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Associations between anthropometric indicators and refraction and ocular biometrics in a cross-sectional study of Chinese schoolchildren

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Complete List of Authors:	Ye, Sheng; School of Public Health, Tianjin Medical University Liu, Shengxin; School of Public Health, Tianjin Medical University Li, Wenlei; School of Public Health, Tianjin Medical University Wang, Qifan; School of Public Health, Tianjin Medical University Xi, Wei; School of Public Health, Tianjin Medical University Zhang , Xin; School of Public Health, Tianjin Medical University

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Associations between anthropometric indicators and refraction and ocular biometrics in a cross-sectional study of Chinese schoolchildren

Sheng Ye, Shengxin Liu, Wenlei Li, Qifan Wang, Wei Xi, and Xin Zhang

Department of Maternal, Child and Adolescent Health, School of Public Health, Tianjin Medical University, Tianjin, China.

SY and SL contributed equally to the work presented here and should therefore be regarded as equivalent authors.

Correspondence to

Prof. Xin Zhang, Department of Maternal, Child and Adolescent Health, School of Public Health, Tianjin Medical University, No. 22 Qixiangtai Road, Tianjin 300070, China; zhangxin@tmu.edu.cn.

Synopsis

Development of refraction may be related to physical development during early adolescent growth. Future studies in endocrine traits, such as the sex hormones, could further provide new insights for the association between height and refraction.

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ABSTRACT

Objective To identify associations between anthropometric indicators, including height, weight, and body mass index (BMI), and refraction and ocular biometrics in Chinese schoolchildren in Tianjin, China.

Design Cross-sectional study.

Participants A total of 482 (86.1%) students (6 to 15 years old) were enrolled using a stratified, clustered, random sampling method in this study, with no recorded history of eye or systemic pathologies.

Methodology Height and weight were measured using standardized protocols. Ocular biometrics, such as axial length (AL), vitreous chamber depth (VCD), and corneal curvature (CC), were measured by a low-coherence optical reflectometry device. The AL/CC ratio was calculated. Cycloplegic refraction was measured using autorefraction.

Results The overall prevalence of myopia was 71.16%. The mean refraction, height, weight and BMI were -1.48 ± 1.82 D, 140.79 ± 13.95 cm, 38.29 ± 10.86 kg, and 19.04 ± 3.18 kg/m^2, respectively. Taller persons tended to have eyes with longer ALs (+0.14 mm for each 10 cm difference in height, P<0.05), deeper VCDs (+0.13 mm, P<0.05), higher AL/CC ratios (+0.02, P<0.05), and more negative refractions (-0.21 D, P<0.05) after controlling for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors. However, although weight was correlated with AL, central

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corneal thickness and VCD, students with different weights or BMIs showed similar refraction.

Conclusions Height remained independently related to refraction and various ocular biometrics after adequately controlling covariates, which could support the idea that the development of refraction is related to physical development. Future work should focus on the effects of sex hormones on the association between height and refraction during early adolescent growth.

Keywords: anthropometric indicators, refraction, ocular biometrics, schoolchildren

Strengths and limitations of this study

- A stratified, clustered, random sampling strategy was applied to recruit participants, which could avoid the potential selection bias present in previous studies performed in specific population groups.
- Ocular biometrics were measured comprehensively and the covariates were controlled adequately, which allowed us to achieve a more detailed analysis.
- This study was cross-sectional design and could not allow an evaluation of causality.
- Puberty parameters were not available in our study, limiting the further research to explore the potential shared mechanism underlies both physical development during early adolescent growth and refractive status.

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Introduction

Myopia has reached almost epidemic proportions in the world, especially in certain areas of East and Southeast Asia.[1] This condition is commonly viewed as etiologically heterogeneous. Genetic and environmental risk factors have been shown to be involved in its progression. The genetic basis of myopia has been supported by evidence indicating high heritability values in twin studies[2] and a higher prevalence of myopia in children with myopic parents.[3] Excessive near work activities,[4 5] limited time spent outdoors,[6 7] and intensive educational pressure[8 9] all have been reported to promote the development of myopia. In our effort to consider other factors, we noted that anthropometric indicators, such as height, are thought to be associated with refraction, although no consensus has been achieved regarding this issue.[10 11]

Refractive status is determined by the balance of refractive power of the cornea and lens, and the axial length (AL) of the eye (representing the combination of anterior chamber depth (ACD), lens thickness (LT), and vitreous chamber depth (VCD)).[12] Myopia usually arises in an eye that has become too long, particularly via the elongation of the vitreous chamber. Several epidemiological studies have demonstrated that the changes in ocular dimensions that occur in early life progress concomitant with physical development in children,[13 14] and the ages of cessation are also similar for increases in height and axial elongation.[13] Furthermore, genetic studies have confirmed that a common genetic pathway underlies both height and AL,[15 16] although no specific genetic variants have yet been

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identified. All of these clues suggest the existence of a shared mechanism that regulates the coordinated growth of body and eye size. It has been suggested that there may be a relationship between body stature and refraction. However, in contrast to the consensus regarding the significant associations between body stature and AL, the relationship between body stature and refraction remains controversial. Whereas many studies have reported that taller[10 17-20] and heavier persons[21 22] have an increased likelihood of having myopia, other studies have found no such association.[23-28] The discrepancies among these findings may be due to differences in sample sizes, concept definitions or other methodological variations (e.g., height and weight obtained via self-reporting).

In China, few studies have comprehensively measured ocular biometrics or further explored their associations with body stature. Wang et al.[14] confirmed that there is a positive association between height and AL in 7- to 15-year-old schoolchildren based on longitudinal data obtained in Guangzhou, China. However, detailed information about the associations between body stature and refraction and other ocular biometrics was not available in that study. Additionally, myopia most commonly starts in young schoolchildren and progresses in early adolescence.[21] It is most appropriate to study the effect of body growth on refractive development in young, growing students. Therefore, in the current survey, we explored the associations between anthropometric indicators, including height, weight, and body mass index (BMI), and both refraction and ocular biometrics in schoolchildren aged 6 to 15 years old in Tianjin, China.

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METHODS

Participants were initially recruited using a stratified, clustered, random sampling method. Two districts were randomly chosen from the 6 main urban districts in Tianjin in November 2016. Next, one school was randomly selected from each selected district. One class was then randomly chosen from each grade level within the two selected schools. All students in these selected classes were invited, but participation in this study was voluntary. After the purposes and procedures of the study were explained to each student and their parents in depth, written informed consent was collected. Students without parental consent and students who had amblyopia, heterotropia, or any eye or systemic pathologies were excluded. Finally, the study consisted of 482 (86.1% response rate) 6- to 15-year-old students (264 boys, 218 girls) out of a total of 560 students who were initially invited. Individuals who were included in the study were older (9.42 ± 2.09 vs 7.60 ± 2.38 years old, $P<0.01$) than those who were excluded (data not shown). There were no significant differences in gender, parental myopia, monthly family income, reading and writing distance, and time spent outdoors between the included and excluded individuals.

The study protocol was approved by the Ethics Committee of Tianjin Medical University and performed in accordance with the tenets of the Declaration of Helsinki.

Ocular examinations

All included participants underwent a comprehensive eye examination, including

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measurements of intraocular pressure, a slit-lamp examination of the anterior and posterior segments, cycloplegic autorefraction and ocular biometrics. The purpose of intraocular pressure measurement and the slit lamp examination was to exclude contraindications for mydriasis.

Ocular biometrics, such as AL, central corneal thickness (CCT), ACD, LT, VCD, and corneal curvature (CC), were measured with a low-coherence optical reflectometry device (Lenstar LS900; Haag-Streit AG, 3098 Koeniz, Switzerland) in both eyes before pupil dilation. The AL/CC ratio, also commonly known as the axial length/corneal radius (AL/CR) ratio, was additionally calculated. Cycloplegia was then induced by administering two drops containing 0.5% tropicamide and 0.5% phenylephrine in a mixed eye agent to each eye at 0 and 5 minutes. At 25 minutes after the second instillation, participants with full cycloplegia underwent autorefraction using an auto-kerato-refractor (Canon Autorefractor RK-F1, Tokyo, Japan), and 3 consecutive measurements were taken in both eyes. The mean value of 3 valid measurements was calculated for statistical analysis. All of the above instruments were calibrated before the ocular examination.

The spherical equivalent refraction (SER) of each eye was then calculated as the spherical refraction + 1/2 of the cylindrical refraction using data obtained using the autorefractor. Myopia was defined as an SER of ≤ -0.5 diopters (D).

Anthropometric measurements

Height and weight were obtained following specific standardized protocols. Height was

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determined with the subject standing barefoot on the floor of the height meter and recorded in centimeters (cm). Weight was measured without shoes and heavy coats on a calibrated electronic weighing scale and recorded in kilograms (kg). BMI was derived as weight/height^2 and recorded in kilograms per square meter (kg/m^2).

Questionnaire

The parents of participants were asked to complete a questionnaire developed to collect information on social-demographic characteristics and potential risk factors for school myopia. Moreover, parents whose children were excluded from the study were also required to finish the same questionnaire.

The basic characteristics of the participants included age (calculated as the date of investigation minus the birth date of the child), gender (boy or girl), the monthly income of the family (less than 4000 RMB, 4000-8000 RMB, 8000-10,000 RMB, 10,000-15,000 RMB, or more than 15,000 RMB), and the number of myopic parents (none, one parent, or both parents). Near work related behaviors were ascertained with the question "What is the distance between your child's eyes and a book when reading or writing?", with answers categorized as follows: <10 cm, 10-19 cm, 20-29 cm, and ≥30 cm. Time spent outdoors was estimated by asking how many hours per day the child spent in outdoor activities during weekdays and weekends separately. The average time spent outdoors was calculated by the following formula: [$T_{weekday}$ (hours spent on weekday) × 5 + $T_{weekend}$ (hours spent on weekend) × 2] ÷ 7.

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Statistical analysis

Because refraction and ocular biometrics were highly correlated between the left and right eyes (the Pearson correlation coefficients (r) for refraction and AL were 0.90, P<0.01, and 0.96, P<0.01, respectively), the data obtained from the right eye were chosen for analyses. Ocular biometrics were all normally distributed, as determined by P-P plots.

T-tests were performed for quantitative variables and chi-square tests were performed for categorical variables to analyze the differences in basic characteristics between persons with and without myopia. Univariate associations between anthropometric indicators and refraction and ocular biometrics were identified. Simple linear regression models were constructed to assess the effects of height, weight, and BMI (as independent variables) on refraction and individual ocular biometrics (as dependent variables). Tests for linear trends were performed by entering the median value of each category of the anthropometric indicator based on quartiles as a continuous variable into the models. Multiple linear regression models were then fitted after adjusting, in turn, for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors. Collinearity diagnostics and a residual analysis were performed for all multiple linear regression models. We found that multicollinearity was absent among the independent variables used in each model, and the points in each residual plot were nearly homogenously distributed on the two sides of the zero horizontal line, suggesting that these fitted models were appropriate. Statistical analyses were performed using commercial statistical software (SPSS for

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181 Windows, version 20.0; IBM-SPSS, Chicago, Illinois, USA), and P values <0.05 were
182 considered statistically significant.

183 **Patient and public involvement**

184 Patients and the public were not involved in developing the research questionnaire,
185 outcome measures and overall design of this study protocol.

186

187 **RESULTS**

188 **Characteristics of participants**

189 Among the 482 included schoolchildren, the prevalence of myopia was 71.16% (343 of
190 482; 95% CI, 67.01% to 75.10%). The mean SER, height, weight and BMI of all
191 participants was -1.48 ± 1.82 D, 140.79 ± 13.95 cm, 38.29 ± 10.86 kg, and 19.04 ± 3.18
192 kg/m^2, respectively (Table 1). Participants with myopia were older (P<0.01), taller
193 (P<0.01), heavier (P<0.01); were more likely to have myopic parents (P<0.01), a higher
194 monthly family income (P<0.05), a closer reading and writing distance (P<0.05), and to
195 spent less time outdoors (P<0.05); and had eyes with longer ALs (P<0.01), deep ACDs
196 and VCDs (P<0.01), thinner LTs (P<0.01), and larger AL/CC ratios (P<0.01).

197 **Bivariate correlations between variables**

198 Height was positively correlated with AL (r= 0.50, P<0.01), CCT (r= 0.17, P<0.01), ACD
199 (r= 0.29, P<0.01), VCD (r= 0.49, P<0.01) and the AL/CC ratio (r= 0.49, P<0.01) and
200 negatively correlated with SER (r= -0.45, P<0.01) and LT (r= -0.24, P<0.01), although

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these correlations were of low to moderate strength. However, there was no correlation between height and CC (Table 2). The correlation analysis of weight with refraction and individual ocular biometrics also produced similar results except that there was a positive correlation between weight and CC. BMI was positively correlated with AL, CCT, VCD and the AL/CC ratio and negatively correlated with SER but was not correlated with ACD, LT or CC.

Linear trends in refraction and ocular biometrics changes by quartiles of body stature

Taller and heavier persons tended to have eyes with longer ALs (*P* for trend, <0.01), thicker CCTs (*P* for trend, <0.05), deeper ACDs (*P* for trend, <0.01), thinner LTs (*P* for trend, <0.01), deeper VCDs (*P* for trend, <0.01), higher AL/CC ratios (*P* for trend, <0.01), and more myopic refractions (*P* for trend, <0.01) (Table 3). In addition to ACD and LT, the above tendencies were also observed among more obese schoolchildren (students with higher BMIs).

Linear regression analysis of the associations between anthropometric indicators and refraction and ocular biometrics

In model 1, we used the association between height and refraction as an example and found that for each 10 cm increase in height, the SER was expected to decrease by 0.59 D (*P*<0.01) without controlling for any covariates (Table 4). In the next two models, we controlled, in turn, for age and gender or for age, gender, parental myopia, family income, reading and writing distance and time spent outdoors, and found that the difference in SER declined by

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0.26 D (P<0.01) and 0.21 D (P<0.05) in each of these models, respectively. In general, taller persons tended to have eyes with longer ALs (+0.14 mm, P<0.05), deeper VCDs (+0.13 mm, P<0.05), greater AL/CC ratios (+0.02, P<0.05), and more negative refractions (-0.21 D, P<0.05). However, after we controlled for the same confounders described above, height was no longer related to CCT, ACD, or LT.

Although weight was correlated with AL, CCT, and VCD in model 3, it was not associated with ACD, LT, the AL/CC ratio or refraction. For each 10 kg increase in weight, AL was 0.15 mm longer (P<0.01), CCT 4.44 μm thicker (P<0.05), and VCD 0.15 mm deeper (P<0.01). Nonetheless, BMI was not correlated with refraction or any individual ocular biometric in multiple linear regression models.

DISCUSSION

In this paper, we comprehensively measured ocular biometrics and then explored the associations between anthropometric indicators and refraction and ocular biometrics after adequately controlling covariates. We were therefore able to achieve a more detailed analysis than has been presented in previous studies. A stratified, clustered, random sampling strategy was applied to recruit participants, and this allowed us to avoid the potential selection bias present in previous studies performed in specific population groups, such as male conscripts.[27 29]

The current results are in almost complete agreement with those of Saw et al.,[17] who

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241 showed that among 1449 Singaporean Chinese children aged 7-9 years old, taller persons were more likely to have eyes with longer ALs (+0.46 mm, *P*<0.01), deeper VCDs (+0.46 mm, *P*<0.01), flatter corneas (+0.10 mm, *P*<0.01), greater AL/CC ratios (+0.02, *P*=0.03), and refractions that tended toward myopia (-0.47 D, *P*<0.01) after controlling for age, gender, parental myopia, and the number of books read per week. A birth cohort performed in Britain to examine the relationship between height growth trajectories and the development of myopia presented similar results.[10] For each SD increase in height during the period the children aged from 2.5 to 10 years old, SER had become more negative by -0.075 D (95% CI, -0.112 to -0.039; *P*<0.01) and -0.081 D (95% CI, -0.129 to -0.034; *P*<0.01) when the children reached 11 and 15 years old, respectively. However, Huang et al.[28] reported that there was no statistically significant correlation between myopia shift and height changes among schoolchildren aged 7 to 9 years old in Taiwan, China.

Although the association remains unclear, these results will help us to further explore the intricate relationship between the development of physical characteristics and refraction. A commonly proposed explanation for a potential association is that both higher height and myopia are independent consequences of better socioeconomic status, and there may therefore be no causal relationship between height and myopia.[17 23] However, in this study, after we controlled for socioeconomic characteristics and myopia-related risk factors, height remained independently related to refraction and various ocular biometrics. Myopia most commonly develops during the period extending from childhood to early adolescence

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261 (from approximately 8 to 14 years old),[30] and this is also the period during which growth
262 spurts occur;[31] we therefore inferred that the development of refraction could be related to
263 physical development during the early period of adolescent growth. The findings of the
264 Singapore Cohort Study of Risk Factors for Myopia (SCORM) support this hypothesis.[19]
265 The SCORM reported that boys and girls who experienced earlier peak height velocity also
266 achieved earlier peak SER velocity (at a mean age of 10.1 vs 10.6 years old for boys,
267 *P*=0.01, and 10.0 vs 10.6 years old for girls, *P*=0.01) and had an earlier age of onset of
268 myopia (9.9 vs 10.4 years old for boys, *P*=0.03, and 9.7 vs 10.1 years old for girls, *P*=0.04).
269 This could be a consequence of the sex hormone surge that occurs during early adolescence,
270 especially during growth spurts. Moreover, sex hormone receptors are present in multiple
271 regions of the human eye, including the iris, lens, and retina, and these receptors have been
272 found to play roles in the development of various ocular diseases.[32] Therefore, sex
273 hormones may be a significant mediator of the association between height and refraction
274 observed in our study. This hypothesis, if valid, suggests that the endocrine traits observed
275 during childhood and adolescence could provide important clues for mechanistic studies
276 aimed at exploring refractive development.

277 The relationships weight and BMI share with refraction are not as extensively studied as
278 those with height, but also presented the inconclusive conclusions. Heavier and more obese
279 Chinese children and adults in Singapore have been shown to have refractions that tend
280 toward hyperopia.[17 23] Heavier adults in rural Myanmar were also reported to have more

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positive refractions.[25] However, a twin study performed in Australia found that compared to females in the lowest quartile weight group, those in the highest weight quartile had a higher risk of myopia (OR: 1.79, P=0.01).[22] Consistent with the results of a cross-sectional study performed in 19-year-old male conscripts in South Korea,[27] in our study, we found that weight and BMI had no effect on refraction. Inconsistencies in data regarding the relationships weight and height share with refraction (i.e., refractions were myopic only in taller children and not in heavier or more obese children) have been more difficult to explain. Some uncontrolled confounders, such as nutritional status, could lead to these differences. Nutritional status not only affects physical development but also influences the development of myopia.[33 34] Therefore, in the future, a comprehensive dietary survey will be needed to determine whether nutritional status itself has any effect on the correlation between physical development and refractive development.

This study has several limitations that warrant consideration. First, information on putative myopia risk factors obtained from our questionnaire (e.g., the distance between the child's eyes and a book when reading or writing) was subjectively estimated by the parents. Although this method has been widely applied in previous studies, it can lead to recall bias. Differences between non-respondents and respondents may also have resulted in non-respondent bias given that a difference in age was identified between the individuals who were included in and excluded from this study. Second, all of the data collected in this study were cross-sectional and did not allow an evaluation of causality. Therefore, it

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remains uncertain whether the conclusions drawn from this study are applicable to longitudinal relationships. Furthermore, we could not analyze data regarding puberty parameters, such as the onset of pubic hair and voice break in boys and breast development and age at menarche in girls. A later age at menarche (older than 14 years old) has been found to be associated with a decreased risk of moderate and high myopia.[35] To determine whether physical development during early adolescent growth affects refractive status, these puberty parameters must be considered in future studies.

In conclusion, we found that taller children tended to have eyes with longer ALs, deeper VCDs, higher AL/CC ratios and more myopic refractions after controlling for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors. The results of this study support the idea that the development of refraction is related to physical development during early adolescent growth. Further research is required to determine whether sex hormones during growth spurts could affects the association between height and refraction.

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Contributors Design of the study: SL and XZ. Collection and management of the data:

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SY, SL, WL and QW. Analysis and interpretation of the data: SY. Review and approval of the manuscript: SY, SL, WL, QW, WX and XZ.

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Competing interests None declared.

Patient consent Obtained.

Ethics approval Ethics Committee of Tianjin Medical University, China.

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Table 1 Summary of the characteristics of the participants.

	Total	Myopia	Nonmyopia	*P* Value
Age (years)	9.42 ± 2.09	9.88 ± 2.14	8.30 ± 1.45	<0.01
Male	264 (54.77)	187 (54.52)	77 (55.40)	0.86
Parental myopia*				<0.01
None	129 (28.48)	74 (23.13)	55 (41.35)	
One parent	188 (41.50)	134 (41.88)	54 (40.60)	
Both parents	136 (30.02)	112 (35.00)	24 (18.05)	
Monthly family income*				<0.05
<4000 RMB	41 (8.78)	27 (8.16)	14 (10.29)	
4000-8000 RMB	136 (29.12)	89 (26.89)	47 (34.56)	
8000-10,000 RMB	133 (28.48)	89 (26.89)	44 (32.35)	
10,000-15,000 RMB	91 (19.49)	73 (22.05)	18 (13.24)	
≥15,000 RMB	66 (14.13)	53 (16.01)	13 (9.56)	
Reading and writing distance*				<0.05
<10 cm	45 (9.62)	36 (10.81)	9 (6.67)	
10-20 cm	200 (42.74)	148 (44.44)	52 (38.52)	
20-30 cm	166 (35.47)	117 (35.14)	49 (36.30)	
≥30 cm	57 (12.18)	32 (9.61)	25 (18.52)	
Time spent outdoors (hours)	1.20 ± 0.70	1.16 ± 0.70	1.31 ± 0.69	<0.05
Height (cm)	140.79 ± 13.95	143.85 ± 14.17	133.22 ± 10.01	<0.01
Weight (kg)	38.29 ± 10.86	40.06 ± 11.05	33.92 ± 9.01	<0.01
BMI (kg/m^2)	19.04 ± 3.18	19.10 ± 3.14	18.89 ± 3.28	0.52
SER (D)	-1.48 ± 1.82	-2.20 ± 1.66	0.30 ± 0.54	<0.01
AL (mm)	23.81 ± 1.12	24.16 ± 1.07	22.95 ± 0.72	<0.01
CCT (µm)	547.65 ± 32.44	548.88 ± 33.32	544.63 ± 30.05	0.19

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ACD (mm)	3.08 ± 0.26	3.14 ± 0.25	2.94 ± 0.23	<0.01
LT (mm)	3.47 ± 0.20	3.43 ± 0.20	3.55 ± 0.19	<0.01
VCD (mm)	17.27 ± 1.09	17.60 ± 1.05	16.46 ± 0.71	<0.01
CC (mm)	7.78 ± 0.26	7.78 ± 0.25	7.79 ± 0.26	0.84
AL/CC ratio	3.06 ± 0.13	3.11 ± 0.13	2.95 ± 0.07	<0.01

Data presented as means with standard deviation (SD) or as n (%).

[*]Numbers of individuals vary due to missing data.

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Table 2 Bivariate correlations of body stature with refraction and ocular biometrics.

	Height (cm)	**Weight (kg)**	**BMI (kg/m^2)**
SER (D)	-0.45**	-0.39**	-0.11*
AL (mm)	0.50**	0.45**	0.15*
CCT (μm)	0.17**	0.19**	0.09*
ACD (mm)	0.29**	0.22**	0.03
LT (mm)	-0.24**	-0.19**	-0.04
VCD (mm)	0.49**	0.44**	0.16**
CC (mm)	0.07	0.10*	0.08
AL/CC ratio	0.49**	0.40**	0.10*

Data are the Pearson correlation coefficients.

*: P<0.05.

**: P<0.01.

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Table 3 Unadjusted mean values of refraction and ocular biometrics by quartiles of height, weight and BMI.

	Range	n	SER (D)	AL (mm)	CCT (µm)	ACD (mm)
Height (cm)						
1st quartile	100.0~130.0	127	-0.48 ± 1.13†	23.09 ± 0.78	542.11 ± 30.93	2.97 ± 0.24
2nd quartile	130.1~140.0	136	-1.08 ± 1.46	23.58 ± 0.98	544.96 ± 32.69	3.05 ± 0.28
3rd quartile	140.1~150.7	99	-1.86 ± 1.80	24.15 ± 1.01	550.04 ± 32.31	3.16 ± 0.23
4th quartile	150.8~182.5	120	-2.68 ± 2.06	24.56 ± 1.14	554.58 ± 32.76	3.18 ± 0.22
P for trend‡			*P*<0.01	*P*<0.01	*P*<0.05	*P*<0.01
Weight (kg)						
1st quartile	20.0~30.0	129	-0.59 ± 1.19	23.19 ± 0.80	541.27 ± 32.75	3.02 ± 0.26
2nd quartile	30.1~36.1	112	-1.12 ± 1.30	23.58 ± 1.00	547.64 ± 31.34	3.04 ± 0.26
3rd quartile	36.2~45.0	128	-1.75 ± 1.92	24.02 ± 1.12	544.17 ± 31.56	3.12 ± 0.24
4th quartile	45.1~82.3	113	-2.54 ± 2.14	24.52 ± 1.12	558.92 ± 31.65	3.16 ± 0.24
P for trend			*P*<0.01	*P*<0.01	*P*<0.01	*P*<0.01
BMI (kg/m²)						
1st quartile	14.0~16.5	121	-1.19 ± 1.62	23.55 ± 1.05	543.79 ± 31.55	3.09 ± 0.25
2nd quartile	16.6~18.4	120	-1.39 ± 1.69	23.80 ± 1.14	545.79 ± 32.26	3.05 ± 0.28
3rd quartile	18.5~20.8	120	-1.59 ± 1.88	23.90 ± 1.12	547.12 ± 32.16	3.09 ± 0.25

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	Range	n	LT (mm)	VCD (mm)	CC (mm)	AL/CC ratio
4th quartile	20.9~30.6	121	-1.74 ± 2.05	24.00 ±1.16	533.90 ± 33.26	3.11 ± 0.25
P for trend			*P*<0.05	*P*<0.01	*P*<0.05	*P*=0.32
	Range	**n**	**LT (mm)**	**VCD (mm)**	**CC (mm)**	**AL/CC ratio**
Height (cm)						
1st quartile	100.0~130.0	127	3.55 ± 0.19	16.57 ± 0.74	7.75 ± 0.25	2.98 ± 0.09
2nd quartile	130.1~140.0	136	3.48 ± 0.23	17.07 ± 0.96	7.79 ± 0.27	3.03 ± 0.11
3rd quartile	140.1~150.7	99	3.42 ± 0.18	17.58 ± 0.99	7.81 ± 0.26	3.09 ± 0.13
4th quartile	150.8~182.5	120	3.41 ± 0.19	17.97 ± 1.12	7.78 ± 0.25	3.16 ± 0.14
P for trend			*P*<0.01	*P*<0.01	*P*=0.36	*P*<0.01
Weight (kg)						
1st quartile	20.0~30.0	129	3.51 ± 0.20	16.64 ± 0.77	7.75 ± 0.25	2.99 ± 0.10
2nd quartile	30.1~36.1	112	3.49 ± 0.21	17.07 ± 0.97	7.78 ± 0.28	3.03 ± 0.11
3rd quartile	36.2~45.0	128	3.45 ± 0.21	17.46 ± 1.10	7.80 ± 0.24	3.08 ± 0.13
4th quartile	45.1~82.3	113	3.40 ± 0.19	17.95 ± 1.08	7.81 ± 0.25	3.14 ± 0.15
P for trend			*P*<0.01	*P*<0.01	*P*=0.08	*P*<0.01
BMI (kg/m²)						
1st quartile	14.0~16.5	121	3.45 ± 0.18	17.01 ± 1.05	7.73 ± 0.26	3.05 ± 0.12
2nd quartile	16.6~18.4	120	3.51 ± 0.23	17.23 ± 1.04	7.81 ± 0.26	3.05 ± 0.13

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3rd quartile	18.5~20.8	120	3.46 ± 0.20	17.38 ± 1.11	7.81 ± 0.26	3.06 ± 0.14
4th quartile	20.9~30.6	121	3.44 ± 0.20	17.46 ± 1.13	7.79 ± 0.24	3.08 ± 0.14
P for trend			*P*=0.37	*P*<0.01	*P*=0.19	*P*<0.05

†Data are expressed as means ± SD.

‡Tests for linear trend is performed by entering the median value of each category of the anthropometric indicator as a continuous variable in the models.

Table 4 Multiple linear regression models of refraction and ocular biometry by height, weight, and BMI.

	Model 1	***P* Value**	**Model 2**	***P* Value**	**Model 3**	***P* Value**
Height (per 10cm)						
SER (D)	-0.59 (-0.70, -0.49)†	<0.01	-0.26 (-0.45, -0.08)	<0.01	-0.21 (-0.40, -0.01)	<0.05
AL (mm)	0.40 (0.34, 0.47)	<0.01	0.18 (0.07, 0.29)	<0.01	0.14 (0.03, 0.26)	<0.05
CCT (μm)	4.03 (1.97, 6.08)	<0.01	2.43 (-1.29, 6.16)	0.20	3.41 (-0.76, 7.58)	0.11
ACD (mm)	0.05 (0.04, 0.07)	<0.01	0.02 (-0.01, 0.05)	0.17	0.02 (-0.02, 0.05)	0.34
LT (mm)	-0.04 (-0.05, -0.02)	<0.01	-0.01 (-0.03, 0.02)	0.57	-0.01 (-0.03, 0.02)	0.75
VCD (mm)	0.38 (0.32, 0.44)	<0.01	0.17 (0.06, 0.27)	<0.01	0.13 (0.02, 0.25)	<0.05
CC (mm)	0.01 (-0.01, 0.03)	0.13	0.01 (-0.02, 0.04)	0.41	0.01 (-0.03, 0.04)	0.81

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AL/CC ratio	0.05 (0.04, 0.06)	<0.01	0.02 (0.01, 0.03)	<0.01	0.02 (0.01, 0.03)	<0.05
Weight (per 10kg)						
SER (D)	-0.65 (-0.79, -0.51)	<0.01	-0.21 (-0.39, -0.03)	<0.05	-0.18 (-0.36, 0.01)	0.07
AL (mm)	0.46 (0.38, 0.55)	<0.01	0.16 (0.05, 0.26)	<0.01	0.15 (0.04, 0.26)	<0.01
CCT (µm)	5.56 (2.93, 8.20)	<0.01	3.68 (0.06, 7.29)	<0.05	4.44 (0.42, 8.47)	<0.05
ACD (mm)	0.05 (0.03, 0.07)	<0.01	-0.01 (-0.03, 0.02)	0.90	-0.01 (-0.03, 0.03)	0.87
LT (mm)	-0.04 (-0.05, -0.02)	<0.01	0.01 (-0.02, 0.02)	0.95	0.01 (-0.02, 0.03)	0.96
VCD (mm)	0.44 (0.36, 0.53)	<0.01	0.16 (0.06, 0.27)	<0.01	0.15 (0.04, 0.26)	<0.01
CC (mm)	0.03 (0.01, 0.05)	<0.05	0.02 (-0.01, 0.05)	0.11	0.02 (-0.01, 0.05)	0.14
AL/CC ratio	0.05 (0.04, 0.06)	<0.01	0.01 (-0.01, 0.02)	0.10	0.01 (-0.01, 0.02)	0.16
BMI (per 10kg/m²)						
SER (D)	-0.64 (-1.15, -0.13)	<0.05	-0.26 (-0.73, 0.20)	0.26	-0.27 (-0.74, 0.20)	0.25
AL (mm)	0.53 (0.21, 0.84)	<0.01	0.20 (-0.07, 0.47)	0.15	0.23 (-0.05, 0.50)	0.10
CCT (µm)	9.50 (0.35, 18.65)	<0.05	6.37 (-2.79, 15.53)	0.17	7.19 (-2.87, 17.25)	0.16
ACD (mm)	0.03 (-0.05, 0.10)	0.50	-0.03 (-0.10, 0.04)	0.46	-0.02 (-0.10, 0.05)	0.52
LT (mm)	-0.02 (-0.08, 0.03)	0.42	0.01 (-0.05, 0.07)	0.79	0.01 (-0.06, 0.07)	0.86
VCD (mm)	0.55 (0.24, 0.85)	<0.01	0.23 (-0.03, 0.50)	0.09	0.25 (-0.03, 0.52)	0.08
CC (mm)	0.06 (-0.01, 0.14)	0.09	0.04 (-0.03, 0.11)	0.25	0.06 (-0.02, 0.14)	0.13

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AL/CC ratio	0.04 (0.01, 0.08)	<0.05	0.01 (-0.02, 0.04)	0.58	0.01 (-0.03, 0.04)	0.67

†Each value represents a separate regression model, with height, weight, or BMI used as the independent variable, the refraction or individual ocular biometrics used as the dependent variable, either alone or with various confounders. Data in parentheses represents the 95% confidence interval.

Model 1 constructs based on crude data. In the next two models, we controlled, in turn, for age and gender or for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors.

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Associations between anthropometric indicators and both refraction and ocular biometrics in a cross-sectional study of Chinese schoolchildren

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Associations between anthropometric indicators and both refraction and ocular biometrics in a cross-sectional study of Chinese schoolchildren

Sheng Ye, Shengxin Liu, Wenlei Li, Qifan Wang, Wei Xi, and Xin Zhang

Department of Maternal, Child and Adolescent Health, School of Public Health, Tianjin Medical University, Tianjin, China.

SY and SL contributed equally to the work presented here and should therefore be regarded as equivalent authors.

Correspondence to

Prof. Xin Zhang, Department of Maternal, Child and Adolescent Health, School of Public Health, Tianjin Medical University, No. 22 Qixiangtai Road, Tianjin 300070, China; zhangxin@tmu.edu.cn.

Synopsis

The development of refraction may be related to physical development during early adolescent growth. The shared mechanism between body stature and refraction could shed new light on the etiology of myopia.

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ABSTRACT

Objective To identify associations between anthropometric indicators, including height, weight, and body mass index (BMI), and both refraction and ocular biometrics in Chinese schoolchildren in Tianjin, China.

Design Cross-sectional study.

Participants A total of 482 (86.07%) students (6 to 15 years old) with no recorded history of ocular or systemic pathologies were enrolled in this study.

Methodology Height and weight were measured using standardized protocols. Ocular biometrics, such as axial length (AL), vitreous chamber depth (VCD), and corneal curvature (CC), were measured by a low-coherence optical reflectometry device. The AL/CC ratio was calculated. Cycloplegic refraction was measured using autorefraction, and spherical equivalent refraction (SER) was calculated. Myopia was defined as SER ≤ -0.50 diopters (D). Multiple linear regression analysis was performed to explore the associations between anthropometric indicators and both refraction and ocular biometrics.

Results The overall prevalence of myopia was 71.16%. Overall, only height was associated with AL, VCDs, AL/CC ratios, and refractions after controlling for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors. Furthermore, age-specific results demonstrated that both height and weight were independently associated with refraction in only 6- to 8-year-old and 9- to 11-year-old participants. Especially from 9 to 11 years of age, higher heights in

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schoolchildren were associated with longer ALs (regression coefficient b=+0.25 for each 10 cm difference in height, $P<0.01$), deeper VCDs (b=+0.23, $P<0.01$), higher AL/CC ratios (b=+0.04, $P<0.01$), and more negative refractions (b=-0.48, $P<0.01$) in their eyes. The association pattern in weight was almost the same as that in height.

Conclusions Height and weight remained independently related to refraction and various ocular biometrics during the early period of adolescent growth after adequately controlling for covariates, which could support the idea that a shared mechanism may regulate the coordinated growth of body and eye size in children.

Keywords: anthropometric indicators, refraction, ocular biometrics, schoolchildren

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Strengths and limitations of this study

- The study participants were schoolchildren ranging in age from 6 to 15 years old, a period when myopia commonly develops, which could allow us to study the association between body stature and refraction during development.
- The overall and age-specific associations between anthropometric indicators and both refraction and ocular biometrics were calculated in this study to help better clarify the coordinated growth of body and eye size.
- Ocular biometrics were measured comprehensively, and the covariates were adequately controlled, which allowed us to achieve a more detailed analysis.
- An evaluation of causality was not possible because this study had a cross-sectional design.

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Introduction

Myopia has reached almost epidemic proportions in the world, especially in certain areas of East and Southeast Asia.[1] This condition is commonly viewed as etiologically heterogeneous. Genetic and environmental risk factors are involved in its progression. The genetic basis of myopia has been supported by evidence indicating high heritability values in twin studies[2] and a higher prevalence of myopia in children with myopic parents.[3] Excessive near work activities,[4 5] limited time spent outdoors,[6 7] and intensive educational pressure[8 9] reportedly to promote the development of myopia. In our effort to consider other factors, we noted that anthropometric indicators, such as height, are thought to be associated with refraction, although no consensus has been achieved regarding this issue.[10 11]

Refractive status is determined by the balance of the refractive power of the cornea and lens, and the axial length (AL) of the eye (representing the combination of anterior chamber depth (ACD), lens thickness (LT), and vitreous chamber depth (VCD)).[12] Myopia usually arises in an eye that has become too long, particularly via vitreous chamber elongation. Several epidemiological studies have demonstrated that changes in ocular dimensions that occur in early life progress concomitant with physical development in children,[13 14] and the ages of cessation are also similar for increases in height and axial elongation.[13] Furthermore, genetic studies have confirmed that a common genetic pathway underlies both height and AL,[15 16] although no specific

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genetic variants have yet been identified. All of these clues suggest a shared mechanism that regulates the coordinated growth of body and eye size. It has been suggested that there may be a relationship between body stature and refraction. However, in contrast to the consensus regarding the significant associations between body stature and AL, the relationship between body stature and refraction remains controversial. Although many studies have reported that taller[10 17-20] and heavier persons[21 22] have an increased likelihood of having myopia, other studies have found no such association.[23-28] The discrepancies among these studies may be due to differences in sample sizes, concept definitions or other methodological variations (e.g., height and weight obtained via self-reporting).

In China, few studies have comprehensively measured ocular biometrics or further explored their associations with body stature. Additionally, myopia most commonly starts in young schoolchildren and progresses in early adolescence.[21] Therefore, it is most appropriate to study the effect of body growth on refractive development in young, growing students. In the current survey, we explored the associations between anthropometric indicators, including height, weight, and BMI, and both refraction and ocular biometrics in schoolchildren aged 6 to 15 years old in Tianjin, China.

METHODS

Recruitment

Participants were recruited based on the following strategies. Two districts were

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randomly chosen from the 6 main urban districts in Tianjin in November 2016. Next, one primary school and one junior high school were randomly selected from each selected district. Then, one class was randomly chosen from each grade level within the two selected schools. All students in these selected classes were invited, but participation in this study was voluntary. After the purposes and procedures of the study were explained to each student and their parents in depth, written informed consent was collected. Students without parental consent and students who had amblyopia, heterotropia, or any ocular or systemic pathologies were excluded.

The study protocol was approved by the Ethics Committee of Tianjin Medical University and performed in accordance with the tenets of the Declaration of Helsinki.

Ocular examinations

All participants underwent a comprehensive eye examination, including measurements of intraocular pressure, a slit-lamp examination of the anterior and posterior segments, cycloplegic autorefraction and ocular biometrics. The purpose of intraocular pressure measurement and slit-lamp examination was to exclude contraindications for mydriasis.

Ocular biometrics, such as AL, central corneal thickness (CCT), ACD, LT, VCD, and corneal curvature (CC), were measured with a low-coherence optical reflectometry device (Lenstar LS900; Haag-Streit AG, 3098 Koeniz, Switzerland) in both eyes before pupil dilation. In addition, the AL/CC ratio, also commonly known as the axial length/corneal radius (AL/CR) ratio, was calculated. Then, cycloplegia was induced by administering one drop containing 0.5% tropicamide and 0.5% phenylephrine in a

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mixed eye agent to each eye at 0 and 5 minutes. Twenty-five minutes after the second instillation, pupillary dilation and the pupillary light reflex were evaluated. Full cycloplegia was considered when the pupil diameter reached 6 mm or more and the light reflex disappeared. A third drop was administered if full cycloplegia was not achieved. Then, participants with full cycloplegia underwent autorefraction using an auto-kerato-refractor (Canon Autorefractor RK-F1, Tokyo, Japan), and 3 consecutive measurements were taken in both eyes. The mean value of 3 valid measurements was calculated for statistical analysis. All of the above instruments were calibrated before the ocular examination. All examinations were performed by board-certified ophthalmologists and certified optometrists.

Definitions

The SER of each eye was calculated as the spherical refraction + 1/2 of the cylindrical refraction using data obtained using the autorefractor. Myopia was defined as an SER of ≤ -0.5 D.

Anthropometric measurements

Height and weight were obtained following specific standardized protocols[29] and measured by community doctors on the students' campus. Height was determined with the subject standing barefoot on the base of the height meter and recorded in centimeters (cm). Weight was measured without shoes and heavy coats on a calibrated electronic weighing scale and recorded in kilograms (kg). BMI was calculated as weight/height^2 and recorded in kilograms per square meter (kg/m^2).

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148 **Questionnaire**

149 The parents of participants and those excluded were all asked to complete a
150 questionnaire developed to collect information on social-demographic characteristics
151 and potential risk factors for school myopia (supplementary Table 1).

152 The basic characteristics of the participants included age, gender, the monthly
153 income of the family, and the number of parents with myopia. Near-work-related
154 behaviors were ascertained with the question "What is the distance between your child's
155 eyes and a book when reading or writing?", with answers categorized as follows: <10
156 cm, 10-19 cm, 20-29 cm, and ≥30 cm. Time spent outdoors was estimated by asking
157 how many hours per day the child spent on outdoor activities during weekdays and
158 weekends separately. The average time spent outdoors was calculated by the following
159 formula: [$T_{weekday}$ (hours spent on weekdays) × 5 + $T_{weekend}$ (hours spent on weekends)
160 × 2] ÷ 7.

161 **Statistical analysis**

162 Because refraction and ocular biometrics were highly correlated between two eyes (the
163 Pearson correlation coefficients (*r*) for refraction and AL were 0.90, P<0.01 and 0.96,
164 P<0.01, respectively), the data obtained from the right eye were chosen for analyses.
165 Ocular biometrics were all normally distributed, as determined by P-P plots.

166 T-tests were performed for quantitative variables, and chi-square tests were
167 performed for categorical variables to analyze the differences in basic characteristics
168 between individuals with and without myopia. Univariate associations between

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anthropometric indicators and both refraction and ocular biometrics were identified. Simple linear regression models were constructed to assess the effects of height, weight, and BMI (as independent variables) on refraction and individual ocular biometrics (as dependent variables). Tests for linear trends were performed by entering the median value of each category of the anthropometric indicator based on quartiles as a continuous variable into the models. Multiple linear regression models were then fitted after adjusting, in turn, for age and gender or for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors. In addition, all participants were divided into the following age groups: 6 to 8 years old, 9 to 11 years old, and 12 to 15 years old. The results of age-specific associations of anthropometric indicators with both refraction and ocular biometrics after controlling for the above covariates were calculated. Collinearity diagnostics were performed, and multicollinearity was absent among the independent variables used in each model.

Statistical analyses were performed using commercial statistical software (SPSS for Windows, version 20.0; IBM-SPSS, Chicago, Illinois, USA), and *P* values <0.05 were considered statistically significant.

Patient and public involvement

Patients and the public were not involved in developing the research questionnaire, outcome measures or overall design of this study protocol.

RESULTS

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Participant characteristics

Among 560 students who were initially invited, a total of 482 participants ranging in age from 6 to 15 years old were available for statistical analysis after excluding 70 students without parental consent, 5 students with heterotropia, and 3 students with amblyopia. The response rate in this study was 86.07% (482 of 560). Individuals who were included were older (9.42 ± 2.09 vs 7.60 ± 2.38 years old, P<0.01) than those who were excluded. There were no significant differences in gender, parental myopia, monthly family income, reading and writing distance, and time spent outdoors between included and excluded individuals.

The overall prevalence of myopia was 71.16% (343 of 482; 95% CI, 67.01% to 75.10%). The mean SER, height, weight and BMI of all participants was -1.48 ± 1.82 D, 140.79 ± 13.95 cm, 38.29 ± 10.86 kg, and 19.04 ± 3.18 kg/m^2, respectively (Table 1). Participants with myopia were older, taller, and heavier. These individuals were more likely to have myopic parents, a higher monthly family income, a closer reading and writing distance and to spend less time outdoors. Moreover, these participants had eyes with longer ALs, deep ACDs and VCDs, thinner LTs, and larger AL/CC ratios (all P values were less than 0.05).

Bivariate correlations between variables

Bivariate correlations of body stature with both refraction and ocular biometrics are presented in Table 2, which was of low to moderate strength. For example, height was positively correlated with AL (r=0.50, P<0.01), CCT (r=0.17, P<0.01), ACD (r=0.29,

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P<0.01), VCD (*r*=0.49, *P*<0.01) and the AL/CC ratio (*r*=0.49, *P*<0.01) and negatively correlated with SER (*r*=-0.45, *P*<0.01) and LT (*r*=-0.24, *P*<0.01).

Linear trends in refraction and ocular biometrics changes by body stature quartiles

Taller and heavier individuals tended to have eyes with longer ALs, thicker CCTs, deeper ACDs, thinner LTs, deeper VCDs, higher AL/CC ratios, and more myopic refractions (all *P* values for trend were less than 0.05) (Table 3). In addition to ACD and LT, the above tendencies were also observed among more obese schoolchildren (students with higher BMIs).

Linear regression analysis of the associations between anthropometric indicators and both refraction and ocular biometrics

In model 1, we used the association between height and refraction as an example and found that for each 10 cm increase in height, the SER was expected to decrease by 0.59 D (*P*<0.01) without controlling for any covariates (Table 4). In the next two models, we controlled, in turn, for age and gender or for age, gender, parental myopia, family income, reading and writing distance and time spent outdoors. The difference in SER declined by 0.26 D (*P*<0.01) and 0.21 D (*P*<0.05) in models 2 and 3, respectively. In general, higher heights were associated with longer ALs (+0.14 mm, *P*<0.05), deeper VCDs (+0.13 mm, *P*<0.05), greater AL/CC ratios (+0.02, *P*<0.05), and more negative refractions (-0.21 D, *P*<0.05) among 6- to 15-year-old participants. Nonetheless, weight and BMI were not correlated with refraction in our multiple linear regression models.

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Furthermore, the participants were categorized into the following age groups: 6 to 8 years old (n=170), 9 to 11 years old (n=158), and 12 to 15 years old (n=154). After controlling for the above covariates, the age-specific associations were calculated (Table 5). Both height and weight remained independently associated with refraction in the age range from 6 to 8 years old and 9 to 11 years old. Particularly from 9 to 11 years old, higher heights in schoolchildren were associated with longer ALs (+0.25 mm, $P<0.01$), deeper VCDs (+0.23 mm, $P<0.01$), higher AL/CC ratios (+0.04, $P<0.01$), and more negative refractions (-0.48 D, $P<0.01$) in their eyes. Heavier weights were also associated with longer ALs (+0.29 mm, $P<0.01$), deeper VCDs (+0.29 mm, $P<0.01$), higher AL/CC ratios (+0.04, $P<0.01$), and more negative refractions (-0.48 D, $P<0.01$). However, from 12 to 15 years of age, no association was detected between body stature and refraction.

DISCUSSION

In this paper, we comprehensively measured ocular biometrics and then explored the overall and age-specific associations between anthropometric indicators and both refraction and ocular biometrics after adequately controlling for covariates among 6- to 15-year-old schoolchildren. In China, few studies such as this one have been conducted. Wang et al.[14] confirmed a positive association between height and AL in 7- to 15-year-old schoolchildren based on longitudinal data obtained in Guangzhou, China. However, detailed information about the associations between body stature and refraction and

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other ocular biometrics was not available in that study. Therefore, compared with previous studies,[14 28] the present study achieved a more detailed analysis.

The current results are in almost complete agreement with those of Saw et al.[17] who showed that among 1449 Singaporean Chinese children aged 7-9 years old, taller individuals were more likely to have eyes with longer ALs (+0.46 mm, P<0.01), deeper VCDs (+0.46 mm, P<0.01), flatter corneas (+0.10 mm, P<0.01), greater AL/CC ratios (+0.02, P=0.03), and refractions that trended toward myopia (-0.47 D, P<0.01) after controlling for age, gender, parental myopia, and the number of books read per week. A birth cohort performed in Britain to examine the relationship between height growth trajectories and the development of myopia presented similar results.[10] For each SD increase in height for children aged from 2.5 to 10 years old, SER became more negative by -0.075 D (95% CI, -0.112 to -0.039; P<0.01) and -0.081 D (95% CI, -0.129 to -0.034; P<0.01) when the children reached 11 and 15 years old, respectively. However, Huang et al.[28] reported that no significant correlation between myopia shift and height changes among schoolchildren aged 7 to 9 years old in Taiwan, China.

Although the association remains unclear, these results will help us to further explore the intricate relationship between the development of physical characteristics and refraction. A commonly proposed explanation for this potential association is that both higher height and myopia are independent consequences of better socioeconomic status; therefore, there may be no causal relationship between height and myopia.[17 23] However, in this study, after we controlled for socioeconomic characteristics and myopia-related

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risk factors, height remained independently related to refraction and various ocular biometrics. Myopia most commonly develops during the period from childhood to early adolescence (from approximately 8 to 14 years old),[30] and growth spurts also occur in this period.[31] Therefore, we inferred that the development of refraction could be related to physical development during the early period of adolescent growth. The findings of the Singapore Cohort Study of Risk Factors for Myopia (SCORM) support this hypothesis.[19] SCORM reported that boys and girls who experienced earlier peak height velocity also achieved earlier peak SER velocity (at a mean age of 10.1 vs 10.6 years old for boys, P=0.01, and 10.0 vs 10.6 years old for girls, P=0.01) and had an earlier age of onset of myopia (9.9 vs 10.4 years old for boys, P=0.03, and 9.7 vs 10.1 years old for girls, P=0.04). The exact biologic pathways underlying these associations are currently unknown. Some major systemic hormones, such as growth hormone, thymic hormone and insulin-like growth factors (IGFs), reportedly could regulate longitudinal bone growth during childhood, which are also involved in the development of experimental myopia.[32 33] In addition, epidemiological studies reported that children with growth hormone deficiency have shorter body stature and ALs than usual.[34] Growth hormone supplementation in these children could partially bring the stature and ALs back within the normal range.[35] Sex hormones may be another significant mediator during puberty,[36] but our age-specific results (no association was detected in 12- to 15-year-old participants) may not support this idea. Although these hormones were not determined in this cross-sectional study, we believe that the shared mechanism between

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height and refraction may shed new light on the etiology of myopia and the efforts to explore the effect of endocrine traits observed during childhood and adolescence on body and eye size in the future studies.

The relationships weight and BMI share with refraction are not as extensively studied as those with height, but the findings regarding these relationships are also inconclusive. Heavier and more obese Chinese children and adults in Singapore have refractions that trend toward hyperopia.[17 23] Moreover, heavier adults in rural Myanmar reportedly have more positive refractions.[25] However, a cross-sectional study performed in 19-year-old male conscripts in South Korea found that weight and BMI had no effect on refraction.[27] Consistent with the results of a twin study performed in Australia,[22] in our study, heavier weights were associated with more negative refractions among participants aged 6 to 8 and 9 to 11 years old.

This study has several limitations that warrant consideration. First, information on putative myopia risk factors obtained from our questionnaire (e.g., the distance between the child's eyes and a book when reading or writing) was subjectively estimated by the parents. Although this method has been widely applied in previous studies,[17 28] it can lead to recall bias. Second, the representativeness of the participants in this study may be affected to some extent because the participants were volunteers. Although there were no significant differences in nearly all basic characteristics between participants and those excluded, individuals who were included were older, which may have resulted in overestimation of the prevalence of myopia in our study. Third, all of the

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data collected in this study were cross-sectional in nature and do not allow an evaluation of causality. Therefore, whether the conclusions drawn from this study are applicable to longitudinal relationships remains uncertain. Despite these limitations, we believe that our study provides a valuable reference regarding the associations between anthropometric indicators and both refraction and ocular biometrics in Chinese schoolchildren aged 6 to 15 years old.

In conclusion, both higher heights and heavier weights were associated with longer ALs, deeper VCDs, higher AL/CC ratios and more myopic refractions during the early period of adolescent growth after controlling for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors. The results of this study support the idea that a shared mechanism may regulate the coordinated growth of body and eye size in children.

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Contributors Design of the study: SL and XZ. Collection and management of the data: SY, SL, WL and QW. Analysis and interpretation of the data: SY. Review and approval of the manuscript: SY, SL, WL, QW, WX and XZ.

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Patient consent Obtained.

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Table 1 Summary of the characteristics of the participants.

	Total	Myopia	Nonmyopia	*P* Value
Age (years)	9.42 ± 2.09	9.88 ± 2.14	8.30 ± 1.45	<0.01
Male	264 (54.77)	187 (54.52)	77 (55.40)	0.86
Female	218 (45.23)	156 (45.48)	62 (44.60)	0.86
Parental myopia*				<0.01
None	129 (28.48)	74 (23.13)	55 (41.35)	
One parent	188 (41.50)	134 (41.88)	54 (40.60)	
Both parents	136 (30.02)	112 (35.00)	24 (18.05)	
Monthly family income*				<0.05
<4000 RMB	41 (8.78)	27 (8.16)	14 (10.29)	
4000-8000 RMB	136 (29.12)	89 (26.89)	47 (34.56)	
8000-10,000 RMB	133 (28.48)	89 (26.89)	44 (32.35)	
10,000-15,000 RMB	91 (19.49)	73 (22.05)	18 (13.24)	
≥15,000 RMB	66 (14.13)	53 (16.01)	13 (9.56)	
Reading and writing distance*				<0.05
<10 cm	45 (9.62)	36 (10.81)	9 (6.67)	
10-20 cm	200 (42.74)	148 (44.44)	52 (38.52)	
20-30 cm	166 (35.47)	117 (35.14)	49 (36.30)	
≥30 cm	57 (12.18)	32 (9.61)	25 (18.52)	
Time spent outdoors (hours)	1.20 ± 0.70	1.16 ± 0.70	1.31 ± 0.69	<0.05
Height (cm)	140.79 ± 13.95	143.85 ± 14.17	133.22 ± 10.01	<0.01
Weight (kg)	38.29 ± 10.86	40.06 ± 11.05	33.92 ± 9.01	<0.01
BMI (kg/m^2)	19.04 ± 3.18	19.10 ± 3.14	18.89 ± 3.28	0.52
SER (D)	-1.48 ± 1.82	-2.20 ± 1.66	0.30 ± 0.54	<0.01
AL (mm)	23.81 ± 1.12	24.16 ± 1.07	22.95 ± 0.72	<0.01
CCT (μm)	547.65 ± 32.44	548.88 ± 33.32	544.63 ± 30.05	0.19
ACD (mm)	3.08 ± 0.26	3.14 ± 0.25	2.94 ± 0.23	<0.01

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LT (mm)	3.47 ± 0.20	3.43 ± 0.20	3.55 ± 0.19	<0.01
VCD (mm)	17.27 ± 1.09	17.60 ± 1.05	16.46 ± 0.71	<0.01
CC (mm)	7.78 ± 0.26	7.78 ± 0.25	7.79 ± 0.26	0.84
AL/CC ratio	3.06 ± 0.13	3.11 ± 0.13	2.95 ± 0.07	<0.01

Data are presented as the means with standard deviation (SD) or as n (%).

*Numbers of individuals vary due to missing data.

Table 2 Bivariate correlations of body stature with refraction and ocular biometrics.

	Height (cm)	**Weight (kg)**	**BMI (kg/m²)**
SER (D)	-0.45**	-0.39**	-0.11*
AL (mm)	0.50**	0.45**	0.15*
CCT (μm)	0.17**	0.19**	0.09*
ACD (mm)	0.29**	0.22**	0.03
LT (mm)	-0.24**	-0.19**	-0.04
VCD (mm)	0.49**	0.44**	0.16**
CC (mm)	0.07	0.10*	0.08
AL/CC ratio	0.49**	0.40**	0.10*

Data are the Pearson correlation coefficients.

*: $P<0.05$.

**: $P<0.01$.

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Table 3 Unadjusted mean values of refraction and ocular biometrics by quartiles of height, weight and BMI.

	Range	n	SER (D)	AL (mm)	CCT (μm)	ACD (mm)
Height (cm)						
1st quartile	100.0~130.0	127	-0.48 ± 1.13†	23.09 ± 0.78	542.11 ± 30.93	2.97 ± 0.24
2nd quartile	130.1~140.0	136	-1.08 ± 1.46	23.58 ± 0.98	544.96 ± 32.69	3.05 ± 0.28
3rd quartile	140.1~150.7	99	-1.86 ± 1.80	24.15 ± 1.01	550.04 ± 32.31	3.16 ± 0.23
4th quartile	150.8~182.5	120	-2.68 ± 2.06	24.56 ± 1.14	554.58 ± 32.76	3.18 ± 0.22
P for trend‡			*P*<0.01	*P*<0.01	*P*<0.05	*P*<0.01
Weight (kg)						
1st quartile	20.0~30.0	129	-0.59 ± 1.19	23.19 ± 0.80	541.27 ± 32.75	3.02 ± 0.26
2nd quartile	30.1~36.1	112	-1.12 ± 1.30	23.58 ± 1.00	547.64 ± 31.34	3.04 ± 0.26
3rd quartile	36.2~45.0	128	-1.75 ± 1.92	24.02 ± 1.12	544.17 ± 31.56	3.12 ± 0.24
4th quartile	45.1~82.3	113	-2.54 ± 2.14	24.52 ± 1.12	558.92 ± 31.65	3.16 ± 0.24
P for trend			*P*<0.01	*P*<0.01	*P*<0.01	*P*<0.01
BMI (kg/m²)						
1st quartile	14.0~16.5	121	-1.19 ± 1.62	23.55 ± 1.05	543.79 ± 31.55	3.09 ± 0.25
2nd quartile	16.6~18.4	120	-1.39 ± 1.69	23.80 ± 1.14	545.79 ± 32.26	3.05 ± 0.28

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	Range	n	LT (mm)	VCD (mm)	CC (mm)	AL/CC ratio
3rd quartile	18.5~20.8	120	-1.59 ± 1.88	23.90 ± 1.12	547.12 ± 32.16	3.09 ± 0.25
4th quartile	20.9~30.6	121	-1.74 ± 2.05	24.00 ±1.16	533.90 ± 33.26	3.11 ± 0.25
P for trend			*P*<0.05	*P*<0.01	*P*<0.05	*P*=0.32

	Range	n	LT (mm)	VCD (mm)	CC (mm)	AL/CC ratio
Height (cm)						
1st quartile	100.0~130.0	127	3.55 ± 0.19	16.57 ± 0.74	7.75 ± 0.25	2.98 ± 0.09
2nd quartile	130.1~140.0	136	3.48 ± 0.23	17.07 ± 0.96	7.79 ± 0.27	3.03 ± 0.11
3rd quartile	140.1~150.7	99	3.42 ± 0.18	17.58 ± 0.99	7.81 ± 0.26	3.09 ± 0.13
4th quartile	150.8~182.5	120	3.41 ± 0.19	17.97 ± 1.12	7.78 ± 0.25	3.16 ± 0.14
P for trend			*P*<0.01	*P*<0.01	*P*=0.36	*P*<0.01
Weight (kg)						
1st quartile	20.0~30.0	129	3.51 ± 0.20	16.64 ± 0.77	7.75 ± 0.25	2.99 ± 0.10
2nd quartile	30.1~36.1	112	3.49 ± 0.21	17.07 ± 0.97	7.78 ± 0.28	3.03 ± 0.11
3rd quartile	36.2~45.0	128	3.45 ± 0.21	17.46 ± 1.10	7.80 ± 0.24	3.08 ± 0.13
4th quartile	45.1~82.3	113	3.40 ± 0.19	17.95 ± 1.08	7.81 ± 0.25	3.14 ± 0.15
P for trend			*P*<0.01	*P*<0.01	*P*=0.08	*P*<0.01
BMI (kg/m²)						

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1st quartile	14.0~16.5	121	3.45 ± 0.18	17.01 ± 1.05	7.73 ± 0.26	3.05 ± 0.12
2nd quartile	16.6~18.4	120	3.51 ± 0.23	17.23 ± 1.04	7.81 ± 0.26	3.05 ± 0.13
3rd quartile	18.5~20.8	120	3.46 ± 0.20	17.38 ± 1.11	7.81 ± 0.26	3.06 ± 0.14
4th quartile	20.9~30.6	121	3.44 ± 0.20	17.46 ± 1.13	7.79 ± 0.24	3.08 ± 0.14
P for trend			*P*=0.37	*P*<0.01	*P*=0.19	*P*<0.05

†Data are expressed as means ± SD.

‡Tests for linear trend is performed by entering the median value of each category of the anthropometric indicator as a continuous variable in the models.

Table 4 Multiple linear regression models of refraction and ocular biometry by height, weight, and BMI.

	Model 1	***P* Value**	**Model 2**	***P* Value**	**Model 3**	***P* Value**
Height (per 10 cm)						
SER (D)	-0.59 (-0.70, -0.49)†	<0.01	-0.26 (-0.45, -0.08)	<0.01	-0.21 (-0.40, -0.01)	<0.05
AL (mm)	0.40 (0.34, 0.47)	<0.01	0.18 (0.07, 0.29)	<0.01	0.14 (0.03, 0.26)	<0.05
CCT (μm)	4.03 (1.97, 6.08)	<0.01	2.43 (-1.29, 6.16)	0.20	3.41 (-0.76, 7.58)	0.11
ACD (mm)	0.05 (0.04, 0.07)	<0.01	0.02 (-0.01, 0.05)	0.17	0.02 (-0.02, 0.05)	0.34

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LT (mm)	-0.04 (-0.05, -0.02)	<0.01	-0.01 (-0.03, 0.02)	0.57	-0.01 (-0.03, 0.02)	0.75
VCD (mm)	0.38 (0.32, 0.44)	<0.01	0.17 (0.06, 0.27)	<0.01	0.13 (0.02, 0.25)	<0.05
CC (mm)	0.01 (-0.01, 0.03)	0.13	0.01 (-0.02, 0.04)	0.41	0.01 (-0.03, 0.04)	0.81
AL/CC ratio	0.05 (0.04, 0.06)	<0.01	0.02 (0.01, 0.03)	<0.01	0.02 (0.01, 0.03)	<0.05
Weight (per 10 kg)						
SER (D)	-0.65 (-0.79, -0.51)	<0.01	-0.21 (-0.39, -0.03)	<0.05	-0.18 (-0.36, 0.01)	0.07
AL (mm)	0.46 (0.38, 0.55)	<0.01	0.16 (0.05, 0.26)	<0.01	0.15 (0.04, 0.26)	<0.01
CCT (µm)	5.56 (2.93, 8.20)	<0.01	3.68 (0.06, 7.29)	<0.05	4.44 (0.42, 8.47)	<0.05
ACD (mm)	0.05 (0.03, 0.07)	<0.01	-0.01 (-0.03, 0.02)	0.90	-0.01 (-0.03, 0.03)	0.87
LT (mm)	-0.04 (-0.05, -0.02)	<0.01	0.01 (-0.02, 0.02)	0.95	0.01 (-0.02, 0.03)	0.96
VCD (mm)	0.44 (0.36, 0.53)	<0.01	0.16 (0.06, 0.27)	<0.01	0.15 (0.04, 0.26)	<0.01
CC (mm)	0.03 (0.01, 0.05)	<0.05	0.02 (-0.01, 0.05)	0.11	0.02 (-0.01, 0.05)	0.14
AL/CC ratio	0.05 (0.04, 0.06)	<0.01	0.01 (-0.01, 0.02)	0.10	0.01 (-0.01, 0.02)	0.16
BMI (per 10 kg/m^2)						
SER (D)	-0.64 (-1.15, -0.13)	<0.05	-0.26 (-0.73, 0.20)	0.26	-0.27 (-0.74, 0.20)	0.25
AL (mm)	0.53 (0.21, 0.84)	<0.01	0.20 (-0.07, 0.47)	0.15	0.23 (-0.05, 0.50)	0.10
CCT (µm)	9.50 (0.35, 18.65)	<0.05	6.37 (-2.79, 15.53)	0.17	7.19 (-2.87, 17.25)	0.16

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ACD (mm)	0.03 (-0.05, 0.10)	0.50	-0.03 (-0.10, 0.04)	0.46	-0.02 (-0.10, 0.05)	0.52
LT (mm)	-0.02 (-0.08, 0.03)	0.42	0.01 (-0.05, 0.07)	0.79	0.01 (-0.06, 0.07)	0.86
VCD (mm)	0.55 (0.24, 0.85)	<0.01	0.23 (-0.03, 0.50)	0.09	0.25 (-0.03, 0.52)	0.08
CC (mm)	0.06 (-0.01, 0.14)	0.09	0.04 (-0.03, 0.11)	0.25	0.06 (-0.02, 0.14)	0.13
AL/CC ratio	0.04 (0.01, 0.08)	<0.05	0.01 (-0.02, 0.04)	0.58	0.01 (-0.03, 0.04)	0.67

†Each value represents a separate regression model, with height, weight, or BMI used as the independent variable, the refraction or individual ocular biometrics used as the dependent variable, either alone or with various confounders. Data in parentheses represents the 95% confidence interval.

Model 1 constructs based on crude data. In the next two models, we controlled, in turn, for age and gender or for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors.

Table 5 Age-specific results of the associations of anthropometric indicators with both refraction and ocular biometrics.

	6-8 years old (n=170)	**9-11 years old (n=158)**	**12-15 years old (n=154)**
	b	***b***	***b***
Height (per 10 cm)			
SER (D)	-0.31 (-0.59, -0.03)*	-0.48 (-0.71, -0.24)**	0.35 (-0.52, 1.22)

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AL (mm)	0.17 (-0.02, 0.35)	0.25 (0.11, 0.38)**	-0.25 (-0.69, 0.18)
CCT (μm)	2.01 (-5.59, 9.60)	0.77 (-3.82, 5.36)	10.49 (-5.41, 26.39)
ACD (mm)	0.04 (-0.02, 0.10)	0.03 (-0.01, 0.06)	-0.09 (-0.17, -0.01)
LT (mm)	-0.03 (-0.08, 0.02)	-0.01 (-0.04, 0.01)	0.07 (-0.02, 0.15)
VCD (mm)	0.18 (-0.004, 0.36)	0.23 (0.09, 0.36)**	-0.23 (-0.69, 0.23)
CC (mm)	-0.01 (-0.07, 0.05)	-0.01 (-0.05, 0.03)	0.01 (-0.09, 0.12)
AL/CC	0.03 (0.003, 0.05)*	0.04 (0.02, 0.05)**	-0.04 (-0.09, 0.02)
Weight (per 10 kg)			
SER (D)	-0.37 (-0.67, -0.07)*	-0.48 (-0.74, -0.23)**	0.39 (-0.23, 1.01)
AL (mm)	0.13 (-0.08, 0.33)	0.29 (0.15, 0.44)**	-0.09 (-0.41, 0.22)
CCT (μm)	1.43 (-6.93, 9.79)	3.00 (-1.99, 7.99)	10.83 (-0.38, 22.04)
ACD (mm)	-0.002 (-0.06, 0.06)	0.03 (-0.01, 0.07)	-0.06 (-0.11, 0.002)
LT (mm)	0.02 (-0.03, 0.08)	-0.03 (-0.06, 0.001)	0.02 (-0.05, 0.08)
VCD (mm)	0.11 (-0.09, 0.31)	0.29 (0.14, 0.44)**	-0.06 (-0.39, 0.28)
CC (mm)	0.02 (-0.05, 0.08)	0.003 (-0.04, 0.04)	0.04 (-0.04, 0.11)
AL/CC	0.01 (-0.01, 0.04)	0.04 (0.02, 0.06)**	-0.03 (-0.07, 0.01)
BMI (per 10 kg/m²)			

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SER (D)	-0.46 (-1.10, 0.17)	-0.63 (-1.38, 0.13)	0.96 (-1.02, 2.93)
AL (mm)	0.06 (-0.36, 0.48)	0.47 (0.05, 0.90)*	0.03 (-0.98, 1.03)
CCT (μm)	0.84 (-16.31, 17.99)	9.14 (-5.10, 23.37)	28.47 (-7.47, 64.41)
ACD (mm)	-0.07 (-0.19, 0.06)	0.04 (-0.07, 0.15)	-0.10 (-0.28, 0.09)
LT (mm)	0.10 (-0.01, 0.21)	-0.07 (-0.16, 0.01)	-0.03 (-0.23, 0.17)
VCD (mm)	0.01 (-0.40, 0.43)	0.51 (0.08, 0.93)*	0.15 (-0.91, 1.21)
CC (mm)	0.05 (-0.09, 0.19)	0.03 (-0.08, 0.14)	0.13 (-0.11, 0.37)
AL/CC	-0.01 (-0.06, 0.04)	0.05 (-0.003, 0.11)	-0.05 (-0.17, 0.08)

*$P<0.05$; **$P<0.01$.

Each value represents a separate regression model with height, weight, or BMI used as the independent variable and the refraction or individual ocular biometrics used as the dependent variable. We controlled for gender, parental myopia, family income, reading and writing distance, and time spent outdoors. Data in parentheses represents the 95% confidence interval.

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Supplementary Table 1 Specific classification of some items in the questionnaire.

What day is your child's birthday?	____________________ (yy/mm/dd)
What's your child's gender?	A. Male B. Female
What is the average monthly income of your family?	A. Less than 4000 RMB B. 4000-8000 RMB C. 8000-10,000 RMB D. 10,000-15,000 RMB E. More than 15,000 RMB
Does the child's mother wear glasses for myopia?	A. Yes B. No
Does the child's father wear glasses for myopia?	A. Yes B. No
What is the distance between your child's eyes and a book when reading or writing?	A. <10 cm B. 10-19 cm C. 20-29 cm D. ≥30 cm
How many hours per day dose the child spend on outdoor activities during weekdays?	_________hours_________minutes
How many hours per day dose the child spend on outdoor activities during weekends?	_________hours_________minutes

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STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5
Methods			
Study design	4	Present key elements of study design early in the paper	Page 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Page 6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 7-8
Bias	9	Describe any efforts to address potential sources of bias	Page 6-9
Study size	10	Explain how the study size was arrived at	Page 10
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 8-9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Page 8-9
		(*b*) Describe any methods used to examine subgroups and interactions	--
		(*c*) Explain how missing data were addressed	--
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	--
		(*e*) Describe any sensitivity analyses	--
Results			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 10
		(b) Give reasons for non-participation at each stage	Page 10
		(c) Consider use of a flow diagram	--
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page 10
		(b) Indicate number of participants with missing data for each variable of interest	Page 10
Outcome data	15*	Report numbers of outcome events or summary measures	Page 10
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Page 10-12
		(*b*) Report category boundaries when continuous variables were categorized	Page 9
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	--
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	--
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 12
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 13-15
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 16

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Associations between anthropometric indicators and both refraction and ocular biometrics in a cross-sectional study of Chinese schoolchildren

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Associations between anthropometric indicators and both refraction and ocular biometrics in a cross-sectional study of Chinese schoolchildren

Sheng Ye[1], Shengxin Liu[1], Wenlei Li[1], Qifan Wang[1], Wei Xi[1], and Xin Zhang[1]

Author affiliation

1. Department of Maternal, Child and Adolescent Health, School of Public Health, Tianjin Medical University, No. 22 Qixiangtai Road, Tianjin 300070, China.

SY and SL contributed equally to the work presented here and should therefore be regarded as equivalent authors.

Correspondence to

Prof. Xin Zhang; zhangxin@tmu.edu.cn.

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ABSTRACT

Objective To identify associations between anthropometric indicators (height, weight, and body mass index (BMI)) and both refraction and ocular biometrics in Chinese schoolchildren in Tianjin, China.

Design Cross-sectional study.

Participants A total of 482 (86.07%) students (6 to 15 years old) with no history of ocular or systemic pathologies were enrolled in this study.

Methodology Height and weight were measured using standardized protocols. Ocular biometrics (axial length (AL), vitreous chamber depth (VCD), and corneal curvature (CC)) were measured by a low-coherence optical reflectometry device. Cycloplegic refraction was measured using autorefraction. The AL/CC ratio and spherical equivalent refraction (SER) were calculated. Myopia was defined as SER≤ −0.50 diopters (D). Multiple linear regression analysis was performed to explore the associations between anthropometric indicators (height, weight and BMI) and both refraction and ocular biometrics.

Results The overall prevalence of myopia was 71.16%. Overall, only height was associated with ALs, VCDs, AL/CC ratios, and refractions after controlling for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors. Furthermore, age-specific results demonstrated that height and weight were independently associated with refraction in 6- to 8-year-old and 9- to 11-year-old participants. Higher heights in schoolchildren were associated with longer ALs

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(regression coefficient *b*=+0.25 for each 10 cm difference in height, *P*<0.01), deeper VCDs (*b*=+0.23, *P*<0.01), higher AL/CC ratios (*b*=+0.04, *P*<0.01), and more negative refractions (*b*=-0.48, *P*<0.01). Heavier weights were also associated with longer ALs (+0.29 mm, *P*<0.01), deeper VCDs (+0.29 mm, *P*<0.01), higher AL/CC ratios (+0.04, *P*<0.01), and more negative refractions (-0.48 D, *P*<0.01).

Conclusions Height and weight remained independently related to refraction and various ocular biometrics during the early adolescent growth period after adequately controlling for covariates, which could support the idea that a shared mechanism may regulate the coordinated growth of body and eye size in children.

Keywords: anthropometric indicators, refraction, ocular biometrics, schoolchildren

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Strengths and limitations of this study

- The study participants were schoolchildren ranging in age from 6 to 15 years old, a period when myopia commonly develops, which could allow us to study the association between body stature and refraction during development.
- The overall and age-specific associations between anthropometric indicators and both refraction and ocular biometrics were calculated in this study to help better clarify the coordinated growth of body and eye size.
- Ocular biometrics were measured comprehensively, and the covariates were adequately controlled, which allowed us to achieve a more detailed analysis.
- An evaluation of causality was not possible because this study had a cross-sectional

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design.

Introduction

Myopia has reached almost epidemic proportions in the world, especially in certain areas of East and Southeast Asia.[1] This condition is commonly viewed as etiologically heterogeneous. Genetic and environmental risk factors are involved in its progression. The genetic basis of myopia has been supported by evidence indicating high heritability values in twin studies[2] and a higher prevalence of myopia in children with myopic parents.[3] Excessive near work activities,[4 5] limited time spent outdoors,[6 7] and intensive educational pressure[8 9] reportedly to promote the development of myopia. In our effort to consider other factors, we noted that anthropometric indicators, such as height, are thought to be associated with refraction, although no consensus has been achieved regarding this issue.[10 11]

Refractive status is determined by the balance of the refractive power of the cornea and lens, and the axial length (AL) of the eye (representing the combination of anterior chamber depth (ACD), lens thickness (LT), and vitreous chamber depth (VCD)).[12] Myopia usually arises in an eye that has become too long, particularly via vitreous chamber elongation. Several epidemiological studies have demonstrated that changes in ocular dimensions that occur in early life progress concomitant with physical development in children,[13 14] and the ages of cessation are also similar for increases in height and axial elongation.[13] Furthermore, genetic studies have confirmed that a

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common genetic pathway underlies both height and AL,[15 16] although no specific genetic variants have yet been identified. All of these clues suggest a shared mechanism that regulates the coordinated growth of body and eye size. It has been suggested that there may be a relationship between body stature and refraction. However, in contrast to the consensus regarding the significant associations between body stature and AL, the relationship between body stature and refraction remains controversial. Although many studies have reported that taller[10 17-20] and heavier persons[21 22] have an increased likelihood of having myopia, other studies have found no such association.[23-28] The discrepancies among these studies may be due to differences in sample sizes, concept definitions or other methodological variations (e.g., height and weight obtained via self-reporting).

In China, few studies have comprehensively measured ocular biometrics or further explored their associations with body stature. Additionally, myopia most commonly starts in young schoolchildren and progresses in early adolescence.[21] Therefore, it is most appropriate to study the effect of body growth on refractive development in young, growing students. In the current survey, we explored the associations between anthropometric indicators, including height, weight, and BMI, and both refraction and ocular biometrics in schoolchildren aged 6 to 15 years old in Tianjin, China.

METHODS

Recruitment

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Participants were recruited based on the following strategies. Two districts were randomly chosen from the 6 main urban districts in Tianjin in November 2016. Next, one primary school and one junior high school were randomly selected from each selected district. Then, one class was randomly chosen from each grade level within the two selected schools. All students in these selected classes were invited, but participation in this study was voluntary. After the purposes and procedures of the study were explained to each student and their parents in depth, written informed consent was collected. Students without parental consent and students who had amblyopia, heterotropia, or any ocular or systemic pathologies were excluded.

The study protocol was approved by the Ethics Committee of Tianjin Medical University and performed in accordance with the tenets of the Declaration of Helsinki.

Ocular examinations

All participants underwent a comprehensive eye examination, including measurements of intraocular pressure, a slit-lamp examination of the anterior and posterior segments, cycloplegic autorefraction and ocular biometrics. The purpose of intraocular pressure measurement and slit-lamp examination was to exclude contraindications for mydriasis.

Ocular biometrics, such as AL, central corneal thickness (CCT), ACD, LT, VCD, and corneal curvature (CC), were measured with a low-coherence optical reflectometry device (Lenstar LS900; Haag-Streit AG, 3098 Koeniz, Switzerland) in both eyes before pupil dilation. In addition, the AL/CC ratio, also commonly known as the axial length/corneal radius (AL/CR) ratio, was calculated. Then, cycloplegia was induced by

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administering one drop containing 0.5% tropicamide and 0.5% phenylephrine in a mixed eye agent to each eye at 0 and 5 minutes. Twenty-five minutes after the second instillation, pupillary dilation and the pupillary light reflex were evaluated. Full cycloplegia was considered when the pupil diameter reached 6 mm or more and the light reflex disappeared. A third drop was administered if full cycloplegia was not achieved. Then, participants with full cycloplegia underwent autorefraction using an auto-kerato-refractor (Canon Autorefractor RK-F1, Tokyo, Japan), and 3 consecutive measurements were taken in both eyes. The mean value of 3 valid measurements was calculated for statistical analysis. All of the above instruments were calibrated before the ocular examination. All examinations were performed by board-certified ophthalmologists and certified optometrists.

Definitions

The SER of each eye was calculated as the spherical refraction + 1/2 of the cylindrical refraction using data obtained using the autorefractor. Myopia was defined as an SER of ≤ -0.5 D.

Anthropometric measurements

Height and weight were obtained following specific standardized protocols[29] and measured by community doctors on the students' campus. Height was determined with the subject standing barefoot on the base of the height meter and recorded in centimeters (cm). Weight was measured without shoes and heavy coats on a calibrated electronic weighing scale and recorded in kilograms (kg). BMI was calculated as weight/height^2

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and recorded in kilograms per square meter (kg/m^2).

Questionnaire

The parents of participants and those excluded were all asked to complete a questionnaire developed to collect information on social-demographic characteristics and potential risk factors for school myopia (supplementary Table 1).

The basic characteristics of the participants included age, gender, the monthly income of the family, and the number of parents with myopia. Near-work-related behaviors were ascertained with the question "What is the distance between your child's eyes and a book when reading or writing?", with answers categorized as follows: <10 cm, 10-19 cm, 20-29 cm, and ≥30 cm. Time spent outdoors was estimated by asking how many hours per day the child spent on outdoor activities during weekdays and weekends separately. The average time spent outdoors was calculated by the following formula: [$T_{weekday}$ (hours spent on weekdays) × 5 + $T_{weekend}$ (hours spent on weekends) × 2] ÷ 7.

Statistical analysis

Because refraction and ocular biometrics were highly correlated between two eyes (the Pearson correlation coefficients (r) for refraction, AL, CCT, ACD, LT, VCD, CC and AL/CC ratio were 0.90, 0.96, 0.89, 0.93, 0.93, 0.95, 0.97 and 0.95, respectively, and all P values were lower than 0.01), the data obtained from the right eye were chosen for analyses. Ocular biometrics were all normally distributed, as determined by P-P plots.

T-tests were performed for quantitative variables, and chi-square tests were

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performed for categorical variables to analyze the differences in basic characteristics between individuals with and without myopia. Univariate associations between anthropometric indicators and both refraction and ocular biometrics were identified. Simple linear regression models were constructed to assess the effects of height, weight, and BMI (as independent variables) on refraction and individual ocular biometrics (as dependent variables). Tests for linear trends were performed by entering the median value of each category of the anthropometric indicator based on quartiles as a continuous variable into the models. Multiple linear regression models were then fitted after adjusting, in turn, for age and gender or for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors. In addition, all participants were divided into the following age groups: 6 to 8 years old, 9 to 11 years old, and 12 to 15 years old. The results of age-specific associations of anthropometric indicators with both refraction and ocular biometrics after controlling for the above covariates were calculated. Collinearity diagnostics were performed, and multicollinearity was absent among the independent variables used in each model.

Statistical analyses were performed using commercial statistical software (SPSS for Windows, version 20.0; IBM-SPSS, Chicago, Illinois, USA), and *P* values <0.05 were considered statistically significant.

Patient and public involvement

Patients and the public were not involved in developing the research questionnaire, outcome measures or overall design of this study protocol.

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RESULTS

Participant characteristics

Among 560 students who were initially invited, a total of 482 participants ranging in age from 6 to 15 years old were available for statistical analysis after excluding 70 students without parental consent, 5 students with heterotropia, and 3 students with amblyopia. The response rate in this study was 86.07% (482 of 560). Individuals who were included were older (9.42 ± 2.09 vs 7.60 ± 2.38 years old, *P*<0.01) than those who were excluded. There were no significant differences in gender, parental myopia, monthly family income, reading and writing distance, and time spent outdoors between included and excluded individuals.

The overall prevalence of myopia was 71.16% (343 of 482; 95% CI, 67.01% to 75.10%). The mean SER, height, weight and BMI of all participants was -1.48 ± 1.82 D, 140.79 ± 13.95 cm, 38.29 ± 10.86 kg, and 19.04 ± 3.18 kg/m^2, respectively (Table 1). Participants with myopia were older, taller, and heavier. These individuals were more likely to have myopic parents, a higher monthly family income, a closer reading and writing distance and to spend less time outdoors. Moreover, these participants had eyes with longer ALs, deep ACDs and VCDs, thinner LTs, and larger AL/CC ratios (all *P* values were less than 0.05).

Bivariate correlations between variables

Bivariate correlations of body stature with both refraction and ocular biometrics are

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presented in Table 2, which was of low to moderate strength. For example, height was positively correlated with AL (*r*=0.50, *P*<0.01), CCT (*r*=0.17, *P*<0.01), ACD (*r*=0.29, *P*<0.01), VCD (*r*=0.49, *P*<0.01) and the AL/CC ratio (*r*=0.49, *P*<0.01) and negatively correlated with SER (*r*=-0.45, *P*<0.01) and LT (*r*=-0.24, *P*<0.01).

Linear trends in refraction and ocular biometrics changes by body stature quartiles

Taller and heavier individuals tended to have eyes with longer ALs, thicker CCTs, deeper ACDs, thinner LTs, deeper VCDs, higher AL/CC ratios, and more myopic refractions (all *P* values for trend were less than 0.05) (Table 3). In addition to ACD and LT, the above tendencies were also observed among more obese schoolchildren (students with higher BMIs).

Linear regression analysis of the associations between anthropometric indicators and both refraction and ocular biometrics

In model 1, we used the association between height and refraction as an example and found that for each 10 cm increase in height, the SER was expected to decrease by 0.59 D (*P*<0.01) without controlling for any covariates (Table 4). In the next two models, we controlled, in turn, for age and gender or for age, gender, parental myopia, family income, reading and writing distance and time spent outdoors. The difference in SER declined by 0.26 D (*P*<0.01) and 0.21 D (*P*<0.05) in models 2 and 3, respectively. In general, higher heights were associated with longer ALs (+0.14 mm, *P*<0.05), deeper VCDs (+0.13 mm, *P*<0.05), greater AL/CC ratios (+0.02, *P*<0.05), and more negative

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refractions (-0.21 D, $P<0.05$) among 6- to 15-year-old participants. Nonetheless, weight and BMI were not correlated with refraction in our multiple linear regression models.

Furthermore, the participants were categorized into the following age groups: 6 to 8 years old (n=170), 9 to 11 years old (n=158), and 12 to 15 years old (n=154). After controlling for the above covariates, the age-specific associations were calculated (Table 5). Both height and weight remained independently associated with refraction in the age range from 6 to 8 years old and 9 to 11 years old. Particularly from 9 to 11 years old, higher heights in schoolchildren were associated with longer ALs (+0.25 mm, $P<0.01$), deeper VCDs (+0.23 mm, $P<0.01$), higher AL/CC ratios (+0.04, $P<0.01$), and more negative refractions (-0.48 D, $P<0.01$) in their eyes. Heavier weights were also associated with longer ALs (+0.29 mm, $P<0.01$), deeper VCDs (+0.29 mm, $P<0.01$), higher AL/CC ratios (+0.04, $P<0.01$), and more negative refractions (-0.48 D, $P<0.01$). However, from 12 to 15 years of age, no association was detected between body stature and refraction.

DISCUSSION

In this paper, we comprehensively measured ocular biometrics and then explored the overall and age-specific associations between anthropometric indicators and both refraction and ocular biometrics after adequately controlling for covariates among 6- to 15-year-old schoolchildren. In China, few studies such as this one have been conducted. Wang et al.[14] confirmed a positive association between height and AL in 7- to 15-year-

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old schoolchildren based on longitudinal data obtained in Guangzhou, China. However, detailed information about the associations between body stature and refraction and other ocular biometrics was not available in that study. Therefore, compared with previous studies,[14,28] the present study achieved a more detailed analysis.

The current results are in almost complete agreement with those of Saw et al.[17] who showed that among 1449 Singaporean Chinese children aged 7-9 years old, taller individuals were more likely to have eyes with longer ALs (+0.46 mm, P<0.01), deeper VCDs (+0.46 mm, P<0.01), flatter corneas (+0.10 mm, P<0.01), greater AL/CC ratios (+0.02, P=0.03), and refractions that trended toward myopia (-0.47 D, P<0.01) after controlling for age, gender, parental myopia, and the number of books read per week. A birth cohort performed in Britain to examine the relationship between height growth trajectories and the development of myopia presented similar results.[10] For each SD increase in height for children aged from 2.5 to 10 years old, SER became more negative by -0.075 D (95% CI, -0.112 to -0.039; P<0.01) and -0.081 D (95% CI, -0.129 to -0.034; P<0.01) when the children reached 11 and 15 years old, respectively. However, Huang et al.[28] reported that no significant correlation between myopia shift and height changes among schoolchildren aged 7 to 9 years old in Taiwan, China.

Although the association remains unclear, these results will help us to further explore the intricate relationship between the development of physical characteristics and refraction. A commonly proposed explanation for this potential association is that both higher height and myopia are independent consequences of better socioeconomic status;

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therefore, there may be no causal relationship between height and myopia.[17 23] However, in this study, after we controlled for socioeconomic characteristics and myopia-related risk factors, height remained independently related to refraction and various ocular biometrics. Myopia most commonly develops during the period from childhood to early adolescence (from approximately 8 to 14 years old),[30] and growth spurts also occur in this period.[31] The early period of adolescence is mainly characterized by growth spurts and the onset of sexual development, which lasts for approximately 2 or 3 years.[32] The age range of early adolescence is approximately 8 to 11 years old. Therefore, we inferred that the development of refraction could be related to physical development during the early period of adolescent growth. The findings of the Singapore Cohort Study of Risk Factors for Myopia (SCORM) support this hypothesis.[19] SCORM reported that boys and girls who experienced earlier peak height velocity also achieved earlier peak SER velocity (at a mean age of 10.1 vs 10.6 years old for boys, *P*=0.01, and 10.0 vs 10.6 years old for girls, *P*=0.01) and had an earlier age of onset of myopia (9.9 vs 10.4 years old for boys, *P*=0.03, and 9.7 vs 10.1 years old for girls, *P*=0.04). The exact biologic pathways underlying these associations are currently unknown. Some major systemic hormones, such as growth hormone, thymic hormone and insulin-like growth factors (IGFs), reportedly could regulate longitudinal bone growth during childhood, which are also involved in the development of experimental myopia.[33 34] In addition, epidemiological studies reported that children with growth hormone deficiency have shorter body stature and ALs than usual.[35] Growth hormone

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supplementation in these children could partially bring the stature and ALs back within the normal range.[36] Sex hormones may be another significant mediator during puberty,[37] but our age-specific results (no association was detected in 12- to 15-year-old participants) may not support this idea. Although these hormones were not determined in this cross-sectional study, we believe that the shared mechanism between height and refraction may shed new light on the etiology of myopia and the efforts to explore the effect of endocrine traits observed during childhood and adolescence on body and eye size in the future studies.

The relationships weight and BMI share with refraction are not as extensively studied as those with height, but the findings regarding these relationships are also inconclusive. Heavier and more obese Chinese children and adults in Singapore have refractions that trend toward hyperopia.[17 23] Moreover, heavier adults in rural Myanmar reportedly have more positive refractions.[25] However, a cross-sectional study performed in 19-year-old male conscripts in South Korea found that weight and BMI had no effect on refraction.[27] Consistent with the results of a twin study performed in Australia,[22] in our study, heavier weights were associated with more negative refractions among participants aged 6 to 8 and 9 to 11 years old.

This study has several limitations that warrant consideration. First, information on putative myopia risk factors obtained from our questionnaire (e.g., the distance between the child's eyes and a book when reading or writing) was subjectively estimated by the parents. Although this method has been widely applied in previous studies,[17 28] it can

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lead to recall bias. Second, the representativeness of the participants in this study may be affected to some extent because the participants were volunteers. Although there were no significant differences in nearly all basic characteristics between participants and those excluded, individuals who were included were older, which may have resulted in overestimation of the prevalence of myopia in our study. Third, all of the data collected in this study were cross-sectional in nature and do not allow an evaluation of causality. Therefore, whether the conclusions drawn from this study are applicable to longitudinal relationships remains uncertain. Additionally, the significant correlation observed in our study needs to be interpreted carefully because of the small sample size. It is important to avoid making strong conclusions about these associations, regardless of whether the results were positive. A larger sample size study is needed in the future to validate our conclusions. Despite these limitations, we believe that our study provides a valuable reference regarding the associations between anthropometric indicators and both refraction and ocular biometrics in Chinese schoolchildren aged 6 to 15 years old.

In conclusion, both higher heights and heavier weights were associated with longer ALs, deeper VCDs, higher AL/CC ratios and more myopic refractions during the early period of adolescent growth after controlling for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors. The results of this study support the idea that a shared mechanism may regulate the coordinated growth of body and eye size in children.

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Table 1 Summary of the characteristics of the participants.

	Total	Myopia	Nonmyopia	*P* Value
Age (years)	9.42 ± 2.09	9.88 ± 2.14	8.30 ± 1.45	<0.01
Male	264 (54.77)	187 (54.52)	77 (55.40)	0.86
Female	218 (45.23)	156 (45.48)	62 (44.60)	0.86
Parental myopia*				<0.01
None	129 (28.48)	74 (23.13)	55 (41.35)	
One parent	188 (41.50)	134 (41.88)	54 (40.60)	
Both parents	136 (30.02)	112 (35.00)	24 (18.05)	
Monthly family income*				<0.05
<4000 RMB	41 (8.78)	27 (8.16)	14 (10.29)	
4000-8000 RMB	136 (29.12)	89 (26.89)	47 (34.56)	
8000-10,000 RMB	133 (28.48)	89 (26.89)	44 (32.35)	
10,000-15,000 RMB	91 (19.49)	73 (22.05)	18 (13.24)	
≥15,000 RMB	66 (14.13)	53 (16.01)	13 (9.56)	
Reading and writing distance*				<0.05
<10 cm	45 (9.62)	36 (10.81)	9 (6.67)	
10-20 cm	200 (42.74)	148 (44.44)	52 (38.52)	
20-30 cm	166 (35.47)	117 (35.14)	49 (36.30)	
≥30 cm	57 (12.18)	32 (9.61)	25 (18.52)	
Time spent outdoors (hours)	1.20 ± 0.70	1.16 ± 0.70	1.31 ± 0.69	<0.05
Height (cm)	140.79 ± 13.95	143.85 ± 14.17	133.22 ± 10.01	<0.01
Weight (kg)	38.29 ± 10.86	40.06 ± 11.05	33.92 ± 9.01	<0.01
BMI (kg/m^2)	19.04 ± 3.18	19.10 ± 3.14	18.89 ± 3.28	0.52
SER (D)	-1.48 ± 1.82	-2.20 ± 1.66	0.30 ± 0.54	<0.01
AL (mm)	23.81 ± 1.12	24.16 ± 1.07	22.95 ± 0.72	<0.01
CCT (μm)	547.65 ± 32.44	548.88 ± 33.32	544.63 ± 30.05	0.19
ACD (mm)	3.08 ± 0.26	3.14 ± 0.25	2.94 ± 0.23	<0.01

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LT (mm)	3.47 ± 0.20	3.43 ± 0.20	3.55 ± 0.19	<0.01
VCD (mm)	17.27 ± 1.09	17.60 ± 1.05	16.46 ± 0.71	<0.01
CC (mm)	7.78 ± 0.26	7.78 ± 0.25	7.79 ± 0.26	0.84
AL/CC ratio	3.06 ± 0.13	3.11 ± 0.13	2.95 ± 0.07	<0.01

Data are presented as the means with standard deviation (SD) or as n (%).

*Numbers of individuals vary due to missing data.

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Table 2 Bivariate correlations of body stature with refraction and ocular biometrics.

	Height (cm)	Weight (kg)	BMI (kg/m^2)
SER (D)	-0.45**	-0.39**	-0.11*
AL (mm)	0.50**	0.45**	0.15*
CCT (μm)	0.17**	0.19**	0.09*
ACD (mm)	0.29**	0.22**	0.03
LT (mm)	-0.24**	-0.19**	-0.04
VCD (mm)	0.49**	0.44**	0.16**
CC (mm)	0.07	0.10*	0.08
AL/CC ratio	0.49**	0.40**	0.10*

Data are the Pearson correlation coefficients.

*: $P<0.05$.

**: $P<0.01$.

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Table 3 Unadjusted mean values of refraction and ocular biometrics by quartiles of height, weight and BMI.

	Range	n	SER (D)	AL (mm)	CCT (μm)	ACD (mm)
Height (cm)						
1st quartile	100.0~130.0	127	-0.48 ± 1.13†	23.09 ± 0.78	542.11 ± 30.93	2.97 ± 0.24
2nd quartile	130.1~140.0	136	-1.08 ± 1.46	23.58 ± 0.98	544.96 ± 32.69	3.05 ± 0.28
3rd quartile	140.1~150.7	99	-1.86 ± 1.80	24.15 ± 1.01	550.04 ± 32.31	3.16 ± 0.23
4th quartile	150.8~182.5	120	-2.68 ± 2.06	24.56 ± 1.14	554.58 ± 32.76	3.18 ± 0.22
P for trend‡			*P*<0.01	*P*<0.01	*P*<0.05	*P*<0.01
Weight (kg)						
1st quartile	20.0~30.0	129	-0.59 ± 1.19	23.19 ± 0.80	541.27 ± 32.75	3.02 ± 0.26
2nd quartile	30.1~36.1	112	-1.12 ± 1.30	23.58 ± 1.00	547.64 ± 31.34	3.04 ± 0.26
3rd quartile	36.2~45.0	128	-1.75 ± 1.92	24.02 ± 1.12	544.17 ± 31.56	3.12 ± 0.24
4th quartile	45.1~82.3	113	-2.54 ± 2.14	24.52 ± 1.12	558.92 ± 31.65	3.16 ± 0.24
P for trend			*P*<0.01	*P*<0.01	*P*<0.01	*P*<0.01
BMI (kg/m²)						
1st quartile	14.0~16.5	121	-1.19 ± 1.62	23.55 ± 1.05	543.79 ± 31.55	3.09 ± 0.25
2nd quartile	16.6~18.4	120	-1.39 ± 1.69	23.80 ± 1.14	545.79 ± 32.26	3.05 ± 0.28

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	Range	n	LT (mm)	VCD (mm)	CC (mm)	AL/CC ratio
3rd quartile	18.5~20.8	120	-1.59 ± 1.88	23.90 ± 1.12	547.12 ± 32.16	3.09 ± 0.25
4th quartile	20.9~30.6	121	-1.74 ± 2.05	24.00 ±1.16	533.90 ± 33.26	3.11 ± 0.25
P for trend			*P*<0.05	*P*<0.01	*P*<0.05	*P*=0.32

	Range	n	LT (mm)	VCD (mm)	CC (mm)	AL/CC ratio
Height (cm)						
1st quartile	100.0~130.0	127	3.55 ± 0.19	16.57 ± 0.74	7.75 ± 0.25	2.98 ± 0.09
2nd quartile	130.1~140.0	136	3.48 ± 0.23	17.07 ± 0.96	7.79 ± 0.27	3.03 ± 0.11
3rd quartile	140.1~150.7	99	3.42 ± 0.18	17.58 ± 0.99	7.81 ± 0.26	3.09 ± 0.13
4th quartile	150.8~182.5	120	3.41 ± 0.19	17.97 ± 1.12	7.78 ± 0.25	3.16 ± 0.14
P for trend			*P*<0.01	*P*<0.01	*P*=0.36	*P*<0.01
Weight (kg)						
1st quartile	20.0~30.0	129	3.51 ± 0.20	16.64 ± 0.77	7.75 ± 0.25	2.99 ± 0.10
2nd quartile	30.1~36.1	112	3.49 ± 0.21	17.07 ± 0.97	7.78 ± 0.28	3.03 ± 0.11
3rd quartile	36.2~45.0	128	3.45 ± 0.21	17.46 ± 1.10	7.80 ± 0.24	3.08 ± 0.13
4th quartile	45.1~82.3	113	3.40 ± 0.19	17.95 ± 1.08	7.81 ± 0.25	3.14 ± 0.15
P for trend			*P*<0.01	*P*<0.01	*P*=0.08	*P*<0.01
BMI (kg/m²)						

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1st quartile	14.0~16.5	121	3.45 ± 0.18	17.01 ± 1.05	7.73 ± 0.26	3.05 ± 0.12
2nd quartile	16.6~18.4	120	3.51 ± 0.23	17.23 ± 1.04	7.81 ± 0.26	3.05 ± 0.13
3rd quartile	18.5~20.8	120	3.46 ± 0.20	17.38 ± 1.11	7.81 ± 0.26	3.06 ± 0.14
4th quartile	20.9~30.6	121	3.44 ± 0.20	17.46 ± 1.13	7.79 ± 0.24	3.08 ± 0.14
P for trend			*P*=0.37	*P*<0.01	*P*=0.19	*P*<0.05

†Data are expressed as means ± SD.

‡Tests for linear trend is performed by entering the median value of each category of the anthropometric indicator as a continuous variable in the models.

Table 4 Multiple linear regression models of refraction and ocular biometry by height, weight, and BMI.

	Model 1	***P* Value**	**Model 2**	***P* Value**	**Model 3**	***P* Value**
Height (per 10 cm)						
SER (D)	-0.59 (-0.70, -0.49)†	<0.01	-0.26 (-0.45, -0.08)	<0.01	-0.21 (-0.40, -0.01)	<0.05
AL (mm)	0.40 (0.34, 0.47)	<0.01	0.18 (0.07, 0.29)	<0.01	0.14 (0.03, 0.26)	<0.05
CCT (μm)	4.03 (1.97, 6.08)	<0.01	2.43 (-1.29, 6.16)	0.20	3.41 (-0.76, 7.58)	0.11
ACD (mm)	0.05 (0.04, 0.07)	<0.01	0.02 (-0.01, 0.05)	0.17	0.02 (-0.02, 0.05)	0.34

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LT (mm)	-0.04 (-0.05, -0.02)	<0.01	-0.01 (-0.03, 0.02)	0.57	-0.01 (-0.03, 0.02)	0.75
VCD (mm)	0.38 (0.32, 0.44)	<0.01	0.17 (0.06, 0.27)	<0.01	0.13 (0.02, 0.25)	<0.05
CC (mm)	0.01 (-0.01, 0.03)	0.13	0.01 (-0.02, 0.04)	0.41	0.01 (-0.03, 0.04)	0.81
AL/CC ratio	0.05 (0.04, 0.06)	<0.01	0.02 (0.01, 0.03)	<0.01	0.02 (0.01, 0.03)	<0.05
Weight (per 10 kg)						
SER (D)	-0.65 (-0.79, -0.51)	<0.01	-0.21 (-0.39, -0.03)	<0.05	-0.18 (-0.36, 0.01)	0.07
AL (mm)	0.46 (0.38, 0.55)	<0.01	0.16 (0.05, 0.26)	<0.01	0.15 (0.04, 0.26)	<0.01
CCT (μm)	5.56 (2.93, 8.20)	<0.01	3.68 (0.06, 7.29)	<0.05	4.44 (0.42, 8.47)	<0.05
ACD (mm)	0.05 (0.03, 0.07)	<0.01	-0.01 (-0.03, 0.02)	0.90	-0.01 (-0.03, 0.03)	0.87
LT (mm)	-0.04 (-0.05, -0.02)	<0.01	0.01 (-0.02, 0.02)	0.95	0.01 (-0.02, 0.03)	0.96
VCD (mm)	0.44 (0.36, 0.53)	<0.01	0.16 (0.06, 0.27)	<0.01	0.15 (0.04, 0.26)	<0.01
CC (mm)	0.03 (0.01, 0.05)	<0.05	0.02 (-0.01, 0.05)	0.11	0.02 (-0.01, 0.05)	0.14
AL/CC ratio	0.05 (0.04, 0.06)	<0.01	0.01 (-0.01, 0.02)	0.10	0.01 (-0.01, 0.02)	0.16
BMI (per 10 kg/m²)						
SER (D)	-0.64 (-1.15, -0.13)	<0.05	-0.26 (-0.73, 0.20)	0.26	-0.27 (-0.74, 0.20)	0.25
AL (mm)	0.53 (0.21, 0.84)	<0.01	0.20 (-0.07, 0.47)	0.15	0.23 (-0.05, 0.50)	0.10
CCT (μm)	9.50 (0.35, 18.65)	<0.05	6.37 (-2.79, 15.53)	0.17	7.19 (-2.87, 17.25)	0.16

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ACD (mm)	0.03 (-0.05, 0.10)	0.50	-0.03 (-0.10, 0.04)	0.46	-0.02 (-0.10, 0.05)	0.52
LT (mm)	-0.02 (-0.08, 0.03)	0.42	0.01 (-0.05, 0.07)	0.79	0.01 (-0.06, 0.07)	0.86
VCD (mm)	0.55 (0.24, 0.85)	<0.01	0.23 (-0.03, 0.50)	0.09	0.25 (-0.03, 0.52)	0.08
CC (mm)	0.06 (-0.01, 0.14)	0.09	0.04 (-0.03, 0.11)	0.25	0.06 (-0.02, 0.14)	0.13
AL/CC ratio	0.04 (0.01, 0.08)	<0.05	0.01 (-0.02, 0.04)	0.58	0.01 (-0.03, 0.04)	0.67

†Each value represents a separate regression model, with height, weight, or BMI used as the independent variable, the refraction or individual ocular biometrics used as the dependent variable, either alone or with various confounders. Data in parentheses represents the 95% confidence interval.

Model 1 constructs based on crude data. In the next two models, we controlled, in turn, for age and gender or for age, gender, parental myopia, family income, reading and writing distance, and time spent outdoors.

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Table 5 Age-specific results of the associations of anthropometric indicators with both refraction and ocular biometrics.

	6-8 years old (n=170)	**9-11 years old (n=158)**	**12-15 years old (n=154)**
	b	***b***	***b***
Height (per 10 cm)			
SER (D)	-0.31 (-0.59, -0.03)*	-0.48 (-0.71, -0.24)**	0.35 (-0.52, 1.22)

AL (mm)	0.17 (-0.02, 0.35)	0.25 (0.11, 0.38)**	-0.25 (-0.69, 0.18)
CCT (μm)	2.01 (-5.59, 9.60)	0.77 (-3.82, 5.36)	10.49 (-5.41, 26.39)
ACD (mm)	0.04 (-0.02, 0.10)	0.03 (-0.01, 0.06)	-0.09 (-0.17, -0.01)
LT (mm)	-0.03 (-0.08, 0.02)	-0.01 (-0.04, 0.01)	0.07 (-0.02, 0.15)
VCD (mm)	0.18 (-0.004, 0.36)	0.23 (0.09, 0.36)**	-0.23 (-0.69, 0.23)
CC (mm)	-0.01 (-0.07, 0.05)	-0.01 (-0.05, 0.03)	0.01 (-0.09, 0.12)
AL/CC	0.03 (0.003, 0.05)*	0.04 (0.02, 0.05)**	-0.04 (-0.09, 0.02)
Weight (per 10 kg)			
SER (D)	-0.37 (-0.67, -0.07)*	-0.48 (-0.74, -0.23)**	0.39 (-0.23, 1.01)
AL (mm)	0.13 (-0.08, 0.33)	0.29 (0.15, 0.44)**	-0.09 (-0.41, 0.22)
CCT (μm)	1.43 (-6.93, 9.79)	3.00 (-1.99, 7.99)	10.83 (-0.38, 22.04)
ACD (mm)	-0.002 (-0.06, 0.06)	0.03 (-0.01, 0.07)	-0.06 (-0.11, 0.002)
LT (mm)	0.02 (-0.03, 0.08)	-0.03 (-0.06, 0.001)	0.02 (-0.05, 0.08)
VCD (mm)	0.11 (-0.09, 0.31)	0.29 (0.14, 0.44)**	-0.06 (-0.39, 0.28)
CC (mm)	0.02 (-0.05, 0.08)	0.003 (-0.04, 0.04)	0.04 (-0.04, 0.11)
AL/CC	0.01 (-0.01, 0.04)	0.04 (0.02, 0.06)**	-0.03 (-0.07, 0.01)
BMI (per 10 kg/m^2)			

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SER (D)	-0.46 (-1.10, 0.17)	-0.63 (-1.38, 0.13)	0.96 (-1.02, 2.93)
AL (mm)	0.06 (-0.36, 0.48)	0.47 (0.05, 0.90)*	0.03 (-0.98, 1.03)
CCT (μm)	0.84 (-16.31, 17.99)	9.14 (-5.10, 23.37)	28.47 (-7.47, 64.41)
ACD (mm)	-0.07 (-0.19, 0.06)	0.04 (-0.07, 0.15)	-0.10 (-0.28, 0.09)
LT (mm)	0.10 (-0.01, 0.21)	-0.07 (-0.16, 0.01)	-0.03 (-0.23, 0.17)
VCD (mm)	0.01 (-0.40, 0.43)	0.51 (0.08, 0.93)*	0.15 (-0.91, 1.21)
CC (mm)	0.05 (-0.09, 0.19)	0.03 (-0.08, 0.14)	0.13 (-0.11, 0.37)
AL/CC	-0.01 (-0.06, 0.04)	0.05 (-0.003, 0.11)	-0.05 (-0.17, 0.08)

*$P<0.05$; **$P<0.01$.

Each value represents a separate regression model with height, weight, or BMI used as the independent variable and the refraction or individual ocular biometrics used as the dependent variable. We controlled for gender, parental myopia, family income, reading and writing distance, and time spent outdoors. Data in parentheses represents the 95% confidence interval.

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Supplementary Table 1 Specific classification of some items in the questionnaire.

What day is your child's birthday?	____________________ (yy/mm/dd)
What's your child's gender?	A. Male B. Female
What is the average monthly income of your family?	A. Less than 4000 RMB B. 4000-8000 RMB C. 8000-10,000 RMB D. 10,000-15,000 RMB E. More than 15,000 RMB
Does the child's mother wear glasses for myopia?	A. Yes B. No
Does the child's father wear glasses for myopia?	A. Yes B. No
What is the distance between your child's eyes and a book when reading or writing?	A. <10 cm B. 10-19 cm C. 20-29 cm D. ≥30 cm
How many hours per day dose the child spend on outdoor activities during weekdays?	_________hours_________minutes
How many hours per day dose the child spend on outdoor activities during weekends?	_________hours_________minutes

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STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cross-sectional studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	Page 2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	Page 2-3
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	Page 4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	Page 5
Methods			
Study design	4	Present key elements of study design early in the paper	Page 6
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	Page 6
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	Page 6
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	Page 7-8
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	Page 7-8
Bias	9	Describe any efforts to address potential sources of bias	Page 6-9
Study size	10	Explain how the study size was arrived at	Page 10
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	Page 8-9
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	Page 8-9
		(*b*) Describe any methods used to examine subgroups and interactions	--
		(*c*) Explain how missing data were addressed	--
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	--
		(*e*) Describe any sensitivity analyses	--
Results			

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Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	Page 10
		(b) Give reasons for non-participation at each stage	Page 10
		(c) Consider use of a flow diagram	--
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	Page 10
		(b) Indicate number of participants with missing data for each variable of interest	Page 10
Outcome data	15*	Report numbers of outcome events or summary measures	Page 10
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	Page 10-12
		(*b*) Report category boundaries when continuous variables were categorized	Page 9
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	--
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	--
Discussion			
Key results	18	Summarise key results with reference to study objectives	Page 12
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	Page 15
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	Page 13-15
Generalisability	21	Discuss the generalisability (external validity) of the study results	Page 15
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	Page 16

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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