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Normative value of hyperopia reserve and myopic shift in Chinese children and adolescents aged 3–16 years

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ABSTRACT

Background This research aims to generate normative values of hyperopia reserve and refractive progression as effective tools to estimate the risk of myopia.

Methods A 1-year follow-up study was conducted among Chinese children and adolescents aged 3–16 years selected from schools and kinder gardens using cluster sampling. All participants underwent examinations including visual acuity, axial length and cycloplegic autorefraction (1% cyclopentolate). Percentiles of spherical equivalent (SE) were calculated using Lambda-Mu-Sigma (LMS) method. Age-specific refractive progression and hyperopia reserve were determined by backward calculation.

Results Of 3118 participants, 1702 (54.6%) were boys with a mean baseline age of 7.30 years. The 50th percentile of SE estimated by LMS decreased from 1.04 D at 3 years to −2.04 D at 16 years in boys, while from 1.29 D to −2.81 D in girls. The 1-year refractive progression of myopes (0.81 D) was greater than that of non-myopes (0.51 D). The normative value of hyperopia reserve was 2.64 (range: 2.40 D–2.88 D) at 3 years and −0.35 (range: −0.50 to −0.17) D at 16 years, with the maximum progression of 0.35 D at the age of 6 years.

Conclusion Age-specific normative values of hyperopia reserve and yearly myopic shift in children and adolescents aged 3–16 years were provided, helping identify and monitor myopia and giving prevention in advance.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Previous research found that the incidence of myopia decreased with the increase of hyperopia reserve at baseline, indicating that it is important to pay attention to the intervention of premyopia children with insufficient hyperopia reserves to reduce the incidence of myopia. Existing studies lack the reference range of normative hyperopia reserve and refractive progression in different age groups of children and adolescents.

WHAT THIS STUDY ADDS

⇒ Explored the law of refractive development of children and adolescents, and put forward the normative value of hyperopia reserve and refractive progression for children and adolescents at 3–16 years.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ Help give early warning and intervention to children with impending myopia or rapid progression, thus reducing the incidence of myopia and high myopia.

INTRODUCTION

Myopia has become a serious clinical and public health problem,[1] and has a great impact on social economy.[2] In the past decades, the prevalence of myopia is increasing year-by-year all over the world, especially in East and Southeast Asia.[3–6] Uncorrected ametropia is the main cause of visual impairment and the second-largest cause of blindness in the world,[7–9] which has brought a burden to patients and their families and society, resulting in a loss of about US $250 billion worldwide every year.[10]

Refractive development is a process in which the refractive state of children and adolescents gradually becomes emmetropia from hyperopia, and the continuous development after emmetropia forms myopia.[11] Schmid mentioned in Myopia Manual that about 80% of young children are hyperopic, and this hyperopia can increase until 7–8 years and then decrease until about 19–20 years.[12] It is worth noting that the state of hyperopia before emmetropia, referred to as hyperopia reserve (HR) (represented as spherical equivalent, SE), may serve as a critical indicator for early prediction of myopia.[13] Previous cohort studies demonstrated that a greater HR at baseline is associated with a reduced likelihood of developing myopia.[14–16] For instance, a study showed that the incidence of myopia decreased with increasing SE at baseline, from 86.8% for individuals with baseline SE≤0.0 D to 0% for those with SE>2.0 D.[14] Children with early-onset myopia have a longer course of the disease, and they are more likely to develop into high myopia.[17 18] Therefore, paying attention to the intervention of premyopia children with insufficient HR is an important strategy to reduce the incidence of myopia.

However, the existing studies lack the reference range of normative HR and refractive progression in different age groups of children and adolescents.

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Cumberland *et al* have investigated the distribution of refractive errors in adult life[19] and Yahya *et al* have explored the distribution of refractive errors among healthy infants and young children aged 6–36 months,[20] whose study population was not children and adolescents. Although there is a cross-sectional survey of non-myopic Chinese children, the age range of the study population is narrow (6–12 years).[21] The SCORM, a cohort study conducted in Singapore, incorporated children aged 7–9 years to measure myopic progression.[22] Similarly, the Finnish study only included 3-year myopic progression in children aged 9 and 11 years.[23] In addition, a multiethnic study merely enrolled children with myopia (−6 D to −1 D) to characterise the myopic progression.[24] Therefore, it is urgent to probe the law of refractive development of children and adolescents, and put forward the normative value (reference range) of HR and refractive progression for each age group.

In order to explore patterns of refractive development and establish normative values for HR across different age groups, our study examines the overall trend in refractive progression among children and adolescents aged 3–16 years. This approach enables an understanding of refractive changes over the course of 1 year and helps establish normative values for HR, which will aid in the identification of individuals at risk of myopia and facilitate preventive measures.

METHODS

Study population

Using cluster sampling method, children aged 3–16 years were recruited from 28 kindergartens, 10 primary schools and 2 middle schools in Shanghai from 2015 to 2016. The participants were excluded from the study if they had an allergic constitution, systemic diseases such as diabetes and hypertension, retinopathy of prematurity, amblyopia, strabismus, congenital glaucoma, congenital cataract and other ocular pathology, and a history of ophthalmic surgery.

Data collection

All the participants underwent comprehensive ophthalmic examinations, including uncorrected visual acuity (UCVA), axial length (AL), intraocular pressure, slit-lamp examination and cycloplegic autorefraction.

Visual acuity was measured at 4 m by an illuminated Early Treatment Diabetic Retinopathy Study chart (LCD backlit lamp, 400 cd/m^2, WH0701, Guangzhou Xieyi Weishikang) under indoor light. Those with UCVA<20/20 in either eye were additionally checked for the best-corrected visual acuity. AL was measured with an IOL Master (V.5.02; Carl Zeiss, Jena, Germany). Intraocular pressure was measured using a non-contact tonometer (NT-1000, Nidek, Tokyo, Japan). For cycloplegia, 1 drop of 0.5% proparacaine hydrochloride (Alcaine; Alcon, Fort Worth, Texas, USA) was first instilled in each eye. After about 15–20 s, 2 drops of 1% cyclopentolate (Alcon) were instilled in each eye at an interval of 5 min. After 30 min, eyes were checked for dilation and pupillary response to light. If necessary, a third drop of cyclopentolate was instilled. Cycloplegia was deemed complete if the pupil size was dilated to 6 mm or greater and the pupil light reflex disappeared. Refraction was determined using a desk-mounted autorefractor (KR-8900; Topcon, Tokyo, Japan). Before measurement, the simulated eye was used for calibration, and each eye shall be measured at least three times. If any two measurements changed by more than 0.50 D, the readings were discarded and the eye was remeasured. At the same time, general information such as age, gender and grade were collected by a questionnaire. All the data collected and analysed in this research are not open due to confidentiality.

Definitions

Based on cycloplegic autorefraction results, the SE was calculated by the standard formula of the sum of the sphere and half of the cylinder. Since the SE of the right and left eyes were highly correlated at baseline and follow-up, the data of the right eye were used in subsequent analysis. Myopia was defined as SE≤−0.5 D. The incidence of myopia was defined as the occurrence of myopia at follow-up in participants without myopia at baseline. One-year refractive progression was calculated as SE in 2015 minus SE in 2016. In order to estimate more conservatively, we exclude all those with negative progression (further sensitivity analysis was provided in online supplemental material).

Statistical analysis

All analysis were performed using SPSS (V.24.0; IBM), R Programming Language (V.4.1.0; R Core Team, 2021) and MedCalc (V.19; MedCalc Software, Ostend, Belgium) were used for statistical analyses. The data distribution was examined using Kolmogorov-Smirnov test. Continuous variables conformed to or approximated to the normal distribution were expressed as means±SD, while those that did not conform were presented as median with quantiles, and categorical data were shown as rates (proportions). A two-sided $p<0.05$ was considered statistically significant. The percentiles growth curve of baseline SE in children and adolescents was drawn with the Lambda-Mu-Sigma (LMS) method developed by Cole and Green.[25] The distribution of refraction in each age group can be described by LMS method.[26] To better present the 1-year refractive progression, participants were classified into myopes and non-myopes.

To analyse the HR among children and adolescents aged 3–16 years, we employed a backward calculation method. The 1-year follow-up data were divided into a baseline database and a follow-up database. From the follow-up database, individuals who were non-myopes (SE>−0.5D) at the age of 17 in the follow-up database were selected as the starting point. The refractive range of these non-myopes at the age of 16 in the baseline database was analysed. Based on this range, the 16-year-old adolescents from the follow-up database were selected, and their refractive range at the age of 15 in the baseline database was analysed. This process was repeated, selecting the corresponding age groups from the follow-up database, and analysing their refractive ranges in the baseline database. This stepwise analysis continued until reaching the youngest age group available in the baseline database. Subsequently, the progression among the selected population in both the baseline and follow-up databases were calculated. The age-specific HR was obtained using the following formula: HRn+1=HRn + meanprogression±SDprogression. The entire process was visually presented in figure 1.

RESULTS

General characteristics

A total of 3118 participants (87.7% of those invited) from Shanghai were involved in this study, and 3093 (99.2%) of them participant in the follow-up study, with no significant difference in age and gender between responders and non-responders ($p>0.05$). At baseline, there were 605 (19.4%) myopes, with 1702 (54.6%) boys. The mean age of myopic children was 9.89±3.24 years and that of non-myopic children was 6.68±2.11 years (both range from 3 to 16). Additionally, the mean SE of the myopic children and non-myopic children was

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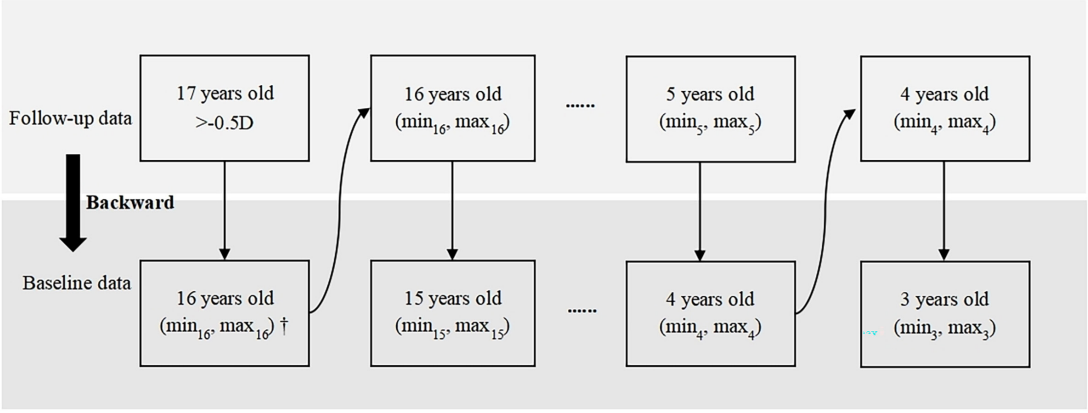

Figure 1 Backward calculation method for obtaining refractive progression and normative hyperopia reserve.

−2.20±1.78 D and 0.94±0.69 D, respectively. The mean AL was 24.35±1.10 mm for myopes and 22.82±0.79 mm for non-myopes (all p<0.001).

Percentiles of baseline SE and estimated SE by LMS methods in each age group at baseline

The raw value of SE at baseline and the estimated SE based on LMS method in each age group were presented in table 1. In boys, the maximum median SE was 1.25 D at the age of 4 and the minimum median SE was −3.25 D at the age of 15. Half of the boys had been suffering from myopia since the age of 13 (median SE: −1.38 D). In girls, baseline SE decreased gradually with age, from 1.5 D at the age of 3 to −4.38 D at the age of 16. And more than 50% of girls had myopia since the age of 12 (median SE: −0.50 D).

The baseline SE of young boys was lower than that of girls (1.13 D vs 1.50D at 3 years), but the opposite was true in older participants (−3.13 D vs −4.28 D at 16 years). When focusing on the estimated SE, this situation was more obvious. The 50th percentile of estimated SE in boys gradually decreased from 1.04 D at the age of 3 to −2.04 D at the age of 16, and this range expanded slightly in girls, from 1.29 D at the age of 3 to −2.81 D at the age of 16–17. Additionally, the range of 2.5th, 25th, 75th and 97.5th percentiles of estimated SE in boys were overall smaller than those of girls.

Age-specific refractive distribution and progression in myopes and non-myopes at baseline

The distribution of baseline SE and 1-year refractive progression in myopes and non-myopes of different ages was shown in table 2. The 1-year refractive progression of myopes (0.81D) was clearly greater than that of non-myopes (0.51 D). The annual refractive progression of all non-myopes was below 0.5 D, and the progression of non-myopes aged 6–8 years was relatively fast (0.50, 0.38 and 0.50 D/year, respectively). Although the annual refractive progression of low-age (3–5 years) myopic participants was slow (0.13, 0.25 and 0.38 D/year, respectively), the refractive progression of myopic participants became faster from the age of 6 to the age of 14. And the largest refractive progression (1.25 D/year) occurred in myopic children with a baseline age of 6 years. The refractive progression of myopes at the age of 15–16 years tended to be gentle again (0.38 D/year). In addition, there was a small difference in the progression between myopes and non-myopes at the ages of 3–5 and 15–16 while the biggest difference occurred at the age of 6 (0.75 D/year) and 7 (0.62 D/year).

Table 1 Age-specific and gender-specific percentiles of baseline spherical equivalent distribution among participants

Age (years)	N	Boys (N=1702)						Girls (N=1416)					
			Estimated percentiles (LMS)						Estimated percentiles (LMS)				
		Raw percentiles P50 (P25, P75)	P2.5	P25	P50	P75	P97.5	Raw percentiles P50 (P25, P75)	P2.5	P25	P50	P75	P97.5
3	147	1.13 (0.88, 1.50)	2.01	0.41	1.04	1.45	3.25	1.50 (0.88, 1.75)	2.11	0.61	1.29	1.71	3.57
4	328	1.25 (0.75, 1.50)	2.01	0.42	1.05	1.45	3.26	1.25 (0.88, 1.75)	2.18	0.53	1.22	1.63	3.49
5	206	1.13 (0.75, 1.50)	2.02	0.40	1.03	1.44	3.24	1.25 (0.75, 1.56)	2.29	0.42	1.11	1.52	3.39
6	373	1.00 (0.50, 1.50)	2.10	0.32	0.95	1.36	3.16	1.00 (0.50, 1.50)	2.44	0.27	0.96	1.37	3.23
7	703	0.88 (0.25, 1.25)	2.26	0.16	0.79	1.20	3.00	0.75 (0.25, 1.22)	2.68	0.03	0.72	1.13	3.00
8	864	0.25(−0.50, 1.00)	2.51	0.09	0.54	0.95	2.75	0.25 (−0.38, 0.88)	2.93	0.21	0.47	0.89	2.75
9	149	0.31(−0.75, 0.75)	2.76	0.34	0.29	0.70	2.50	0.25 (−1.50, 0.75)	3.17	0.45	0.23	0.65	2.51
10	46	0.00 (−1.38, 0.75)	2.99	0.57	0.06	0.47	2.27	0.50 (−0.88, 1.00)	3.42	0.71	0.02	0.39	2.25
11	45	0.00 (−1.63, 0.50)	3.23	0.81	0.18	0.23	2.03	0.13 (−1.88, 0.53)	3.74	1.02	0.34	0.08	1.94
12	56	0.13 (−0.88, 0.75)	3.51	1.09	0.46	0.05	1.75	0.50 (−1.81, 0.06)	4.14	1.42	0.74	0.32	1.54
13	52	1.38 (−2.00, 0.47)	3.85	1.43	0.80	0.39	1.41	2.06 (−3.44, −0.56)	4.61	1.90	1.21	0.80	1.06
14	18	1.25 (−2.00, 0.25)	4.24	1.82	1.19	0.78	1.02	0.75 (−1.50, 0.00)	5.13	2.42	1.73	1.32	0.54
15	73	3.25 (−3.88, −0.88)	4.66	2.23	1.61	1.20	0.60	2.94 (−5.34, −1.47)	5.67	2.96	2.27	1.86	0.01
16	58	3.13 (−4.38, −1.28)	5.09	2.66	2.04	1.63	0.17	4.38 (−5.38, −0.84)	6.22	3.50	2.81	2.40	0.54

LMS, Lambda-Mu-Sigma.

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Table 2 Age-specific refractive distribution and progression in myopes and non-myopes

		Myopes (N=605)		Non-myopes (N=2513)	
Age (years)	N	Baseline SE P50 (P25, P75)	1-year progression P50 (P25, P75)	Baseline SE P50 (P25, P75)	1-year progression P50 (P25, P75)
3	147	0.88 (–5.75, –0.75)	0.13 (0.13, 0.63)	1.25 (0.88, 1.75)	0.25 (0.00, 0.50)
4	328	1.31 (–1.66, –0.97)	0.25 (0.25, 0.25)	1.25 (0.88, 1.59)	0.25 (0.00, 0.50)
5	206	0.75 (–0.94, –0.63)	0.38 (0.19, 0.81)	1.25 (0.75, 1.50)	0.25 (0.00, 0.38)
6	373	0.63 (–0.94, –0.63)	1.25 (1.00, 1.50)	1.00 (0.63, 1.50)	0.50 (0.25, 0.75)
7	703	1.00 (–1.53, –0.63)	1.00 (0.63, 1.25)	1.00 (0.50, 1.25)	0.38 (0.19, 0.88)
8	864	1.50 (–2.38, –0.88)	0.88 (0.63, 1.25)	0.63 (0.25, 1.00)	0.50 (0.25, 0.88)
9	149	1.75 (–2.75, –0.97)	0.75 (0.50, 1.00)	0.50 (0.25, 1.00)	0.38 (0.13, 0.63)
10	46	1.75 (–2.00, –1.19)	0.88 (0.59, 1.16)	0.69 (0.25, 1.00)	0.25 (0.25, 0.81)
11	45	2.25 (–2.88, –1.63)	0.88 (0.66, 1.00)	0.50 (0.25, 0.75)	0.25 (0.13, 0.56)
12	56	1.63 (–2.25, –0.88)	0.88 (0.53, 1.00)	0.50 (0.00, 0.75)	0.25 (0.13, 0.50)
13	52	2.50 (–3.88, –1.63)	0.63 (0.25, 0.88)	0.50 (0.25, 0.75)	0.25 (0.13, 0.50)
14	18	1.50 (–2.28, –1.19)	0.56 (0.25, 0.75)	0.25 (0.25, 0.34)	0.25 (0.25, 0.34)
15	73	3.50 (–5.63, –2.00)	0.38 (0.25, 0.63)	0.25 (0.06, 0.75)	0.38 (0.19, 0.44)
16	58	3.88 (–5.28, –2.22)	0.38 (0.25, 0.53)	0.31 (0.00, 0.75)	0.19 (0.03, 0.38)

Refractive progression by backward calculation and normative HR in each age group

Through backward calculation, the 1-year refractive progression and normative HR of these selected participants were presented in table 3 and figure 2. The 1-year refractive progression had a peak at 6 years old, which was 0.35±0.37 D/year. The normative value of HR was 2.64 (range: 2.40D–2.88D) at 3 years and −0.35 (range: −0.50D to −0.17D) at 16 years. The HR was 2.08 (range: 1.72D–2.45 D) at 6 years, 1.49 (range: 1.19 D–1.79 D) at 8 years and 1.04 (range: 0.92D–1.16D) at 10 years, respectively.

When the above range was applied to the baseline SE of participants in this study, we found that most participants were far from reaching the normative HR (10.8%). Only 0.7% of 3-year-old children had ideal HR. The percentage of reaching the normal HR in 12-year-old children was 19.6%, which is greater than any other age group from 3 to 16.

DISCUSSION

This study provided age-specific normative values of HR and yearly myopic shift in children and adolescents aged 3–16 years, aiding in identifying and monitoring individuals at risk of myopia and giving prevention in advance.

In this study, we found the median SE of preschool children (3–6 years old) was above 1.0 D, and was about 0.88 D to −0.50 D in primary school students (7–12 years old), less than −0.50 D in junior and senior high school students (13–17 years old). Our results are similar to the previous Shandong Children Eye Study in coastal east China, in which the refractive range of boys aged 4–18 in urban areas was 1.50 D to −3.81 D and that of girls was 1.13 D to −4.67 D.[27] In the observational cohort study in Guangzhou, the mean refraction of primary school students was about 0.5 D to −1.5D, while that of junior high school students was about −2D.[28] Since the results of Guangzhou cohort was based on refraction without cycloplegia, the SE of their school-aged children were lower than ours.

In addition, we found that girls were more hyperopic than boys at the age of 6 and below but the SE of the girls drops faster than that of the boys. Previous studies have suggested that the gender difference begin to appear at about the age of 9 among whites and East Asians, and become more obvious with age, indicating that girls are more likely to suffer from myopia than boys.[29] It

Table 3 Age-specific means of refractive progression and standard value of hyperopia reserve by backward calculation

Age (years)	N	Refractive progression Mean±SD	Hyperopia reserve mean	Hyperopia reserve range	Proportion of baseline participants that fall within the hyperopia reserve range (%)
3	144	0.19±0.24	2.64	2.40 to 2.88	0.7
4	326	0.18±0.22	2.45	2.23 to 2.66	5.5
5	199	0.18±0.21	2.26	2.05 to 2.48	6.8
6	358	0.35±0.37	2.08	1.72 to 2.45	17.4
7	615	0.25±0.26	1.74	1.48 to 2.00	14.5
8	641	0.25±0.30	1.49	1.19 to 1.79	11.8
9	97	0.20±0.13	1.24	1.11 to 1.38	4.7
10	30	0.09±0.12	1.04	0.92 to 1.16	4.3
11	27	0.22±0.12	0.95	0.83 to 1.07	6.7
12	30	0.27±0.12	0.73	0.61 to 0.85	19.6
13	19	0.29±0.19	0.46	0.27 to 0.65	13.5
14	6	0.29±0.07	0.17	0.09 to 0.24	0.0
15	11	0.23±0.18	0.13	–0.31 to 0.06	2.7
16	9	0.15±0.18	0.35	–0.50 to –0.17	3.4
17			0.50	>–0.5	

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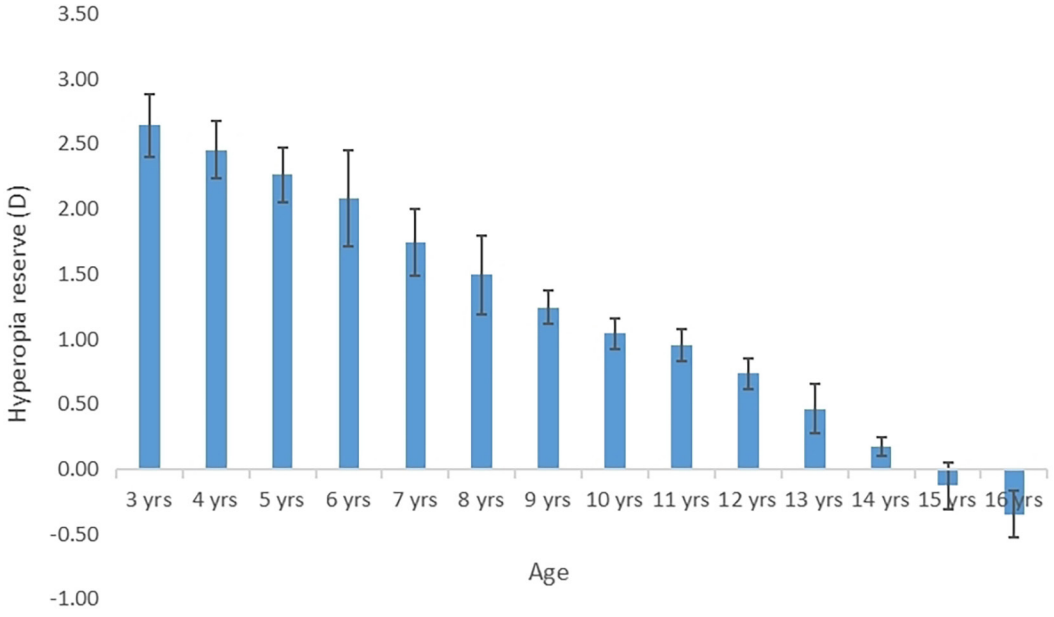

Figure 2 Bar graph showing age-specific hyperopia reserve by backward calculation.

may be related to the education levels, near work and outdoor activity.[30] However, some studies believe that the gender difference may be caused by the different puberty stages of boys and girls of the same age.[31 32] Besides, we observed that the actual median SE of children and adolescents did not decrease linearly with age, and inversion occurs at some ages, especially at 3–5 years. The inversion may not be as significant as it should be, since we have excluded participants with negative progression. The balance between the refractive power of the lens and the axial growth may account for the inversion.

Through classification of refractive status, we observed that non-myopic participants had a slower rate of refractive progression, with a refractive progression of about 0.5 D/year only when they first entered elementary school (6–8 years old). However, myopic participants maintained a high 1-year refractive progression from the age of 6 until the age of 14. We speculate that myopic children will experience extra non-physiological refractive progression on the basis of their annual physiological refractive progression.

The SE percentile curve of non-myopia children mentioned above does not really reflect the HR. Through 1-year follow-up data, we extrapolated the annual refractive progression of healthy children and adolescents from non-myopic (defined as SE>−0.5D) 17-year-old participants to establish standard value of HR. In comparison with the refractive progression of 0.35 D in 6-year-old children and 0.25D in 7-year-old children in our study, progression of SE was much lower (0.13 D) in Northern Irish children aged 6–7 years.[33] In Delhi, the 1-year refractive progression of 50.8% children aged 5–15 years was 0D, while 49.2% children had an average dioptric change of −0.27 D.[34] Our findings suggested that Chinese children may need more HR compared with children in other countries to reduce the risk of myopia in the future. However, we need to be careful when draw the conclusion that refractive progression in Chinese children were faster, since some data with negative progression were excluded.

The standard value and range of the HR derived from our study should be applied with caution, because the HR obtained in this study is a relatively ideal value and does not represent the refractive distribution of the real population. The proportion of baseline SE within this age-specific HR was only 10.8%, indicating that the condition of HR among children and adolescents is tough and more attention should be paid. When we included those cases with negative progression in sensitivity analysis, we could see the average progression in ages 3–5 was negative, which was in accordance with Ma *et al*'s study.[35] However, the value of HR could be too low for daily practice in myopia prevention.

There were several limitations. First, due to the lack of long-term follow-up data, a 1-year cohort data with a backward calculation was used. Compared with birth cohort analysis, it may cause bias. Hopefully, validation of this newly derived normative range on an external cohort would be important work to undertake in the near future. Second, this study is population, region and time-specific with small sample size in some age groups, thus it should be careful when generalised the results to other cities and countries. Third, since we used 1% cyclopentolate for cycloplegia, children aged 3–6 years may not be fully cyclopleged, bringing measurement bias. More adequate mydriatic agent was recommended for this population in the future.

In conclusion, our study presented the distribution of SE and refractive progression of children and adolescents aged 3–16 in Shanghai, China. Our study also explored the normal value and reference range of age-specific HR, which may be useful as a key tool to monitor the refractive development in Chinese children at a specific age. It may also serve as an instrument to predict the risk of developing myopia in children in the future. Doctors and parents are able to use these charts to determine whether a child's current SE or refractive progression are higher than average level of his or her age. Naturally, those high-risk children can be found relatively early and receive more active preventive treatment at an early stage.

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Ethics approval This study involves human participants and the Ethics Committee of Shanghai General Hospital approval (2015KY150) was obtained. Written informed consent was signed by all subjects and their guardians before participation. The described research adhered to the tenets of the Declaration of Helsinki. Participants gave informed consent to participate in the study before taking part.

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