

Age-dependent Distribution of Astigmatism and its Component in Chinese Preschool Children

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Research Article

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Abstract

Background: There is a compensatory effect between corneal astigmatism (CA) and internal astigmatism (IA). And the refractive astigmatism (RA) decreased fast in the early 3 years. Nevertheless, little attention was paid to the change in astigmatism in preschool children. Thus, we aimed to investigate the age-dependent distribution of astigmatism and its component in Chinese preschool children from year 3 to year 6 and also, to study the relationship between ocular biometry and IA.

Methods: Automated refraction, keratometry and axial length (AL) were performed in this cross-sectional study. The IA was determined as the vector difference between RA and CA. The magnitude and type (with-the-rule WTR, against-the-rule ATR, oblique) of RA, CA and IA were investigated according to the age. Spearman correlation was adopted to detect the factors that may influence IA.

Results: A total of 2315 subjects (2315 right eyes) (47.38% female) with a mean age of 4.52 ± 0.88 years (range 3-6 years) were included. The magnitude and the ratio of three kinds of CA components did not change with aging ($p=0.1233$ and $p>0.1$, respectively). Though the axial distribution of RA remained unchanged with aging, a significant reduction in RA was seen in year 6 compared to that of year 3 and year 4 ($p=0.036$ and 0.041 , respectively). Conversely, the ATR component in IA was lower in year 6 (68.02%) than it in year 3 (81.92%) and year 4 (77.12%) (both $p<0.001$) accompanied by increased frequency of oblique astigmatism in year 6 than it in year 3 and year 4 ($p<0.001$ and $p=0.012$, respectively). Negative relationship was found between IA and AL.

Conclusion: RA decreased from year 3 to year 6. The shift of the axis in IA from ATR to Oblique and WTR may account for the reduction in RA. Eyes with shorter AL had larger IA.

Keywords: Internal astigmatism; corneal astigmatism; axial length; with-the-rule.

Background

Astigmatism is a common refractive error in population. Generally, refractive astigmatism (RA) is composed of corneal astigmatism (CA) and an internal astigmatism (IA) component arising from surfaces of the crystalline lens and any retinal astigmatism [1]. Infants are born to be characterized by a high prevalence of RA reported from 40% to 53% [2-4]. Usually, much of this astigmatism resolves with age and reaches stable levels of astigmatism at 18 to 24 months [5]. A compensatory effect has been reported to exist between CA and IA to minimize the total astigmatism [6-8]. The fast reduction of RA in infancy and early childhood indicates a positive compensatory relation between CA and IA [5]. Astigmatism of Chinese students has been reported in several surveys. Nevertheless, the age-related changes of RA and its component (CA and IA) in preschool children from year 3 to year 6 has not been definitively demonstrated. Besides, it has been demonstrated changes in astigmatism are associated with the development of ocular biometry and structure [9]. The relationship between ocular biometry and IA remains less known in such population.

In this study, we sought to (1) report and compare the distribution of RA, CA, IA, axial length (AL) and intraocular pressure (IOP) in children from 3 to 6 years, and (2) document the effectiveness of the AL in anticipation of IA development.

Methods

This study was approved by the Institutional Review Board of the Eye & ENT Hospital of Fudan University. All procedures were performed in accordance with the Declaration of Helsinki and with the approved research protocol. Informed consent was obtained from all the participants' parents before their enrolment.

Study population

This was a cross-sectional study conducted in the Pujiang area of Shanghai that examined a total of 2429 participants in 11 kindergartens between May 2014 and July 2015. Subjects who were uncooperative to take the examinations and with previous intraocular or corneal surgery were excluded from the analysis. For this analysis, 2315 subjects (2315 right eyes) were included with a mean age of 4.52 ± 0.88 years (range 3-6 years old). Within this population, 47.38% were female.

Ocular examinations and calculations

Automated refraction and keratometry (RK-8100, Topcon, Tokyo, Japan) were conducted to analyze the RA and CA without cycloplegia. Axial length (AL) was performed using IOLMaster (Carl Zeiss Meditec, Dublin, CA, USA). Repeated automatic consecutive measurements were taken and the mean values were recorded.

All astigmatism was expressed in negative cylinder notation and described at the corneal vertex surface. RA was given by noncycloplegic autorefraction. The CA was the difference between the corneal powers of the principal meridians, with the cylindrical axis corresponding to the meridian of minimum power. Data from the keratometric values were multiplied by 1.3375 to derive the real CA powers. The RA was converted to the corneal plane using a vertex of 12.0 mm.

RA and CA were converted to power vector notation using [10]:

$$J_0 = -C/2 * \cos(2\alpha)$$

$$J_{45} = -C/2 * \sin(2\alpha)$$

where C is negative-cylinder power and angle α is cylinder axis. The difference vector was then computed to determine the magnitude and axis of IA by subtracting the corresponding values along each of the coordinate axes separately.

With-the-rule (WTR) astigmatism was defined as an axis of astigmatism of 180 ± 30 degrees, against-the-rule (ATR) astigmatism as 90 ± 30 degrees, and the rest were defined as oblique astigmatism.

Statistical analysis

Statistical analyses were performed using Stata 14.0 (Stata Corp., College Station, TX, USA). Quantitative data were expressed as the mean \pm SD. Analysis of variance (ANOVA) or the Kruskal–Wallis test was used to test for difference among different groups, and the Bonferroni test was used to identify which pairs of treated groups were significantly different. Categorized variables were compared using the χ^2 test or Fisher's exact test. The Spearman correlation coefficient (r) was used to perform the correlation analysis. Results were considered statistically significant when the two-tailed $p < 0.05$.

Results

Table 1 shows the prevalences for RA, CA and IA at different magnitudes with different ages. Prevalences of CA and IA were higher than for RA. The prevalences of RA and its components remained stable in children from year 3 to year 6 (Table 1) (all $p > 0.05$). The magnitude of CA and IA remained stable from year 3 to year 6 ($p = 0.1233$ and 0.4208 , respectively). A significant reduction in RA was seen in year 6 compared to that of year 3 and year 4 ($p = 0.036$ and 0.041 , respectively) (Table 2).

Obviously, the CA and RA mainly occurred in the WTR position whereas it was ATR in IA distribution (Fig 1). With a classification limit of astigmatism axes of $\pm 30^\circ$, the ratio of three kinds of astigmatism components was relatively stable in RA and CA and did not change with aging (all $p > 0.1$) (Fig 1). However, the age-dependent changes were seen in the IA regarding to the ratio of three kinds of astigmatism. The ATR component in IA was lower in year 6 (68.02%) than it in year 3 (81.92%) and year 4 (77.12%) (both $p < 0.001$). The incidence of ATR astigmatism in IA was also lower in year 5 (73.92%) than that of year 3 ($p = 0.004$). In contrast, the incidence of oblique astigmatism in IA was increased with the aging as evidenced by lower frequency in year 3 (15.77%) and year 4 (20.54%) than it in year 6 (26.90%) ($p < 0.001$ and $p = 0.012$, respectively). The similar trend was found comparing the incidence of oblique component of IA in year 5 (22.56%) to year 3 ($p = 0.01$). Though significant difference was observed in the incidence of WTR astigmatism between year 6 (5.08%) and year 4 (2.34%) ($p = 0.01$), no age-related changes were seen among the other groups.

Besides, the eyes with higher amount of IA showed shorter AL and larger corneal cylinder powers (Table 3). The parameters of age, IOP and RA didn't affect the magnitude of IA (Table 3). In the regression analysis, the CA ($r = 0.6047, p < 0.001$) and AL ($r = 0.1307, p = 0.0094$) were proven to be associated with the IA (Figure 2).

Discussion

As a kind of refractive anomaly, astigmatism has been investigated in different groups of children. However, little research concerns the astigmatic development in preschool children from year 3 to year 6. Therefore, we have reported the prevalences of RA and its corneal and internal components in such population in eastern China. Prevalences of RA, CA and IA were stable in children from year 3 to year 6 at

1.0 D, 1.5D and 2.0D criterion. Prevalences of CA and IA were comparable but higher than for RA (Table 1). Nearly two-thirds of the children had IA and CA more than 1.0 D in all ages, while it was less than 20% in RA. In another word, compensation between CA and IA reduced the magnitude of RA which is consistent with the previous studies [6-8]. Not only the prevalence but also the values in RA, which was far less than the values in CA and IA (Table 2), could also indicate the existence of the compensatory effect. Evidence of this compensation of astigmatism was also found in the positive relationship between the CA and IA in our study.

Though the prevalences were unchanged in children from year 3 to year 6, a significant reduction of value in RA was seen in year 6 compared to that of year 3 and year 4. It was similar to that reported in earlier studies that astigmatism decreased with age [3,4,11,12]. However, it is not clear of the reasons contributed to such decrease. In current study, the magnitude of IA and CA were relatively stable across all age groups. The ratio of three kinds of astigmatism components in CA did not change from year 3 to year 6 with WTR predominantly. Nevertheless, a slight shift of the axis of IA from ATR to Oblique and WTR was observed in present study (Figure 2). Since the RA is the vectorial determination of the CA and IA, the shift in axis of IA could consequently change the compensatory type between CA and IA. For another, we suspected the axial change of IA is slow and mild with aging from year 3 to year 6, contributing only to the reduction in magnitude in RA but not the axial distribution.

Numerous reports have linked astigmatism to the development and progression of myopia in children [13-15]. Some studies reported children with higher astigmatism at baseline had greater myopic shift and longer axial length growth in follow-ups [14]. The other demonstrated a similar myopic shift in astigmatic preschool children and nonastigmatic children over a 4- to 8-year follow-up period [15]. The relationship between astigmatism and refractive error is controversial and needs more supportable evidence. Nevertheless, IA was also reported to be involved in the progress of myopia in school-age children [16]. In their results, IA was positively associated with AL and considered to be a risk factor of the onset and progress of myopia in school-age children. In contrast to previous conclusions [16], IA was observed to be negatively associated with AL in our study. And another study showed J0 component of IA was greater in the non-myopes compared to the Myopes [17]. It is convinced that AL can explain up to 96% of the variation of refraction in populations [18]. Subsequently, the IA was greater in population with shorter AL in Manny's study which is consistent with our finding [17]. Moreover, our results is also confirmed with another Chinese study that a larger IA is more prevalent with less myopia and greater corneal astigmatism [19]. Generally, a shorter axial length is usually related with a relatively crowding anterior segment of eyeball [20]. And it was indicated that subjects with smaller axial length had larger lens thickness [21]. Consequently, more IA will be induced with larger lens thickness as IA mainly arising from surfaces of the crystalline lens [1].

Some limitations should be acknowledged. It was a cross-sectional study, and longitudinal observation is necessary to clarify the relation between IA and AL development in children. Then, the cycloplegic refraction was not applied in present study though it was indicated cycloplegia is mostly applicable for

spherical power and has only a subtle effect on cylindrical power [22]. Finally, the relatively narrow span of age was also a limitation. A longitudinal analysis should be conducted in the further study.

Conclusion

In summary, the prevalences of RA, CA and IA were stable from year 3 to year 6, however, age-dependent decrease in RA was seen with age. The shift of the axis of IA from ATR to Oblique and WTR with aging could account for the reduction in RA from year 3 to year 6. Besides, a negative relationship was observed between the IA and AL.

Abbreviations

CA:corneal astigmatism; IA:internal astigmatism; RA:refractive astigmatism; AL: axial length; WTR: with-the-rule; ATR:against-the-rule; IOP: intraocular pressure; SD: standard deviation; ANOVA: Analysis of variance. D:dioptr

Declarations

- Ethics approval and consent to participate

This study was approved by the Institutional Review Board of the Eye & ENT Hospital of Fudan University. All procedures adhered to the Declaration of Helsinki and were conducted in accordance with the approved research protocol.

- Ethics,consent and permissions

Written informed consent was obtained from all participants' parents before enrollment.

- Consent for publication

Not applied.

- Availability of data and material

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

- Competing interests

The authors declare that they have no competing interests

- Funding

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- Authors' contributions

CMJ, SXH and DJH analyzed and interpreted the patient data. CMJ and DJH were major contributors in writing the manuscript. DJH and SXH conceived the project idea. All authors read and approved the final manuscript.

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Not applicable

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Tables

Table 1. Prevalence of RA, CA, IA at different magnitudes according to the different age.

	≤-1.0D			≤-1.5D			≤-2.0D		
	RA	CA	IA	RA	CA	IA	RA	CA	IA
Year 3 (n=260)	18.85%	63.46%	70.38%	7.69%	25%	26.92%	3.46%	8.85%	7.31%
Year 4 (n=896)	16.74%	62.05%	68.42%	6.14%	23.10%	21.09%	3.24%	7.37%	5.02%
Year 5 (n=823)	16.40%	64.52%	71.45%	6.56%	24.42%	25.15%	3.52%	9.60%	4.98%
Year 6 (n=336)	15.77%	66.67%	76.19%	5.65%	23.21%	24.40%	2.08%	6.25%	5.65%
p-value	0.772	0.462	0.061	0.759	0.338	0.116	0.638	0.185	0.487

RA=refractive astigmatism;CA=corneal astigmatism;IA=internal astigmatism;D=dioptr;N=number.

Table 2. Mean RA, CA, and IA of Children according to the different age.

	Year 3 (n=260)	Year 4 (n=896)	Year 5 (n=823)	Year 6 (n=336)	p
RA(D)	-0.71±0.56	-0.68±0.57	-0.66±0.58	-0.59±0.45	0.0147
CA(D)	-1.12±0.59	-1.09±0.57	-1.10±0.57	-1.01±0.49	0.1233
IA(D)	-1.27±0.66	-1.19±0.50	-1.19±0.49	-1.16±0.46	0.4208

RA=refractive astigmatism;CA=corneal astigmatism;IA=internal astigmatism;D=dioptr;N=number.

Table 3. Characteristics of children from year 3 to year 6 according to the magnitude of IA.

IA (D)	Age (years)	RA (D)	IOP (mmHg)	CA (D)	AL (mm)
≤-1.5 (n=529)	4.52 ±0.9	-0.69± 0.56	14.57±2.96	-2.05 ±0.78	22.11 ±0.72
≤-0.75 and >-1.5 (n=1403)	4.54 ±0.87	-0.62 ±0.53	14.57±2.74	-1.38±0.62	22.32± 0.71
>-0.75 (n=383)	4.55± 0.86	-0.70 ±0.59	14.41±2.92	-0.90± 0.59	22.49± 0.72
p	0.9242	0.051	0.6623	0.0001	0.001

RA=refractive astigmatism;CA=corneal astigmatism;IA=internal astigmatism;D=dioptr;N=number;IOP=intraocular pressure; AL=axial length.

Figures

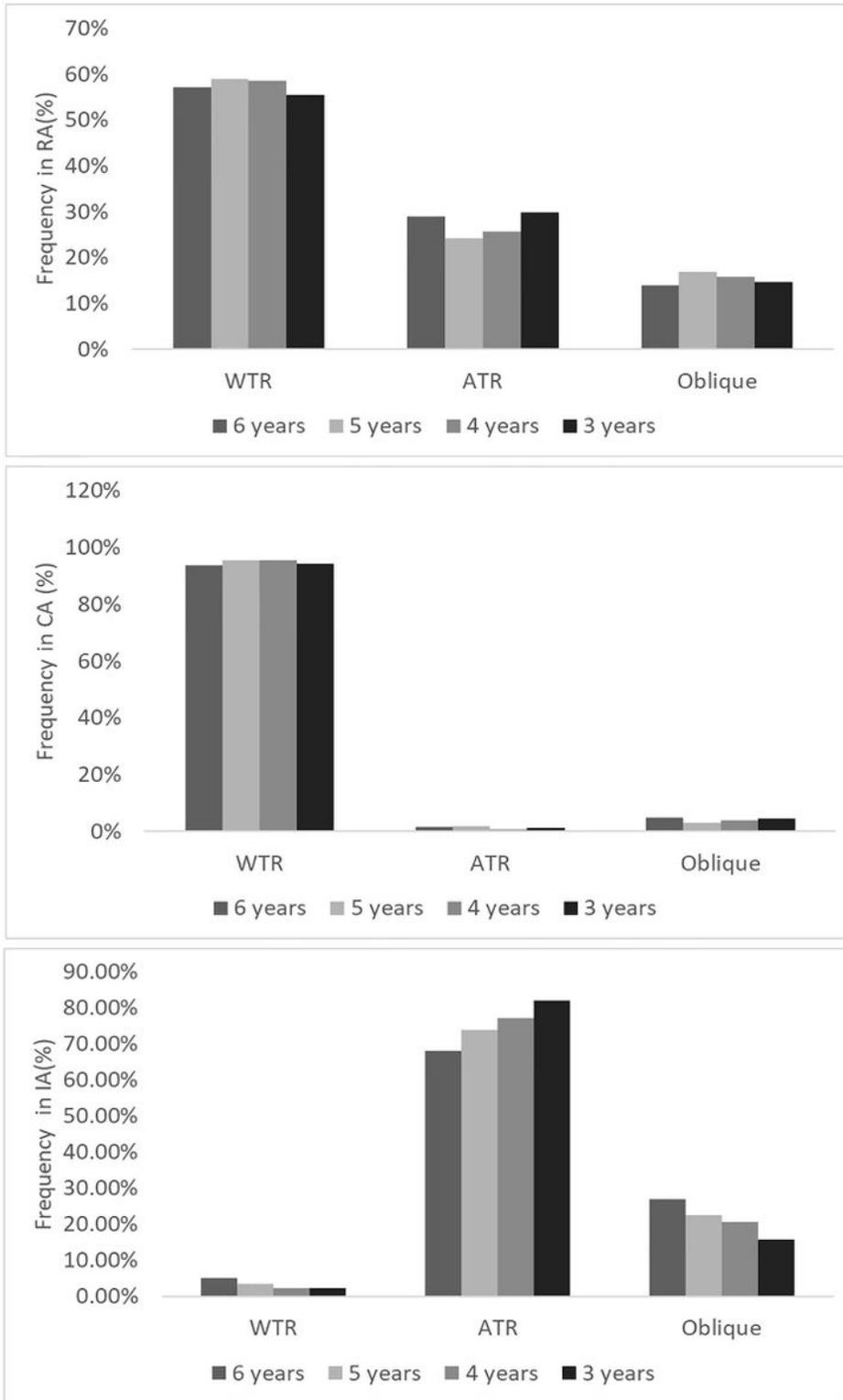


Figure 1

The axial distribution of RA, CA and IA from year 3 to year 6. RA=refractive astigmatism;CA=corneal astigmatism; IA= internal astigmatism; WTR= with-the-rule;ATR=against-the-rule.

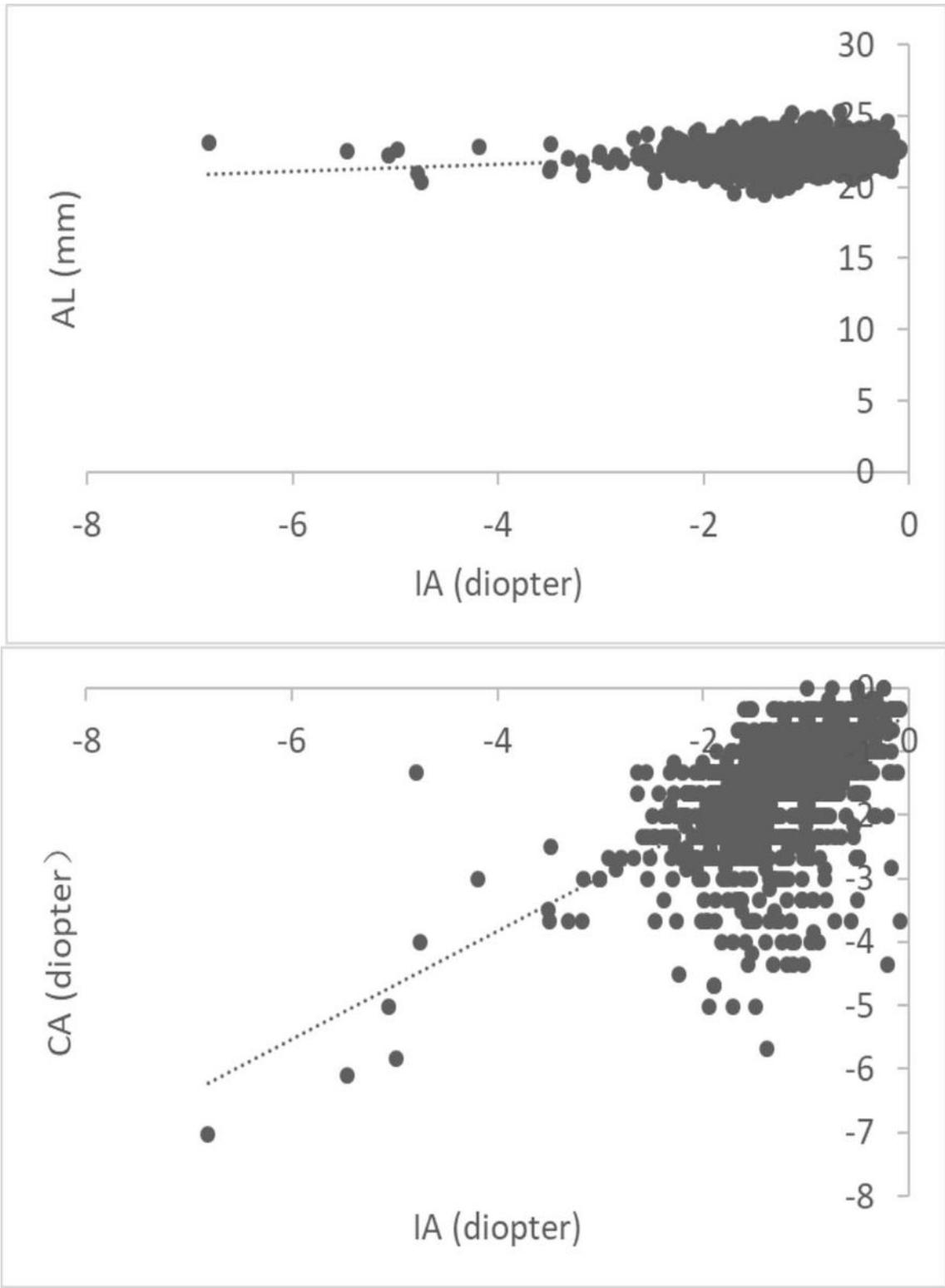


Figure 2

Scatter diagrams showing the factors that influence IA. (upper) Negative correlations between IA and AL ($r=0.1307, p=0.0094$). (lower) Positive correlations between IA and CA ($r=0.6047, p<0.001$). CA=corneal astigmatism; IA= internal astigmatism; AL=axial length.