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RESEARCH

Visceral adiposity index (VAI) association with suicidal ideation among U.S. adults: a cross-sectional study using NHANES 2005–2018 data

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Abstract

Background and objective Suicidal ideation (SI) poses a significant public health challenge, and understanding its predictors, especially modifiable factors like visceral obesity, is essential for prevention. The purpose of this study is to investigate the association between the visceral adiposity index (VAI) and suicidal ideation (SI) among adults in the United States.

Methods A cross-sectional study using NHANES data from 2005–2018 included adults aged 18 and above with complete SI and VAI data. Suicidal thoughts were evaluated using item 9 from the Patient Health Questionnaire-9 (PHQ-9), while VAI was calculated using gender-specific formulas based on waist circumference, body mass index (BMI), total triglycerides (TG), and high-density lipoproteins (HDL-C). Multivariate logistic regression analysis was implemented after adjusting for several factors to assess the relationship between VAI and SI. Additionally, subgroup analysis and interaction testing were employed to investigate the consistency of this relationship with other demographic parameters.

Result Our study included a cohort of 15,830 participants, of whom 3.59% exhibited signs of suicidal ideation. Following multivariate logistic regression analysis, we observed a significant positive association between VAI and SI (odds ratio [OR] = 1.03; 95% CI 1.01, 1.04; $P = 0.0057$), which remained significant after adjusting for various confounding factors. Moreover, utilizing a two-segment linear regression approach, we uncovered a nonlinear relationship between VAI and SI, demonstrating a U-shaped pattern with a critical point at 5.28.

Conclusion Elevated levels of VAI were consistently associated with an increased probability of SI, and this association remained consistent across various demographic variables.

Level of evidence Level V—cross-sectional observational study.

Keywords Visceral adiposity index · Suicidal ideation · NHANES · Cross-sectional study · Obesity

Abbreviations

SI	Suicidal ideation
HDL-C	High-density lipoprotein cholesterol
VAI	Visceral adiposity index
BMI	Body mass index
TG	Triglycerides

Introduction

Suicidal ideation (SI) poses a substantial public health problem, imposing a significant financial and human costs on society. It is a symptom of severe emotional and psychological strain [1]. Globally, nearly one million people die by suicide each year [2], making it one of the leading causes of death. Persistent or recurring suicidal ideation plays a crucial role in the progression toward suicide, suicide attempts, and completed suicides, as claimed by the World Health Organization (WHO) [3]. In 2022, the US witnessed a 2.6% increase in suicides, with the number rising from 48,183 in 2021 to 49,449, according to the US Centers for Disease Control and Prevention (CDC) [4]. According to the Interpersonal Theory of Suicide, suicide ideation is the first step in developing the potential to commit suicide, with

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suicide being the last act [5]. Therefore, improving suicide prevention strategies entails promptly identifying the onset of suicidal ideation and identifying modifiable factors [6].

According to nationally representative measurements, obesity rates in the U.S. have grown significantly over the last 30 years. Data from 1999–2002 show that approximately 27.6% of men, 33.2% of women, and 16.7% of children and adolescents met the criteria for obesity or being overweight [7]. In recent years, a growing body of evidence has established a link between excess body weight or obesity and an increased risk of mental health issues, such as depression and suicidal tendencies [8]. Body mass index (BMI), commonly used as an indicator of obesity, reflects the extent of obesity within the body [9]. However, a limitation of BMI is its inability to distinguish between visceral fat and total body fat, compromising its accuracy as an obesity indicator [10, 11]. The visceral adiposity index (VAI) has merged as a unique tool for identifying dysfunction associated with visceral adiposity. It measures visceral fat accumulation by combining BMI, waist circumference, triglycerides, and HDL cholesterol [12]. Recent research has highlighted the enhanced predictive capacity of VAI compared to traditional metrics such as BMI or waist circumference in evaluating the risk of cardiometabolic diseases [13]. Multiple studies have identified VAI as an independent risk factor for various systemic diseases, including diabetes, kidney stones, male erectile dysfunction, and even periodontitis [14–17].

In the domain of mental health and visceral obesity research, previous cross-sectional studies initially demonstrated a correlation between high VAI and psychological disorders. Lei Jun et al. revealed a significant association between depressive symptoms and elevated ratios of VAI in a cohort of 2577 participants [18]. However, the relationship between VAI and the presence of suicidal ideation remains inadequately elucidated. Therefore, we aimed to investigate the connection between VAI and the occurrence of suicidal ideation by analyzing cross-sectional data derived from the National Health and Nutrition Examination Survey (NHANES). We hypothesized a direct association between elevated VAI levels and an increased incidence of suicidal ideation.

Materials and methods

Study population

The NHANES employs a comprehensive, multistage, probabilistic sampling method, providing extensive insights into the overall health and nutritional status of the American population. It stands as a representative study of the country's populace [19]. To obtain a representative sample of American citizens, the NHANES utilizes a multi-staged, stratified sampling technique. This includes both home interviews and health evaluations and is conducted biennially [20]. Prior to participation, each individual provides written consent, and the NCHS Research Ethics Review Board has approved NHANES as a study involving human subjects. For further details regarding the NHANES survey, please visit https://www.cdc.gov/nchs/nhanes/index.htm.

Utilizing a cross-sectional approach, data from the NHANES dataset spanning from 2005 to 2018 were extracted for analysis in this study. Particularly, participants included in our study have complete data for both SI and VAI. A total of 70,190 individuals were enrolled. After excluding participants who were under the age of 18, pregnant, and those with missing data on SI ($n = 5653$) and VAI ($n = 19{,}923$), as well as individuals under 18 years old ($n = 28{,}047$), 15,830 participants remained in our final analysis (Fig. 1).

Definition of suicidal ideation

The Patient Health Questionnaire-9 (PHQ-9), specifically focusing on question 9, was utilized to assess suicidal ideation, representing a widely respected assessment tool for detecting depression-related signs in primary care and health clinics [21]. With a composite score ranging from 0 to 27, the PHQ-9 score categorizes individuals into two groups: those scoring below 10 are considered not experiencing depression, while those scoring above 10 are classified as having depression [22]. Suicidal ideation was assessed using item 9 from the PHQ-9 questionnaire, which inquired how frequently individuals had experienced thoughts of harming or dying in the preceding 2 weeks [23]. Responses options included "None", "several days", "More than half the days", or "Nearly every day". We categorized responses into two groups: not present (No) and present at any frequency (Yes) [24].

Assessment of visceral adiposity index

Gender-specific formulas were utilized to generate the VAI, which served as the exposure variable. These formulas utilize waist circumference (WC), body mass index (BMI), total triglycerides (TG), and high-density lipoproteins (HDL-C). For males, the formula is [WC (cm) + (1.88 × BMI)/39.68] 1.31 × (TG (mmol/L)/1.03) × (1.31/HDL (mmol/L)), while for females, it is [WC (cm)/[36.58 + (1.89 × BMI)]) × (TG (mmol/L)/0.81) × (1.52/HDL (mmol/L)) [25].

Covariables

Several covariates may influence the association between SI and VAI, including gender, age (years), race, education

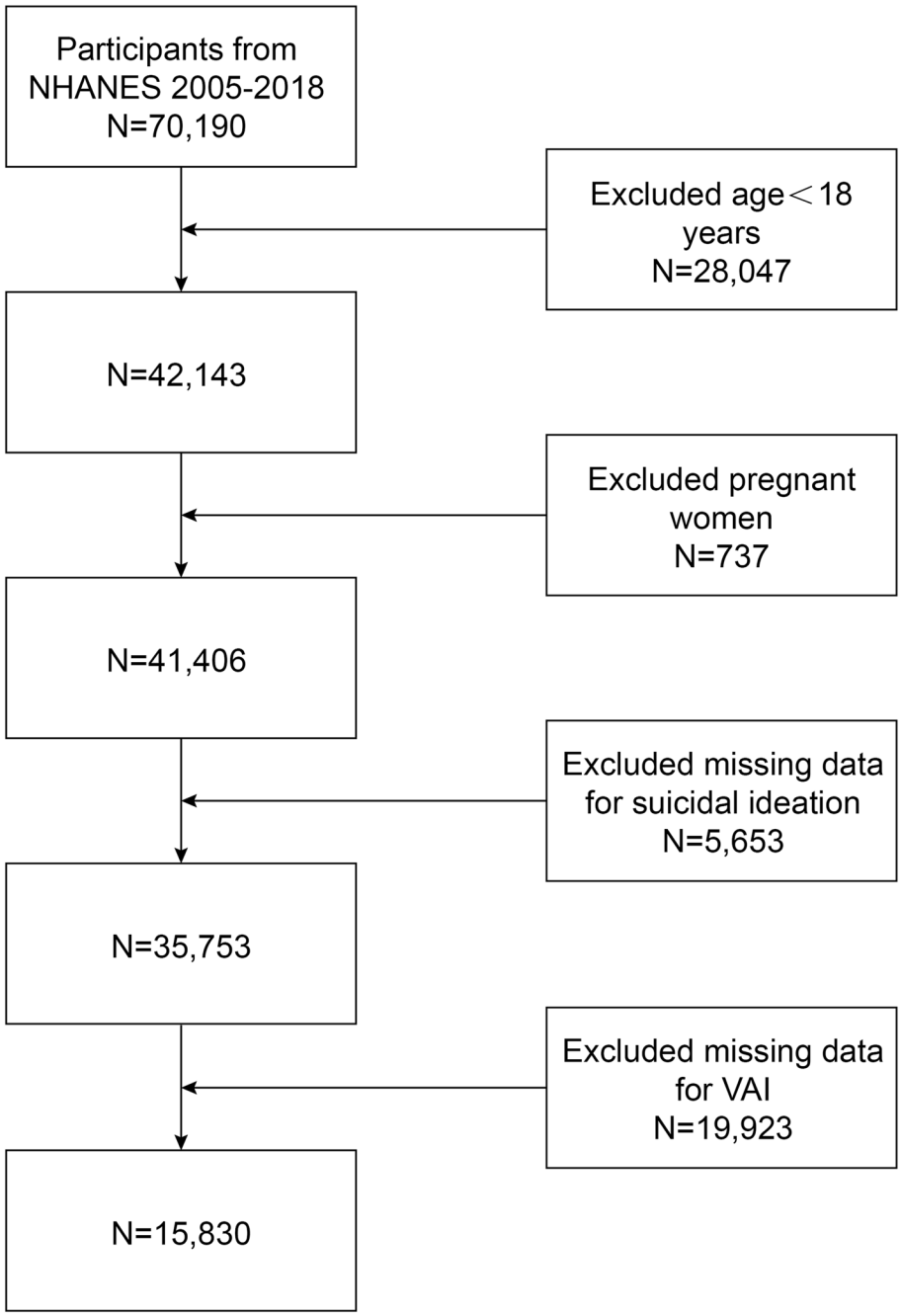

Fig. 1 Flowchart of participant selection. NHANES, National Health and Nutrition Examination Survey

level, marital status (married or living with partner/widowed, divorced, separated, and never married), waist circumference (cm), poverty-to-income ratio (PIR), smoking status (smoke or not), diabetes, hypertension, hyperlipidemia, depressive symptoms (without depression/with depression), weight (cm), total cholesterol (TC) (mg/dl), high-density lipoprotein cholesterol (HDL-C) (mmol/L), low-density lipoprotein cholesterol (LDL-C) (mmol/L), and triglycerides (TG) (mmol/L). Every individual's BMI was categorized into three groups: underweight, overweight, and obese, with values of < 25, 25–30, and < 30 kg/m^2 [26]. For comprehensive details on the quantifiable processes of study variables, the public can refer to the official website at www.cdc.gov/nchs/nhanes/.

Statistical analysis

In accordance with CDC standards, all statistical analyses considered the complexities of multistage cluster surveys, adhering to NHANES analytical and reporting criteria, which encompassed intricate survey design considerations. To evaluate group differences based on the presence or

absence of SI, we employed the weighted Student's *t*-test for continuous variables meeting normality assumptions and the weighted Mann–Whitney *U* test for non-normally distributed continuous variables. For categorical data, we utilized the weighted Chi-square test with Rao and Scott's second-order correction to account for the potential underestimation of standard errors in complex survey designs. Using multivariate logistic regression analysis, we investigated the relationship between VAI and the presence of SI across three separate models. Model 1 represented the unadjusted mode, while Model 2 incorporated adjustments for gender, age, and race. Model 3 included adjustments for age, gender, race, marital status, education level, income-to-poverty ratio, smoking status, diabetes, and hypertension. Additionally, we employed weighted generalized additive model (GAM) regression and smooth curve fitting, utilizing the penalized spline approach, to explore the nonlinear relationship between VAI and SI. A two-piecewise linear regression model was utilized to explore potential threshold effects to have a more comprehensive understanding of the link between VAI and SI. Tests of interactions and subgroup analysis were conducted to investigate the robustness of this association across demographic backgrounds. Participants were categorized based on age, gender, race, BMI, education level, marital status, hypertension, hyperlipidemia, diabetes, and smoking status. A significant level of p-value < 0.05 delineated significant disparities. All statistical analyses were conducted using the R software program (http://www.r-project.org) and EmpowerStats (http://www.empowerstats.com).

Results

Baseline characteristics of participants

Table 1 displays the demographic characteristics and additional covariates of the participants included in the study, categorized into two groups based on the presence or absence of suicidal ideation. The sample comprised 15,830 individuals, with an average age of 48.29 ± 18.58 years, and an almost equal distribution of males (50.52%) and females (49.48%). Across the research group, the average occurrence of SI was 3.59%, and the mean VAI levels were 2.01 ± 2.80. Every variable, except for weight, TC, LDL-C, age, and hyperlipidemia, showed a significant difference between participants with and without SI. Notably, individuals experiencing suicidal ideation were more likely to be female, of non-Hispanic White ethnicity, and categorized as widowed, divorced, separated, or never married. Additionally, this group exhibited a higher prevalence of smoking, lower income, some college education or an associate degree, elevated BMI levels, larger waist circumference, reduced HDL-C, and increased TG values. They also reported a higher occurrence of depression. However, low incidences of diabetes and hypertension were observed in this population (all $p < 0.05$).

The association between VAI and SI

Multivariate regression analysis revealed a significant association between SI and VAI levels. In the unadjusted model, the association was [1.03 (1.01, 1.04), $p = 0.0057$], indicating a 3% increased risk of SI for every unit rise in VAI levels. After adjusting for age, gender, and ethnicity in the primary model, the association remained significant [1.02 (1.00, 1.04), $p = 0.0187$]. However, the relationship between VAI and SI lacked statistical significance in model 3 [1.00 (0.98, 1.02), $p = 0.6523$], which includes comprehensive variables [27–29]. In sensitivity analysis using partially adjusted models, VAI was categorized into tertiles. Tertile 3 exhibited a significant 55% increased likelihood of SI compared to Tertile 1, which had the lowest VAI (OR = 1.55; 95% CI 1.25, 1.92; p for trend < 0.0001). However, there was no statistically significant difference between Tertile 1 and Tertile 2 (OR = 1.15; 95% CI 0.92, 1.44; p for trend = 0.2171) (refer to Table 2 for detailed information).

A nonlinear relationship between VAI and SI

To investigate the potential nonlinear association between VAI and SI, we employed a two-part linear regression model to assess threshold effects. The analysis identified a significant nonlinear relationship at a breakpoint of VAI = 5.28 (logarithmic likelihood ratio test, $p = 0.007$) in Table 3. Below this threshold, VAI was positively associated with SI risk (OR = 1.11, 95% CI 1.03–1.19, $p = 0.0041$), whereas above the threshold, the association reversed (OR = 0.88, 95% CI 0.80–0.97, $p = 0.0137$). These findings, visualized in Fig. 2, confirm a nonlinear relationship statistically supported by the likelihood ratio test (Table 4).

Subgroup analysis

We conducted interaction tests and subgroup analysis stratified by age (< 50, ≥ 50), gender, race, BMI (< 25, 25–30, > 30), education level, marital status, hypertension, hyperlipidemia, diabetes, and smoking status to evaluate the consistency of the association between VAI levels and SI across various demographic situations. However, no statistically significant relationship was observed, as indicated by the p-values for interaction. This suggests that age, gender, race, BMI, education level, marital status, hypertension, hyperlipidemia, diabetes, and smoking status did not significantly influence this relationship (all P for interaction > 0.05).

Table 1 Characteristics of the study population

Characteristic	Total (N = 15,830)	Without suicidal ideation (N = 15,261)	With suicidal ideation (N = 569)	*P*-value
Age(year)	48.29 ± 18.58	48.29 ± 18.60	48.36 ± 18.12	0.947
Gender (%)				0.008
Male	7997 (50.52%)	7738 (50.70%)	259 (45.52%)	
Female	7833 (49.48%)	7523 (49.30%)	310 (54.48%)	
Race(%)				< 0.001
Mexican American	2571 (16.24%)	2472 (16.20%)	99 (17.40%)	
Other Hispanic	1571 (9.92%)	1473 (9.65%)	98 (17.22%)	
Non-Hispanic White	6773 (42.79%)	6541 (42.86%)	232 (40.77%)	
Non-Hispanic Black	3270 (20.66%)	3175 (20.80%)	95 (16.70%)	
Other race	1645 (10.39%)	1600 (10.48%)	45 (7.91%)	
Marital status(%)				< 0.001
Married or living with partner	9025 (59.60%)	8771 (60.08%)	254 (46.69%)	
Widowed, divorced, separated, and never married	6117 (40.40%)	5827 (39.92%)	290 (53.31%)	
Education level(%)				< 0.001
Less than 9 th grade	1501 (10.07%)	1416 (9.85%)	85 (15.98%)	
9–11 th grade	2149 (14.41%)	2040 (14.19%)	109 (20.49%)	
High school grad/GED or equivalent	3430 (23.01%)	3302 (22.97%)	128 (24.06%)	
Some college or AA degree	4353 (29.20%)	4205 (29.25%)	148 (27.82%)	
College graduate or above	3476 (23.31%)	3414 (23.75%)	62 (11.65%)	
Body mass index(kg/m^2), (%)				< 0.001
< 25	4815 (30.42%)	4662 (30.55%)	153 (26.89%)	
25 to < 30	5190 (32.79%)	5025 (32.93%)	165 (29.00%)	
≥ 30	5825 (36.80%)	5574 (36.52%)	251 (44.11%)	
Waist circumference(cm)	98.74 ± 16.57	98.65 ± 16.53	101.17 ± 17.52	< 0.001
Income-to-poverty ratio	2.50 ± 1.62	2.53 ± 1.62	1.84 ± 1.43	0.003
Smoking status(%)				< 0.001
Yes	6873 (45.13%)	6557 (44.66%)	316 (57.77%)	
No	8356 (54.87%)	8125 (55.34%)	231 (42.23%)	
Diabetes (%)				< 0.001
Yes	1965 (12.42%)	1865 (12.23%)	100 (17.57%)	
No	13,484 (85.25%)	13,029 (85.45%)	455 (79.96%)	
Borderline	368 (2.33%)	354 (2.32%)	14 (2.46%)	
Hypertension (%)				< 0.001
Yes	5560 (35.17%)	5310 (34.84%)	250 (43.94%)	
No	10,248 (64.83%)	9929 (65.16%)	319 (56.06%)	
Hyperlipidemia (%)				0.237
Yes	8267 (69.95%)	8000 (70.06%)	267 (66.75%)	
No	3552 (30.05%)	3419 (29.94%)	133 (33.25%)	
Depressive symptom (%)				< 0.001
Without depression	14,284 (90.23%)	14,098 (92.38%)	186 (32.69%)	
With depression	1546 (9.77%)	1163 (7.62%)	383 (67.31%)	
Weight (kg)	81.51 ± 21.22	81.46 ± 21.19	82.68 ± 21.97	0.187
TC (mg/dL)	190.62 ± 41.75	190.54 ± 41.62	192.54 ± 45.04	0.584
HDL-C (mmol/L)	1.39 ± 0.41	1.39 ± 0.41	1.33 ± 0.39	< 0.001
LDL-C (mg/dL)	112.42 ± 35.48	112.37 ± 35.35	113.77 ± 39.00	0.600
TG (mmol/L)	1.41 ± 1.25	1.41 ± 1.25	1.57 ± 1.27	< 0.001
VAI	2.01 ± 2.80	2.00 ± 2.81	2.36 ± 2.47	< 0.001

Table 2 The association between VAI and suicidal ideation

	Crude model (model 1)	Partially adjusted model (model 2)	Comprehensive adjusted model (model 3)
	OR (95% CI) *p*-value	OR (95% CI) *p*-value	OR (95% CI) *p*-value
VAI	1.03 (1.01, 1.04) 0.0057	1.02 (1.00, 1.04) 0.0187	1.00 (0.98, 1.02) 0.6523
VAI tertiles			
Tertile 1	Reference	Reference	Reference
Tertile 2	1.19 (0.96, 1.49) 0.1163	1.15 (0.92, 1.44) 0.2171	1.08 (0.85, 1.37) 0.5124
Tertile 3	1.64 (1.33, 2.01) < 0.0001	1.55 (1.25, 1.92) < 0.0001	1.05 (0.95, 1.16) 0.3256
P for trend	1.24 (1.14, 1.35) < 0.0001	1.21 (1.11, 1.33) < 0.0001	1.05 (0.95, 1.16) 0.3013

Model 1, no covariates were adjusted. Model 2, age, gender, and race were adjusted. Model 3, age, gender, race, marital status, education level, income-to-poverty ratio, smoking status, diabetes, asthma, liver disease, limitations in vision, hearing, or mobility, and hypertension were adjusted. 95% CI, 95% confidence interval; OR, odds ratio

Table 3 The threshold effect of VAI on suicidal ideation was analyzed using a two-part linear regression model

Suicidal ideation	Model: saturation effect analysis
Fitting by the standard linear model	
OR (95% CI)	1.01 (0.99, 1.03)
P-value	0.3525
Fitting by two-piecewise linear model	
Breakpoint (K)	5.28
OR1(< K)	1.11 (1.03, 1.19) 0.0041
OR2(> K)	0.88 (0.80, 0.97) 0.0137
Logarithmic likelihood ratio test *P*-value	0.007

Model 1, no covariates were adjusted. Model 2, age, gender, and race were adjusted. Model 3, age, gender, race, marital status, education level, income-to-poverty ratio, smoking status, diabetes, and hypertension were adjusted. 95% CI, 95% confidence interval

OR: odds ratio

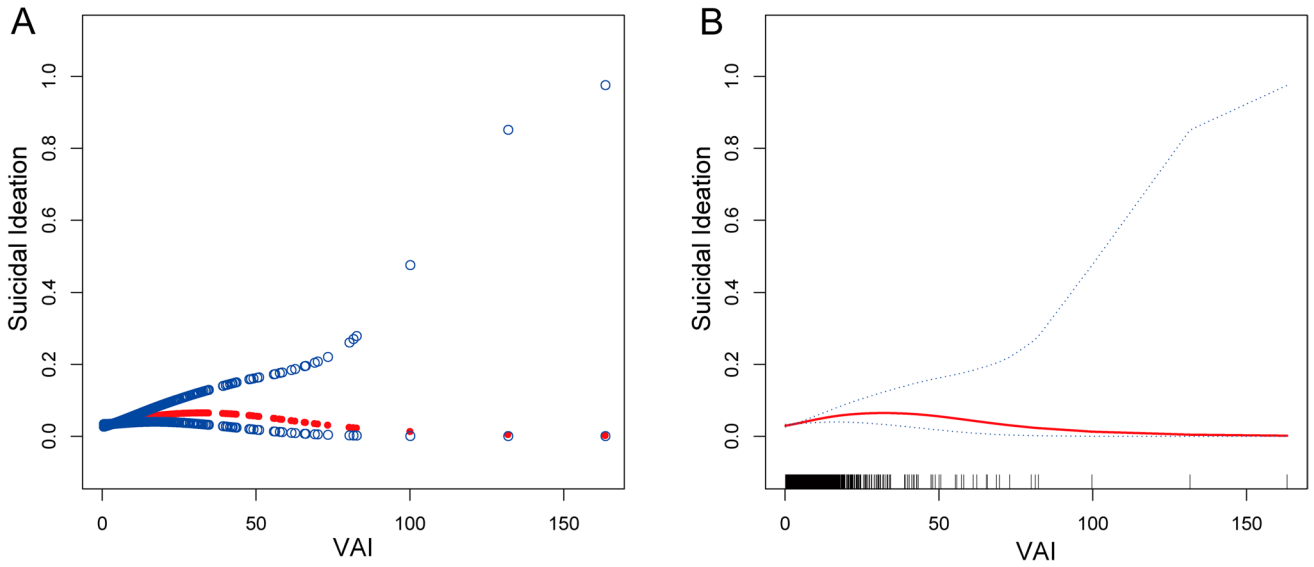

Fig. 2 Nonlinear association between VAI and suicidal ideation. Logarithmic likelihood ratio test for nonlinearity: p = 0.007 (Table 3). A The solid red line represents the smooth curve fit between variables. B Blue bands represent the 95% confidence interval from the fit

Table 4 Association between VAI and suicidal ideation in subgroups

Subgroup		OR (95%CI)	*P* for interaction
Age(year)			0.9552
< 50	*N* = 6751	1.01 (0.98, 1.04)	
≥ 50	*N* = 6932	1.01 (0.98, 1.04)	
Gender			0.2816
Male	*N* = 6888	1.03 (0.99, 1.06)	
Female	*N* = 6795	1.00 (0.97, 1.03)	
Race			0.7171
Mexican American	*N* = 2076	1.03 (0.96, 1.11)	
Other Hispanic	*N* = 1272	1.02 (0.98, 1.07)	
Non-Hispanic White	*N* = 6197	0.99 (0.96, 1.03)	
Non-Hispanic Black	*N* = 2726	1.05 (0.94, 1.18)	
Other race	*N* = 1412	1.02 (0.88, 1.20)	
BMI(kg/m2)			0.5387
< 25	*N* = 3971	1.08 (0.96, 1.21)	
25–30	*N* = 4554	1.01 (0.97, 1.06)	
> 30	*N* = 5158	1.01 (0.98, 1.04)	
Education level			0.1582
Less than 9 th grade	*N* = 1273	1.04 (1.00, 1.08)	
9–11 th grade	*N* = 1933	0.99 (0.92, 1.06)	
High school grad/GED or equivalent	*N* = 3155	1.00 (0.94, 1.07)	
Some college or AA degree	*N* = 4058	0.96 (0.88, 1.05)	
College graduate or above	*N* = 3257	1.09 (1.00, 1.18)	
Marital status			0.3740
Married/living with partner	*N* = 8273	1.02 (0.99, 1.05)	
Widowed/divorced/separated/never married	*N* = 5409	1.00 (0.96, 1.04)	
Hypertension			0.8743
Yes	*N* = 5044	1.01 (0.98, 1.04)	
No	*N* = 8619	1.01 (0.98, 1.05)	
Hyperlipidemia			0.3221
Yes	*N* = 7534	1.01 (0.97, 1.04)	
No	*N* = 3076	1.04 (0.98, 1.11)	
Diabetes			0.1492
Yes	*N* = 1770	1.01 (0.97, 1.04)	
No	*N* = 11572	1.02 (0.99, 1.05)	
Borderline	*N* = 333	0.79 (0.56, 1.11)	
Smoking status			0.5394
Yes	*N* = 6303	1.02 (0.98, 1.05)	
No	*N* = 7362	1.00 (0.97, 1.03)	

The results show that the subgroup analysis was adjusted for all presented covariates except the effect modifier. 95% CI, 95% confidence interval

OR: odds ratio

Discussion

The cross-sectional investigation, involving 15,830 participants, aimed to explore the association between VAI and the presence of SI among adults in the United States. The findings revealed an increased likelihood of SI among those with higher levels of VAI. Notably, nonlinear positive relationships were observed, with differing correlations on either side of the breakpoint at VAI = 5.28. Subgroup analyses and interaction testing indicated that this relationship between VAI and SI was consistent across various demographic scenarios. Our findings suggest that VAI may be used as a predictor for the development of SI, and controlling visceral fat as determined by VAI may help reduce SI and related behaviors. Thus, VAI may offer valuable insights for identifying individuals at risk of SI and

implementing preventative measures to address both SI and actual suicide.

To the best of our knowledge, this research represents the initial attempt to investigate the association between VAI and SI. VAI has widely gained acceptance as a reliable measure of visceral obesity and as a prognostic parameter for various obesity-related disorders [30]. While numerous studies have explored the connections between obesity and SI, there remains an insufficiency of studies examining the association between VAI and SI. Gareth R. Dutton and his colleagues conducted a cross-sectional study involving 271 participants, utilizing BMI as a measure of overall obesity. Their results indicated a significant correlation between higher levels of obesity and an increased occurrence of suicidal thoughts, accompanied by a heightened sense of burden [31]. In another cross-sectional study by Hwanjin Park and colleagues, which included 299,594 individuals undergoing medical checkups, waist circumference was chosen as a metric more indicative of visceral and metabolic obesity. Interestingly, severe abdominal obesity did not exert an impact on suicidal thoughts in either gender, especially when accounting for depressive feelings [32]. Guixiang Zhao et al. conducted a comprehensive study on the adult female population in the United States, showing a positive correlation between SI and waist circumference. This correlation persisted even after adjusting for current depression or chronic disease, lifestyle-related behaviors, and sociodemographic characteristics [33]. In 2011, a study by Birgit Wagner and her colleagues, a representative sample of 2436 individuals from the German population was investigated to assess the prevalence of suicide attempts and suicidal behavior across various BMI categories. The findings demonstrated that those who were extremely obese had a higher chance of engaging in suicidal behavior [34]. While the relationship between obesity and depression has been repeatedly discussed in previous studies, results remain inconsistent, and no specific conclusion has been made. Our investigation aligns with the majority of prior findings, suggesting that VAI, as a reliable marker of visceral obesity, exhibits a positive correlation with an increased likelihood of SI. This correlation persists across diverse population backgrounds. Hence, we can extrapolate and validate the outcomes of previous studies, as empirical evidence suggests a positive association between obesity and suicidal ideation. However, additional prospective experiments are required for further validation.

While the exact mechanism behind the association between VAI and SI remains uncertain, we may examine and provide some insight into it by considering the reciprocal mechanism of the relationship between obesity and SI. From a psychosocial perspective, this association can be elucidated by weight stigma, which encompasses adverse attitudes and beliefs associated with body weight [35]. Individuals with obesity often face significant stigma, and encounters with weight stigma are strongly linked to symptoms of depression, diminished self-esteem, and inclinations toward suicidal thoughts [36]. Obesity may exacerbate mental health issues by influencing the experience of weight stigma, thereby contributing to suicidal ideation [37]. From a biological perspective, the widely recognized serotonin hypothesis offers context, linking reduced central serotonin levels to suicidal tendencies, aggressive awareness, and increased behavioral risks [38]. In animal models of obesity, induction of obesity through a 7-week high-fat diet diminishes baseline serotonin release in the hypothalamus and serotoninergic neuron activity [39, 40]. Postmortem analysis of hypothalamic tissue from overweight or obese individuals reveals decreased levels of SERT protein in the infundibular nucleus, responsible for transporting extracellular serotonin into neurons [41]. Additionally, obese females, compared to lean counterparts, exhibit lower levels of serotonin and its metabolites in cerebrospinal fluid [42]. Hence, it is plausible to infer that reduced serotonin levels in obese individuals contribute to an elevated risk of suicidal ideation or behavior.

VAI serves as a promising alternative to BMI and waist circumference in overcoming the limitations associated with discerning between muscle and fat content [43]. VAI exhibits superior predictive capabilities for metabolic diseases compared to indicators such as BMI and WC [44]. This widely accessible and cost-effective technology makes it an attractive option, providing a gateway to more comprehensive illness prediction parameters and facilitating the clinical exploration of innovative therapeutic advancements.

GLP-1 receptor agonists—known to reduce visceral fat through AMPK-mediated lipolysis and suppression of adipocyte hypertrophy [45], may indirectly mitigate SI risk by improving metabolic-inflammatory profiles linked to obesity. Preclinical studies indicate GLP-1 agonists enhance central serotonin synthesis via CREB-BDNF signaling, counteracting obesity-related 5-HT deficiency implicated in SI pathogenesis [46, 47]. Additionally, their anti-inflammatory effects (e.g., TNF-α and IL-6 inhibition) may attenuate neuroinflammation-driven depressive phenotypes [48, 49]. Given the significance of SI as a public health concern and the potential role of GLP-1 in modulating visceral fat, future clinical trials are needed to assess the effectiveness of GLP-1-mediated visceral fat modulation in reducing SI.

Strengths and limits

Our research offers several valuable advantages. Firstly, by utilizing a nationally representative sample that captures the features of a demographically diverse cohort of adult

individuals in the United States, this research is the first to examine the relationship between VAI and the risk of SI. Secondly, the results of this study were strengthened through subgroup analysis and adjustment for relevant factors. Finally, we investigated nonlinearity in greater detail and conducted threshold analysis, providing a more precise depiction of the variations in this relationship. However, it is imperative to recognize the intrinsic limitations of this study. Initially, the cross-sectional design makes our study vulnerable to reverse causality. Secondly, relying solely on a self-administered questionnaire, rather than conducting in-depth psychiatric interviews, the PHQ-9 was originally intended for screening depressive symptoms and assessing their severity rather than directly gauging suicidal ideation risk [50]. However, PHQ-9 item 9 has been shown to be an effective indicator of suicidal ideation and should be utilized by medical practitioners in screening, diagnosing, and dealing with suicidal ideation. Finally, the PHQ-9 utilizes personal questionnaires as an evaluation method for SI, which introduces inevitable recall bias.

Conclusion

The study findings highlight a significant and independent association between elevated VAI and the risk of SI, even after robust adjustments. This underscores the importance of early intervention to mitigate the progression of SI in individuals with elevated VAI levels. Further prospective research is warranted to validate these findings, elucidate the underlying pathophysiological mechanisms, and explore potential treatment strategies.

What is already known on this subject?

Previous studies have shown that obesity is linked to mental health issues, including suicidal tendencies. BMI has limitations in differentiating visceral fat. The VAI is a better indicator of visceral adiposity and is associated with various diseases. Also, a correlation between high VAI and psychological disorders like depression has been found.

What this study adds?

This study is the first to explore the relationship between VAI and SI in U.S. adults. It reveals a significant positive and nonlinear association between VAI and SI. The relationship is consistent across different demographic groups. The findings suggest VAI could be a useful predictor for SI, offering potential for suicide prevention strategies.

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Author contributions GQ contributed to conception, design, data collection, data analysis, data interpretation and critically revised the manuscript. JT contributed to data analysis, data interpretation and critically revised the manuscript. HH contributed to conception, design and drafted the manuscript. MS and YC contributed to conception and critically revised the manuscript. BW, YY, BZ, and GY contributed to conception and critically revised the manuscript. All authors contributed to the article and approved the submitted version.

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Data availability In this study, publicly accessible datasets were examined. These data can be found here: (https://wwwn.cdc.gov/nchs/nhanes/analyticguidelines.aspx, accessed on 1 November 2022).

Declarations

Ethics approval and consent to participate This study was reviewed and approved by the NCHS Ethics Review Board. The patients/participants provided written informed consent to participate in this study.

Competing interests The authors declare no competing interests.

Informed consent The informed consent forms of the NHANES database can all be found on its official website.

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