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Relative fat mass and myopia in adolescents: a cross-sectional study using NHANES data

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Original Article

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Abstract

Adolescence is a peak period for myopia onset, which is closely related to environmental and lifestyle factors. Relative fat mass (RFM), a novel indicator of body fat, provides a more precise measure of adiposity. However, its relationship with myopia in adolescents remains poorly understood. To probe the connection between RFM and myopia in adolescents, this study included 8746 adolescents aged 12–19 years, utilizing data from the National Health and Nutrition Examination Survey (1999–2008). Myopia was defined as a spherical equivalent (SE) ≤ -1.0 D. The relationship between RFM and adolescent myopia was assessed using a weighted logistic regression model. Restricted cubic spline analysis was employed to examine the nonlinear relationship between RFM and the odds of myopia. Subgroup analysis and interaction tests were also conducted. Sensitivity analyses were performed using broader myopia diagnostic criteria (SE ≤ -0.75 D and SE ≤ -0.50 D). After adjusting for all confounding factors, the odds of myopia in the third and highest quartiles of RFM were 33% higher (odds ratio (OR) = 1.33, 95% CI: 1.07–1.64) and 35% higher (OR = 1.35, 95% CI: 1.01–1.80), respectively, compared to the lowest quartile. Each one-standard-deviation (9.06) increase in RFM was associated with a 12% higher odds of myopia in adolescents (OR = 1.12, 95% CI: 1.01–1.25). This association was more pronounced in males (OR = 1.25, 95% CI: 1.09–1.43). A significant positive association was also observed in the low-income population (OR = 1.27, 95% CI: 1.08–1.49). Sensitivity analysis showed that when using SE ≤ -0.75 D and SE ≤ -0.50 D as the diagnostic criteria for myopia, RFM remained significantly positively associated with the odds of adolescent myopia, indicating the robustness of the results. Increased RFM was significantly associated with higher odds of myopia in adolescents, with a stronger association observed among males, suggesting that body fat control and RFM reduction may represent a promising direction for comprehensive myopia prevention and management in adolescents. Targeted interventions integrating weight management, healthy diet, regular physical activity, and accessible eye health services could be developed, particularly for male and low-income adolescents. However, longitudinal studies are needed for further validation.

Introduction

Myopia is a major eye condition with a high prevalence worldwide, manifesting as an elongated eye axis that causes light to focus in front of the retina, resulting in blurred distance vision.[1] Global prevalence of myopia is rising, with projections indicating that by 2050, around 49.8% of the world's population, or approximately 4.758 billion people, will be affected.[2] Adolescents have a greater risk of myopia than younger children.[3,4] Myopia, which progresses over time, heightens the risk of ocular complications such as myopic macular degeneration, retinal detachment, cataracts, and open-angle glaucoma.[5] As such, the prevalence of myopia in adolescents is now a significant public health issue of global concern.

Myopia develops because of genetic predisposition and environmental influences. Although genetic susceptibility is important, evidence suggests that lifestyle choices, such as prolonged near work and insufficient outdoor activity, are equally critical in driving myopia progression.[6,7] The connection between body metrics and myopia has gained attention in recent research, with some studies indicating that higher body mass index (BMI) may be indicative of a higher risk of myopia.[8] However, BMI does not account for differences in body fat distribution.[9] Our study introduces relative fat mass (RFM), a metric that incorporates waist circumference and height to more accurately assess body fat. As reported, in South Korea, myopia in young adults aged 19–39 has been correlated with higher body fat percentages (BFP), and those with central and general obesity appear to be at an elevated risk of developing myopia.[10] However, the impact of RFM on myopia in adolescents remains unclear and requires additional research.

Utilizing data from the National Health and Nutrition Examination Survey (NHANES), this study examined the link between RFM and myopia in adolescents. The analysis of large-scale population data aimed to uncover metabolic factors that could contribute to myopia, offering insights for its prevention and control.

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Methods

Study population

Data were sourced from NHANES (https://www.cdc.gov/nchs/nhanes/index.html), a large-scale survey coordinated by the Centers for Disease Control and Prevention and the National Center for Health Statistics. NHANES employed a stratified, multi-stage sampling scheme to evaluate the health and nutrition of the U.S. population. We focused on adolescents aged 12–19 years (n = 10,731) from the 1999–2008 survey cycles. After excluding cases with incomplete data on myopia status (n = 833), RFM (n = 207), and other relevant covariates (n = 945), a final sample of 8746 adolescents was included in the analysis (Fig. 1).

Deriving RFM values

RFM was calculated using height and waist circumference. Given age- and gender-related differences in body composition, fat distribution, and height-to-waist ratios across developmental stages in adolescents, this study adopted age- and gender-specific RFM formulas based on previous adolescent studies to minimize estimation bias that might arise from applying a single adult formula to this population.[11,12] For adolescents aged 15–19 years, the formula for females was RFM = 76−(20 × [height/waist circumference]) and for males it was RFM = 64−(20 × [height/waist circumference]). For those aged 12–14 years, the formula for females was RFM = 79−(22 × [height/waist circumference]) and for males was RFM = 74−(22 × [height/waist circumference]). These age- and gender-specific formulas have been applied in prior adolescent studies and are considered more appropriate than adult formulas for capturing pubertal differences in body composition; however, they have not been directly validated against gold-standard measures such as DXA in the present sample, and the results should therefore be interpreted with caution.

Myopia screening

NHANES conducted refractive exams on participants aged 12 years and older using the Nidek ARK-760 autorefractor. Each eye was measured three times consecutively, and the median values of spherical power, cylindrical power, and axis were recorded. The spherical equivalent (SE) was calculated as the spherical power plus half of the cylindrical power. Myopia was defined as SE ≤ −1.0 D.[13] Specifically, myopia was classified as mild (−3.00 D < SE ≤ −1.00 D), moderate (−6.00 D < SE ≤ −3.00 D), or high (SE ≤ −6.00 D).[14] Since cycloplegia was not used in the NHANES refractive measurements, broader criteria (SE ≤ −0.75 D and SE ≤ −0.50 D) were also applied in sensitivity analyses to identify more myopic individuals and validate the robustness of the results.

Covariates

The covariates in this study included age, gender, race, poverty-income ratio (PIR), vitamin A intake, vitamin E intake, total energy intake, physical activity, outdoor activity, and screen usage time. Participants were categorized into low-age (12–14 years) and high-age (15–19 years) groups based on their age. According to the PIR, participants were classified into three groups: low income (≤1.3), middle income (1.3–3.5), and high income (>3.5).[15] Vitamin A, vitamin E, and total energy intake were assessed via 24-hour dietary recall interviews. Data on physical activity and outdoor activity were collected using the Global Physical Activity Questionnaire. Physical activity (in MET-min/week) was calculated as follows: Frequency of activity per week × Duration per session × MET value of the activity. NHANES provides recommended MET values for each type of physical activity. According to the World Health Organization, adolescents are recommended to engage in more than 60 minutes of moderate-to-vigorous physical activity per day (equivalent to 240 MET-min/day),[16] which translates to 1680 MET-min per week. Activities were recorded as either outdoor or non-outdoor (including indoor activities and sedentary behavior). Outdoor activities included aerobic exercise, baseball, basketball, dance, cycling, and similar pursuits. Screen usage time was defined as the time spent watching television or using a computer. Screen usage time exceeding 2 hours per day was classified as excessive screen use.[17]

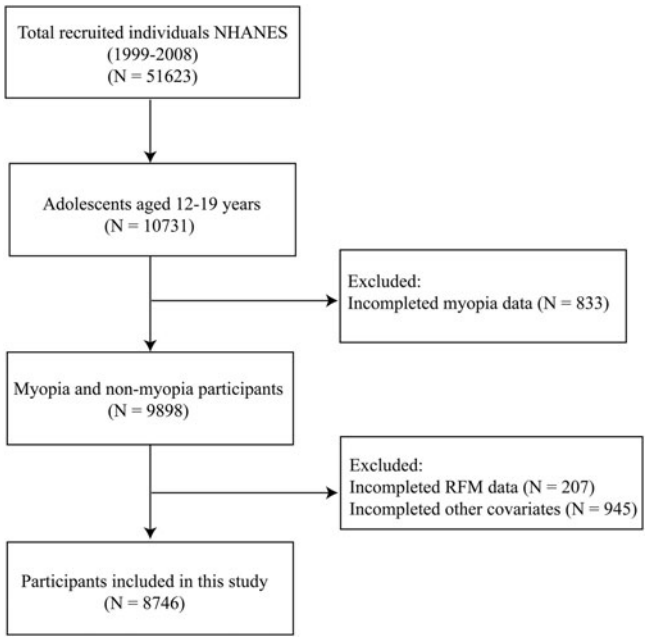


Figure 1. Flowchart showing the selection of the studied population.

Statistical analysis

Statistical analyses were performed using R (v4.4.2). Baseline data were organized with the *gtsummary* package, grouped by whether participants had myopia. The weights used in this study were the MEC weights (WTMEC2YR/5). Categorical variables were reported as weighted counts and proportions, and continuous variables were expressed as weighted means ± standard deviations. Weighted logistic regression models were constructed with the *survey* package to assess the relationship between RFM and myopia. Model I was adjusted for basic demographics (age, gender, and race). In Model II, PIR, vitamin A intake, vitamin E intake, energy intake, sufficient physical activity, outdoor activity, and screen usage time were further adjusted. In the fully adjusted model, restricted cubic spline (RCS) analysis (*rms* package) was used to examine the nonlinear relationship between RFM and adolescent myopia, with three knots at the 10th, 50th, and 90th percentiles of RFM, to balance flexibility and reproducibility. Stratified multivariate logistic regression was conducted for subgroup analysis, with stratification factors including age group, gender, race, and PIR. Interaction analyses were performed, and multiple testing correction was applied using the Benjamini–Hochberg method. Finally, sensitivity analyses were carried out

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using two alternative diagnostic criteria for myopia (SE ≤ −0.75 D and SE ≤ −0.50 D) in the fully adjusted weighted logistic regression model. This study described the distribution of myopia severity (mild, moderate, high). Given the limited sample size, particularly for high myopia, these results are presented as descriptive and exploratory information and are not the main basis for inference. To compare the strength of association between RFM and BMI as obesity indicators, both metrics were standardized, and ORs with 95% CIs per 1-SD increase were calculated in the fully adjusted model. A two-sided $P < 0.05$ was considered statistically significant.

Results

Baseline characteristics

Table 1 summarizes baseline characteristics of 8746 participants, including 2819 myopic individuals (1805 with mild myopia, 807 with moderate myopia, and 207 with high myopia), with an average age of 15.37 ± 2.24 years and a myopia prevalence of 32.5%. Participants were grouped based on the presence or absence of myopia. The results showed that, compared to non-myopic adolescents, those with myopia tended to be older (proportion in the high-age group: 63.1% vs. 59.4%, $P = 0.036$), were more likely to lack sufficient physical activity (51.8% vs. 46.8%, $P = 0.003$), and had larger waist circumference (82.51 vs. 80.62, $P = 0.003$) and higher RFM values (29.44 vs. 28.55, $P = 0.011$). Additionally, although the between-group difference in total continuous physical activity (MET-min/week) was not statistically significant, the proportion of sufficient physical activity (based on the recommended threshold) differed significantly.

Association of RFM with adolescent myopia

A weighted logistic regression model was employed to investigate the association between RFM and adolescent myopia (SE ≤ −1.0 D). The results demonstrated a positive correlation between RFM and adolescent myopia across all three models. In the fully adjusted model, each one-standard-deviation (9.06) increase in RFM was associated with a 12% higher odds of myopia (OR = 1.12, 95% CI: 1.01–1.25, $P = 0.037$). Compared to the lowest quartile group, the third and highest quartile groups showed a significantly increased odds of myopia by 33% (OR = 1.33, 95% CI: 1.07–1.64, $P = 0.010$) and 35% (OR = 1.35, 95% CI: 1.01–1.80, $P = 0.041$), respectively (Table 2).

Subsequently, an RCS model was used to further explore the nonlinear relationship between RFM and adolescent myopia. As RFM increased, the odds of myopia showed a significant upward trend (P for overall association = 0.004), but no significant nonlinear relationship was observed (P for nonlinearity = 0.406) (Fig. 2).

Subgroup analysis

Table 3 shows the relationship between RFM and the odds of myopia across different subgroups. After adjusting for all confounding factors, the results showed that RFM was significantly positively associated with the odds of myopia in males (OR = 1.25, 95% CI: 1.09–1.43, $P = 0.002$), Mexican Americans (OR = 1.28, 95% CI: 1.13–1.45, $P = 0.003$), and low-income populations (OR = 1.27, 95% CI: 1.08–1.49, $P = 0.005$). Furthermore, interaction analysis indicated that gender had a significant interactive effect on the association between RFM and the odds of myopia (P for interaction = 0.001).

Sensitivity analysis

We conducted sensitivity analyses using myopia diagnostic criteria of SE ≤ −0.50 D and SE ≤ −0.75 D. After adjusting for all confounding factors, when SE ≤ −0.50 D was used as the diagnostic criterion, the highest quartile of RFM was associated with a 42% higher odds of myopia compared to the lowest quartile (OR = 1.42, 95% CI: 1.12–1.81, $P = 0.005$). When SE ≤ −0.75 D was used as the diagnostic criterion, the third and highest quartiles showed 1.29-fold (95% CI: 1.07–1.57, $P = 0.010$) and 1.37-fold (95% CI: 1.07–1.76, $P = 0.014$) higher odds of myopia, respectively, compared to the lowest quartile (Table 4). Each one-standard-deviation (9.06) increase in RFM was consistently associated with significantly elevated odds of myopia under both diagnostic criteria. These results demonstrate that the main findings of this study are robust.

Comparison between RFM and BMI

To compare the strength of association between RFM and BMI as obesity indicators, both metrics were standardized per 1-SD increase. In the fully adjusted model, both RFM and BMI were associated with higher odds of myopia in adolescents. The effect estimate for RFM was slightly higher than that for BMI (RFM: OR = 1.15, 95% CI: 1.04–1.26; BMI: OR = 1.13, 95% CI: 1.05–1.21) (Table S1). These findings support the use of RFM as an adiposity-related indicator in this study. However, given the close effect estimates and overlapping confidence intervals, the incremental advantage of RFM over BMI should be interpreted with caution.

Discussion

Using nationally representative data, this study revealed a significant positive association between RFM and adolescent myopia, with a stronger association observed in males. Sensitivity analyses using a broader myopia definition confirmed the robustness of our findings. In the comparative analysis, both RFM and BMI were positively associated with the odds of myopia, with RFM showing a slightly higher effect estimate, suggesting that RFM – which incorporates both height and waist circumference – may provide complementary information for assessing obesity-related myopia risk in adolescents. However, given the close effect estimates, the incremental predictive value of RFM over BMI requires further validation in longitudinal studies and external populations.

Recent research has begun to unravel the relationship between obesity and myopia. Data from Korean NHANES allowed the following researchers to conclude that obese children and adolescents are 3.77 times more likely to develop high myopia compared to normal-weight peers.[18] This trend was also observed in a study from Ireland, which surveyed children from 37 schools and showed considerably higher myopia prevalence among overweight and obese children compared to those who were within a healthy weight range.[19] Another study highlighted that individuals with myopia generally have higher BFP, BMI, and waist circumference compared to those with unimpaired vision.[10] In a cross-sectional study conducted in China with 35,108 children and adolescents aged 6–17, researchers observed that overweight and obese girls, compared to those with normal weight-for-age, had a 33% and 22% higher odds of myopia in the 6–8 and 9–11 age groups, respectively.[20] The study also showed that higher BFP and BMI were closely linked to myopia.[20] In agreement with earlier studies, our research indicates

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Table 1. Characteristics of NHANES participants between 1999–2008

	Overall ($N = 8746$)	Non-myopia ($N = 5927$, 67.5%)	Myopia ($N = 2819$, 32.5%)	*P*-value
Age (years)	15.37 (2.24)	15.29 (2.24)	15.53 (2.25)	0.002
Age group				0.036
Low age	3432 (39.4%)	2367 (40.6%)	1065 (36.9%)	
High age	5314 (60.6%)	3560 (59.4%)	1754 (63.1%)	
Gender				0.260
Female	4332 (48.7%)	2869 (48.0%)	1463 (50.0%)	
Male	4414 (51.3%)	3058 (52.0%)	1356 (50.0%)	
Race				0.008
Mexican American	2838 (10.6%)	1912 (10.2%)	926 (11.4%)	
Other Hispanic	446 (6.4%)	290 (5.9%)	156 (7.6%)	
Non-Hispanic White	2399 (62.7%)	1658 (64.2%)	741 (59.6%)	
Non-Hispanic Black	2687 (13.8%)	1828 (13.9%)	859 (13.7%)	
Other race	376 (6.5%)	239 (5.9%)	137 (7.7%)	
PIR				0.338
≤1.3	3710 (31.0%)	2571 (31.7%)	1139 (29.6%)	
1.3–3.5	3127 (35.2%)	2115 (35.3%)	1012 (35.1%)	
>3.5	1909 (33.8%)	1241 (33.0%)	668 (35.3%)	
Physical activity (MET-min/week)	2290.54 (3,741.04)	2377.18 (3,758.64)	2109.85 (3,698.21)	0.176
Sufficient physical activity				0.003
<1680 Mets/week	4621 (48.4%)	3064 (46.8%)	1557 (51.8%)	
≥1680 Mets/week	4125 (51.6%)	2863 (53.2%)	1262 (48.2%)	
Outdoor exercise				0.289
No	2247 (30.7%)	1506 (31.2%)	741 (29.6%)	
Yes	6499 (69.3%)	4421 (68.8%)	2078 (70.4%)	
Screen time	3.00 (2.13)	2.97 (2.16)	3.07 (2.05)	0.076
Excessive screen time (≥2 h/day)				0.079
No	1984 (26.5%)	1391 (27.4%)	593 (24.7%)	
Yes	5791 (73.5%)	3884 (72.6%)	1907 (75.3%)	
Vitamin A (mcg)	589.14 (564.40)	581.67 (576.43)	604.63 (538.39)	0.073
Vitamin E (mg)	6.84 (6.31)	6.77 (6.00)	6.98 (6.91)	0.729
Energy intake (kcal)	2290.73 (1134.80)	2278.74 (1102.49)	2315.57 (1198.79)	0.721
Height (cm)	166.08 (10.40)	165.80 (10.37)	166.66 (10.45)	0.086
Waist circumference (cm)	81.24 (14.37)	80.62 (14.01)	82.51 (15.01)	0.003
RFM	28.84 (8.72)	28.55 (8.74)	29.44 (8.63)	0.011
RFM quartiles				0.080
Q1 (≤21.80)	2120 (25.0%)	1514 (26.1%)	606 (22.8%)	
Q2 (21.80–28.98)	2084 (25.0%)	1446 (25.1%)	638 (24.8%)	
Q3 (28.98–34.85)	2050 (25.0%)	1351 (24.7%)	699 (25.7%)	
Q4 (>34.85)	2492 (25.0%)	1616 (24.1%)	876 (26.8%)	

Continuous variables were presented as mean (SD), and categorical variables were expressed as *N* (%). Mean (SD) and percentage (%) are weighted.

that RFM, which measures obesity and body fat content, is positively correlated with the odds of myopia in adolescents. Yet, there are studies that have found otherwise. According to a Mendelian randomization study, higher BMI and fat mass, as determined by genetic factors, are associated with a lower odds of myopia; in other words, higher levels of BMI and fat mass may act as protective

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Table 2. The odds ratios between RFM and myopia in adolescents, NHANES 1999–2008

	Crude		Model I		Model II	
	OR (95% CI)	*P*-value	OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
RFM quartiles						
Q1 (≤21.80)	Ref		Ref		Ref	
Q2 (21.80–28.98)	1.13 (0.92, 1.38)	0.239	1.20 (0.98, 1.47)	0.073	1.14 (0.90, 1.43)	0.274
Q3 (28.98–34.85)	1.19 (1.01, 1.40)	0.036	1.28 (1.05, 1.55)	0.014	1.33 (1.07, 1.64)	0.010
Q4 (>34.85)	1.27 (1.03, 1.57)	0.026	1.35 (1.05, 1.74)	0.020	1.35 (1.01, 1.80)	0.041
Per-SD increase (SD = 9.06)	1.10 (1.02, 1.19)	0.012	1.13 (1.03, 1.24)	0.010	1.12 (1.01, 1.25)	0.037

No covariates were adjusted in Crude model. Model I was adjusted for age, gender, race. Model II was adjusted for age, gender, race, PIR, vitamin A, vitamin E, energy intake, sufficient physical activity, outdoor exercise, screen usage time.

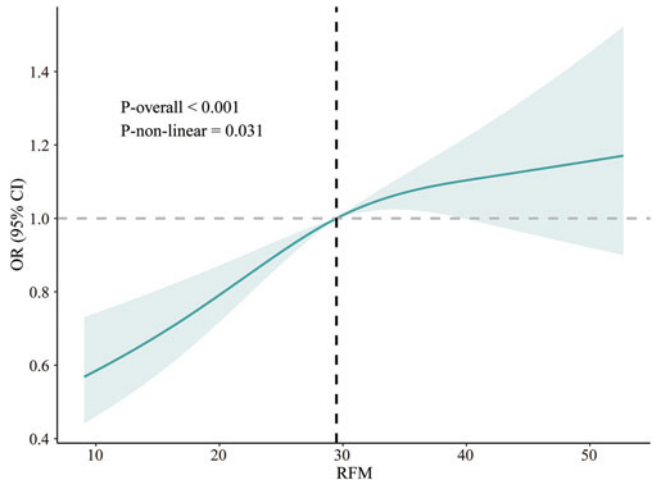


Figure 2. Analysis of the nonlinear relationship between RFM and adolescent myopia using the restricted cubic spline model. The model was adjusted for age, gender, race, PIR, vitamin A, vitamin E, energy intake, sufficient physical activity, outdoor exercise, screen usage time. The OR is represented by the green line, and shaped part represents the 95% CI.

Table 3. Subgroup analysis for the association between RFM and myopia in adolescents, NHANES 1999–2008

Participants	OR (95% CI)	*P*-value	*P* for interaction
Age group			0.786
Low age	1.14 (0.98, 1.33)	0.085	
High age	1.10 (0.95, 1.27)	0.199	
Gender			0.001
Female	0.98 (0.84, 1.13)	0.736	
Male	1.25 (1.09, 1.43)	0.002	
Race			0.583
Mexican American	1.28 (1.13, 1.45)	0.003	
Other Hispanic	1.12 (0.69, 1.83)	0.626	
Non-Hispanic White	1.12 (0.95, 1.32)	0.161	
Non-Hispanic Black	1.09 (1.00, 1.19)	0.058	
Other race	0.81 (0.54, 1.24)	0.326	
PIR			0.275
≤1.3	1.27 (1.08, 1.49)	0.005	
1.3-3.5	1.03 (0.84, 1.26)	0.777	
>3.5	1.09 (0.91, 1.31)	0.351	

The model was adjusted for age, gender, race, PIR, vitamin A, vitamin E, energy intake, sufficient physical activity, outdoor exercise, screen usage time.

factors against myopia.[21] Intriguingly, educational attainment has been identified as a potential mediator in this relationship.[21] A nationwide study of 1.3 million adolescents demonstrated a J-shaped association between BMI and myopia, indicating that low and high BMI values are connected to an increased likelihood of myopia.[22] Unlike the BMI studies mentioned above, our RSC analysis did not reveal a significant nonlinear relationship between RFM and the odds of myopia. A possible explanation is that BMI is influenced by both fat mass and lean mass, making it less reflective of fat distribution, whereas RFM, calculated from waist circumference and height, more directly reflects central fat accumulation,[23,24] thus showing a more linear increasing trend in the odds of myopia in our study population. Additionally, differences in age, racial composition, myopia definition, adjustment for lifestyle factors, and study design across studies may also contribute to the inconsistent dose-response patterns.

The precise mechanisms through which elevated RFM increases the odds of myopia in adolescents remain unclear but may involve chronic inflammation and insulin resistance. Obesity-induced adipose tissue dysfunction leads to the excessive release of free fatty acids, reactive oxygen species, and pro-inflammatory cytokines, resulting in lipid deposition in non-adipose organs and organelle dysfunction, thereby exacerbating systemic inflammation.[25] Patients with inflammatory diseases have a higher incidence of myopia compared to those without, and inflammatory markers such as interleukin-6 (IL-6), tumor necrosis factor-α (TNF-α), and transforming growth factor-β (TGF-β) are significantly elevated in the sclera of experimental myopia models. Notably, treatment with the immunosuppressant cyclosporine A has been shown to alleviate myopia progression.[26] Proteomic analyses further support the activation of inflammation-related signaling pathways, such as the S100 family, which are closely associated with myopia development.[27] Additionally, chronic low-grade inflammation disrupts insulin signaling, leading to glucose dysregulation and insulin resistance.[28] Mendelian randomization evidence indicates a significant causal relationship between elevated glycated hemoglobin levels and an increased risk of myopia.[29] Compensatory hyperinsulinemia due to insulin resistance may reduce plasma IGFBP-3 levels and impair retinoic acid receptor signaling, promoting scleral growth and axial elongation, ultimately contributing to myopia development.[30–32]

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Table 4. Odds ratios for the association between RFM and myopia using different definitions of spherical equivalent in adolescents, NHANES 1999–2008

	Spherical equivalent ≤ −0.5 D		Spherical equivalent ≤ −0.75 D	
	OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
RFM quartiles				
Q1 (≤21.80)	Ref		Ref	
Q2 (21.80–28.98)	1.06 (0.84, 1.35)	0.602	1.03 (0.82, 1.32)	0.756
Q3 (28.98–34.85)	1.21 (1.00, 1.46)	0.054	1.29 (1.07, 1.57)	0.010
Q4 (>34.85)	1.42 (1.12, 1.81)	0.005	1.37 (1.07, 1.76)	0.014
Per-SD increase (SD = 9.06)	1.14 (1.04, 1.26)	0.008	1.14 (1.03, 1.25)	0.009

The model was adjusted for age, gender, race, PIR, vitamin A, vitamin E, energy intake, sufficient physical activity, outdoor exercise, screen usage time.

Subgroup analysis revealed that sex was the only variable showing an interaction with the association between RFM and adolescent myopia. A significant positive association was observed in males, but not in females. This sex difference may be attributable to distinct fat distribution patterns between sexes.[33] Males tend to accumulate abdominal fat with higher visceral adiposity, whereas females are more likely to store fat in the gluteal and femoral regions.[34,35] Consequently, males are more prone to metabolic disturbances such as insulin resistance, which may exacerbate myopia risk.[36] Additionally, the positive association between RFM and myopia reached statistical significance among Mexican American and low-income populations. Of note, the interaction tests for race and PIR were not statistically significant; therefore, these subgroup findings should be interpreted as exploratory rather than as definitive evidence of racial or socioeconomic disparities. The significant association in Mexican Americans may be explained by a combination of genetic background, dietary patterns, obesity phenotypes, outdoor activity, and screen exposure.[37,38] The significant association in the low-income population may reflect socioeconomic factors such as access to healthy food, eye health services, educational resources, neighborhood environment, and extracurricular activity opportunities.[39–41] These interpretations warrant further validation through targeted external studies.

This study has important public health implications. Adolescents may reduce the odds of myopia by adopting healthy lifestyles and dietary habits to lower RFM, including reducing high-fat food intake, appropriately supplementing prebiotics to modulate gut microbiota, and engaging in moderate-to-vigorous physical training.[42–44] Based on the subgroup results, future myopia prevention and weight management strategies could particularly target male and low-income adolescents, integrating affordable outdoor activity opportunities, nutritional improvement, regular physical activity, and eye health screening into conventional myopia prevention programs to enhance intervention accessibility and practicality.[45]

Nevertheless, this study has several limitations. First, due to the cross-sectional design of the NHANES data, causality between RFM and myopia cannot be established. Second, this study used NHANES data from 1999 to 2008, which are now dated; screen use patterns, near-work behaviors, and outdoor activity habits among adolescents may have changed substantially since then, warranting caution when extrapolating the findings to contemporary adolescent populations. Third, refractive assessments were performed without cycloplegia, which may compromise measurement accuracy, particularly in individuals with mild myopia. Fourth, although the distribution of mild, moderate, and high myopia was descriptively reported, the limited sample size – especially for high myopia – may lead to unstable regression estimates; therefore, no strong conclusions were drawn regarding myopia severity. Fifth, vitamin A, vitamin E, and energy intake were derived from 24-hour dietary recalls, which are subject to recall bias and intraday intake variability. Serum nutrient levels were not included, so long-term nutritional status cannot be fully reflected. Sixth, despite adjustment for multiple confounders, key genetic information such as parental myopia history was unavailable in NHANES, and residual confounding may still affect the estimated association between RFM and myopia. Finally, although chronic inflammation and insulin resistance were proposed as potential mechanisms in the discussion, no biomarker verification was performed using C-reactive protein, fasting glucose, or insulin. Considering the availability of these biomarkers, the fasting subsample design, and the potential reduction in sample size after including them, future studies using datasets with complete biomarker information and appropriate weighting designs are needed to further validate these mechanisms.

Conclusion

Increased RFM was significantly associated with higher odds of myopia in adolescents, with a stronger association observed in males. These findings suggest that body fat control and RFM reduction may represent a promising direction for comprehensive myopia prevention in youth. For male and low-income adolescents, weight management, healthy diet, regular moderate-to-vigorous physical activity, and accessible eye health services could be integrated into conventional myopia prevention strategies. However, given the cross-sectional design of this study, the value of these interventions requires further validation through longitudinal and interventional studies.

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Data availability statement. The data supporting the current study are available from the corresponding author on reasonable request.

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