High Myopia Risk Prediction Model for Primary and Secondary School Students: A Nested Case-Control Study (Epub ahead of print)

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Abstract

Background Due to academic pressure, widespread use of electronic devices, and poor eye care habits, primary and secondary school students are increasingly experiencing serious vision health problems, becoming a high-risk group for myopia. High myopia, as a severe stage of myopia, has become a global public health issue. Although numerous studies have explored risk factors for myopia, few have specifically elucidated the complex nonlinear relationships between risk factors and the development of high myopia. This study combines a nested case-control study and restricted cubic splines to develop a risk prediction model for high myopia among primary and secondary school students. By identifying high-risk individuals early, this model can delay or prevent the progression of high myopia, achieving tertiary prevention of myopia, which has positive implications for students' academic performance and quality of life.

Objective To investigate the prevalence and risk factors of high myopia among primary and secondary school students, construct a risk prediction model, and provide a scientific basis for the prevention and control of high myopia in this population.

Methods A nested case-control study was conducted. In 2023, students with moderate myopia from 12 schools in Hangzhou were selected as study subjects to establish a cohort. According to the National Student Common Diseases and Health Influencing Factors Monitoring and Intervention Work Plan, myopia status monitoring was conducted among the included primary and secondary school students. Students who progressed to high myopia during the study period were designated as the high myopia incidence group, while those who did not progress to high myopia served as the control group. Vision care behaviors were investigated in both groups. Lasso regression was used to screen characteristic variables, followed by multivariate Logistic regression analysis to identify influencing factors for high myopia development among primary and secondary school students. A nomogram was used to visualize the risk prediction model. Model performance was evaluated using the Hosmer-Lemeshow test, receiver operating characteristic (ROC) curve, calibration curve, and decision curve analysis (DCA). Finally, restricted cubic splines were used to further clarify the relationship between age and high myopia risk.

Results A total of 2,468 students from 12 primary and secondary schools were included, comprising 1,293 students who did not progress to high myopia and 1,175 students whose moderate myopia progressed to high myopia, yielding a high myopia incidence rate of 47.61% (1,175/2,468). Statistically significant differences were observed between the two groups in age, grade, BMI, daily bedtime, region, outdoor activity time, electronic device usage time, after-school homework time, and desk lamp use ($P<0.05$). Lasso regression identified eight characteristic variables: grade, BMI, daily bedtime, region, outdoor activity time, electronic device usage time, after-school homework time, and desk lamp use. Multivariate Logistic regression analysis revealed that junior high school grade (OR=2.612, 95%CI=2.185~3.127), BMI indicating overweight or obesity (OR=2.140, 95%CI=1.458~3.169) or underweight (OR=1.807, 95%CI=1.430~2.290), daily bedtime after 22:00 (OR=1.408, 95%CI=1.188~1.670), outdoor activity time of 1~2 h/d (OR=1.371, 95%CI=1.122~1.675) or <1 h/d (OR=1.648, 95%CI=1.342~2.027), electronic device usage time >2 h/d (OR=1.440, 95%CI=1.119~1.856), and after-school homework time of 1~2 h/d (OR=1.461, 95%CI=1.126~1.899) or >2 h/d (OR=1.534, 95%CI=1.218~1.935) were risk factors for high myopia development among primary and secondary school students ($P<0.05$). Senior high school grade (OR=0.560, 95%CI=0.419~0.743) was a protective factor ($P<0.05$). The prediction model constructed based on six variables—grade, BMI, daily bedtime, outdoor activity time, electronic device usage time, and after-school homework time—achieved an AUC of 0.840 (95%CI=0.825~0.855), demonstrating good goodness-of-fit, consistency, and applicability. Restricted cubic spline analysis indicated that ages 13~15 represent the high-incidence period for high myopia.

Conclusion The incidence of high myopia among primary and secondary school students is relatively high. The risk prediction model provides a scientific basis for the prevention and control of high myopia. Additionally, strengthening myopia prevention and control measures in junior high school grades, improving students' vision care behaviors, and reducing the incidence of high myopia are recommended.

Full Text

Risk Prediction Model for High Myopia in Primary and Secondary School Students: Based on a Nested Case-Control Study

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Abstract

Background: The vision health of primary and secondary school students has become an increasing concern due to mounting academic pressure, widespread use of electronic devices, and poor eye care habits. As an advanced stage of myopia, high myopia has emerged as a global public health issue. While numerous studies have explored risk factors for myopia, few have specifically examined the complex non-linear relationships between these factors and high myopia development. This study combines a nested case-control design with restricted cubic splines to develop a risk prediction model for high myopia in primary and secondary school students. By enabling early identification of high-risk individuals, this model aims to delay or prevent high myopia progression, contributing to tertiary myopia prevention and positively impacting students' academic performance and quality of life.

Objective: To investigate the prevalence and risk factors of high myopia among primary and secondary school students and to construct a risk prediction model to provide a scientific basis for prevention and control efforts.

Methods: We conducted a nested case-control study in 2023, establishing a cohort of students with moderate myopia from 12 schools in Hangzhou. Following the National Monitoring and Intervention Program for Common Diseases and Health-Related Factors in Students, we monitored myopia status over a one-year period. Students who progressed to high myopia were classified as the case group, while those who did not progress formed the control group. Vision care behaviors were surveyed in both groups. Lasso regression was used for feature selection, followed by multivariate logistic regression to identify factors influencing high myopia development. A nomogram was employed to visualize the risk prediction model. Model performance was evaluated using the Hosmer-Lemeshow test, receiver operating characteristic (ROC) curve, calibration curve, and decision curve analysis (DCA). Restricted cubic splines were further used to clarify the relationship between age and high myopia risk.

Results: A total of 2,468 students from 12 primary and secondary schools were enrolled, including 1,293 who did not progress to high myopia and 1,175 who progressed from moderate to high myopia, yielding an incidence rate of 47.61% (1,175/2,468). Significant differences between groups were observed in age, grade level, BMI, daily sleep time, geographic region, outdoor activity time, electronic device usage time, after-school homework time, and household lamp usage ($P<0.05$). Lasso regression identified eight feature variables: grade level, BMI, daily sleep time, geographic region, outdoor activity time, electronic device usage time, after-school homework time, and household lamp usage. Multivariate logistic regression revealed that middle school grade (OR=2.612, 95%CI=2.185–3.127), overweight or obese BMI (OR=2.140, 95%CI=1.458–3.169), underweight BMI (OR=1.807, 95%CI=1.430–2.290), sleeping after 22:00 daily (OR=1.408, 95%CI=1.188–1.670), outdoor activity time of 1–2 h/d (OR=1.371, 95%CI=1.122–1.675) or <1 h/d (OR=1.648, 95%CI=1.342–2.027), electronic device usage >2 h/d (OR=1.440, 95%CI=1.119–1.856), and after-school homework time of 1–2 h/d (OR=1.461, 95%CI=1.126–1.899) or >2 h/d (OR=1.534, 95%CI=1.218–1.935) were risk factors for high myopia ($P<0.05$). In contrast, high school grade was a protective factor (OR=0.560, 95%CI=0.419–0.743, $P<0.05$). The prediction model based on six variables (grade, BMI, daily sleep time, outdoor activity time, electronic device usage time, and after-school homework time) achieved an area under the curve (AUC) of 0.840 (95%CI=0.825–0.855), demonstrating good fit, consistency, and applicability. Restricted cubic spline analysis indicated that ages 13–15 years represent the high-risk period for high myopia development.

Conclusion: The incidence of high myopia among primary and secondary school students was notably high. The risk prediction model provides a scientific basis for high myopia prevention and control, emphasizing the need to strengthen myopia prevention measures in middle school and improve students' vision care behaviors to reduce high myopia occurrence.

Keywords: Myopia; Student; High myopia; Nested case-control study; Restricted cubic spline; Prediction model

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Introduction

Myopia is a refractive error in which parallel rays of light entering the eye are focused in front of the retina rather than on it, resulting in blurred vision under relaxed accommodation. Its etiology is complex, involving interactions between genetic and environmental factors, and its progression mechanisms remain incompletely understood. In recent years, despite various governmental measures to prevent and control myopia in China, the incidence of myopia among primary and secondary school students continues to rise, with the overall prevalence among Chinese children and adolescents exceeding 50% in 2020, making it a significant public health concern. Myopia, particularly high myopia, not only severely impacts students' learning and quality of life but can also lead to irreversible vision complications such as retinal detachment, macular degeneration, and glaucoma. This study aims to investigate the risk factors for high myopia development among primary and secondary school students, construct a risk prediction model, and provide a theoretical basis for scientific myopia prevention strategies to achieve tertiary prevention.

Methods

1.1 Study Subjects We employed multi-stage stratified cluster sampling to select 2,468 students with moderate myopia from 12 schools in Hangzhou (4 primary schools, 4 middle schools, and 4 high schools). Inclusion criteria were: (1) moderate myopia, (2) adequate reading comprehension, (3) good compliance, and (4) informed consent. Exclusion criteria included: normal vision or mild myopia, high myopia, hyperopia, history of eye surgery, congenital eye disease, or other serious ocular conditions (such as nystagmus, glaucoma, cataract, photosensitivity, or retinal detachment). This study was approved by the Ethics Committee of the First Affiliated Hospital, Zhejiang University School of Medicine (Approval No. 2023 Research No. 0988).

1.2 Study Design We conducted a nested case-control study in 2023, establishing a cohort of students with moderate myopia from 12 Hangzhou schools. Following the National Monitoring and Intervention Program for Common Diseases and Health-Related Factors in Students, we monitored myopia status over a one-year period. Students who progressed to high myopia during the study period were designated as the case group, while those who did not progress served as the control group. Both groups completed a survey on vision care behaviors to analyze risk factors and high-incidence stages for high myopia development and to evaluate the prediction model.

1.3 Measurements **1.3.1 Vision and Refraction Examination:** Trained ophthalmology professionals conducted examinations following GB/T 11533-2011 standards using a 5-meter standard logarithmic visual acuity chart to assess uncorrected and corrected visual acuity in both eyes, with results recorded using the 5-point scale. Non-cycloplegic autorefraction was performed using a NIDEK ARK-1 autorefractor, recording sphere, cylinder, and axis values. Three measurements were taken for each eye and averaged.

1.3.2 Myopia Definition: Myopia was defined as uncorrected visual acuity <5.0 and spherical equivalent (SE) $<$ -0.50 D in either eye under non-cycloplegic conditions, where SE = sphere + (cylinder/2). Myopia was classified as mild (-3.00 D to -0.50 D), moderate (-6.00 D to -3.00 D), or high (SE $\leq$ -6.00 D).

1.3.3 BMI Classification: Since school-age children and adolescents are in a period of growth and development with BMI values changing with age, we used the WHO standard deviation method to evaluate BMI. Categories were defined as underweight (BMI < 18.5 kg/m^2), normal (18.5–24.0 kg/m^2), and overweight or obese (BMI $\geq$ 24 kg/m^2).

1.4 Statistical Analysis All analyses were performed using R version 4.4.0. Continuous variables were described as mean $\pm$ standard deviation ($\bar{x}\pm s$) and compared using t-tests. Categorical variables were expressed as percentages and compared using ^{2} tests. Variables showing significant differences in univariate analysis were subjected to Lasso regression for dimensionality reduction and feature selection. Subsequent multivariate logistic regression analysis identified factors influencing high myopia development. A nomogram visualized the risk prediction model. Model performance was assessed using the Hosmer-Lemeshow test, ROC curve, calibration curve, and DCA. Restricted cubic splines further elucidated the relationship between age and high myopia risk. The significance level was set at α=0.05, with P<0.05 considered statistically significant.

Results

2.1 General Characteristics Among the 2,468 enrolled students, 975 (39.51%) were male and 1,493 (60.49%) were female, with a mean age of 12.8$±$2.8 years. The cohort included 989 primary school students (40.07%), 1,160 middle school students (47.00%), and 319 high school students (12.93%). A total of 1,293 students did not progress to high myopia, while 1,175 students with moderate myopia progressed to high myopia, resulting in an incidence rate of 47.61% (1,175/2,468). No significant differences were observed between groups in gender, parental myopia history, classroom lighting, or eye exercise frequency (P>0.05). However, significant differences were found in age, grade level, BMI, daily sleep time, geographic region, outdoor activity time, electronic device usage time, after-school homework time, and household lamp usage (P<0.05) .

2.2 Feature Selection and Multivariate Analysis To address potential multicollinearity, variables showing significant differences in univariate analysis were entered into Lasso regression for feature selection. Ten-fold cross-validation identified the optimal λ value (λ_1 =0.012561) [Figure 1: see original paper], resulting in eight selected features: grade level, BMI, daily sleep time, geographic region, outdoor activity time, electronic device usage time, after-school homework time, and household lamp usage .

Multivariate logistic regression analysis, with high myopia occurrence as the dependent variable and the eight features as independent variables, revealed that middle school grade (OR=2.612, 95%CI=2.185–3.127), overweight or obese BMI (OR=2.140, 95%CI=1.458–3.169), underweight BMI (OR=1.807, 95%CI=1.430–2.290), sleeping after 22:00 (OR=1.408, 95%CI=1.188–1.670), outdoor activity time of 1–2 h/d (OR=1.371, 95%CI=1.122–1.675) or <1 h/d (OR=1.648, 95%CI=1.342–2.027), electronic device usage >2 h/d (OR=1.440, 95%CI=1.119–1.856), and after-school homework time of 1–2 h/d (OR=1.461, 95%CI=1.126–1.899) or >2 h/d (OR=1.534, 95%CI=1.218–1.935) were risk factors for high myopia ($P<0.05$). In contrast, high school grade was a protective factor (OR=0.560, 95%CI=0.419–0.743, $P<0.05$) .

2.3 Model Development and Evaluation Based on the Akaike Information Criterion (AIC), the final prediction model included six variables: grade level, BMI, daily sleep time, outdoor activity time, electronic device usage time, and after-school homework time. A nomogram was constructed to visualize the model, allowing probability estimation of high myopia risk by summing individual variable points [Figure 2: see original paper].

Model evaluation demonstrated strong performance: the Hosmer-Lemeshow test yielded P=0.419, indicating good fit; the ROC curve showed an area under the curve (AUC) of 0.840 (95%CI=0.825–0.855), confirming good discriminative accuracy [Figure 3: see original paper]; the calibration curve showed close alignment between predicted and observed probabilities, indicating excellent agreement [Figure 4: see original paper]; and DCA demonstrated that the model provided positive net benefit across a wide range of threshold probabilities, confirming good clinical utility [Figure 5: see original paper].

2.4 Restricted Cubic Spline Analysis Given the potential non-linear relationship between age and high myopia risk, restricted cubic spline analysis with four knots was performed [Figure 6: see original paper]. The results revealed a significant non-linear association ($P_{nonlinear}<0.001$) characterized by an inverted U-shaped curve, with ages 13–15 years identified as the high-risk period for high myopia development—corresponding predominantly to middle school grades.

Discussion

With increasing educational burden and the development of unhealthy behavioral habits, myopia among primary and secondary school students has become a progressively serious global public health problem. The prevalence of myopia in China continues to rise, with studies reporting that over 50% of Chinese school-age children are myopic, and projections estimate nearly 200 million myopic students by 2030. High myopia not only affects quality of life but is also associated with various ocular complications, including glaucoma and cataract, which can cause severe vision loss or even blindness. Identifying and intervening on risk factors for myopia, particularly high myopia, is therefore critically important.

During our follow-up period, we observed that nearly 50% of students with moderate myopia progressed to high myopia, suggesting that current myopia control measures may be insufficient to effectively slow progression. Our results identified middle school grade, abnormal BMI (both overweight/obese and underweight), sleeping after 22:00, insufficient outdoor activity (<2 h/d), excessive electronic device use (>2 h/d), and prolonged homework time (>1 h/d) as significant risk factors for high myopia, while high school grade was unexpectedly identified as a protective factor.

The association between BMI and high myopia is notable. Both underweight and overweight/obese students showed increased risk of myopia progression. Higher BMI may correlate with increased saturated fatty acid intake, which elevates free insulin-like growth factor binding protein levels, potentially promoting scleral fiber elongation and axial length increase. Underweight may relate to nutritional deficiencies affecting ocular development. Late sleep and insufficient outdoor activity were also associated with increased high myopia risk, consistent with previous research on sleep deprivation and the protective effects of outdoor time. Potential mechanisms include retinal dopamine secretion and vitamin D utilization stimulated by outdoor light, which inhibit axial elongation, while adequate sleep alleviates eye fatigue and restores ciliary muscle function. Prolonged electronic device use and homework time increase visual burden from sustained near work, with inadequate rest breaks and poor posture potentially exacerbating myopia progression.

Our risk prediction model demonstrated excellent predictive performance and practical applicability, providing a scientific basis for targeted interventions. The restricted cubic spline analysis revealed that the high-risk period for high myopia occurs at ages 13–15 years (middle school), contrary to previous studies suggesting high school as the peak period. This finding provides a critical time window for targeted interventions and underscores the importance of strengthening myopia prevention measures during middle school.

This study has several limitations. First, the sample was limited to Hangzhou, which may restrict generalizability to other regions; external validation with broader populations is needed. Second, the observation period was relatively short; future longitudinal studies with longer follow-up and inclusion of more environmental and genetic factors are needed to improve model generalizability and accuracy.

Conclusion

Middle school grade, overweight or obese BMI, underweight BMI, sleeping after 22:00, outdoor activity time of 1–2 h/d or <1 h/d, electronic device usage >2 h/d, and after-school homework time of 1–2 h/d or >2 h/d are risk factors for high myopia among primary and secondary school students, while high school grade is a protective factor. Through a nested case-control design and restricted cubic spline analysis, this study identified key risk factors for high myopia and constructed a prediction model with excellent performance. This model can be integrated into school health monitoring systems for early risk assessment of students with moderate myopia, enabling timely intervention by schools and parents. It can also be applied in ophthalmology clinics to provide personalized prevention recommendations based on students' lifestyle and vision health status, allowing clinicians to develop more precise interventions for high-risk individuals to delay or prevent high myopia progression. The study emphasizes the importance of vision care interventions targeting middle school students and provides robust scientific evidence and strategic support for myopia prevention and control in primary and secondary schools.

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Author Contributions: CHEN Shenglan was responsible for data curation and initial draft writing. ZHENG Yongtao and HU Wangcheng handled data integration and analysis, created figures and tables, and participated in content and format revision. NI Zuowei, XIA Bing, and YE Chunmei conducted field epidemiological investigations and collected and entered raw data. DU Chixin validated the paper's structure and logic. CHEN Xiaodan conceptualized the study, provided research resources and funding support, finalized the content, and took responsibility for the paper.

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Tables and Figures

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[Figure 6: see original paper] Restricted cubic spline curve fitting of student age and the occurrence of high myopia

Note: Figure translations are in progress. See original paper for figures.