysis**

The Statistical Package for the Social Sciences (V.13.0; IBM, Chicago, IL, USA) was employed for all the statistical analyses. Results were presented as mean ± SD for normally distributed data, median (1st and 3rd quartile) for skewed continuous measures, percentage and 95% CI for categoric measurements. Spearman correlation coefficient ($\rho$) was used to evaluate the relationships between magnitude of different types of astigmatism. AL/CR between boys and girls was compared using independent-samples t-test. Univariate logistic regression models were performed to evaluate the risk factors of each type of astigmatism (defined as their astigmatism magnitude ≥1.0 D). All statistical tests were two-sided and $P$ less than 0.05 was considered statistically significant.
RESULTS

Characteristics of Study Population

Among 2300 eligible preschoolers, 1986 (participation rate 86.4%) children were examined. As 169 children were uncooperative and no refraction measurements were obtained after repeated attempts, 1817 children (response rate 79.0%) had complete data from noncycloplegic autorefraction and corneal curvature in right eye, thus were included in this study. The mean (±SD) age was 54.9 ± 3.5 months and 984 (54.2%) participants were boys. Han nationality children (1800, 99.1%) constituted the majority of the population.

Magnitude and Prevalence of Astigmatism

The distribution of TA, CA, and RA were shown in Figure 1. The magnitude of TA indicated left skewness, meaning that most children having minimal or no astigmatism (61.6%, <0.5 D). The distributions of CA and RA magnitude were also left skewed.

The median (1st and 3rd quartile) was /C0.25 (/C0.50, 0) D for TA, /C1.06 (/C1.49, /C0.72) D for CA, and /C0.92 (/C1.23, /C0.62) D for RA.

The prevalence of TA, CA, and RA using various cutpoints (‡0.5, ‡1, ‡1.5 D) were shown in Table 1. The prevalence rate of TA, CA, and RA 1.0 D or more was 14.2%, 56.1%, and 44.2%, respectively. TA and CA were predominantly WTR (75.2% and 88.2%), followed by OBL and a small proportion of ATR. By contrast, RA was mainly ATR (75.6%), followed by OBL and a small proportion of WTR.

Relationships Between Different Types of Astigmatism

When magnitude of TA, ACA, and IA was compared, ACA exceeds TA in 1702 (93.7%) children with median difference (1st and 3rd quartile) of 0.88 D (0.54, 1.24 D). Figure 2 shows the relationships between decomposers of TA and ACA. Figure 2A shows that most J0 values were below the line of equality, indicating that children have more ACA than TA along the Cartesian axes. Figure 2B shows that most J0 values were above the line of equality, suggesting most children had more TA than IA along the Cartesian axes. The correlation was 0.37 (P < 0.001) between total and anterior corneal J0 and 0.24 (P < 0.001) between total and internal J0. Negative correlation was found between anterior corneal and internal J0 (ρ = -0.74, P < 0.001). Figures 2C and 2D show that values for total and anterior corneal J45 distributed almost evenly above or below the line of equality, as well as values for total and internal J45. The correlation between total and anterior corneal J45 was 0.10 and 0.30 (both P < 0.001). Anterior corneal and internal J45 were negatively correlated (ρ = -0.87, P < 0.001).

Table 1. Distribution and Constitution of Total Astigmatism, Corneal Astigmatism, and Residual Astigmatism

<table>
<thead>
<tr>
<th>Astigmatism</th>
<th>WTR</th>
<th>ATR</th>
<th>OBL</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>TA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‡0.5</td>
<td>698</td>
<td>38.4 (36.2–40.6)</td>
<td>447</td>
</tr>
<tr>
<td>‡1</td>
<td>258</td>
<td>14.2 (12.6–15.8)</td>
<td>194</td>
</tr>
<tr>
<td>‡1.5</td>
<td>114</td>
<td>6.3 (5.2–7.4)</td>
<td>100</td>
</tr>
<tr>
<td>CA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‡0.5</td>
<td>1605</td>
<td>88.3 (86.8–89.8)</td>
<td>1310</td>
</tr>
<tr>
<td>‡1</td>
<td>1019</td>
<td>56.1 (53.8–58.4)</td>
<td>899</td>
</tr>
<tr>
<td>‡1.5</td>
<td>567</td>
<td>31.2 (29.1–33.3)</td>
<td>405</td>
</tr>
<tr>
<td>RA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>‡0.5</td>
<td>1544</td>
<td>85.0 (83.4–86.6)</td>
<td>37</td>
</tr>
<tr>
<td>‡1</td>
<td>803</td>
<td>44.2 (41.7–46.3)</td>
<td>15</td>
</tr>
<tr>
<td>‡1.5</td>
<td>221</td>
<td>12.2 (10.7–13.7)</td>
<td>4</td>
</tr>
</tbody>
</table>

FIGURE 1. Distribution of the magnitude of total, corneal, and internal astigmatism.

TABLE 1. Distribution and Constitution of Total Astigmatism, Corneal Astigmatism, and Residual Astigmatism
The denominator of CF was zero for anterior corneal J0 in 40 children and for anterior corneal J45 in 98 children, thus were excluded from the calculation of CF. The compensation type of each child was displayed in Figure 3.

Risk Factors
AL/CR value ranged from 2.42 to 3.47 and was similar between boys and girls (\(P = 0.80\)). Sex, age, and AL/CR were evaluated as risk factors of astigmatism using univariate logistic regression. When astigmatism defined as 1 D or more, older age was significantly associated with lower risk of TA (odds ratio [OR] = 0.96 for every month increase, \(P = 0.03\)), while sex or AL/CR was not significantly associated with TA (\(P = 0.26\) and \(P = 0.38\), respectively). For CA, none of these factors was significantly associated (\(P = 0.13\), \(P = 0.09\), and \(P = 0.12\) for sex, age, and AL/CR, respectively). For RA, larger AL/CR was significantly associated with higher risk of RA (OR = 2.28 per unit increase, \(P = 0.03\)), while neither sex nor age was significantly associated with RA (\(P = 0.37\) and \(P = 0.35\), respectively).

DISCUSSION
This study evaluated the prevalence of astigmatism at various cutpoints in Chinese preschool children. Results of prevalence of TA from previous studies on similar age population are shown in Table 2.5,7,16–27 These studies, varied in the children ethnicity and the definition of astigmatism, reported wide range of prevalence rate of astigmatism. The prevalence of TA in the present study was lower than that found in the Tohono O’odham Native American children (26.5%, >2D),16 concurring with the high prevalence of astigmatism in American Indian children. This difference has been attributed to the higher lid tension of the Mongoloid race. Although the Chinese are racially related to American Indians, results

Figure 2. Scatter plots of total versus corneal astigmatism (J0 and J45). (A) Total J0 versus corneal J0. (B) Total J0 versus internal J0. (C) Total J45 versus corneal J45. (D) Total J45 versus internal J45. Each plot has a equality line of unit slope.
suggest that difference exists among different nations of one race. The prevalence of astigmatism found in the present study was similar to that from the East Asian group, but higher than that from the South Asian, Middle Eastern, and European Caucasian groups. The prevalence of TA in Canadian children was similar to our result,\(^{17}\) while white children in the UK NICER study\(^{19}\) and African American and Hispanic children in the MEPDS\(^{59}\) had a higher prevalence of TA than those in the current study. When compared with studies of Chinese children, the TA prevalence in this study was similar to that of studies conducted in Hongkong,\(^{20}\) Xiamen city and countryside,\(^{21}\) Guangzhou,\(^{22}\) Singapore,\(^{23}\) and Guangzhou.\(^{24}\) The prevalence of TA was higher in the study in Singapore,\(^{21}\) Hongkong,\(^{2}\) and Weihai.\(^{25}\) The prevalence of TA was lower in two studies carried out in rural area of Heilongjiang\(^{26}\) and Shunyi District.\(^{27}\)
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Location</th>
<th>Age</th>
<th>Design</th>
<th>Sample Size</th>
<th>Astigmatism Definition, D</th>
<th>Astigmatism Prevalence</th>
<th>Predominant Type of Astigmatism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cowen and Bobier 17</td>
<td>2003</td>
<td>Oxford County, Canada</td>
<td>38–86 mo</td>
<td>Population-based</td>
<td>1162</td>
<td>≥0.25</td>
<td>76.1%</td>
<td>WTR (45%), ATR (40%), and then oblique (15%)</td>
</tr>
<tr>
<td>Huynh et al. 7</td>
<td>2006</td>
<td>Sydney, Australia</td>
<td>6–7 y</td>
<td>Population-based</td>
<td>Whole: 1724</td>
<td>≥0.5, ≥1</td>
<td>Whole: 22.6%, 4.8%</td>
<td>East Asian: 33.5%, 11.2%</td>
</tr>
<tr>
<td>Harvey et al. 16</td>
<td>2010</td>
<td>Tohono O’odham, America</td>
<td>4–5 y</td>
<td>Population-based</td>
<td>211</td>
<td>&gt;2</td>
<td>East Asian: 26.5%</td>
<td>East Asian: WTR 49.6%</td>
</tr>
<tr>
<td>O’Donoghue et al. 18</td>
<td>2011</td>
<td>Northern Ireland, UK</td>
<td>6–7 y</td>
<td>Population-based</td>
<td>392</td>
<td>≥1</td>
<td>29%</td>
<td>OBL 76%</td>
</tr>
<tr>
<td>Fozailoff et al. 19</td>
<td>2011</td>
<td>Los Angeles, America</td>
<td>48–59 mo</td>
<td>Population-based</td>
<td>548</td>
<td>≥1.5</td>
<td>African American: 8.0%</td>
<td>African American: WTR 75%</td>
</tr>
<tr>
<td>Chen and Edwards 20</td>
<td>1993</td>
<td>Honkong, China</td>
<td>36–65 mo</td>
<td>Population-based</td>
<td>570</td>
<td>≥0.5</td>
<td>38.60%</td>
<td>WTR</td>
</tr>
<tr>
<td>Zhan et al. 21</td>
<td>2000</td>
<td>Xiamen, China</td>
<td>6–7 y</td>
<td>Population-based</td>
<td>Xiamen: City: 142</td>
<td>&gt;1</td>
<td>Xiamen: City: 6.8%</td>
<td>Xiamen: City WTR 88.9%</td>
</tr>
<tr>
<td>Zhao et al. 27</td>
<td>2000</td>
<td>Shunyi District, China</td>
<td>5–15 y</td>
<td>Population-based</td>
<td>5878</td>
<td>≥0.75</td>
<td>Singapore City: 146</td>
<td>Singapore City: ATR 64%</td>
</tr>
<tr>
<td>Fan et al. 5</td>
<td>2004</td>
<td>Hong Kong, China</td>
<td>3–6 y</td>
<td>Population-based</td>
<td>522</td>
<td>≥1</td>
<td>13.50%</td>
<td>WTR (55%), ATR (7.9%), and oblique (39.1%)</td>
</tr>
<tr>
<td>He et al. 22</td>
<td>2004</td>
<td>Guangzhou, China</td>
<td>5–15 y</td>
<td>Population-based</td>
<td>Retinoscopy: 4347</td>
<td>≥0.75</td>
<td>Retinoscopy: 21.4%</td>
<td>WTR 80.5%</td>
</tr>
<tr>
<td>Dirani et al. 23</td>
<td>2010</td>
<td>Singapore</td>
<td>6–72 mo</td>
<td>Population-based</td>
<td>2639</td>
<td>≥1.5</td>
<td>Autorefraction: 4522</td>
<td>Autorefraction: 26.3%</td>
</tr>
<tr>
<td>Li et al. 26</td>
<td>2014</td>
<td>Heilongjiang, China</td>
<td>5–9 y</td>
<td>Population-based</td>
<td>436</td>
<td>≥0.75</td>
<td>Autorefraction: 8.30%</td>
<td>Autorefraction: 25.0%</td>
</tr>
<tr>
<td>Wu et al. 25</td>
<td>2013</td>
<td>Weihai, China</td>
<td>4–5 y</td>
<td>Population-based</td>
<td>476</td>
<td>≥0.75</td>
<td>31.00%</td>
<td>WTR 85.8%</td>
</tr>
<tr>
<td>Lan et al. 24</td>
<td>2013</td>
<td>Guangzhou, China</td>
<td>4–5 y</td>
<td>Population-based</td>
<td>1663</td>
<td>≥0.5, ≥0.75</td>
<td>8.10%</td>
<td>WTR</td>
</tr>
<tr>
<td>Current study</td>
<td></td>
<td>Nanjing, China</td>
<td>48–60 mo</td>
<td>Population-based</td>
<td>1817</td>
<td>≥1, ≥1.5</td>
<td>38.4%, 23.3%, 14.2%, 6.3%</td>
<td>WTR</td>
</tr>
</tbody>
</table>

**Notes:**
- WTR = Wounda-Right
- ATR = Anterior-Top-
- OBL = Oblique-
- Singapore City = Singapore City
A recent review suggests that intensive near work activities and limited outdoors time are major risk factors of myopia. A recent review suggests that intensive near work activities and limited outdoors time are major risk factors of myopia and the localization of the epidemic difference is considered to be due to the different educational pressures and outdoors time. Studies have shown that children with myopia were more likely to have astigmatism than children without spherical refractive error. The association between astigmatism and myopia prevalence might be a possible reason for the localization of the astigmatism epidemic. WTR was predominant in TA in most studies in Chinese children.

The prevalence and the distribution characteristics of CA were previously studied mainly among cataract patients and healthy adults. Few studies have studied the CA among young children. Compared with the CA prevalence rate (38%) in Australian children and (29%) in Northern Ireland children, the prevalence of CA (≥1 D) in current study was higher (56%), likely attributed to ethnic differences. Consistent with the two previous studies, this study showed that WTR was the primary type of CA. Studies suggest that CA orientation may change with age, and WTR, common in young children, gradually shifts to ATR and OBL as age increases.33,34

IA has been attributed to the refracting power of the lens, posterior cornea, and errors in optical centration. Some studies have concluded that CA exceeds TA in 20% to 50% of cases and that no internal compensation for CA exists. This conclusion was contradicted with other studies. Various methods were used to demonstrate the compensatory relationship between internal and corneal astigmatism. Kelly et al. found a significant negative correlation between internal and corneal astigmatism (r = –0.52, P = 0.005). However, this study only included 30 adult subjects and the vectorial feature of astigmatism was not completely considered into the analysis. Sayed obtained similar results (r = –0.32, P < 0.001) among 307 infants and young children; however, cylinder power was analyzed without vectorial decomposition. Figures were drawn by Huynh et al. to demonstrate the compensation of the magnitude, J0, and J15, but their quantitative demonstration was inadequate. In our study, we first demonstrated that ACA exceeds TA in 104 (93.7%) children with median difference of 0.88 D. Second, we demonstrated strong negative correlation between anterior corneal and internal J0 (r = –0.74, P < 0.001), as well as anterior corneal and internal J15 (r = –0.87, P < 0.001). Third, we used the CF and found that internal J0 compensated for total J0 in varying degrees in 91.5% cases, and in 77.2% cases for J15. These data strongly suggest the substantial compensatory role of IA in reducing CA. Park et al. analyzed the compensation of IA among 356 myopic eyes from 178 adults (aged 19–46 years) based on CF. They found that in J0, 4% was full compensation, 66% was undercompensation, and 8% was overcompensation. In J15, 12% was full compensation, 35% was undercompensation, and 12% was overcompensation. Their percentages of compensation (80% in J0 and 59% in J15) were lower than that of our study both in J0 and J15 components, particularly in the full compensation. In a similar study among 206 myopic eyes of 206 Chinese children (6 to 16-years old), CF analysis revealed that compensation constituted 89.3% in J0 and 65.6% in J15, with 29.1% full compensation, 54.4% undercompensation, and 5.8% overcompensation in J0, and with 40.3% full compensation, 18.0% undercompensation, and 5.3% overcompensation in J15. The total compensation percentage was similar to that of the present study, but the constitution was different. The percentage of full compensation in our study was the highest. This difference may be attributed to age effect. The compensation weakens because of the shift of CA from WTR to ATR as age increases. The above two studies, as with our study, were carried out under noncycloplegic condition. In the study of 15,448 patients (median age of 74 years), the prevalence of CA (≥1 D) was 36.4%, which is lower than that of the present study. However, the prevalence of TA (≥1 D) was 32.0%, which is much higher. These results clearly demonstrated the attenuation of IA compensation in elderly people.

Genetic and environmental factors may play a role in the development of astigmatism. A meta-analysis of five Asian cohorts identifies PDGFA on chromosome 4q12 as a susceptibility locus for corneal astigmatism. PDGFA, a receptor for platelet-derived growth factor, is expressed in many retinal tissues in the eyes and is associated with ocular development. Interactions between the cornea and the eyelids, the extraocular muscles and the visual feedback dysfunction are the possible causes of astigmatism. However, no exact factor has been proved to lead to the development or progression of astigmatism. Ethnicity, age, myopia, hyperopia, maternal smoking during pregnancy, education level, ocular surgery, sex, accommodative convergence/accommodation (AC/A) ratio, and number of hours per day spent playing video games or on the computer were found to be associated with astigmatism.2,29,37 However, conflicting results exist in different studies. Spherical equivalent was the factor mostly studied. Researches have reported that for children, when spherical refraction is difficult to perform, AL/CR may be the second choice in predicting spherical equivalent. In this study, all children received noncycloplegic refraction. There may be bias in refraction directly using noncycloplegic spherical refractive error due to accommodation, thus AL/CR was introduced. It is known that the higher is the AL/CR ratio the more myopic is the refraction. Generally, AL/CR has not been considered as a possible risk factor for astigmatism before. This study showed that AL/CR was not associated with TA or CA, but was associated with RA. This finding is interesting as the risk factors of RA has not been studied previously. Studies in the United States have found that children with myopia or hyperopia were more likely to have astigmatism than children without spherical refractive error. Interpreting the results of the present study on the association between AL/CR and spherical equivalent seems difficult, thus further studies are needed. The prevalence of TA was similar between sexes, which was consistent with the results from most previous studies. Association was found between age and TA, which should be verified in future studies.

The strengths of the present study include its population-based design, large sample size, and standardized examination protocols performed by a trained team of two optometrists and two ophthalmologists. This study is limited in the less comprehensive collection of risk factors and the use of refraction data under noncycloplegic condition. However, one of the purposes of this study was to determine the role of IA under daily compensation status. The IA compensation after cycloplegia should be studied in the future. The simulated formula to calculate CA was used in this study. In the future, examination of posterior corneal astigmatism should be considered to derive accurate CA.

In summary, in the population aged 48 to 60-month-old children in the Yuhuatai District, the prevalence of TA was similar to that found in most previous studies among Chinese young children in cities and higher than that found in rural area. The CA prevalence was higher compared with limited studies in other countries. WTR was dominant in TA and CA, whereas ATR was most common in RA. By quantifying CE we demonstrated the compensatory role of IA in reducing CA, and this role was predominant in preschool children. Finally, the
larger AL/CR was significantly associated with higher risk of RA.

Acknowledgments

The authors thank the children, the corresponding parents or legal guardians, and all the members of the Maternal and Child Healthcare Hospital of Yuhua District, Nanjing, China, for helpful advice and support.

Supported by grants from the National Natural Science Foundation of China (Grant No. 81673198); the Natural Science Foundation of Jiangsu Province (Grant No. BK20161595); the Scientific Research Projects of Jiangsu Provincial Commission of Health and Family Planning (Grant No. H201507); and Jiangsu Province’s Key Provincial Talents Program (Grant No. QNRC2016563).

Disclosure: Z. Wang, None; D. Huang, None; X. Chen, None; H. Zhu, None; Q. Sun, None; Y. Wang, None; X. Zhang, None; Y. Wang, None; L. Zhai, None; C. Wang, None; H. Liu, None

References


