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Association between metabolic score for visceral fat index and BMI-adjusted skeletal muscle mass index in American adults

Yifan Zhou¹, Xiangjie Su¹, Haitao Tan^{1*} and Jun Xiao^{1,2*} 

Abstract

Background The metabolic score for visceral fat (METS-VF) is a recently identified index for evaluating visceral fat, also referred to as abdominal obesity. The skeletal muscle mass index (SMI) serves as a critical measure for assessing muscle mass and sarcopenia. Both obesity and the reduction of muscle mass can significantly affect human health. However, research exploring the relationship between METS-VF and SMI remains limited. This study aims to investigate whether an association exists between these two indices, and if so, to elucidate the nature of their interactions.

Methods We conducted a cross-sectional study using data from the NHANES database, focusing on U.S. adults aged 20 years and older from 2013 to 2018. Controlling for relevant covariables, we primarily investigated the association between METS-VF and SMI values utilizing weighted multivariable linear regression models. Additionally, we assessed the diagnostic efficacy of METS-VF for sarcopenia.

Results A total of 3,594 participants were included in this study for analysis. The final adjusted model from the weighted multivariable linear regression indicated that METS-VF was negatively associated with SMI, with a coefficient of $\beta = -0.13$ (95% CI: -0.14, -0.12; $P < 0.001$). Subgroup analyses further demonstrated that this negative association was consistent across different populations. Notably, the negative association varied significantly between diabetic and nondiabetic population, as well as among populations classified by different BMI categories. Additionally, threshold effect analysis identified a significant inflection knot at 6.33. The characteristic curves of the subjects' work illustrated that, compared to other indicators, METS-VF exhibited excellent diagnostic efficacy for sarcopenia, with an area under the curve (AUC) of 0.825.

Conclusion Our results indicate that METS-VF is negatively correlated with SMI among adults in the United States, suggesting that visceral obesity exerts a detrimental effect on muscle mass. Furthermore, METS-VF shows potential as a valuable indicator for assessing SMI and sarcopenia. These findings underscore the importance of considering lipid metabolism disorders in the context of muscle health and highlight the potential for developing prevention strategies for sarcopenia.

Keywords METS-VF, SMI, NHANES, Visceral fat, Sarcopenia

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Introduction

Obesity has long been a serious challenge to global public health, affecting more than 2 billion people [1], of whom about 10% are children [2]. The health risks associated with obesity are also alarming and cannot be ignored. According to studies, obesity increases the chance of developing conditions including type 2 diabetes, asthma, high blood pressure, and coronary artery disease [3–5], and these illnesses' incidence has been rising for a long time [6]. At the same time, more and more scholars are focusing on the link between obesity and muscle mass-related diseases. Studies have shown that obese patients are often associated with sarcopenia and their obesity is often referred to as sarcopenic obesity (SO) [7–10]. Sarcopenia is defined using the gender-specific Skeletal Muscle Index (SMI) threshold (0.789 for men and 0.512 for women) established by the National Institutes of Health (NIH) [11]. SMI is an index for assessing skeletal muscle mass in the body, and its calculation usually involves the use of imaging techniques (e.g., CT or MRI) to measure the area of skeletal muscle in a specific area (arm or leg), and the subsequent comparison of this data with parameters such as height or body surface area to obtain a standardized index. It is commonly used to assess an individual's muscular health, especially in the elderly, obese patients, or in certain disease states. Lower SMI values may be associated with muscle atrophy, metabolic health problems, or limited physical function. Therefore, SMI is important in clinical assessment and health monitoring. Sarcopenia, on the other hand, is typified by a gradual loss of strength and skeletal muscle mass, which directly affects body function and quality of life [12–14]. At the same time, sarcopenia is strongly associated with physical disability, osteoporosis, and increased risk of falls [15, 16], as well as with metabolic syndrome and total mortality risk [17, 18].

Although body mass index (BMI) is widely used for rapid assessment of obesity, it has obvious limitations in measuring whole-body fat distribution [19]. Relying on BMI alone to assess an individual's obesity status is not scientific. Vague [20] emphasized the importance of body fat distribution, emphasizing the strong relationship between adipocyte dysfunction and visceral adipose tissue (VAT), while more and more researchers have begun to pay attention to the health risks posed by visceral fat. Waist circumference (WC) is widely used to assess central obesity because of its ease of measurement. Still, its accuracy is affected by several factors, such as the height and BMI of the person being assessed [21, 22], and WC alone is not able to differentiate between visceral fat and subcutaneous fat distribution.

Recognizing the health risks posed by central obesity and promoting the development of new assessment standards are necessary measures to address the challenge of obesity and will provide important support for improving public health. By adopting more effective assessment tools, we can better identify and intervene in obesity, thereby improving global health. An innovative assessment metric, the Metabolic Score for Visceral Fat (METS-VF), has been proposed by Bello-Chavolla et al. to effectively quantify visceral fat accumulation and cardiometabolic risk [23]. METS-VF integrates a variety of factors such as insulin resistance, waist-to-height ratio, age, and gender, providing a comprehensive assessment method with a nonlinear fit [23, 24]. METS-VF provides the scientific community with a more accurate and comprehensive assessment of obesity, which will help researchers and clinicians to better evaluate the health status of individuals and develop appropriate interventions.

Therefore, to more accurately evaluate the effects of lipids on muscle tissue *in vivo*, it is essential to establish novel protocols for exploring visceral fat in relation to muscle mass-associated diseases. This study aims to investigate the potential of a new visceral fat index for the assessment of Skeletal Muscle Index (SMI) values.

Methods

Selection of research subjects

We ultimately included 3,594 U.S. adults from the NHANES database (<https://www.cdc.gov/nchs/nhanes/index.htm>) as participants in this study, all of whom underwent blood biochemistry assessments and dual-energy X-ray absorptiometry during the 2013–2018 NHANES survey. Initially, a total of 29,400 individuals participated in the survey; however, we excluded those who were younger than 20 years (12,343), those with missing data related to METS-VF (10,209), and those with incomplete information pertaining to SMI (3,254). Consequently, 3,594 subjects with complete METS-VF and SMI data were included in our study (Fig. 1). The remaining missing values were subsequently imputed using the “missForest” R package through multiple interpolation methods.

Definition of visceral fat-related indicators

In our study, the exposure variable was the visceral fat distribution index, METS-VF, which was treated as a continuous variable. Additionally, we categorized METS-VF into quartiles to extract more meaningful information. The following formula was employed to calculate the METS-VF in this research:

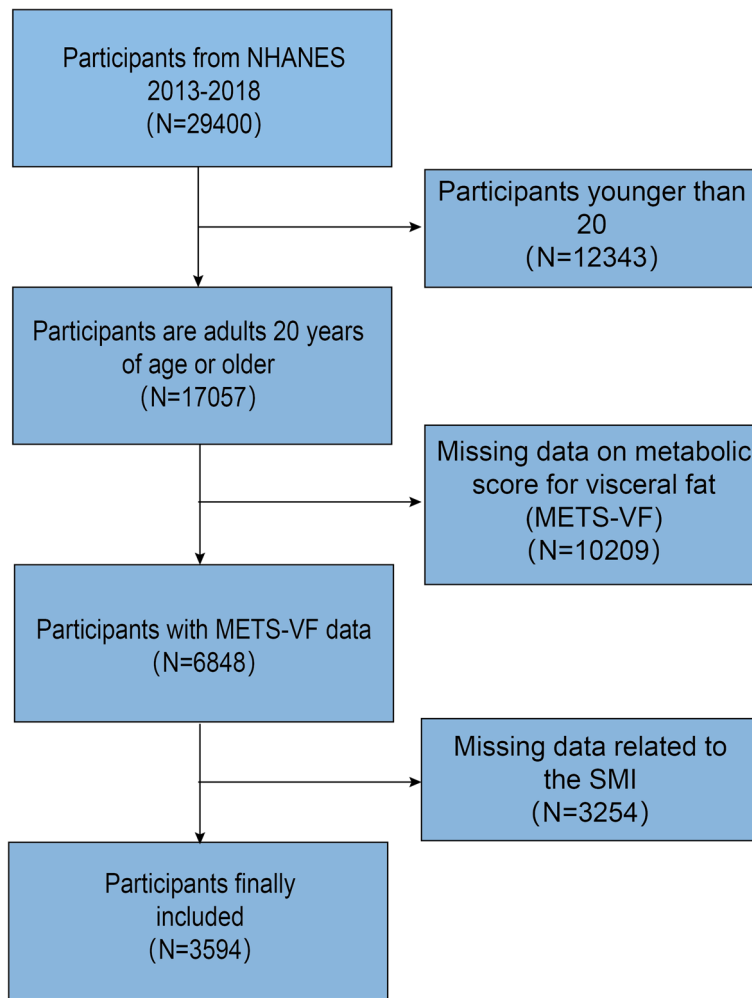


Fig. 1 Inclusion Exclusion Flowchart

$$\text{METS-VF} = 4.466 + 0.011 \times (\ln(\text{METS-IR}))^3 + 3.239 \times (\ln(\text{WHtR}))^3 + 0.319 \times (\text{gender}) + 0.594 \times (\ln(\text{age}))$$

In this equation, the variable “gender” was coded as “male” = 1 and “female” = 0.

The metabolic score for the insulin resistance index (METS-IR) was calculated using the formula:

$$\text{METS-IR} = \frac{\ln[(2 \times \text{fasting glucose}) + (\text{fasting triglycerids}) \times \text{BMI}]}{\ln(\text{HDL-cholesterol})}$$

The Waist-to-Height Ratio (WHtR) was computed as:

$$\text{WHtR} = \frac{\text{WC}}{\text{HT}}$$

According to personnel from the National Health and Nutrition Examination Survey (NHANES), only

serum fasting triglyceride data from participants who were screened in the morning were accepted. Furthermore, the inclusion criteria mandated that subjects be 12 years of age or older and have undergone fasting for a period of at least 8 h but no more than 24 h. Specific fasting durations could be verified through the official fasting questionnaire published under the title “Fasting Questionnaire”.

Calculation formula for visceral adiposity index

We incorporated the obesity-related index known as the visceral adiposity index (VAI) into the Receiver Operating Characteristic Curve analysis. VAI was computed using established formulas [25, 26] as follows:

Males :

$$VAI = \left(\frac{WC}{39.68 + 1.88 \times BMI} \right) \times \left(\frac{TG}{1.03} \right) \times \left(\frac{1.31}{HDL} \right)$$

Females :

$$VAI = \left(\frac{WC}{39.58 + 1.89 \times BMI} \right) \times \left(\frac{TG}{0.81} \right) \times \left(\frac{1.52}{HDL} \right)$$

Definition of muscle mass-related indicators

In this study, skeletal muscle index (SMI) served as the outcome variable and was treated as a continuous variable. SMI is calculated as the ratio of appendicular skeletal muscle mass (ASM) to body mass index (BMI), specifically using BMI-adjusted SMI, defined as ASM (kg) divided by BMI (kg/m²). Whole-body scans were conducted using a Hologic Discovery Model A densitometer (Hologic, Inc., Bedford, Massachusetts) with Apex version 3.2 software, as referenced on the official NHANES website and in prior studies utilizing muscle-related metric [27]. These DXA scans deliver a minimal radiation dose of less than 20 μSv. All scans included in this analysis were processed using Hologic APEX version 4.0 software, with the NHANES BCA option. The DXA examinations were carried out by trained and certified radiologic technologists.

Definition of sarcopenia

Definitions of sarcopenia vary among different sources. In this study, we primarily utilized the diagnostic criteria established by the National Institutes of Health (FNIH). In 2018, the FNIH introduced new criteria for the diagnosis of sarcopenia, which specifically include: 1. Low muscle mass: This is operationally derived from standardized comparisons of Appendicular Skeletal Muscle mass (ASM) relative to gender and Body Mass Index (BMI), utilizing gender-specific Skeletal Muscle Index (SMI) thresholds of 0.789 for men and 0.512 for women [11]. The definitions and calculations of ASM and SMI are detailed in the relevant section of this study. An SMI below 0.789 for men or 0.512 for women is indicative of sarcopenia. 2. Low muscle strength: Grip strength is measured as an independent metric, with thresholds set at <26 kg for men and <16 kg for women. 3. Reduced functional status: A gait speed of less than 0.8 m/sec is used to assess functional status. According to the FNIH criteria, an individual can be diagnosed with sarcopenia if they meet any one or more of these conditions. Among these three elements, we selected relatively objective muscle mass data as the primary diagnostic criterion.

Selection of covariables

Based on previous population-based studies [28, 29], our current study includes several covariables: age, gender, race, education, marital status, poverty-income ratio (PIR), total protein, creatinine, smoking status, hypertension, diabetes, alcohol consumption status, and total cholesterol. A comprehensive description of each variable can be found on the official NHANES website.

It is important to note that while we have also included body mass index (BMI), waist circumference, triglycerides, high-density lipoprotein (HDL), low-density lipoprotein (LDL), and total appendicular skeletal muscle mass in the population baseline table, these variables were not used as covariables. Instead, they served solely to illustrate the overall characteristics of the data, as they were found to be highly correlated with both the exposure and outcome variables.

Statistical analysis

First, we constructed a baseline table categorizing the population by quartiles of the exposure variable, METS-VF. We assessed the normality of continuity variables using the Anderson-Darling test, and the results indicated that all continuity variables were skewed (refer to Supplementary materials Table 1). Consequently, Differences in participant profiles were analyzed using Mann-Whitney U tests for continuous variables and chi-square tests for categorical variables, reporting results as median values with interquartile ranges (IQR) for continuous data and as percentages for categorical data. In reference to previous studies [30, 31], we developed three distinct models for weighted multivariable linear regression analyses to investigate the association between METS-VF and SMI. Model 1 served as the crude model, which did not adjust for any covariables. Model 2 included specific demographic covariables, such as age, gender, race, education, marital status, and poverty income ratio (PIR). Model 3 expanded upon this by incorporating additional covariables, namely age, gender, race, education, marital status, PIR, total protein, creatinine levels, smoking status, hypertension, diabetes, alcohol consumption, and total cholesterol. We calculated the Variance Inflation Factor (VIF) for both Model 2 and Model 3 and determined that there was no evidence of multicollinearity in these two models (See Supplementary materials Table 2). Subsequently, we assessed gender, race, education, age, body mass index (BMI), prevalence of diabetes, prevalence of hypertension, smoking status, and alcohol consumption for subgroup stratification and interaction analysis. To minimize the likelihood of false-positive results, we adjusted the final outcomes for multiple comparisons

using the Bonferroni, Holm, and Benjamini-Hochberg correction methods, respectively (see Supplementary materials Table 3). In reference to previous cross-sectional studies employing threshold effect analysis [32, 33], we utilized smoothed curve fitting to further investigate the relationship between METS-VF and SMI, identifying a knot at METS-VF = 6.33 for the threshold effect analysis. Additionally, we assessed the diagnostic efficacy of five different lipid-related indices for sarcopenia, measuring this discriminatory capacity using the area under the curve (AUC) of the receiver operating characteristic (ROC) analysis.

Each analysis presented in this paper was conducted using the appropriate sample weights, as specified in the NHANES 2013–2018 documentation titled ‘Demographic Variables and Sample Weights.’ Given that this study involved laboratory research, the weight applied was “WTMEC2YR”.

The Empower program (version 2.0) and R studio (Version 4.4.1) were used for all analyses (<http://www.empowerstats.com>) & (<https://www.r-project.org/>). A two-sided $P < 0.05$ was used as the default for statistical significance.

Results

Population baseline table characteristics

Our analysis included 3,594 participants, whose statistical characteristics are presented in Table 1. We categorized the METS-VF values into quartiles. The results indicated that higher METS-VF quartiles were more prevalent among older adults, men, married individuals, lower-educated participants, smokers, hypertensive individuals, diabetics, Patients with sarcopenia, those who consume alcohol, and other Hispanic groups, while they were less common among individuals of other races and those with higher education levels. Furthermore, participants in the high METS-VF quartile exhibited elevated levels of total cholesterol, triglycerides, LDL cholesterol, body mass index (BMI), and waist circumference; conversely, their HDL cholesterol levels were lower. Notably, the high METS-VF quartile group demonstrated greater total limb muscle mass. However, their skeletal muscle index (SMI) values were lower. Additionally, our study sample comprised 1,726 males and 1,868 females, of which 86 males and 78 females were found to have sarcopenia. The prevalence rates were 4.98% in males and 4.18% in females, indicating a higher prevalence in males compared to females.

The association between METS-VF and SMI

The results of the weighted multivariable linear regression model presented in Table 2 demonstrate the relationship between METS-VF and SMI. Our analysis

revealed a negative association between METS-VF and SMI, which was statistically significant across all three models ($P < 0.05$). Specifically, in Model 3, for each unit increase in METS-VF, SMI decreased by 0.13 units.

Smooth curve fitting and threshold effect analysis

The results of the smoothed curve fitting and threshold effect analysis are presented in Fig. 2; Table 3. After adjusting for all relevant factors, we observed an “L”-shaped negative association between METS-VF and SMI values. Threshold effect analysis revealed that the inflection knot for the entire sample occurred at a METS-VF value of 6.33, which was statistically significant ($P < 0.001$ for the log-likelihood ratio test). Prior to reaching this inflection knot, SMI decreased by 0.1 units for each unit increase in METS-VF, whereas beyond this threshold, SMI decreased by 0.23 units for each unit increase in METS-VF. These findings indicate that as METS-VF increases, SMI values decline, with the rate of decline becoming more pronounced after the inflection knot of 6.33.

Subgroup analysis

To further assess the reliability and sensitivity of the relationship between METS-VF and SMI, we conducted subgroup analyses based on several factors: gender, age, race, educational status, marital status, smoking status, alcohol consumption, prevalence of hypertension, prevalence of diabetes, and BMI. The findings indicated that the negative association between METS-VF and SMI persisted across all subgroups in the fully adjusted statistical model ($P < 0.05$). Additionally, in conjunction with the results of multiple comparisons adjustment (refer to Supplementary Material Table 3), we observed significant interactions in the subgroups classified by prevalence of diabetes and BMI (P for interaction < 0.05). Specifically, the negative association between METS-VF and SMI was more pronounced in diabetic individuals compared to non-diabetic individuals. Furthermore, this association was stronger in overweight individuals ($25 \leq \text{BMI} < 30$) relative to non-overweight individuals ($\text{BMI} < 25$), and the negative association was greater in the obese population ($\text{BMI} > 30$) compared to both the overweight ($25 \leq \text{BMI} < 30$) and non-overweight populations. Figure 3 illustrates the interactions and provides specific values for each subgroup.

METS-VF has excellent diagnostic efficacy for Sarcopenia

Figure 4 illustrates the area under the curve (AUC) for evaluating the diagnostic capability of sarcopenia (refer

Table 1 Fundamental attributes of the subjects according to the METS-VF quartile

Characteristics	Q1 (N=899)	Q2 (N=898)	Q3 (N=898)	Q4 (N=899)	P value
Age (year)	29 ± 15	36 ± 16	42 ± 17	49.5 ± 11	<0.001
Gender (%)					<0.001
Male	42.48	42.68	48.82	67.14	
Female	57.52	57.32	51.18	32.86	
Race (%)					<0.001
Mexican American	5.54	11.98	13.76	13.05	
Other Hispanic	6.94	7.77	7.99	8.69	
Non-Hispanic White	62.84	56.76	59.62	61.34	
Non-Hispanic Black	11.66	10.77	9.58	11.89	
Other Race	13.02	12.72	9.05	5.03	
PIR	2.24 ± 3.03	2.18 ± 3.03	2.08 ± 3.02	1.96 ± 2.64	0.163
Marital status (%)					<0.001
Previously married	48.10	64.60	71.31	78.14	
Never married	51.90	35.40	28.69	21.86	
Education level (%)					<0.001
Less than high school	1.88	3.63	5.44	6.50	
High school	7.90	8.80	9.62	11.21	
Above high school	90.22	87.57	84.93	82.29	
Total protein (g/dL)	7.14 ± 0.40	7.15 ± 0.41	7.09 ± 0.44	7.11 ± 0.41	0.003
Creatinine (mg/dl)	0.8 ± 0.26	0.79 ± 0.27	0.8 ± 0.27	0.83 ± 0.26	<0.001
BMI (kg/m ²)	21.9 ± 3.4	26.4 ± 4.75	30 ± 6.3	33.9 ± 8.4	<0.001
Waist circumference (cm)	79 ± 8.7	91.4 ± 8.95	101 ± 12.2	112 ± 17.2	<0.001
Total cholesterol (mg/dl)	171 ± 44.5	185 ± 49	192 ± 51	196 ± 49.8	<0.001
Triglyceride (mg/dl)	62 ± 44	85 ± 67	102 ± 88.8	118 ± 91	<0.001
HDL (mg/dl)	59 ± 21	52 ± 18	48 ± 17	45 ± 15	<0.001
LDL (mg/dl)	95 ± 41	111 ± 43	116 ± 44.2	119 ± 44	<0.001
Smoked at least 100 cigarettes in life (%)					<0.001
Yes	37.94	39.90	43.15	50.20	
No	62.06	60.10	56.85	49.80	
High blood pressure (%)					<0.001
Yes	6.43	17.69	28.15	42.35	
No	93.57	82.31	71.85	57.65	
Diabetes (%)					<0.001
Yes	0.60	3.31	4.67	16.64	
No	99.40	96.69	95.33	83.36	
Ever have 4/5 or more drinks every day (%)					<0.001
Yes	12.11	12.74	14.57	21.90	
No	87.89	87.26	85.43	78.10	
Sarcopenia (%)					<0.001
Yes	0.03	0.75	2.96	10.63	
No	99.97	99.25	97.04	89.37	
METS-VF	5.27 ± 0.61	6.02 ± 0.24	6.38 ± 0.16	6.69 ± 0.19	<0.001
Total limb muscle mass (kg)	19.6 ± 8.57	22 ± 8.83	24.2 ± 8.33	27.3 ± 9	<0.001
SMI	0.89 ± 0.38	0.77 ± 0.37	0.75 ± 0.35	0.74 ± 0.32	<0.001

Q Quartiles, PIR Household income to poverty ratio, LDL Low-density lipoprotein cholesterol, HDL Direct high-density lipoprotein cholesterol, BMI Body mass index

Table 2 Association between the METS-VF and SMI

Exposure	Model 1 β (95% CI), <i>P</i> -value	Model 2 β (95% CI), <i>P</i> -value	Model 3 β (95% CI), <i>P</i> -value
METS-VF (continuous)	-0.08 (-0.09, -0.06) <0.001	-0.13 (-0.14, -0.13) <0.001	-0.13 (-0.14, -0.12) <0.001

Model 1: No covariable adjustment

Model 2: Age, gender, race, education, marital status and PIR adjustments
 Model 3: Age, gender, race, education, marital status, PIR, total protein, creatinine, smoking status, hypertension, diabetes, alcohol consumption status and total cholesterol were all adjusted for

to the Methodology section for a detailed definition of sarcopenia). The results indicated that METS-VF, METS-IR, waist circumference (WC), visceral adiposity index (VAI), and body mass index (BMI) all demonstrated statistically significant AUC values ($AUC > 0.5$) for diagnosing sarcopenia. Notably, METS-VF exhibited the highest performance among these indices, with an AUC of 0.825.

Discussion

The aim of this study was to investigate the relationship between the novel visceral fat accumulation index, METS-VF, and body mass index (BMI)-adjusted skeletal muscle index (SMI) values. The study included a total of 3,594 adult participants from the United States. Our findings demonstrate a negative association between METS-VF and SMI, characterized by an “L”-shaped relationship, with a significant inflection knot identified at 6.33. Subgroup analyses revealed that this negative association was consistent across all categories within the population.

Table 3 Threshold effect analysis of METS-VF and SMI

SMI	β (95% CI)	<i>P</i> -value
METS-VF		
Model I	-0.13 (-0.14, -0.12)	<0.001
Model II		
Inflection knot	6.33	
< 6.33	-0.10 (-0.12, -0.08)	<0.001
>6.33	-0.23 (-0.27, -0.19)	<0.001
Log-likelihood ratio test		<0.001

Age, gender, race, education, marital status, PIR, total protein, creatinine, smoking status, hypertension, diabetes, alcohol consumption status and total cholesterol were all adjusted for

Model I: univariable linear regression; Model II: two-part regression model

Furthermore, we examined the relationship between five lipid-related markers and sarcopenia, and the results indicated that METS-VF exhibited the highest diagnostic power among these markers. These findings suggest the

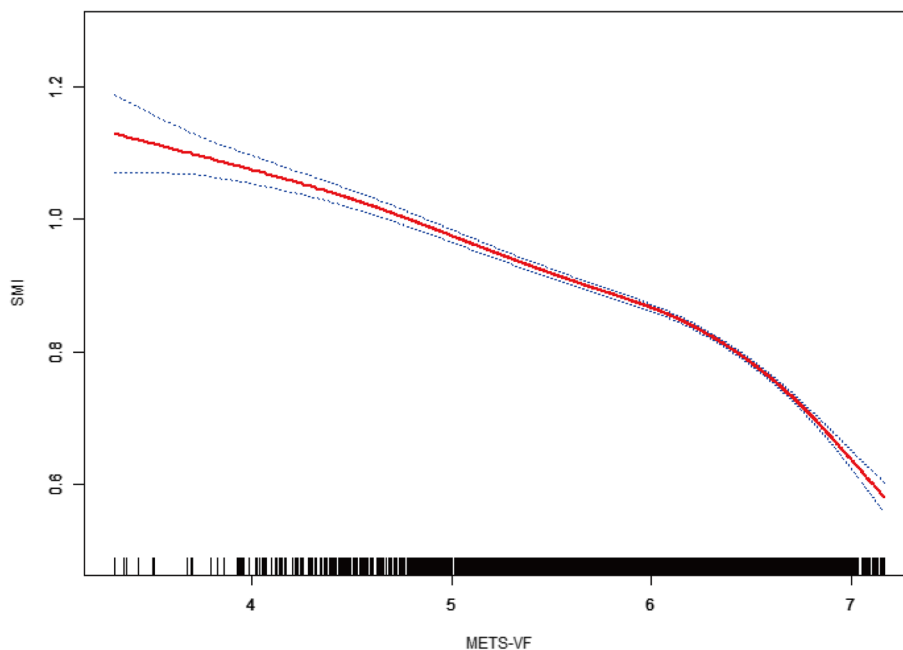


Fig. 2 Illustrates the relationship between METS-VF and SMI. The solid red line represents the smooth curve fit for these variables. The blue dashed line denotes the 95% confidence interval for the fit. Additionally, the black bar at the bottom displays the distribution of the sample. METS-VF refers to the visceral fat metabolism score, while SMI stands for the BMI-adjusted skeletal muscle mass index

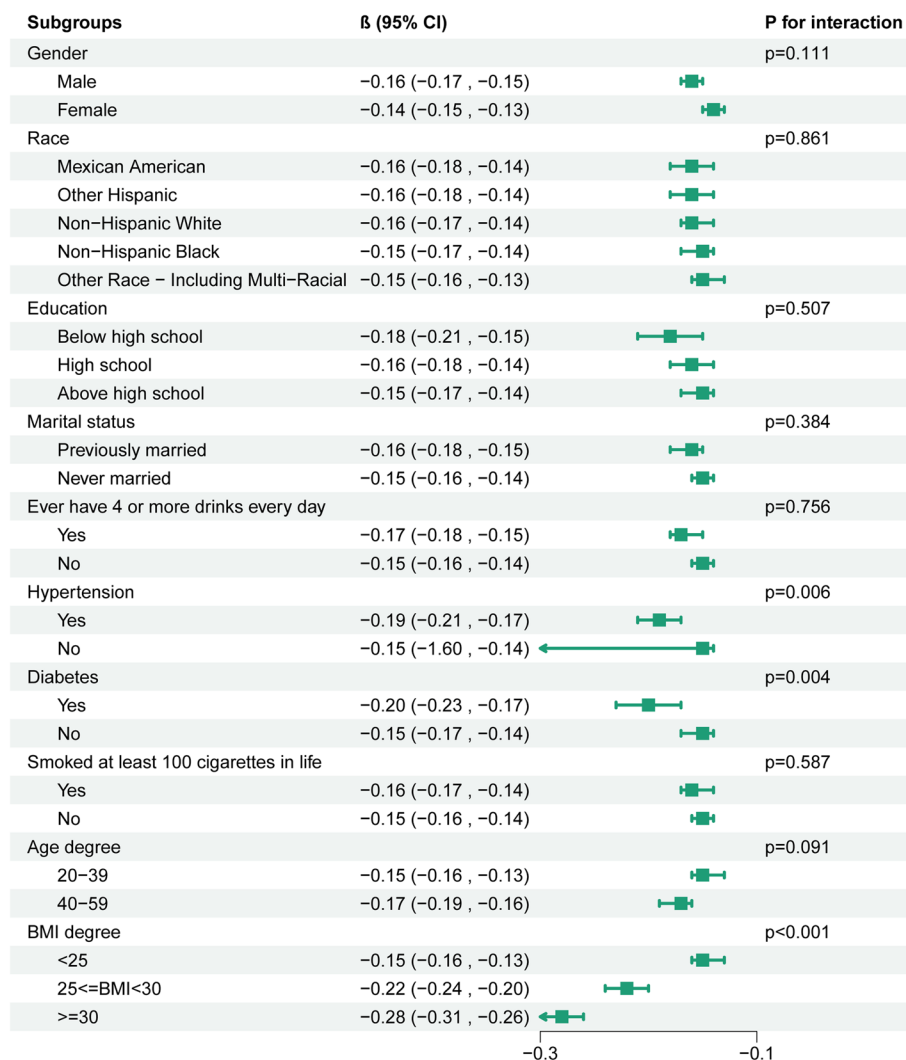


Fig. 3 Forest plot produced from the results of the interaction test of the association between METS-VF and SMI. Adjustments have been made for all relevant covariables

potential clinical significance of maintaining an optimal METS-VF level to mitigate muscle loss.

Obesity and muscle loss exhibit a complex interdependence. Specifically, obesity, particularly excessive abdominal fat, is a significant risk factor for both the onset and progression of muscle loss. Several specific mechanisms may contribute to this relationship: 1. Inflammatory Response: Obesity is often associated with chronic low-grade inflammation. The body experiences elevated levels of inflammatory markers (e.g., cytokines), which can disrupt normal muscle metabolism and promote muscle mass loss [34]. 2. Insulin Resistance: Obesity frequently leads to insulin resistance, a condition critical for protein synthesis and muscle metabolism. When insulin's effectiveness is diminished, muscles may struggle to efficiently

absorb and utilize glucose and amino acids, ultimately resulting in reduced synthesis and growth [8]. 3. Decreased Activity: Individuals with obesity often exhibit reduced physical activity, which can further contribute to muscle mass decline. Regular exercise is a crucial determinant in the preservation of muscle mass [35]. 4. Poor Nutrition: Although caloric intake may be high in obese individuals, a diet deficient in essential nutrients (e.g., proteins, vitamins, and minerals) can hinder muscle synthesis and repair [36]. 5. Hormonal Changes: Obesity impacts the body's levels of hormones such as testosterone and growth hormone, both of which are essential for muscle growth and maintenance. 6. Imbalance of Muscle Synthesis and Catabolism: Interactions induced by obesity between hypertrophy and diminished anabolic

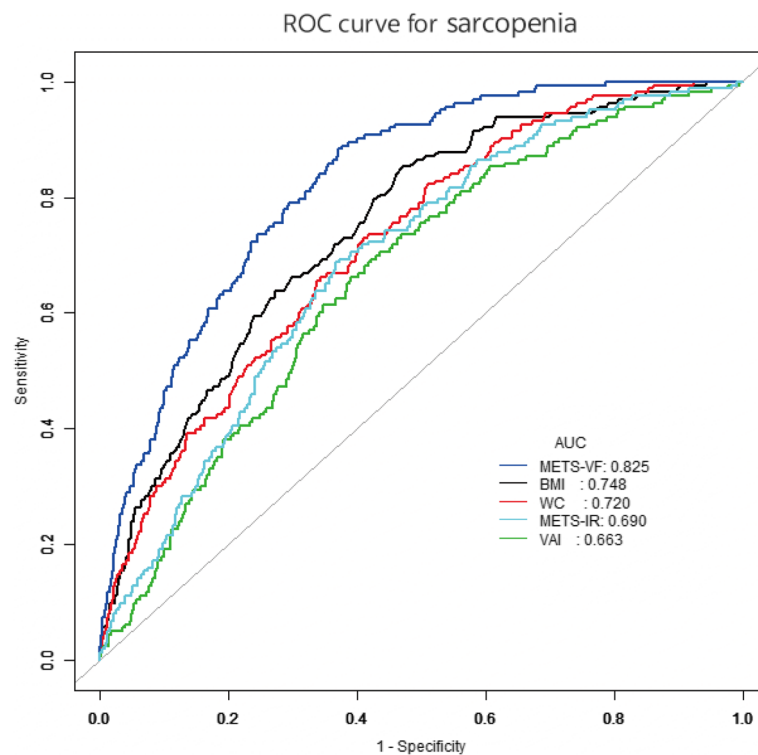


Fig. 4 ROC curves for the diagnostic ability of METS-VF, METS-IR, WC, VAI and BMI for sarcopenia. Abbreviations: AUC: area under the curve, ROC: receiver operating characteristic, METS-VF: metabolic score for visceral fat index, METS-IR: metabolic score for the insulin resistance index, WC: waist circumference, VAI: visceral adiposity index, BMI: body mass index

processes may result in increased muscle catabolism or decreased anabolism, ultimately leading to reduced muscle mass [37].

Identifying an appropriate obesity-related index for the assessment of sarcopenia has garnered significant interest in recent years. Previous studies have indicated that a higher body mass index (BMI) is associated with a protective effect against sarcopenia [38, 39], whereas a high body fat percentage serves as a risk factor for this condition [40, 41]. Relying solely on BMI may pose certain challenges, as it does not effectively differentiate between fat mass and lean mass, and these different components exert varying effects on sarcopenia. Consequently, it is crucial to prioritize the evaluation of visceral fat and central obesity when assessing sarcopenia. Waist circumference (WC) is directly correlated with visceral fat and serves as a straightforward indicator for its assessment [42]. However, in individuals with similar WC values but differing heights, the risk may be overestimated in taller individuals and underestimated in shorter ones [21]. In response to these limitations, alternative indicators such as waist-to-height ratio (WHtR) and visceral adiposity index (VAI) have emerged, while the metabolic score for visceral fat index (METS-VF) was selected as the primary

indicator for analysis in this study. Because the METS-VF encompasses a comprehensive set of components, including demographic indicators, a surrogate measure of fat accumulation, WHtR, and an insulin resistance assessment indicator, namely METS-IR, which includes lipid biomarkers indicative of the degree of fat accumulation [43, 44]. Moreover, findings from the receiver operating characteristic (ROC) analysis demonstrated that METS-VF surpassed other obesity-related markers in the diagnosis of sarcopenia.

Biological hypotheses regarding the relationship between METS-VF and SMI may encompass several key aspects: 1. Impact of Lipid Accumulation on Muscle Tissue: Elevated METS-VF is indicative of increased lipid accumulation, particularly visceral fat, which is associated with intramuscular fat deposition. This accumulation can impair muscle protein synthesis and result in a reduction of muscle mass, thereby decreasing SMI. 2. Chronic Inflammation and Sarcopenia: The presence of increased visceral fat is linked to chronic low-grade inflammation. Inflammatory cytokines released during this process can adversely affect muscle metabolism, contributing to muscle wasting—referred to as sarcopenia—and consequently leading to a reduction in SMI [45]. 3. Sarcopenic Obesity: The phenomenon of sarcopenic

obesity, characterized by a simultaneous increase in fat mass and a decrease in muscle mass, may establish a connection between METS-VF and SMI. This condition underscores the intricate interplay between fat and muscle dynamics [46].

Regarding the specific findings, each 1-unit increase in METS-VF corresponded to a 0.13-unit decrease in the Skeletal Muscle Mass Index (SMI). Notably, this study revealed an L-shaped relationship between METS-VF and SMI. Specifically, when the METS-VF value exceeded 6.33, there was a significant decline in SMI with further increases in METS-VF. This inflection knot may signify a critical threshold beyond which metabolic dysregulation occurs, potentially leading to adverse health outcomes. It is conceivable that excessive lipid accumulation beyond this threshold initiates a cascade of metabolic disturbances, including increased insulin resistance and systemic inflammation, which may contribute to muscle loss and overall health deterioration in patients [47]. Clinically, these findings suggest that maintaining METS-VF levels below 6.33 is essential for mitigating the risks associated with sarcopenia and other metabolic disorders. Further investigation into the underlying mechanisms at this inflection knot, as well as its implications for patient management and prevention strategies, is warranted.

It is noteworthy to highlight that our subgroup analysis yielded significant differences between diabetic and non-diabetic population. Specifically, diabetic population exhibited a stronger negative association between METS-VF and SMI compared to their non-diabetic population. This finding supports the previously discussed negative impact of insulin resistance on muscle loss. Additionally, within the BMI subgroups, we observed that the negative association between METS-VF and SMI was more pronounced in the obese population than in the non-obese population. Furthermore, a greater BMI was associated with an increased negative association, reinforcing our conclusion that lipid accumulation adversely affects muscle loss. This relationship also provides insight into the overall negative association observed in the smoothed curve fitting and somewhat elucidates the emergence of inflection knots in the threshold effect analysis.

Strengths and limitations

This study represents the first known investigation into the relationship between METS-VF and SMI, demonstrating a noteworthy contribution to the existing literature. We developed an initial model to assess the association between METS-VF and SMI. After adjusting for covariables, we conducted multiple linear regression analyses for Model 2, Model 3, and their respective subgroups, which did not indicate any significant

multicollinearity. To mitigate the risk of false-positive findings, we performed multiple comparisons. The final results consistently revealed a negative association between METS-VF and SMI, thereby affirming the inter-relationship between these two variables and underscoring the scientific robustness of our overall study.

Despite these significant findings, certain limitations warrant acknowledgment. First, as this is a cross-sectional study, we are unable to fully elucidate the causal relationship between METS-VF and SMI. Consequently, larger sample sizes and prospective studies are recommended for further verification. Second, the NHANES database contains population data exclusively from the United States, which necessitates further exploration of the applicability of our findings to populations in other countries. Third, while we accounted for several covariables, other relevant covariables remain unaddressed, which could potentially influence the experimental results. Finally, the SMI values utilized in this study are calibrated to BMI, and the definition of sarcopenia is based on guidelines from the Foundation for the National Institutes of Health (FNIH), which may not align with other diagnostic criteria.

It is important to highlight that the National Health and Nutrition Examination Survey (NHANES) is designed to represent the U.S. civilian, non-institutionalized population using a complex multistage sampling method, ensuring demographic diversity in age, gender, race/ethnicity, and socioeconomic status. NHANES data are widely used in public health research and policy decisions in the U.S. However, the applicability of these findings to other countries is limited due to significant cultural, dietary, and healthcare differences that can affect generalizability. Additionally, issues like non-response bias and reliance on self-reported data may impact data quality. Thus, while NHANES provides valuable insights into U.S. health and nutrition, researchers must consider these factors when applying findings internationally, as varying health behaviors and systems may lead to different outcomes.

Our study utilizing NHANES data reveals insights into the relationship between METS-VF and SMI, but it has inherent limitations associated with its cross-sectional design, primarily the inability to establish causality. Since data are collected at one point in time, we cannot determine if changes in METS-VF result from or cause variations in SMI. This limitation affects our ability to draw definitive conclusions about the relationship's directionality.

Moreover, cross-sectional studies are subject to temporal bias, where participants' responses may be influenced by recent events, not reflecting their long-term health behaviors. Consequently, findings may not accurately depict the relationship dynamics over time.

The study's cross-sectional nature also restricts the investigation of temporal trends in the METS-VF and SMI association. Longitudinal studies would be better suited to explore these trends and provide a deeper understanding of their interactions across life stages.

In summary, while our analysis adds to the literature, it is crucial to interpret the results with these limitations in mind. Future research using longitudinal designs and objective measures is needed to clarify the relationship between METS-VF and SMI further.

Conclusion

Our findings demonstrate a significant negative association between METS-VF and SMI among adults in the United States, indicating that visceral obesity may adversely affect muscle mass. Furthermore, elevated METS-VF levels appear to be associated with an increased prevalence of sarcopenia within this population. These findings underline the critical importance of monitoring visceral fat levels in clinical practice, as well as the necessity of maintaining healthy lipid metabolism.

In light of these results, we advocate that clinicians consider visceral adiposity as a potential risk factor when assessing the overall health status of their patients. We recommend implementing individualized interventions, such as nutritional counseling and tailored exercise programs, for high-risk populations. This approach aims to identify and address potential muscle health issues at an early stage, thereby optimizing the maintenance and enhancement of muscle health.

Moreover, future public health initiatives should explore strategies to integrate visceral fat assessment into routine physical examinations. This integration would facilitate early intervention for associated health risks and contribute to the broader goal of maintaining muscle health in the general population.

Abbreviations

METS-VF	Metabolic score for visceral fat index
SMI	Skeletal muscle mass index
SO	Sarcopenia obesity
AUC	Area under the curve
FNIH	Foundation for the National Institutes of Health
METS-IR	Metabolic score for the insulin resistance index
WHtR	Waist-to-height ratio
VAI	Visceral adiposity index
ASM	Appendicular skeletal muscle mass
PIR	Household income to poverty ratio
ROC	Receiver operating characteristic
NHANES	National Health, and Nutrition Examination Survey
DXA	Dual-energy X-ray absorptiometry
BMI	Body mass index
WC	Waist circumference
TC	Total cholesterol
TG	Triglycerides
HDL	High-density lipoprotein cholesterol
LDL	Low-density lipoprotein cholesterol
CI	Confidence interval

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12944-025-02439-3>.

Supplementary Material 1.

Acknowledgements

We would like to express our heartfelt thanks to all the participants who took part in the NHANES survey.

Authors' contributions

Yifan Zhou: article conceptualization, methodology, software and writing-original draft. Xiangjie Su: analysis and data integration. Jun Xiao: review, editing and methodology. Haitao Tan: funding, review and management. All authors approved the final manuscript as submitted and agreed to take responsibility for all aspects of the work.

Funding

None.

Data availability

This study used publicly available databases, and specific information can be obtained through the NHANES official website (<https://www.cdc.gov/nchs/nhanes/index.htm>).

Declarations

Ethics approval and consent to participate

This survey of the United States population was approved by the authorities of the National Center for Health Statistics, and the survey was conducted in accordance with local institutional and regulatory standards. All participants signed an informed consent form.

Competing interests

The authors declare no competing interests.

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Received: 9 November 2024 Accepted: 13 January 2025

Published online: 28 January 2025

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