The association between metabolic equivalent and visceral adiposity index among children and adolescents
Ten-cycle cross-sectional study on NHANES (1999–2018)

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Abstract

Metabolic disorder is globally prevalent in children and adolescents, and physical activity may have a protective role against metabolic disorder. However, the association between metabolic equivalent (MET) and visceral adiposity index (VAI) among children and adolescents remains unclear. This study aimed to address this concern. Data were retrieved from the National Health and Nutrition Examination Survey (NHANES), which used the Global Physical Activity Questionnaire to assess the physical activity levels. VAI was calculated according to body mass index (BMI), waist circumference (WC), triglyceride (TG), and high-density lipoprotein (HDL). Linear regression was adopted to assess the association between MET and VAI. Restricted cubic spline regression was used to further explore the nonlinear relationship, Interaction effect analysis was conducted to identify whether the sample characteristic could modify the effect of MET on VAI. After data cleansing, a total of 3402 participants aged <18 years were enrolled. In the fully adjusted linear regression model, the β for VAI was 0.01 (95% confidence interval [CI]: –0.08, 0.09) for the second tertile and –0.11 (95% CI: –0.20, –0.03) for the third tertile. A linear downward trend was found in the restricted cubic spline regression (overall $P < .05$). Interaction effect analysis revealed no significant effects of age, gender, race, income poverty ratio, and insurance (all P for interaction >0.05). High physical activity intensity is associated with decreased VAI scores in children and adolescents.

Abbreviations: BMI = body mass index, CI = confidence interval, HDL = high-density lipoprotein, MET = metabolic equivalent, NHANES = National Health and Nutrition Examination Survey, OR = odds ratio, PIR = poverty-to-income ratio, T = tertile, TG = triglyceride, VAI = visceral adiposity index, WC = waist circumference.

Keywords: adolescents, children, metabolic equivalent, NHANES, physical activity, visceral adiposity index

1. Introduction

Overweight and obesity are common threats to physical and psychological health and are indicative of an underlying disordered metabolism. According to the latest report involving 21,399 Americans, the prevalence of obesity in 2011–2012 was 35.4%, which increased to 43.4% in 2017 to 2018.[1] Quantified by the waist circumference (WC), the prevalence of abdominal obesity was 54.5% in 2011 to 2012 and 59.1% in 2017 to 2018. The high prevalence of obesity is also noted in children and adolescents. As reported by Rivera JÁ et al,[2] the prevalence of overweight and obesity was 18.9% to 36.9% in children (5–11 years old) and 16.6% to 35.8% in adolescents (12–19 years old). Compared with normal-weight children/adolescents, their overweight/obesity counterparts have higher

risks of depression, anxiety, hypertension, type 2 diabetes, and malignancies.[3,4] Owing to these serious adverse effects, endeavors to counteract unhealthy metabolism in children and adolescents should be explored to improve their individual health and future quality of life.[4]

Prevention and management of obesity in childhood and adolescence are a requisite. Family-targeted lifestyle intervention, including physical activity, may alleviate dysregulated metabolisms.[5,6] Sénéchal M et al[7] reported that a high physical activity was negatively associated with overweight/obesity. In a survey of 2049 primary school children, the WC, fat mass index, diastolic blood pressure, and low-density lipoprotein decreased with the increase in physical activity levels. However, in the study by Reinehr T et al, no protective effects of physical activity were observed. After a systematic literature search, the 2017

Cochrane Review investigated the effect of physical activity on the health of <6-, 6- to 11-, and 12- to 17-year-olds and found that physical activity combined with diet and behavioral change can lead to a slight and short-term reduction in body mass index (BMI).[9–11] However, the quality of the evidence was ranked as low or extremely low, requiring further studies with adequate sample sizes and additional objective indicators of obesity to address the concern.

Several indicators, including BMI, WC, body fat percentage, and blood lipids, have been proposed and applied in clinical and epidemiological studies to identify metabolic disorders.[12] Among them, BMI and WC are the most widely used measure to quantify overweight/obesity. However, an obese individual can display the same metabolic profiles as a normal-weight person, and normal-weight individuals may also have disordered metabolisms.[13] In this study, we adopted a new index, namely, visceral adiposity index (VAI), to quantify the metabolic status of the enrolled participants. This sex-specific index is derived from BMI, WC, triglyceride (TG), and high-density lipoprotein (HDL) and is a better predictor of unhealthy metabolic phenotype than traditional adiposity measures.[14] We downloaded the dataset from National Health and Nutrition Examination Survey (NHANES) and used VAI to explore the association between physical activity and metabolic disorder to provide novel and objective evidence.

2. Materials and Methods

2.1. Study design and data sources

NHANES is a nationally ongoing program designed to evaluate the health condition and nutritional status of adults, adolescents, and children in the US (https://www.cdc.gov/nchs/nhanes/) and was approved by National Centre for Health Statistics Institutional Ethics Review Board. All the subjects agreed to the survey and provided a written consent. Data of the participants under 18 years of age from 1999 to 2018 NHANES were obtained, including the demographic characteristics (e.g., age, races, and sex), questionnaire information of health insurance and poverty income ratio (PIR), examination data of BMI and WC, and laboratory data of HDL and TG. This study was reviewed and approved by the National Centre for Health Statistics Institutional Ethics Review Board. Written and oral informed consent was obtained from all participants prior to their enrollment in this study.

2.2. Sex-independent equations of VAI

The sex-independent equations of VAI were defined as follows: VAI = (WC/(39.68 + 1.88 × BMI)) × (TG/1.03) × (1.31/HDL) for men, and VAI = (WC/(36.58 + 1.89 × BMI)) × (TG/0.81) × (1.52/HDL) for women. WC, TG, and HDL were the abbreviations of WC (cm), TG (mmol/L), and HDL, respectively.[15]

2.3. Calculation of metabolic equivalent (MET)

The Global Physical Activity Questionnaire was used to assess the physical activity levels of NHANES participants.[16] This questionnaire consisted of the frequency (the times of days per month/per week) and the duration spent on the item during 30 days or 7 days. The physical activity included 2 parts, namely, the types of daily activities and the intensify of physical activity. The types of daily activities comprised recreational activities (e.g., sports, fitness, and other recreational activities) and walking or bicycling for transportation or work. The intensity of physical activity consisted of moderate- and vigorous-intensity activities. The former included activities leading to a slight increase in heart and respiratory rate, and the latter comprised items causing a dramatic increase in heart and respiratory rate.

MET is the unit that measures the energy expenditure after the participants have completed a specific activity. One MET is the equivalent of 3.5 mL O^2 kg^{-1} min^{-1}.[17] In accordance with previous recommendation, vigorous-intensity activities, including vigorous work-associated activities and vigorous leisure-associated activities, were defined as 8.0 MET. In addition, moderate-intensity activities, including moderate leisure-related activities and walking or bicycling for transportation, were assigned as 4.0 MET. Each physical activity was estimated by multiplying the number of days by the average time by the corresponding MET and then summing up the obtained values to calculate the total MET for each participant.

2.4. Assessment of confounding factors

Data on the characteristics of teenagers and children were collected, including age (years), sex (male and female), races (Mexican American, black, white, and other races), status of health insurance (yes and no), and family PIR (tertiles: low, median, and high). Specific data were obtained from the following questions/records: for age, "Age at screening adjudicated-recode"; for sex, "Gender"; for race, "Recode of reported race and ethnicity information"; for status of health insurance, "Covered by health insurance"; and for family PIR, "family PIR/ratio of family income to poverty."

2.5. Statistical analysis

The MET was grouped into tertiles from lowest (T1) to highest (T3). The characteristics of subjects were presented as mean ± standard deviation for age, VAI, and WS. The cases and proportion were present for sex, races, PIR, insurance, and BMI. Univariate test was conducted between sample variables and MET tertiles. Kruskal–Wallis rank sum test, 1-way ANOVA, and Chi-square test were used for skew distributional data, normal distributional data, and categorical data, respectively. A 10-cycle weight was constructed to address the study design of oversampling. Three multivariate linear regressions were adopted to evaluate the association of VAI across MET tertiles. In model 1, age and sex were controlled; in model 2, further races were controlled; and in model 3, further PIR and insurance were controlled. Alternatively, restricted cubic spline methods controlling full covariates were used to fit smooth curve with 4 knots at 25%, 50%, 75%, and 95% to investigate the nonlinear relationship between MET and VAI. Interaction effect analysis was conducted to identify whether the sample characteristic could modify the effect of MET on VAI, and the possible moderators were age (under 12 and between 12 and 18), races, sex, PIR, insurance, and BMI. Two sensitivity analysis methods were used in this study. First, the quartiles of MET were taken as independent variable instead of MET tertiles in the multivariate linear regression. Second, VAI scores were divided into 2 subgroups with median as the threshold (i.e., low or high degree), which was used as a new dependent variable in the multivariate logistic regression. STATA software (Version 16.1, Stata Corporation) was used for data cleaning and all analyses.

3. Results

3.1. Subject characteristics

A total of 3402 participants were included in the final analysis (Table 1). With the increase in the MET of adolescents and children, a significant increase in the average age ($P < .001$) and proportion of men (from 53.5% to 59.8%) ($P < .001$) were observed. Meanwhile, the proportion of Mexican–American race gradually decreased from 33.2% to 24.6% ($P < .001$), and VAI scores presented a decline in the third MET tertile

Table 1

Sample characteristic among 3402 people in NHANES (1999–2018).

Variables	MET T1 N = 1140	MET T2 N = 1128	MET T3 N = 1134	P value
Age (yrs)	13.9 (1.4)	14.0 (1.4)	14.2 (1.4)	<.001
Sex				
Female	530 (46.5%)	563 (49.9%)	456 (40.2%)	<.001
Male	610 (53.5%)	565 (50.1%)	678 (59.8%)	
Races				
Mexican American	379 (33.2%)	377 (33.4%)	279 (24.6%)	<.001
Non-Hispanic Black	373 (32.7%)	313 (27.7%)	293 (25.8%)	
Non-Hispanic White	283 (24.8%)	278 (24.6%)	339 (29.9%)	
Other	105 (9.2%)	160 (14.2%)	223 (19.7%)	
IPR				
Low	314 (29.4%)	322 (30.5%)	310 (29.3%)	.22
Median	334 (31.3%)	357 (33.8%)	374 (35.3%)	
High	420 (39.3%)	377 (35.7%)	375 (35.4%)	
BMI				
Underweight	406 (35.6%)	377 (33.4%)	350 (30.9%)	.33
Normal	431 (37.8%)	425 (37.7%)	443 (39.1%)	
Overweight	168 (14.7%)	178 (15.8%)	191 (16.8%)	
Obese	135 (11.8%)	148 (13.1%)	150 (13.2%)	
Waist circumstance (mean ± SD)	79.0 (14.7)	79.9 (14.5)	80.0 (14.4)	.16
Health insurance				
No	167 (14.8%)	183 (16.3%)	141 (12.4%)	.030
Yes	961 (85.2%)	937 (83.7%)	992 (87.6%)	
VAI score (mean ± SD)	1.2 (1.0)	1.2 (1.1)	1.0 (0.9)	<.001

BMI = body mass index, IPR = income poverty ratio, MET = metabolic equivalent, N = number, T1 = first tertile, T2 = second tertile, T3 = third tertile, SD = standard deviation, VAI = visceral adiposity index.

(P < .001). In addition, the proportion of having health insurance increased (P < .05). No significant change was observed in PIR, BMI categories, and WS across all MET tertiles (P > .05).

3.2. Multivariate linear regression between MET tertiles and VAI scores

Table 2 shows the 3 nested multivariate linear regressions in this study. In model 1, after the adjustment for sex and age, the β for VAI across the MET tertiles was 0.04 (95% confidence interval [CI]: –0.04, 0.12) and –0.09 (95% CI: –0.18, –0.01). In model 2, after the further adjustment for races, the β for VAI across the MET tertiles was 0, 0.02 (95% CI: –0.06, 0.10), and –0.11 (95% CI: –0.19, –0.03). In model 3, after the further adjustment for PIR and insurance, the β for VAI across the MET tertiles was 0.01 (95% CI: –0.08, 0.09) and –0.11 (95% CI: –0.20, –0.03). In addition, a linear downward trend was found in the restricted cubic spline (overall P < .05) (Fig. 1).

3.3. Interaction effect analysis

In the Table 3, a series of covariates, including age, sex, races, PIR, and health insurance was analyzed as subgroup variables. The association of MET levels and VAI scores is not changeable owing to different age (P for interaction: .61), sex (P for interaction: .21), races (P for interaction: .32), IPR (P for interaction: .73), and insurance (P for interaction: .11).

3.4. Sensitivity analysis

The MET quartiles were used in the multivariate linear regressions (Table 4). In model 1, after the adjustment for sex and

Table 2

The multivariate linear regression between MET tertiles and VAI.

Model	Three tertiles of MET		
	T1	T2	T3
Model 1	0	0.04 (–0.04, 0.12)	–0.09 (–0.18, –0.01)
Model 2	0	0.02 (–0.06, 0.10)	–0.11 (–0.19, –0.03)
Model 3	0	0.01 (–0.08, 0.09)	–0.11 (–0.20, –0.03)

MET = metabolic equivalent, T1 = first tertile, T2 = second tertile, T3 = third tertile, VAI = visceral adiposity index.
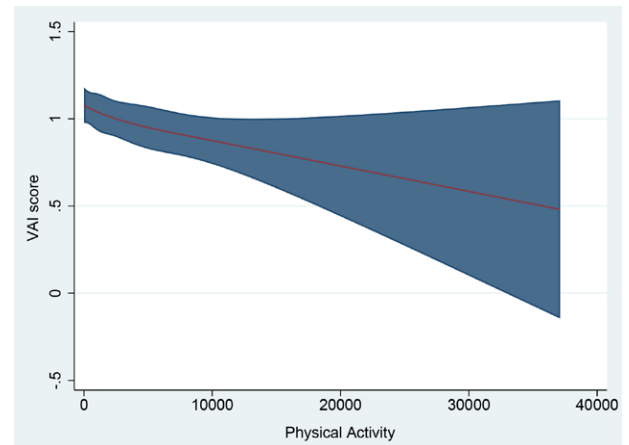

Figure 1. The restricted cubic spline between MET and VAI score. MET = metabolic equivalent, VAI = visceral adiposity index.

age, the β for VAI across the MET quartiles was 0, 0.02 (95% CI: –0.07, 0.12), –0.02 (95% CI: –0.11, 0.08) and –0.09 (95% CI: –0.18, 0.01). In model 2, after the further adjustment for races, the β for VAI across the MET quartiles was 0, 0.01 (95% CI: –0.09, 0.10), –0.04 (95% CI: –0.14, 0.05), and –0.10 (95% CI: –0.20, –0.01). In model 3, after the further adjustment for health insurance and PIR, the β for VAI across the MET quartiles was 0, –0.01 (95% CI: –0.10, 0.09), –0.06 (95% CI: –0.16, 0.03) and –0.11 (95% CI: –0.21, –0.01).

Binary VAI was used as dependent variable with the cutoff of median value (Table 5). In model 1, after the adjustment for sex and age, the OR for high VAI group was 1.00, 1.06 (95% CI: 0.89, 1.25) and 0.79 (95% CI: 0.67, 0.94). In model 2, after the further adjustment for races, the OR for high VAI group was 1.00, 1.02 (95% CI: 0.86, 1.21), and 0.75 (95% CI: 0.63, 0.89). In model 3, after the further adjustment for health insurance and PIR, the OR for high VAI group was 1.00, 1.01 (95% CI: 0.84, 1.20), and 0.74 (95% CI: 0.61, 0.89).

4. Discussion

By analyzing the national data in NHANES, this study provides novel evidence that physical activity is negatively associated with VAI, an index for evaluating unfavorable metabolic outcomes.[14] The results confirm the protective effect of physical activity, which may benefit the amelioration of disordered metabolisms in children and adolescents.

The role of physical activity in alleviating disordered metabolisms in children and adolescents has been highlighted. In a cross-sectional study on 374 children aged 9 to 11 years, Wilkie H J et al[18] reported that children with moderate to vigorous intensity physical activity had 0.69-fold risk of being overweight/obese than their sedentary counterparts. Opposite to

Table 3

The associations between MET tertiles and VAI scores.

Variables	T1	T2		T3		P for interaction
			Three tertiles of MET			
Age (yrs)						.61
<12	Reference	−0.07	(−0.25 to 0.11)	−0.12	(−0.31 to 0.07)	
12–18	Reference	0.03	(−0.07 to 0.12)	−0.11	(−0.20 to −0.02)	
Sex						.21
Female	Reference	−0.07	(−0.20 to 0.06)	−0.14	(−0.28 to −0.00)	
Male	Reference	0.08	(−0.02 to 0.18)	−0.09	(−0.18 to 0.01)	
Races						.32
Mexican American	Reference	0.05	(−0.10 to 0.21)	−0.03	(−0.20 to 0.14)	
Non-Hispanic Black	Reference	−0.08	(−0.18 to 0.02)	−0.13	(−0.23 to −0.03)	
Non-Hispanic White	Reference	−0.06	(−0.25 to 0.12)	−0.23	(−0.41 to −0.05)	
Other	Reference	0.22	(−0.04 to 0.49)	0.05	(−0.20 to 0.30)	
IPR						.73
Low	Reference	0.02	(−0.13 to 0.17)	−0.15	(−0.30 to 0.00)	
Median	Reference	0.03	(−0.11 to 0.17)	−0.03	(−0.17 to 0.11)	
High	Reference	−0.02	(−0.16 to 0.12)	−0.14	(−0.28 to 0.01)	
Insurance						.11
No	Reference	0.21	(−0.04 to 0.45)	−0.07	(−0.35 to 0.21)	
Yes	Reference	−0.03	(−0.12 to 0.05)	−0.13	(−0.21 to −0.04)	

IPR = income poverty ratio, MET = metabolic equivalent, T1 = first tertile, T2 = second tertile, T3 = third tertile, VAI = visceral adiposity index.

Table 4

Sensitivity analysis using MET quartiles.

Model	Q1	Q2		Q3		Q4	
			Four quartiles of MET				
Model 1	0.00	0.02	(−0.07, 0.12)	−0.02	(−0.11, 0.08)	−0.09	(−0.18, 0.01)
Model 2	0.00	0.00	(−0.09, 0.10)	−0.04	(−0.14, 0.05)	−0.10	(−0.20, −0.01)
Model 3	0.00	−0.00	(−0.10, 0.09)	−0.06	(−0.16, 0.03)	−0.11	(−0.21, −0.01)

MET = metabolic equivalent, Q1 = first quartile, Q2 = second quartile, Q3 = third quartile, Q4 = fourth quartile.

Table 5

Sensitivity analysis using binary VAI scores.

Model	T1	T2		T3	
			Three tertiles of MET		
Model 1	1.00	1.06	(0.89, 1.25)	0.79	(0.67, 0.94)
Model 2	1.00	1.02	(0.86, 1.21)	0.75	(0.63, 0.89)
Model 3	1.00	1.00	(0.84, 1.20)	0.74	(0.61, 0.89)

MET = metabolic equivalent, T1 = first tertile, T2 = second tertile, T3 = third tertile, VAI = visceral adiposity index.

the protective role of physical activity, Ding et al[19] investigated 28,048 Chinese children aged 6 to 17 years and revealed the insignificant relationship between active physical activity and overweight/obesity. These inconsistent findings may be partly explained by the discordant ways of evaluating physical activity. Physical activity evaluation was self-reported in Ding's study and was measured using an objective accelerometer in Wilkie H J's study. Meanwhile, the limited sample size may reduce the robustness of the conclusion by Wilkie H J et al In our study, we adopted the Global Physical Activity Questionnaire, which has been verified as effective in other studies,[20] to assess the physical activity levels of participants. The results based on adequate sample size are reliable and can be used to clarify the discrepancy in literature.

The assessment of disordered metabolisms varies in different publications. The majority of previous studies employed BMI, WC, TG, and waist-to-height and waist-to-hip ratios.[21,22]

However, accumulating evidence revealed that these indices may not accurately predict long-term metabolic outcomes, such as cardiovascular disease.[13,23] As reported by Mirzaei B et al, the risk of cardiovascular disease remained high in metabolically healthy overweight/obese participants. Therefore, regardless of BMI, all metabolically unhealthy phenotypes are associated with increased risks of cardiovascular disease. Similarly, Doustmohamadian S et al[23] reported that participants defined as "metabolically healthy abdominally obese" had similar risks of all-cause mortality during the 12-year follow-up to those defined as "metabolically healthy non-abdominally obese." Hence, in the present study, we adopted a novel index, VAT, to quantify the metabolic status of children and adolescents. According to Ferreira F G et al,[14] VAI predicts unhealthy metabolic phenotype better than other metabolic indicators such as BMI and waist-to-height and waist-to-hip ratios. Our results disclosed that a high physical activity intensity can reduce VAT for children and adolescents. Therefore, VAI can address the deficiency of BMI in predicting metabolic outcomes.

The major strength of this study is the representative data from NHANES, which contained data from the whole America. In addition, RCS regression disclosed a linear association between physical activity and VAI index as opposed to a simple OR value. On the basis of this finding, a high physical activity intensity at a certain range can be considered for children and adolescents.

However, this study still has some limitations. It did not identify the causal estimates of physical activity on metabolic disorders. Owing to the limit of the cross-sectional design, the discovered association may be biased by the potential

confounders not collected in this study. Further rigorously designed randomized control trials or Mendelian randomization studies are warranted to verify the protective effects of physical activity prior to implementation in clinical practice. In addition, the observed linear downward trend between physical activity intensity and VAI index exists against the background of cross-sectional design. Whether this downward trend remains solid or not in longitudinal follow-up is still unclear and awaits future verification.

In conclusion, this study suggested that high physical activity intensity is associated with low VAI index. Given the linear downward trend, physical activity at a certain range can be recommended for children and adolescents to alleviate their metabolic disorders.

5. Conclusion

High physical activity intensity is associated with low VAI index in children and adolescents.

Authors' contributions

YMZ carried out the data analyses and drafted the manuscript; QS helped to carry out the statistical analysis and draft the manuscript; BWD participated in its design and coordination; STL, and WCD helped to revise the manuscript; LH conceived of the study, and participated in its design and coordination and helped to draft the manuscript. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

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