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Full Length Article

Relationship between axial length and spherical equivalent refraction in Chinese children

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ABSTRACT

Purpose: To evaluate the relationship between axial length (AL) and spherical equivalent refraction (SER) in Chinese children.

Methods: This hospital-based cross-sectional study included 1208 eyes (from 617 Chinese boys and 591 Chinese girls), ranging between 2 and 12 years. All subjects were divided into subgroups according to the spherical equivalent refraction (SER) (hyperopia, emmetropia, and myopia) and age (2–6 years, 7–9 years, and 10–12 years). Comparisons were made between age, sex, and SER groups. Multiple linear regression analysis was used to evaluate the correlation of AL and SER for all groups.

Results: The mean AL and SER were significantly different among the three age groups: 2–6 years group (AL: 22.24 ± 1.59 mm; SER: 0.73 ± 2.67 D); 7–9 years group (AL: 23.49 ± 1.10 mm; SE: -0.68 ± 1.97 D) and 10–12 years group (AL: 24.33 ± 1.02 mm; SER: -1.72 ± 1.86 D). Boys showed longer AL compared with the girls (23.66 ± 1.51 mm vs 23.05 ± 1.32 mm). However, as for SER, the girls (−0.70 ± 2.17 D) showed smaller SER (more myopia) compared with the boys (−0.4 ± 2.48 D). After adjusting for age and sex, the SER tended to decrease (became more myopic) 1.23 D (95% CI: 1.15–1.30D) with a 1 mm increase of AL. Among the different SER groups, the SER tended to become more myopic per mm of AL by 1.09 D (95% CI: 0.97–1.21D) for the myopia group, 1.38 D (95% CI: 1.23–1.54 D) for the hyperopia group, and 0.05 D (95% CI: 0.02–0.08 D) for the emmetropic group. In addition, an increase of 1 mm elongation of AL showed a decrease of SER by 1.05 D (95% CI: 0.90–1.20 D) among 2 – 6-year-olds, by 1.40 D (95% CI: 1.30–1.51 D) among 7 – 9-year-olds, and by 1.37 D (95% CI: 1.21–1.52 D) among 10–12-year-olds. As for sexual differences, the girls 1.68 D, (95% CI: 1.57–1.79 D) showed a more significant myopic shift of SER with a 1 mm increase of AL compared with the boys (0.94 D, 95% CI: 0.84–1.04 D).

Conclusions: Our results indicated a strong linear relationship between SER and AL and an early-rising trend of myopia in Chinese children.

1. Introduction

The axial length (AL) of the eye is considered to be a main determining factor for refraction.[1] The AL is not completely fixed and tends to elongate as the eye grows. As reported by Iribarren et al., it grows gradually in the first 20 years of a person's life, from 15 mm at birth to about 24 mm in early adult years, with a speed of about 0.36 mm per year.[2] The growth of AL is generally in accordance with the emmetropization process, which is often followed by a myopic shift.

The mismatch between the AL and various optical components, mainly including the cornea and crystalline lens, is the main cause of refractive errors. As the most prevalent type of refractive error across the globe, especially in East Asia,[3] myopia is mainly due to the excessive elongation of the AL.[4] It can also be used as a complementary diagnostic criterion for axial myopia, which helps to distinguish true myopia from mixed pseudo myopia.[1,2,5]

The prevalence of myopia, including high myopia, has increased rapidly in the last few decades, leading to the increased risk of ocular complications, such as early cataract, retinal detachment, glaucoma, and myopia macular degeneration,[6] which are leading causes of legal blindness. The incidence of high myopia and myopia-associated complications have led to increased awareness and public health burdens. It was found that AL demonstrated a bimodal distribution in an adult myopic population, in which the first peak appears roughly at the AL of 24 mm for low

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myopia, while the second peak appears around the AL of 30 mm for high myopia.[7]

Studies have shown that, compared with those with high myopia, few eyes with mild to moderate myopia develop ocular pathology.[6,8,9] A population-based cross-sectional study indicated that a longer AL was significantly associated with a higher incidence of myopic maculopathy in both sexes.[10] These indicate that a longer AL is associated with a higher risk of vision impairment. Therefore, the measurement of AL is essential to predict the progression of the refractive status of eyes to allow identification of those at risk of developing high myopia, thus allowing early intervention and reducing the risk of vision loss.

The measurement of AL is widely employed in studies on refractive error, considering that the speed of eye growth to become emmetropic or a low hyperope varies in different populations,[11] and AL is heavily dependent on the underlying ethnicity and the respective prevalent conditions. The aim of this study was to evaluate the relationship between AL and SER in Chinese children of different age groups.

2. Methods

2.1. Study design

This was a retrospective hospital-based cross-sectional study. The data were randomly collected from outpatients attending the Second Affiliated Hospital of College of Medicine, Zhejiang University, from October 2020 to April 2021. The study was carried out in accordance with the ethics guidelines of the Second Affiliated Hospital of College of Medicine, Zhejiang University, and adhered to the tenets of the Declaration of Helsinki.

2.2. Subjects

A total of 1208 patients (617 Chinese boys and 591 Chinese girls) were recruited, and only data of the left eye were extracted. Subjects meet our criteria were randomly selected in those months. For each participant, data was retrieved from only one visit, the first visit which had the most complete pertinent data set. The inclusion criteria were: ① Having IOL master data; ② Having optometry data (including spherical and cylindrical degree) after mydriasis. Atropine or cyclopentolate was used in children with moderate to high myopia and hyperopia, and tropicamide for the rest; ③ The ages were between 2 and 12 years at examination. The exclusion criteria included any ocular and systemic abnormalities that might affect visual functions or refractive development (e.g., intraocular pressure >21 mmHg, glaucoma, ocular surgery), history of contact lens wear or myopia control treatment.

2.3. AL and refractive error measurement

Each subject received two drops of compound tropicamide three times 10 min apart, or atropine (once daily for seven days), or cyclopentolate (two drops of compound tropicamide three times 10 min apart) was used in children with moderate to high hyperopia and myopia. Refraction was first performed with an autorefractor (KR800; Topcon, Tokyo, Japan) after cycloplegia, followed by streak retinoscopy.

Subjective refraction was performed, but for uncooperative children, data on refraction was obtained using streak retinoscopy. The final refraction was recorded, including spherical refractive error, cylinder refractive error, and its axis. The subjects were divided into three subgroups (i) based on SER: hyperopia (SER greater than + 0.50 D), emmetropia (SER between + 0.50 and - 0.50 D), myopia (SER less than - 0.50 D), and (ii) based on age: 2–6 years old; 7–9 years old; and 10–12 years old. The AL measurements were taken by an experienced ophthalmic technician utilizing optical biometry (IOLMaster 700; Carl Zeiss Meditec AG, Jena, Germany).

2.4. Statistical analysis

The statistical analysis was performed using Stata software for Windows (12.0). For the description of the baseline characteristics of included subjects, the categorical data were presented as percentages, and the continuous data were presented as means with standard deviation. The AL and SER differences between boys and girls were tested using an independent samples *t*-test. A one-way ANOVA was used to analyze the differences between the AL and SER among the different subgroups, defined according to the SER and age. Pearson correlation coefficient was calculated to evaluate the relationship between AL and SER in different subgroups. A multiple linear regression analysis (employing the enter mode) was further used to evaluate the correlation between AL and SER after adjusting for age and sex. In all the statistical analyses, values of $P < 0.05$ were defined as statistically significant.

3. Results

A total of 1208 eyes (from 617 Chinese boys and 591 Chinese girls) were included in the present study, with a mean age of 7.92 ± 2.24 years (range: 2–12 years). All participants were stratified based on age and SER. The general demographic characteristics of all participants in all three age categories are shown in Table 1.

The mean difference of the AL among three age groups was evaluated, and the results indicated an increasing trend of AL with age ($P < 0.001$, Table 1). A statistically significant difference was also found between boys and girls ($P < 0.001$); boys (23.66 ± 1.51 mm) showed a longer AL compared with girls (23.05 ± 1.32).

In terms of SER, in accordance with the AL, there was a significant difference among three age groups ($P < 0.001$, Table 1). Interestingly, in contrast to AL, girls showed more myopic SER (−0.7 ± 2.17D) compared with the boys (−0.4 ± 2.48 D) ($P < 0.05$).

Before conducting the multiple linear regression, Pearson correlation coefficient was calculated to evaluate the relationship between AL and SER in each subgroup. The correlation coefficients ranged from −0.54 to −0.817, which indicated moderate to high correlation. For the whole population, the r is −0.736($P < 0.000$); for the myopia group, the r is -0.537(p < 0.000); for the hyperopia group, the r is - 0.694($P < 0.000$); for the boys group, the r is - 0.679($P < 0.000$); for the girls group, the r is -

Table 1
The general demographic characteristics of all participants in all three age categories

	All	2-6 years	7-9 years	10-12 years	P
N	1208	331	574	303	-
Age in years (means±SD)	7.92±2.24	5.10±0.82	8.02±0.86	10.80±0.96	-
Gender (male %)	51.08	52.87	50.35	51.16	0.551
SER in diopters	-0.56±2.33	0.73±2.67	-0.68±1.97	-1.72±1.86	<0.001
AL in mm	23.36±1.45	22.24±1.59	23.49±1.10	24.33±1.02	<0.001
Myopia (%)	52.24	22.66	56.44	76.57	<0.001
Emmetropia (%)	29.80	18.43	18.47	16.50	<0.001
Hyperopia (%)	17.96	58.91	25.09	6.93	<0.001

SER: spherical equivalent refraction AL: axial length

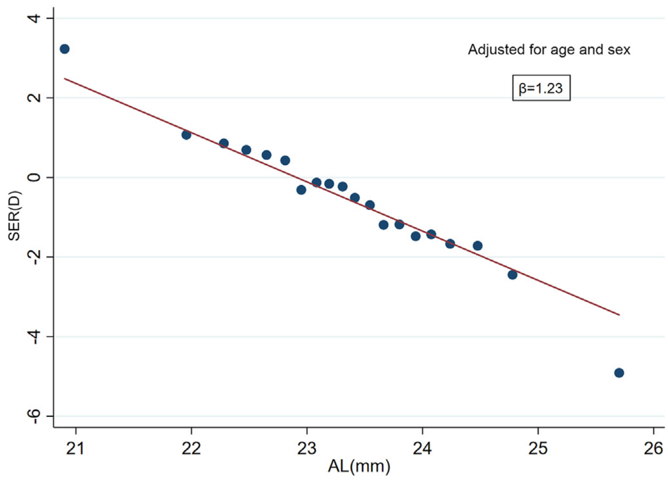

Fig. 1. The linear correlation between SER and AL for the whole population.

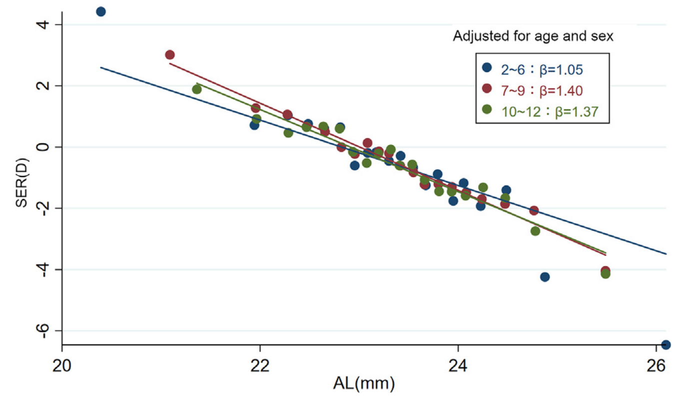

Fig. 2. The linear correlation between SER and AL in different age groups.

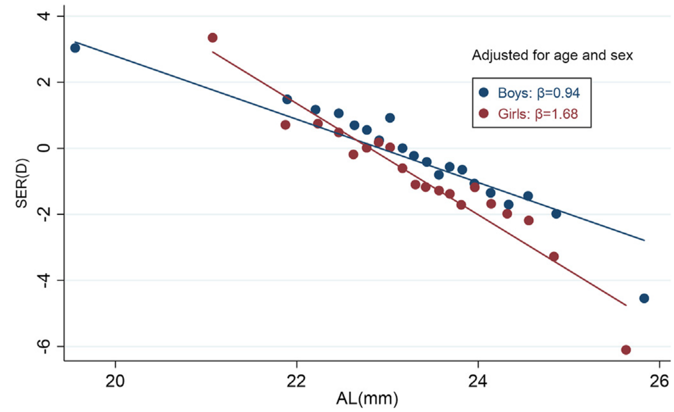

Fig. 3. The linear correlation between SER and AL for the two sexes.

0.817($P < 0.000$); for the emmetropia group, the r is - 0.243($P < 0.000$) ; for the 2–6 years group, the r is - 0.620($P < 0.000$); for the 7-to-9-year group, the r is - 0751($P < 0.000$); and for the 10–12 years group, the r is - 0.679($P < 0.000$).

With the multiple linear regression method, the SER tended to decrease 1.23 D (95% CI: 1.15–1.30D, Fig. 1, Table 2) with a 1 mm increase of the AL for the whole population, after adjusting for age and sex. For the myopia group, the SER tended to decrease 1.09 D (95% CI: 0.97–1.21 D, Supplemental Fig. S1, Table 2) with a 1 mm increase of the AL, and for the hyperopia group, the SER tended to decrease 1.38D (95% CI: 1.23–1.54 D, Supplemental Fig. S2, Table 2). It is worth noting that SER only showed slight changes for the emmetropia group compared with the other two groups, about 0.05 D (95% CI: 0.02–0.08 D, Supplemental Fig. S3, Table 2). In addition, the decrease of SER caused by the 1 mm elongation of the AL tended to increase with age (2–6 years: 1.05 D (95% CI: 0.90–1.20 D); 7–9 years: 1.40 D (95% CI: 1.30–1.51 D); and 10–12 years: 1.37 D (95% CI: 1.21–1.52D, Fig. 2, Table 2). Linear correlation coefficient for the two sexes also be calculated.

For girls, SER increased by 1.68 D (95% CI: 1.57–1.79 D) for 1 mm increase in AL, whereas for boys, the increase was 0.94 D (95% CI: 0.84–1.04 D) (Fig. 3, Table 2) ($P < 0.001$).

4. Discussion

The present study mainly indicated the trend of AL and SER with age, and summarized the linear relationship between AL and SER in Chinese children aged 2–12 years. For the whole population, after adjusting for age and sex, the SER tended to decrease 1.23 D (95% CI: 1.15–1.30 D) per mm increase of AL. In addition, according to our results, boys showed a significantly longer AL compared with girls, yet girls were more likely to develop myopia.

This finding is in agreement with previous reports that myopia occurs more often in girls, about 1.15–2.56 times compared with boys,[12–16] although there are also some reports that boys were more myopic.[17–19] The differences are generally biologically and socially or behaviorally determined, and the main influencing factors include genetic, dietary, education, neural input, the amount of near work.[20] Girls usually enter puberty earlier than boys, which might also lead to a rise in the prevalence of myopia.[12] The results of the current study are in agreement with that reported by Yotsukura et al., who also reported longer AL in boys.[21]

Notably, the definition of myopia is not based on the objective parameter of the AL, and the accurate linear correlation between AL and myopia progress is individual heterogeneity. Children at risk of the development of myopia may have an excessively long AL before myopia onset, but remain emmetropic, which may be caused by the compensation effect of lens and cornea power. And this suggests that the value of AL does not necessarily indicate refractive state. Besides, considering the

Table 2
The β, CI, p, F and adjusted R^2 values of the multiple linear regression model in different groups.

	β	CI	*P*	F	adjusted R^2
All	−1.226	(−1.303 to −1.150)	0.000	489.845	0.549
Myopia	−1.090	(−1.206 to −0.974)	0.000	114.597	0.354
Hyperopia	−1.386	(−1.537 to −1.234)	0.000	124.703	0.512
Emmetropia	−0.047	(−0.076 to −0.018)	0.002	4.583	0.048
Girls	−1.682	(−1.794 to −1.569)	0.000	613.522	0.677
Boys	−0.942	(−1.041 to 0.843)	0.000	264.854	0.464
2–6 years old	−1.052	(−1.201 to −0.903)	0.000	68.587	0.381
7–9 years old	−1.404	(−1.513 to −1.295)	0.000	268.750	0.586
10–12 years old	−1.367	(−1.134 to −0.500)	0.000	101.625	0.506

emmetropization effect,[22] which suggests that longer AL tends to be related to lower lens and cornea power to compensate for the refractive change, the mismatch between myopia and AL between males and females may be due to differences in lens power between the sexes.

Compared with other ocular components, such as the cornea and crystalline lens, AL is generally considered to be the most important determinant of axial myopia. Olsen et al. have confirmed that AL could explain up to 96% of the variation of refraction.[23] The linear correlation between AL and refractive degree varies due to different ethnicities and environmental factors. In the present study, SER tended to decrease by 1.23 D with a 1-mm increase of AL in Chinese children aged 2–12 years. He et al. reported a 1.01 D shift towards myopia for every 1 mm increase in AL in Chinese schoolchildren.[24] Li et al. reported that AL tended to increase by 1.69 D per mm of AL in primary school–aged children in China.[25] SER was reported to decrease by 1.67 D with a 1-mm increase of AL in Danish children aged 6–12 years.[26] Considering the difference in study design, our results generally agreed with those provided by other authors. This fact is also due to the fact that longer eyes have lower lens power that compensates for the refractive change.[27]

Juvenile-onset myopia usually starts between the ages of 6 and 14 years. We found that compared with younger children, children aged 7–9 displayed an average SER of - 0.68 diopter, and continued to decrease to −1.72 D for children aged 10–12. The current situation is worrisome because the underlying excessive axial elongation significantly increases the risk of maculopathy, glaucoma, and other myopia-related complications.[23] Several studies have suggested that outdoor activity of more than 2 h per day could help to control myopia progress.[21,28,29] It has been reported that children in Europe spend about 2.5 times more hours outdoors than children in Asia.[21] At the same time, myopia prevalence in school children remains lower in Europe (40%) compared with Asia (60%).[30] Despite differences in genetic background and other environmental factors, this indicates that more outdoor activities might result in less myopia.

Our study has several limitations. Firstly, considering the hospital-based study design, the results may not be a broad enough representation of Chinese children aged 2–12, and a population-based study with a multistage, stratified cluster sampling method needs to be performed to confirm the results. Secondly, in our hospital, atropine or cyclopentolate was used in children with moderate to high myopia and hyperopia. For other children, cycloplegia in our study was obtained by tropicamide instead, considering some children's photophobia and rejections from parents. However, as a recent prospective observational study shows similar effects in producing cycloplegia using tropicamide and cyclopentolate in Chinese young people,[31] the SER of children who received tropicamide may be overestimated. Thirdly, previous studies indicated that axial elongation usually occurred concurrently with loss of lens power in children.[32,33] However, anterior chamber depth and lens thickness (which can be used to calculate lens power using Bennett's equation[34]) are not routine test items for children diagnosed with refractive error in our hospital. Thus, lens power was not included in the analysis in the present study, which may contribute the negative correlation between SER and AL.

5. Conclusions

In conclusion, the current study generally aimed to provide a better understanding of SER and AL in Chinese children aged 2–12 years. A linear relationship between SER and AL was significant in the whole population, including in both sexes and in different age and SER groups, which indicated that AL might serve as a key instrument for monitoring refractive change, especially myopia progression. Also, the trend toward myopia in young children should draw the attention of parents and educators, and proper lifestyle advice and interventions are essential to prevent myopia among young children in China.

Study Approval

The authors confirm that any aspect of the work covered in this manuscript that involved human patients or animals was conducted with the ethical approval of all relevant bodies and the study was performed in accordance with the Declaration of Helsinki,and the protocol was approved by the Ethics Committee of the second affiliated hospital of Zhejiang university (approval number: 20210730).

Author Contributions

The authors confirm contribution to the paper as follows: conception and design of study: XN Yu, SY Chen; Data collection: XN Yu, SY Chen; Analysis and interpretation of results: XL, XN Yu, SY Chen; Drafting the manuscript: XL, XN Yu, SY Chen, XT Sha, XX Yang; All authors reviewed the results and approved the final version of the manuscript.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.aopr.2021.100010.

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