

# Inverse L-Shaped Association Between Body Mass Index and Myopia in Chinese Schoolchildren: A Pilot Study

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**Purpose:** The prevalence of obesity and myopia in young people is increasing worldwide; however, the association between body mass index (BMI) and myopia remains controversial. This study aimed to assess the association between BMI and myopia in Chinese schoolchildren.

**Patients and Methods:** In this study, the open data for analysis were obtained from DATADRYAD website ([www.datadryad.org](http://www.datadryad.org)). A total of 3658 children were enrolled in this study. Logistic regression model was used to analyze the relationship between BMI and myopia.

**Results:** Compared with individuals with lower BMI Q1 (less than 25 kg/m<sup>2</sup>), the adjusted odds ratios (ORs) for BMI and myopia were 2.15 (95% confidence interval [CI]: 1.62–2.86) in Q2 (25.0–29.9 kg/m<sup>2</sup>) and 2.39 (95% CI: 1.37–4.18) in Q3 (30.0 kg/m<sup>2</sup> or more). Moreover, the association between BMI and myopia exhibited an inverted L-shaped curve (nonlinear;  $p < 0.001$ ). When the BMI was  $< 25$  kg/m<sup>2</sup>, an increased BMI was significantly associated with a higher risk of myopia (OR = 1.244 [95% CI: 1.211–1.277],  $p < 0.001$ ). However, when the BMI was  $\geq 25$  kg/m<sup>2</sup>, the association lost its significance (OR = 1.063 [95% CI: 0.964–1.171],  $p = 0.219$ ).

**Conclusion:** This study found an inverted L-shaped association between BMI and myopia in Chinese schoolchildren. A higher BMI was associated with a higher risk of myopia reaching 25 kg/m<sup>2</sup>, after which an increase in BMI was no longer associated with an increased risk of myopia.

**Keywords:** myopia, body mass index, cross-sectional, schoolchildren, logistic regression

## Introduction

Myopia, or nearsightedness, is a prevalent refractive error that affects individuals globally. It has become a significant public health concern due to its increasing prevalence and related ocular complications.<sup>1</sup> In 2010, approximately 28.3% of the global population was affected by myopia, and this figure is projected to rise to 49.8% by 2050.<sup>2</sup> Uncorrected myopia is the major cause of vision impairment worldwide. Moreover, high myopia can lead to severe ocular damage and is linked to various ocular diseases, including retinal detachment, glaucoma, myopic maculopathy, and blindness.<sup>3–5</sup> Typically, myopia develops and progresses most rapidly during childhood,<sup>6</sup> and stabilizes gradually for most individuals after adolescence.<sup>7</sup> However, early-onset myopia in Asian school-aged children is associated with longer progression duration and, in some cases, a faster rate of progression (–1D per year).<sup>8</sup> Consequently, there is a higher prevalence of high myopia among young people in Asia and an increased risk of complications such as pathologic myopia.<sup>9</sup> Therefore, children and adolescents are the primary target population for myopia prevention and control.

The cause of myopia is complex and not yet fully understood, and it is currently believed that genetic, environmental, and racial factors may all play a role in the development of myopia.<sup>1</sup> Furthermore, researchers are also investigating the potential association between body mass index (BMI) and myopia. While current research findings on the relationship between BMI and myopia are inconsistent, with conflicting reports. Some studies indicate a positive correlation between the two,<sup>10–12</sup> others suggest a negative correlation or no clear association.<sup>13–15</sup> A study by Cordain showed that a carbohydrate diet with high

glycemic load may be associated with myopia.<sup>16</sup> Moreover, insulin resistance stimulates the production of insulin-like growth factor 1 (IGF-1), leading to axial elongation, which is also associated with the development of myopia. The high risk of insulin resistance is closely related to obesity, which can lead to increased levels of insulin and IGF in the blood, further increasing the risk of myopia.<sup>17–19</sup> Notably, obese individuals tend to show higher BMIs.<sup>20</sup> Therefore, the study on the relationship between BMI and myopia is of great significance. However, limited studies have been conducted in China to investigate this association. Consequently, this study explored the association between BMI and myopia in school-aged children in China.

## Methods

### Study Participants

The data for this study were obtained from a population-based observational study conducted in Jinshan District, Shanghai, China.<sup>21</sup> This study included cross-sectional data from 3658 children and adolescents aged 7 to 18 years. Participants with a history of severe ocular and systemic diseases (such as glaucoma and cataracts), those who used low-concentration atropine eye drops or those who had undergone orthokeratology lens correction were excluded, as previously described. Measurements were collected after obtaining approval from the Medical Ethics Committee of Jinshan Hospital of Fudan University, China. This study was conducted in accordance with the tenets of the Declaration of Helsinki. Written informed consent of the parents or guardians was obtained from all the participants.

The data used in this study are publicly available through dryad, and the information is recorded in a manner that prevents direct or indirect identification of the subjects through relevant identifiers, as a result, this study has received an exemption from obtaining ethical approval from the medical ethics committee of the Ethics Review Board of The Third Affiliated Hospital of Jinzhou Medical University. Additionally, due to the utilization of existing data and the absence of personal privacy and commercial interests in the research project, written informed consent from the aforementioned ethics committee is also exempted as the subjects cannot be located.

### Examinations

Participants underwent a comprehensive ophthalmological examination, as well as height and weight measurements, as previously described.<sup>21</sup> The ophthalmological examination included the assessment of refractive error in both eyes using an automatic refractive instrument (RK-F1; Canon Corporation, Tokyo, Japan) without cycloplegia. Axial length was measured using an ocular Biometrics System (IOLMaster; Carl Zeiss Meditec, Oberkochen, Germany). The height and weight of all children were recorded in a standardized manner, without shoes or heavy clothing.

### Variables and Measurement

The spherical equivalent refraction (SER) was calculated by adding the sphere power and half-cylinder power. Myopia was defined as an SER of  $-0.50$  D or less, according to a study reported by the International Myopia Institute (IMI).<sup>22</sup> It has been widely accepted that an SER of  $\leq -0.50$  D is used as the definition of myopia in nearly 90% of epidemiological studies on myopia. In this study, the right eye was included in this study for evaluation because previous studies have shown a high correlation between refractive errors in the right and left eyes.<sup>23</sup>

According to the definition provided by the World Health Organization (WHO), BMI was calculated by dividing the body weight in kilograms by the square of the height in meters. This study adopted the BMI cutoff points according based on the Asia-Pacific classification provided by the World Health Organization. BMI was categorized into three groups: Q1 (less than  $25 \text{ kg/m}^2$ ), Q2 ( $25.0\text{--}29.9 \text{ kg/m}^2$ ), and Q3 ( $30.0 \text{ kg/m}^2$  or more).<sup>24</sup>

Each student completed a questionnaire with their parents to gather information about their lifestyles, including factors such as the amount of time spent outdoors and the duration of daily studying. Time spent outdoors was defined as the total time spent on leisure and sports activities in an outdoor setting. The average number of hours spent outdoors per day was calculated using the following formula:  $[(\text{hours spent on weekdays}) \times 5 + (\text{hours spent on weekend days}) \times 2] / 7$ .<sup>25</sup>

## Statistical Analysis

For the baseline data of the subjects, the measurement data in accordance with the normal distribution were described by the mean  $\pm$  standard deviation (SD), the measurement data that did not comply with the normal distribution were described by median (first quartile, third quartile), and the count data were described by n (%). Multivariate logistic regression analysis was performed to evaluate the association between BMI and myopia. Model 1 was adjusted for sex. Model 2 was adjusted sex, weekday study time, weekend study time, weekday outdoor time, and weekend outdoor time. The smooth curve fitting graph was established to evaluate the linearity between BMI and myopia. Considering the effect of extreme values, only the middle 95% of BMI data are shown.

All statistical analyses were conducted using the statistical package R version 4.1.0 (<http://www.R-project.org>, The R Foundation, Vienna, Austria) and the Free Statistics platform (version 1.8). Statistical significance was set at a two-sided P-value of  $<0.05$ .

## Results

### Baseline Characteristics of the Study Population

The baseline characteristics of the study population, consisting of 3658 enrolled participants (1841 boys and 1817 girls), were stratified by myopia category and presented in Table 1. The prevalence of myopia in this study was found to be 57.8% (N = 2116). Participants with myopia were observed to have a higher likelihood of being females, having a higher BMI, spending more time studying, and spending less time outdoors on weekends.

### Association Between BMI and Myopia

The association between BMI and myopia was examined using multiple logistic regression models, as shown in Table 2. BMI was correlated with myopia, with each 1 kg/m<sup>2</sup> increase in BMI associated with a 14% increase in the risk of myopia

**Table 1** Baseline Characteristics of the Participants

Characteristics	All participants	With Myopia		P-value
		Yes	No	
No.	3658	2116	1542	
Sex, n (%)				0.001
Female	1817 (49.7)	1102 (52.1)	715 (46.4)	
Male	1841 (50.3)	1014 (47.9)	827 (53.6)	
BMI (kg/m <sup>2</sup> ), Mean $\pm$ SD	19.8 $\pm$ 4.0	20.8 $\pm$ 4.1	18.5 $\pm$ 3.6	< 0.001
AL (mm), Mean $\pm$ SD	23.9 $\pm$ 1.3	24.5 $\pm$ 1.3	23.0 $\pm$ 0.8	< 0.001
SE (D), Mean $\pm$ SD	-1.6 $\pm$ 2.3	-3.0 $\pm$ 2.1	0.2 $\pm$ 0.6	< 0.001
Weekdays study time (hours), (IQR)	150.0 (110.0, 210.0)	180.0 (120.0, 240.0)	120.0 (90.0, 180.0)	< 0.001
Weekend study time (hours), (IQR)	180.0 (120.0, 280.0)	210.0 (120.0, 300.0)	150.0 (90.5, 237.5)	< 0.001
Weekdays outdoor time (hours), (IQR)	30.0 (20.0, 60.0)	35.0 (20.0, 60.0)	30.0 (20.0, 60.0)	< 0.001
Weekend outdoor time (hours), (IQR)	90.0 (60.0, 120.0)	60.0 (60.0, 120.0)	120.0 (60.0, 120.0)	< 0.001

**Abbreviations:** BMI, body mass index; AL, axial length; SE, spherical equivalent; D, diopters.

**Table 2** Association Between BMI and Myopia in Multivariate Logistic Regression

BMI	Total (n)	Event (%)	Crude OR (95% CI)	Adjusted OR (95% CI)	
				Model 1	Model 2
BMI, kg/m <sup>2</sup>	3658	2116 (57.8)	1.18 (1.16–1.20)	1.19 (1.16–1.21)	1.14 (1.12–1.17)
BMI group					
Q1	3269	1820 (55.7)	1 (Reference)	1 (Reference)	1 (Reference)
Q2	307	232 (75.6)	2.46 (1.88–3.22)	2.59 (1.97–3.39)	2.15 (1.62–2.86)
Q3	82	64 (78)	2.83 (1.67–4.8)	2.9 (1.74–5.01)	2.39 (1.37–4.18)

**Notes:** Model 1 was adjusted for sex. Model 2 was adjusted for sex, time spent studying on weekdays, time spent studying on weekends, time spent outdoors on weekdays, and time spent outdoors on weekends. BMI group: Q1 (less than 25 kg/m<sup>2</sup>); Q2: (25.0–29.9 kg/m<sup>2</sup>); Q3: (30.0 kg/m<sup>2</sup> or more).

**Abbreviations:** OR, odds ratio; CI, confidence interval; BMI, body mass index.

(OR = 1.14 [95% CI: 1.12,1.17]). In the non-adjusted model, compared with the reference group (Q1), Q2 group had a 146% increased risk of myopia (OR = 2.46 [95% CI: 1.88, 3.22]), while Q3 group had a 183% increased risk (OR = 2.83 [95% CI: 1.67, 4.80]). After adjusting for confounding factors listed in model 2 (gender, weekday study time, weekend study time, weekday outdoor time, and weekend outdoor time), the adjusted ORs for myopia in Q2 and Q3 group were 2.15 [95% CI: 1.62, 2.86] and 2.39 [95% CI: 1.37, 4.18], respectively, compared to Q1 (p < 0.001).

### Stratified Analyses Based on Baseline Variables

The results of subgroup analysis and interactions were summarized in Figure 1. Additive interaction between BMI and myopia was observed in gender (P-value for interaction < 0.05). However, significant interactions were not found in axial length, weekday study time, weekend study time, weekday outdoor time, and weekend outdoor time.

### An Inverse L-Shaped Association Between BMI and Myopia

The analysis using RCS regression revealed an inverse L-shaped curve (nonlinear, p = 0.011) in the association between BMI and myopia (as shown in Figure 2). In the threshold analysis, participants with a BMI < 25 kg/m<sup>2</sup> had an OR of

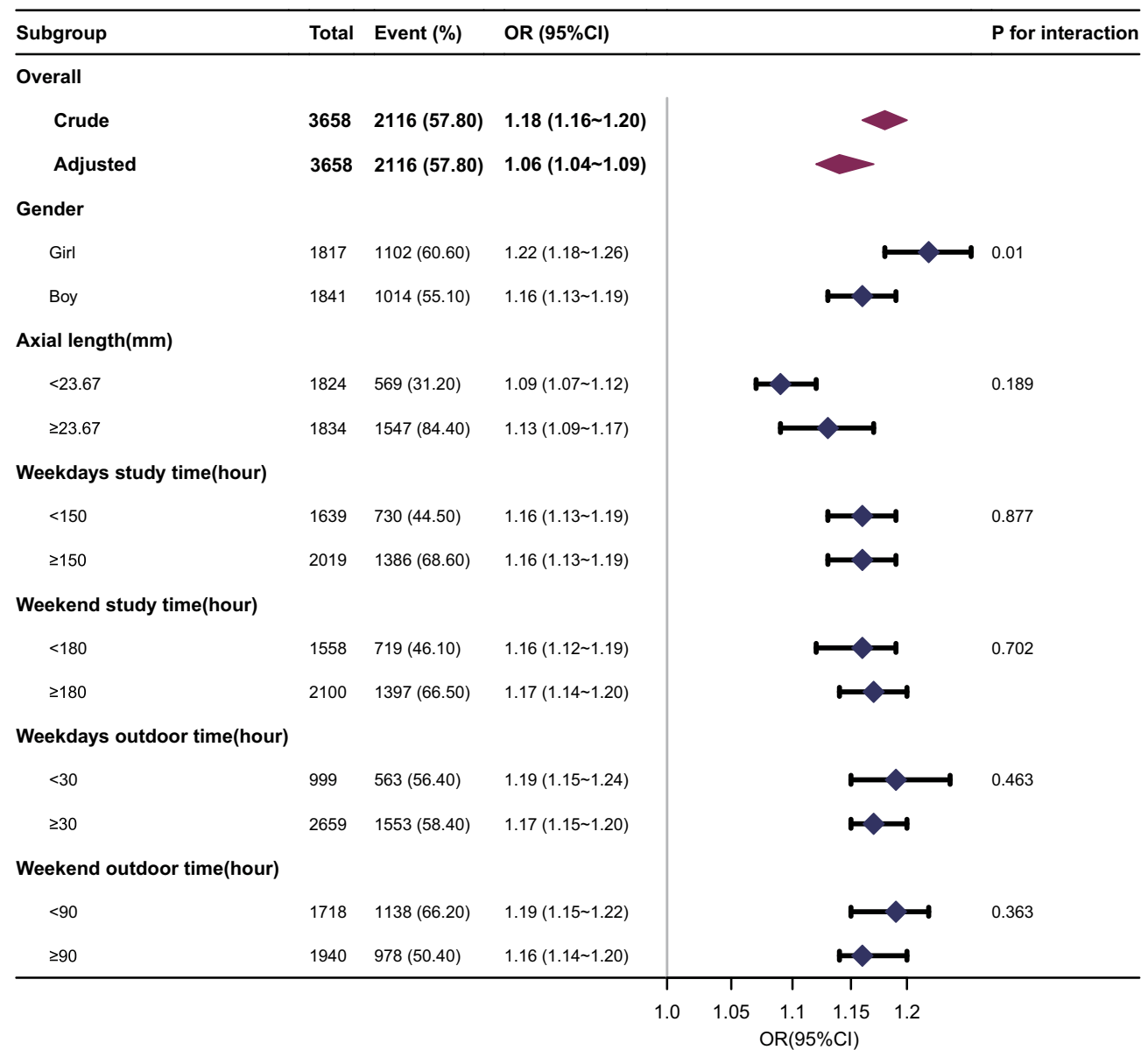
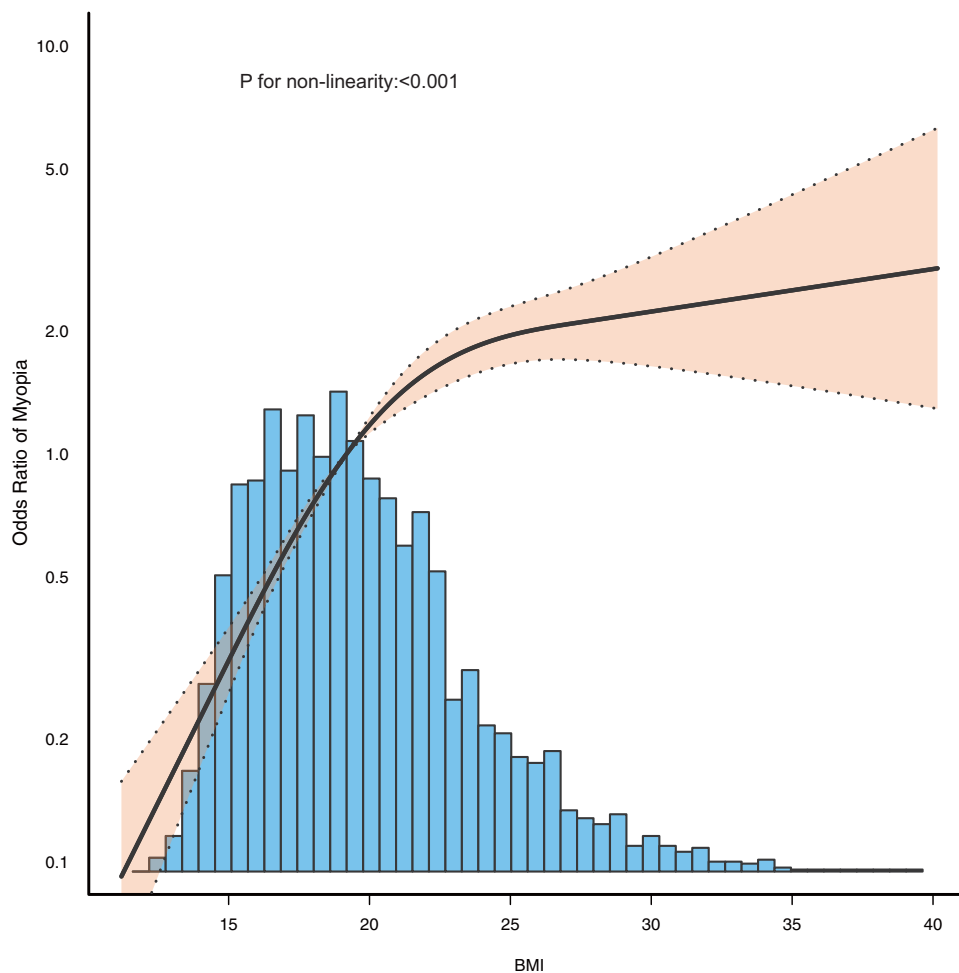


Figure 1 Association between BMI and myopia.



**Figure 2** Association between BMI and myopia odds ratio. Solid and dashed lines represent the predicted value and 95% confidence intervals. Only 99% of the data are shown.

myopia of 1.244 (95% CI: 1.211–1.277,  $p < 0.001$ ) (as shown in Table 3). This means that the risk of myopia increased by 24.4% for every 1  $\text{kg}/\text{m}^2$  increase in BMI. However, no significant association was found between BMI and myopia when the BMI was  $\geq 25 \text{ kg}/\text{m}^2$  (as shown in Table 3). This suggests that the risk of myopia does not significantly increase with increasing BMI once the BMI reaches  $\geq 25 \text{ kg}/\text{m}^2$ .

## Discussion

In this population-based cross-sectional study, BMI was positively associated with the risk of myopia (OR = 1.14 [95% CI: 1.12, 1.17]), especially among girls. There was a positive association between BMI and myopia up to  $25 \text{ kg}/\text{m}^2$ , while no significant correlation was observed between BMI and myopia when BMI is  $> 25 \text{ kg}/\text{m}^2$ .

**Table 3** Threshold Effect Analysis of the Relationship Between BMI and Myopia

Threshold of BMI, $\text{kg}/\text{m}^2$	OR	95% CI	P-value
<25	1.244	1.211–1.277	<0.001
$\geq 25$	1.063	0.964–1.171	0.219
Nonlinear test			0.004

**Abbreviations:** OR, odds ratio; CI, confidence interval; BMI, body mass index.

Previous studies conducted a school-based survey of 25,644 children aged 7 to 12 in Tianjin, China, revealing a negative correlation between BMI and spherical equivalent refraction (SER).<sup>26</sup> Similarly, another cross-sectional study of 482 children aged 6 to 15 in Tianjin showed that BMI did not show correlation with SER in a multiple linear regression model.<sup>27</sup> Univariate and multivariate logistic regression analysis methods were utilized in our study to investigate the direct relationship between BMI and myopia. We found a reverse L-shaped positive correlation between BMI and myopia. A recent study involving 8000 participants from the National Health and Nutrition Examination Survey (NHANES) in the United States from 1999 to 2008 found a linear relationship between myopia and BMI, with higher BMI being positively associated with myopia.<sup>10</sup> Another cross-sectional study conducted in Israel involving 1.3 million adolescents revealed a J-shaped relationship between body mass index and myopia, with the effect being more prominent in adolescent males than females.<sup>11</sup> In our study, we evaluated the association between BMI and myopia in the Chinese population, along with exploring the dose–response relationship, while conducting stratified analysis based on gender, axial length, weekday study time, weekend study time, weekday outdoor time, and weekend outdoor time. Overall, our conclusions were similar with those of the two previous studies; however, we observed that an increase in BMI among Chinese girls may be associated with a higher risk of myopia compared to boys. The reason for this difference may be attributed to variations in the study population selection.

The relationship between myopia and BMI exhibits a unique inverted L-shaped pattern, as shown in [Figure 2](#). This relationship suggests that myopia may cease to progress once body weight reaches a certain level of obesity. This finding may be related to the increase in retrobulbar fat, as reported by Gunes,<sup>28</sup> which in obese individuals may be constrained by the limited orbital space, potentially slowing down the growth of the axial growth and eye expansion. However, the underlying mechanisms of the relationship between BMI and myopia are not fully understood. Furthermore, subgroup analysis further revealed a significant gender-specific association between BMI and myopia, as shown in [Figure 1](#). In the female population, the relationship between BMI and myopia is more pronounced, indicating that gender factors may need to be considered when assessing and managing myopia risk. Nonetheless, from a broader perspective, regardless of gender, maintaining a healthy weight is an important strategy to reduce overall health risks and alleviate myopia risk.

There are some limitations to this study. First, the data utilized in this study were obtained from a study in 2018,<sup>21</sup> which lacked detailed inclusion and exclusion criteria. Therefore, the reliability of the data may be affected by selection bias. Second, the authors did not disclose age data, which are relevant to BMI and particularly crucial for children and adolescents who are still in the process of growth and development. Third, non-cycloplegic refraction was employed in this study to measure myopia, which may have led to an overestimate of its prevalence. Fourth, too few adjusted variables have been discussed in multivariate analysis, and more covariates such as exercise, diet, and lifestyle should be added. To address these limitations, a further study is planned to be conducted that comprehensively investigates the correlation between BMI and myopia.

## Conclusion

Our study indicates an inverse L-shaped association between BMI and myopia. These findings underscore the significance of monitoring BMI and promoting healthy lifestyles in the prevention of myopia. Further research is necessary to investigate the underlying mechanisms and formulate effective strategies for the prevention and control strategies of myopia.

## Data Sharing Statement

Publicly available datasets were used in this study. These can be found in [DRYAD] at <http://doi.org/10.5061/dryad.c2fqz615c>, reference number [20].

## Ethics Approval and Informed Consent

Study approval statement: This study has been granted an exemption from requiring ethics approval by the Ethics Review Board of The Third Affiliated Hospital of Jinzhou Medical University.

Consent to Participate Statement: This study has been granted an exemption from requiring written informed consent by the Ethics Review Board of The Third Affiliated Hospital of Jinzhou Medical University.

## Acknowledgment

We thank the authors of the article from which our data are cited. We thank those responsible for planning and managing this population-based study and providing the data set.

## Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

## Funding

This data research was funded by the Youth Innovation Promotion Association of the Chinese Academy of Sciences (Y202072).

## Disclosure

The authors have no conflicts of interest to declare in this work.

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