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Exploring the relationship between fat mass index and metabolic syndrome among cancer patients in the U.S: An NHANES analysis

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Data regarding the connection between Fat Mass Index (FMI) and Metabolic Syndrome (MetS) in cancer survivors remain limited. This study aimed to assess the association between FMI and the likelihood of MetS among cancer survivors by conducting a population-based cross-sectional study. This cross-sectional study utilized data from the National Health and Nutrition Examination Survey (NHANES) to examine a sample of 799 adult cancer survivors, aged over 20 years old, spanning the years 1999–2006 and 2011–2018. MetS was defined according to the criteria established by the Adult Treatment Panel III of the National Cholesterol Education Program (NCEP). To explore the association between fat mass index FMI and the prevalence of MetS among cancer survivors, multivariate logistic regression analyses were conducted. Additionally, restricted cubic splines were used to assess both linear and nonlinear relationships between FMI and MetS. After adjusting for potential confounders, the logistic regression analysis of multistage weighted complex sampling data demonstrated that a higher FMI significantly increased the odds of developing MetS (odds ratio [OR] = 1.33, 95% confidence interval [CI]: 1.09–1.61, $p = 0.01$). This association remained robust when FMI was categorized into tertiles. Specifically, the adjusted ORs for MetS in the second and third tertiles were 4.80 (95% CI: 1.95–11.79) and 8.95 (95% CI: 2.51–31.94), respectively (p for trend = 0.001). Furthermore, our analysis indicated a significant nonlinear relationship between FMI and the likelihood of MetS ($p < 0.0001$). In this research, we discovered that an elevated FMI is significantly associated with a higher prevalence of MetS among cancer survivors in the U.S. adult population. These findings underscore the importance of managing body fat to prevent MetS in this group.

Keywords Metabolic syndrome, Fat mass index, Cancer patient, NHANES, Cross-sectional study

Abbreviations

NHANES	National Health and Nutrition Examination Survey
FMI	Fat Mass Index
MetS	metabolic syndrome
MET	metabolic equivalents
HDL	High-Density Lipoprotein
LDL	Low-Density Lipoprotein
TC	total cholesterol
TG	triglyceride
CHD	coronary heart disease
CKD	chronic kidney disease
IFG	impaired fasting glucose
IGT	impaired glucose tolerance
DM	diabetes mellitus
BMI	Body Mass Index
OR	Odds Ratio
CI	Confidence Interval

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P-value In bold indicates statistical significance

Cancer survivors face various health challenges, including an increased likelihood of developing metabolic syndrome (MetS)[1].MetS is a prevalent long-term complication associated with cancer, impacting both health outcomes and quality of life. It includes conditions such as obesity, diabetes, and insulin resistance[2], along with imbalances in reproductive hormones[3], which have been shown to influence both the development and progression of cancer, thereby affecting cancer-related mortality[4].MetS may also develop as a common long-term complication following treatment, negatively impacting quality of life[5].Cancer survivors with MetS face harmful consequences, such as atherosclerotic disease and cancer recurrence[1].

The fat mass index (FMI) provides a more accurate evaluation of body fat by relating fat mass to height, marking it as an important measure compared to conventional indicators such as body mass index (BMI)[6]. Assessment of body composition and morphological analysis indicate the presence of smaller adipocytes and adipose atrophy. In cancer patients, fat loss is linked to a decreased quality of life[7]. The FMI provides crucial insights into how adiposity affects metabolic health, especially in populations with altered body compositions, such as cancer survivors. Previous studies have highlighted the impact of body composition on metabolic health[8]. Specifically, an increase in fat mass and the buildup of visceral fat significantly heighten the risk of developing MetS[9]. Understanding the relationship between FMI and MetS in cancer survivors is essential for developing targeted interventions aimed at reducing the risk of MetS and improving overall health outcomes for this vulnerable population.This study aims to explore the connection between FMI and MetS among U.S. cancer survivors, utilizing NHANES data. The objective is to offer insights that could guide clinical practices and public health strategies, ultimately improving the long-term health of cancer survivors.

Materials and methods

Data sources

The data for this study were obtained from eight cycles of the National Health and Nutrition Examination Survey (NHANES), covering the years 1999–2006 and 2011–2018. The NHANES database regularly gathers nationally representative health-related data from the non-institutionalized U.S. population using a stratified, multistage probability sampling design[10]. The survey received approval from the NCHS Research Ethics Review Committee, ensuring that informed consent was obtained from all participants. Additional details regarding the study samples can be found on the NHANES website(https://www.cdc.gov/nchs/nhanes/).

Study design and population

The National Center for Health Statistics (NCHS) Research Ethics Review Board approved all NHANES study protocols for the periods 1999–2006 (Protocols #98 – 12 and #2005-06) and 2011–2018 (Protocol #2011-17). Written informed consent was obtained from participants during each survey cycle. Consequently, no additional ethical approval or informed consent was required. All analyses were conducted in compliance with NHANES guidelines and regulations.

Strict exclusion criteria were applied to ensure the scientific rigor and consistency of the study sample. This cross-sectional study utilized data from the NHANES, spanning two periods: 1999–2006 and 2011–2018. The analysis focused on adults aged 20 years and older.The exclusion criteria were as follows: 34,181 participants under 20 years old were excluded, 42,537 participants without information on MetS and cancer were removed, 596 participants missing data required for FMI calculation were excluded, and 2,517 participants with incomplete covariate data were also excluded. Ultimately, out of the initial 80,630 participants, only 799 met the eligibility criteria and were included in the final analysis (Fig. 1).

Measurement of fat mass index

FMI was calculated based on body fat mass, which was measured using dual-energy X-ray absorptiometry (DXA), a well-established and reliable method for body composition analysis. FMI was determined by dividing participants' total fat mass (in kilograms) by the square of their height (in meters), according to the following formula:

FMI = Fat Mass (kg) / Height (m^2)[11].

To address missing DXA data, we adhered to the Centers for Disease Control and Prevention (CDC) guidelines, which recommend applying multiple imputation techniques. Specifically, five imputed datasets were generated to handle missing values within the NHANES dataset. These imputed datasets were then pooled, and subsequent analyses were performed using the R statistical software. For the purpose of the analysis, participants' total fat mass was categorized into tertiles (T1-T3) to assess variations in FMI across different levels of fat mass.

Ascertainment of cancer

NHANES includes a medical conditions section that gathers self-reported health information. By focusing on individuals who have been diagnosed with cancer, we aim to understand the long-term effects of cancer and its treatment on metabolic health, which is crucial for developing tailored interventions and improving the quality of life for cancer survivors.

Individuals who had a history of cancer or malignancy were identified based on their affirmative responses to the inquiry, 'Have you ever been informed by a medical doctor or health care provider that you have had cancer or any form of malignancy?'Subsequently, those who acknowledged a cancer diagnosis were asked to specify the exact type of cancer they were diagnosed with.

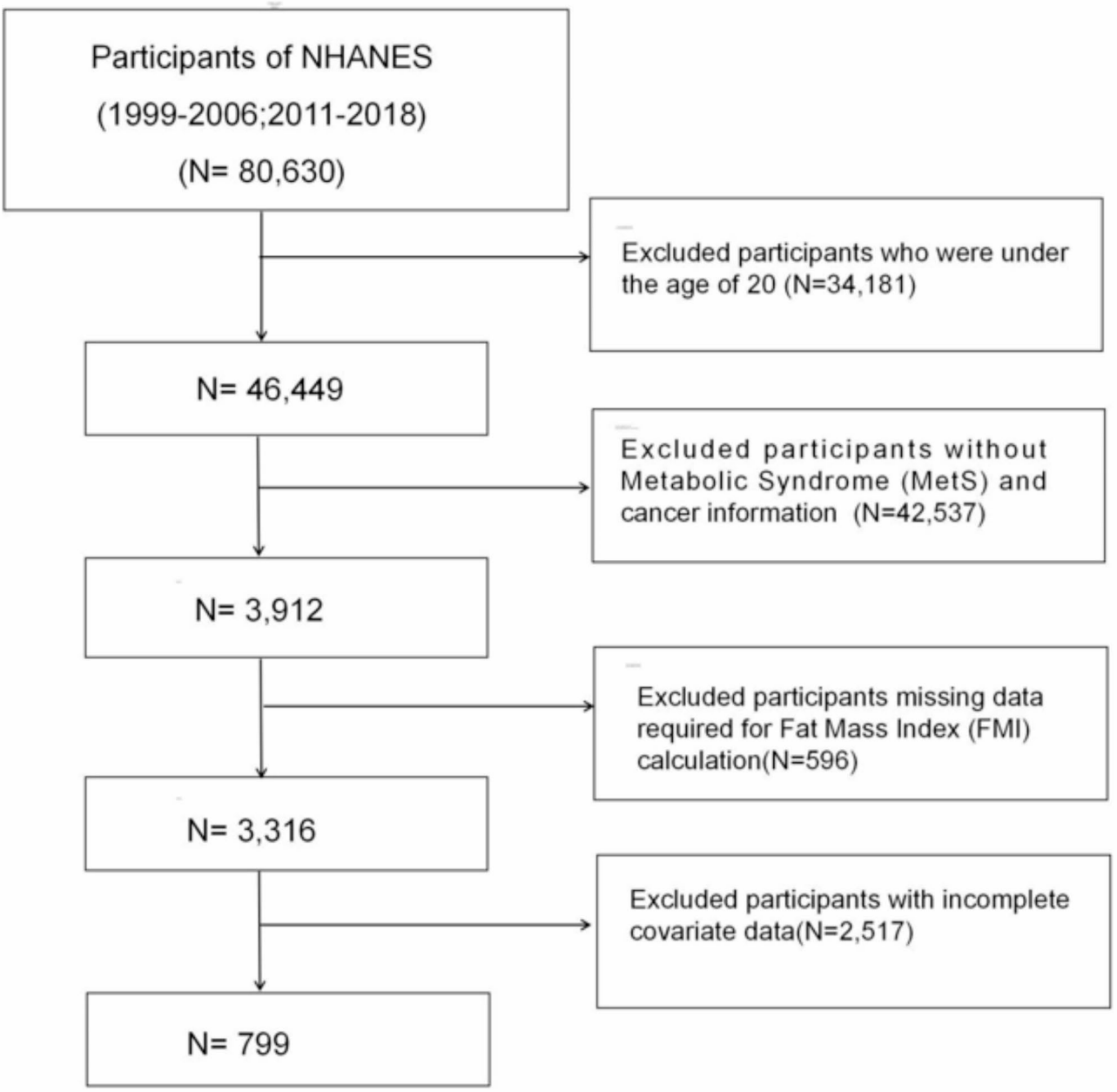

Fig. 1. Flowchart for Study Participant Selection: NHANES 1999–2006 & 2011–2018.

Ascertainment of MetS

MetS is defined according to the diagnostic criteria established by the National Cholesterol Education Program Adult Treatment Panel III (NCEP ATP III)[12]. According to the International Diabetes Federation (IDF), metabolic syndrome is diagnosed if at least three of the following conditions are met: (1) Waist circumference of at least 102 cm in men or 88 cm in women; (2) Triglyceride levels at or above 1.69 mmol/L (150 mg/dL); (3) Low HDL cholesterol, defined as levels below 1.03 mmol/L in men or below 1.29 mmol/L in women; (4) Hypertension, defined as a systolic blood pressure of 130 mmHg or higher, diastolic blood pressure of 85 mmHg or higher, current use of antihypertensive medication, or a diagnosis of hypertension by a physician; (5) Hyperglycemia, defined by fasting blood glucose levels of 100 mg/dL or higher, current use of glucose-lowering therapy, or a diagnosis of diabetes.

Covariates

In our study, covariates included a variety of factors: Age (years, continuous), gender (female/male), race/ethnicity (Mexican American, Non-Hispanic Black, Non-Hispanic White, Others), educational level (below high school, high school or above), marital status (married/cohabitant, widowed, divorced/separated, never married), Poverty Income Ratio (PIR, continuous).Alcohol consumption was assessed using self-reported data

from the previous year, collected through the Alcohol Use Questionnaire (ALQ101), which inquired whether participants had consumed at least 12 alcoholic drinks in the past year. Based on this data, participants were classified into five groups (never, mild, moderate, heavyand former)[13].Additional covariates included smoking status (never, former, current), and the presence of various disease conditions, such as diabetes, hypertension, hyperlipidemia, stroke, coronary heart disease (CHD), chronic kidney disease (CKD). The diabetes category was further divided into diabetes mellitus (DM), impaired fasting glycemia (IFG), and impaired glucose tolerance (IGT). Hypertension, hyperlipidemia, stroke, CHD, and CKD were diagnosed based on index measurements, medication usage, and self-report. BMI was calculated as weight (kg) divided by the square of height (m^2). It was categorized as < 25 kg/m^2,25–29.9 kg/m^2, and ≥ 30 kg/m^2 based on their BMI.Physical activity (PA) is measured using Metabolic Equivalent of Task (MET) minutes on a weekly basis. It is divided into three levels: low (less than 600 min per week), moderate (600 to 8,000 min per week), and high (8,000 min or more per week). The MET values, which are calculated from the responses to the Physical Activity Questionnaire (PAQ), serve as the basis for assigning PA into these respective categories[14].The NHANES laboratory data from 1999 to 2006 and 2011–2018 included both males and females and encompassed measurements for triglycerides (TG, mg/dL, continuous), high-density lipoprotein (HDL, mg/dL, continuous), low-density lipoprotein cholesterol (LDL, mg/dL, continuous), fasting glucose (mg/dL, continuous), total cholesterol (TC, mg/dL, continuous), and other relevant biomarkers.

Statistical analysis

In this study, the sample weights, stratifications, and clustering methods utilized in the NHANES study were applied to all statistical analyses to account for the complex, multistage sampling design employed to select a representative sample of the noninstitutionalized civilian U.S. population[15]. Our study sample comprised eight cycles of continuous NHANES data, spanning from 1999 to 2006 and from 2011 to 2018. To account for the U.S. population, sampling weights were adjusted, with distinct reference populations assigned to each of the two periods. For the 1999–2002 cycles, the 4-year sampling weights (wtsaf4 year) were used, whereas the 2-year sampling weights (wtsaf2 year) were applied to the cycles from 2003 to 2006 and 2011–2018. Furthermore, the NHANES stratification variable (SDMVSTRA) and the primary sampling unit variable (SDMVPSU) were included according to the survey design to ensure precise variance estimation. The survey design R package was used to process the dataset's sampling weights, which were then integrated into the survey design analyses.

Participants were categorized into groups with and without MetS. Differences between the groups were assessed using Chi-square (χ^2) tests for categorical variables and ANOVA for continuous variables. Continuous variables are reported as weighted means ± standard errors (SEs), and categorical variables are presented as weighted proportions. Descriptive statistics for the entire study population were computed, and the FMI was categorized into tertiles. The association between FMI and MetS was evaluated using multivariate logistic regression, with results presented as odds ratios (ORs) accompanied by 95% confidence intervals (CIs).Model 1 did not include any variable adjustments, while Model 2 adjusted only for age, ethnicity, and gender. Model 3 further adjusted for marital status, BMI, education, alcohol consumption, smoking status, PIR, MET, total energy, stroke, CHD, CKD, and cancer types.Then, an analysis using a weighted restricted cubic spline (RCS) with four knots was conducted to explore the nonlinear relationships between the risk of MetS and FMI among cancer patients. Additionally, subgroup analyses and interaction tests were conducted to further explore the association between FMI and MetS.The results were visually represented with forest plots generated using the "forestplot" R package, which effectively highlight subgroup-specific effects.All statistical analyses were performed using R software (version 4.4.1), with a two-sided $p < 0.05$ deemed statistically significant.

Results

Baseline characteristics of study participants

A total of 799 participants were enrolled in the study, with 44.53% (415) males and 55.47% (384) females. Table 1 presents the baseline characteristics of cancer survivors, stratified by the presence or absence of MetS. Of the total participants, 44.80% (358) were diagnosed with MetS.

Participants with MetS tended to be older, predominantly male, and had a lower PIR.They also exhibited higher BMI, lower physical activity levels, TC, and elevated TG, fasting glucose, and FMI. Additionally, individuals with MetS had a higher prevalence of hypertension, hyperlipidemia, diabetes (including 40.50% with DM, 21.19% with IFG, and 6.11% with IGT), CKD, and CHD.

The relationship between FMI and MetS

Table 2 presents the results of the multivariate regression analysis. After adjusting for potential confounders, all four models showed a positive association between FMI and MetS. Specifically, in Model 3, which controlled for a range of confounding variables, a significant positive correlation was observed between FMI and MetS, with an odds ratio (OR) of 1.33 and a 95% confidence interval (CI) of 1.09 to 1.61.

FMI was also reclassified as a categorical variable (T1–T3) based on tertiles, with T1 serving as the reference group. Model 3 incorporated various covariates, and compared to the lowest FMI category (T1), the adjusted ORs for MetS in T2 and T3 were 6.13 (95% CI: 3.56–10.54) and 13.40 (95% CI: 7.37–24.38) in Model 1, respectively. In Model 3, participants in higher FMI tertiles exhibited a significantly increased likelihood of MetS compared to those in the lowest tertile (OR = 8.95; 95% CI: 2.51–31.94, $P = 0.001$).

The p-values for the linear trend across FMI tertiles in relation to MetS for Models 1, 2, and 3 were < 0.0001, < 0.0001, and 0.001, respectively. All detailed results are presented in Table 2. These findings consistently demonstrate that higher FMI is associated with an increased risk of MetS, with a significant relationship observed across all analytical models.

Characteristic	Overall	MetS	Without MetS	*P*-value
		N = 358	*N* = 441	
Age(year)	60.36 ± 0.65	62.62 ± 0.76	58.70 ± 0.93	0.001
Gender,%				0.03
Male	415(44.53)	185(50.70)	230(40.01)	
Female	384(55.47)	173(49.30)	211(59.99)	
Ethnicity, %				0.29
Mexican	43(1.43)	26(2.10)	17(0.94)	
White	586(88.01)	254(86.49)	332(89.12)	
Black	99(4.63)	46(5.29)	53(4.15)	
Other	71(5.92)	32(6.12)	39(5.78)	
Education level, %				0.07
High school or above	751(97.22)	330(96.15)	421(98.01)	
Below high school	48(2.78)	28(3.85)	20(1.99)	
PIR	3.45 ± 0.08	3.23 ± 0.12	3.62 ± 0.09	0.01
BMI (kg/m^2)				< 0.0001
< 25	256(32.75)	33(8.61)	223(50.43)	
25-29.9	259(31.24)	121(32.74)	138(30.15)	
≥ 30	284(36.00)	204(58.64)	80(19.43)	
Marital status,%				0.05
Married/Cohabitant	542(73.02)	249(75.91)	293(70.91)	
Widowed	100(10.27)	49(11.36)	51(9.48)	
Divorced/separated	119(12.32)	53(10.91)	66(13.35)	
Never married	38(4.38)	7(1.82)	31(6.25)	
Drinking status,%				0.09
Former	170(17.92)	90(21.62)	80(15.21)	
Heavy	82(11.56)	30(9.70)	52(12.92)	
Mild	359(45.41)	158(44.96)	201(45.74)	
Moderate	104(17.32)	35(14.30)	69(19.53)	
Never	84(7.80)	45(9.41)	39(6.61)	
Smoking status,%				0.6
Former	329(38.21)	158(40.82)	171(36.30)	
Never	344(45.50)	150(43.79)	194(46.76)	
Now	126(16.29)	50(15.39)	76(16.94)	
MET				0.22
Low	290(34.98)	134(36.51)	156(33.86)	
Moderate	447(57.34)	205(58.10)	242(56.79)	
High	62(7.68)	19(5.39)	43(9.35)	
TC(mg/dL)	199.28 ± 2.11	193.96 ± 3.29	203.18 ± 2.70	0.03
TG(mg/dL)	125.10 ± 3.12	167.01 ± 5.37	94.41 ± 2.91	< 0.0001
Fasting Glucose(mg/dL)	107.76 ± 1.24	120.02 ± 2.20	98.78 ± 0.96	< 0.0001
LDL(mg/dL)	116.96 ± 1.67	113.33 ± 2.64	119.62 ± 2.19	0.08
HDL (mg/dL)	57.31 ± 0.94	47.21 ± 0.82	64.71 ± 1.30	< 0.0001
FMI (kg/m^2)	10.64 ± 0.19	12.67 ± 0.31	9.16 ± 0.23	< 0.0001
FMI group				< 0.0001
Tertile1	266(31.46)	38(9.22)	228(47.74)	
Tertile2	266(34.11)	133(37.46)	133(31.66)	
Tertile3	267(34.43)	187(53.32)	80(20.60)	
Hypertension,%				< 0.0001
No	311(44.16)	80(23.62)	231(59.21)	
Yes	488(55.84)	278(76.38)	210(40.79)	
Hyperlipidemia, %				< 0.0001
No	165(20.19)	28(7.20)	137(29.69)	
Yes	634(79.81)	330(92.80)	304(70.31)	
Diabetes, %				< 0.0001
DM	186(20.25)	153(40.50)	33(5.43)	
IFG	110(12.79)	69(21.19)	41(6.64)	

Continued

Characteristic	Overall	MetS	Without MetS	*P*-value
		N = 358	*N* = 441	
IGT	57(6.03)	21(6.11)	36(5.96)	
No	446(60.93)	115(32.19)	331(81.96)	
Stroke, %				0.72
No	754(96.17)	338(95.83)	416(96.41)	
Yes	45(3.83)	20(4.17)	25(3.59)	
CKD, %				< 0.001
No	578(80.41)	233(73.74)	345(85.30)	
Yes	221(19.59)	125(26.26)	96(14.70)	
CHD, %				< 0.001
No	734(93.76)	315(89.96)	419(96.55)	
Yes	65(6.24)	43(10.04)	22(3.45)	

Table 1. Baseline characteristics of cancer survivors by MetS status (*N* = 799). NHANES: National Health and Nutrition Examination Survey; BMI: Body Mass Index; IFG: Impaired Fasting Glucose; IGT: Impaired Glucose Tolerance; DM: Diabetes Mellitus; CKD: Chronic Kidney Disease; CHD: Coronary Heart Disease; TG: Triglycerides; FMI: Fat Mass Index; MET: Metabolic Equivalents; HDL: High-Density Lipoprotein; LDL: Low-Density Lipoprotein. Continuous variables are presented as the mean ± standard deviation (SD), and categorical variables are shown as n (%). A p-value < 0.05 was considered statistically significant.

Total FMI score	Model 1[a] (OR,95%CI,*P*-value)	Model 2[b] (OR, 95% CI, *P*-value)	Model 3[c] (OR, 95% CI, *P*-value)
Continuous	1.28(1.19—1.38) < 0.0001	1.46(1.32—1.62) < 0.0001	1.33(1.09—1.61) 0.01
Four categorical groups			
T1	ref	ref	ref
T2	6.13(3.5—10.54) <0.0001	9.15(4.74—17.65) <0.0001	4.80(1.95—11.79) <0.001
T3	13.40(7.3—24.38) <0.0001	34.75(14.58—82.80) <0.0001	8.95(2.51—31.94) 0.001
p for trend	< 0.0001	< 0.0001	0.001

Table 2. ORs (95% CIs) for MetS according to the FMI. [a]Model 1 Unadjusted (no covariates included); [b]Model 2 Adjusted for continuous variable (age, years) and categorical variables (ethnicity: Non-Hispanic White, Non-Hispanic Black, Mexican American, Other; gender: Male, Female); [C]Model 3 Further adjusted for additional covariates, including continuous variables (PIR, MET, total energy intake) and categorical variables (marital status: Married/Cohabitant, Widowed, Divorced/Separated, Never married; educational level: Below high school, High school or above; alcohol consumption: Never, Mild, Moderate, Heavy, Former; smoking status: Current smoker, Former smoker, Never smoker; BMI group: < 25 kg/m^2,25–29.9 kg/m^2, ≥ 30 kg/m^2;presence of stroke, CHD, CKD(Yes, No), and various cancer types).

Statistical analysis of restricted cubic spline regression

After adjusting for covariates, our analysis revealed a significant nonlinear relationship between FMI and MetS, as demonstrated by the RCS regression (p-value for overall < 0.0001, p-value for nonlinearity < 0.0001). The RCS curve showed that as FMI increased, the log odds of MetS rose steeply when FMI exceeded 25 and continued to increase at a slower but consistent rate at higher FMI levels, eventually plateauing beyond 40. For instance, at an FMI of 30, the log odds of MetS was approximately 0.5, compared to -2.5 at an FMI of 20 (Fig. 2). These findings highlight a threshold effect, where FMI levels above 25 are strongly associated with an elevated risk of MetS.

Subgroup analysis

As shown in Fig. 3, interaction tests and stratified analyses were conducted to further evaluate the association between FMI and MetS across various subgroups. The analyses accounted for gender, ethnicity, marital status, BMI, education level, alcohol intake, smoking habits, PIR, MET, hypertension, hyperlipidemia, diabetes, stroke, CKD, and CHD.

The results indicated that the positive association between FMI and MetS was not significantly influenced by marital status, ethnicity, education level, alcohol intake, smoking habits, MET, hyperlipidemia, hypertension, stroke, CKD or CHD (all interaction p-values > 0.05). However, significant interactions were observed for gender, diabetes and BMI (interaction p-values < 0.05), suggesting these factors may modify the relationship between FMI and MetS.

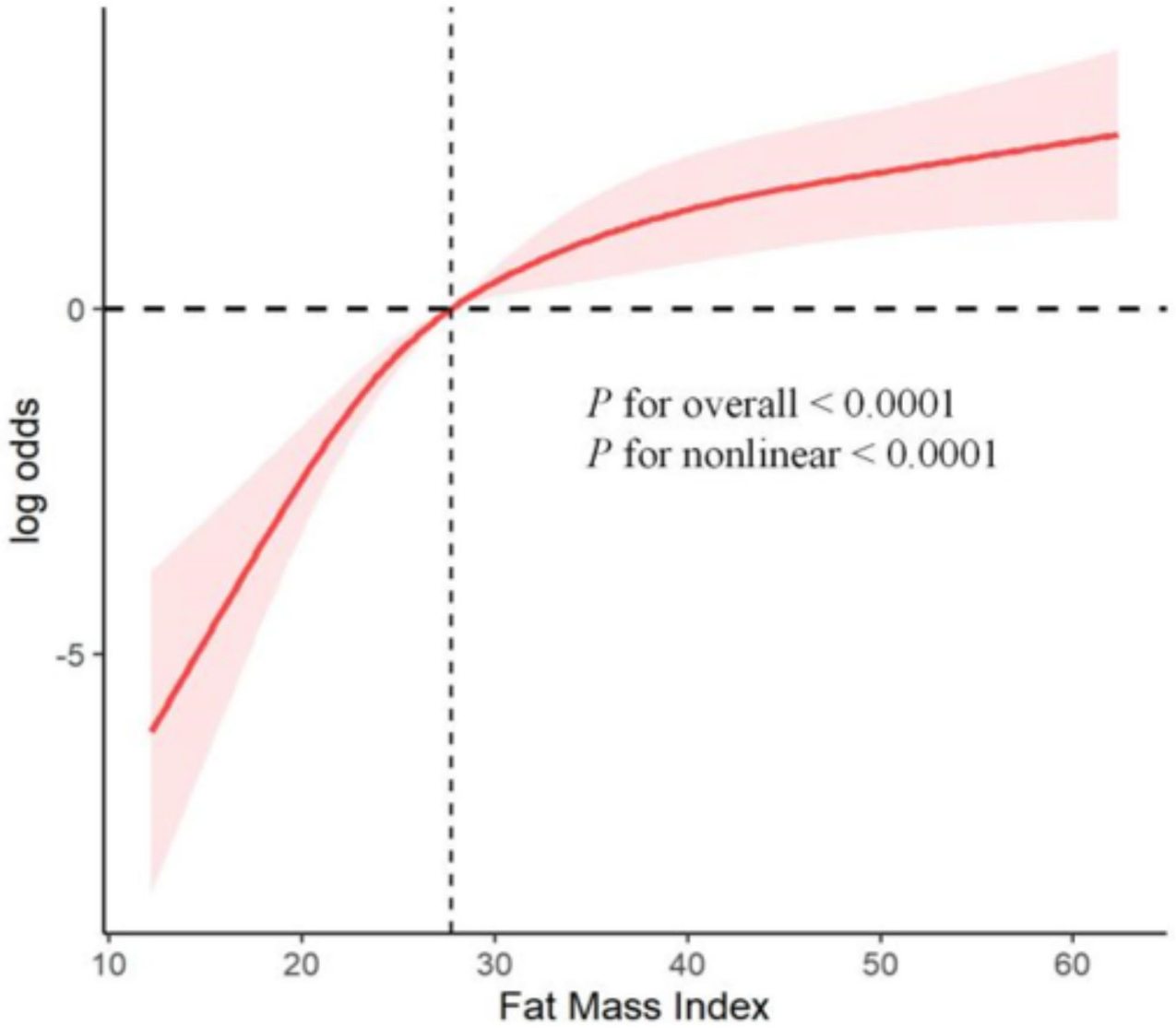

Fig. 2. The restricted cubic spline (RCS) curve illustrates the association between FMI and the risk of MetS among U.S. cancer survivors. The analysis adjusted for continuous variables (age, PIR, MET, total energy intake) and categorical variables (gender: Female/Male; ethnicity: Mexican American, Non-Hispanic Black, Non-Hispanic White, Others; marital status: Married/Cohabitant, Widowed, Divorced/Separated, Never married; educational level: Below high school, High school or above; alcohol intake: Never, Mild, Moderate, Heavy, Former; smoking status: Never, Former, Current; BMI group: < 25 kg/m^2,25–29.9 kg/m^2, ≥ 30 kg/m^2;presence of chronic conditions: stroke, CKD, CHD, and various cancer types).

Discussion

In this cross-sectional study, we explored the relationship between FMI and MetS among cancer survivors in the United States, using NHANES data from 1999 to 2006 and 2011–2018. Our findings demonstrate a robust positive correlation between increased FMI and an elevated risk of MetS, with this association remaining consistent across tertiles (T1–T3). Furthermore, our analysis identifies a significant nonlinear relationship between FMI and MetS, as evidenced by smooth curve fitting, suggesting that higher body fat levels in cancer survivors are associated with a heightened risk of MetS, regardless of other conventional risk factors. Additionally, this study provides detailed stratified analyses to date, offering insights into the interplay between FMI and MetS across various subgroups of adult cancer survivors.

Our research confirms a strong link between increased FMI and the risk of MetS in cancer survivors. These results are consistent with prior studies, which suggest that the distribution of body fat[16], rather than overall body weight, is key in the onset of MetS[17]. FMI is a gender-specific, innovative metric designed to assess body composition with enhanced accuracy in measuring fat mass quantities in individuals with metabolic abnormalities.

Cancer survivors with higher FMI may require targeted interventions to manage body fat and mitigate the risk of MetS.The potential mechanisms that connect FMI to MetS may involve insulin resistance, chronic

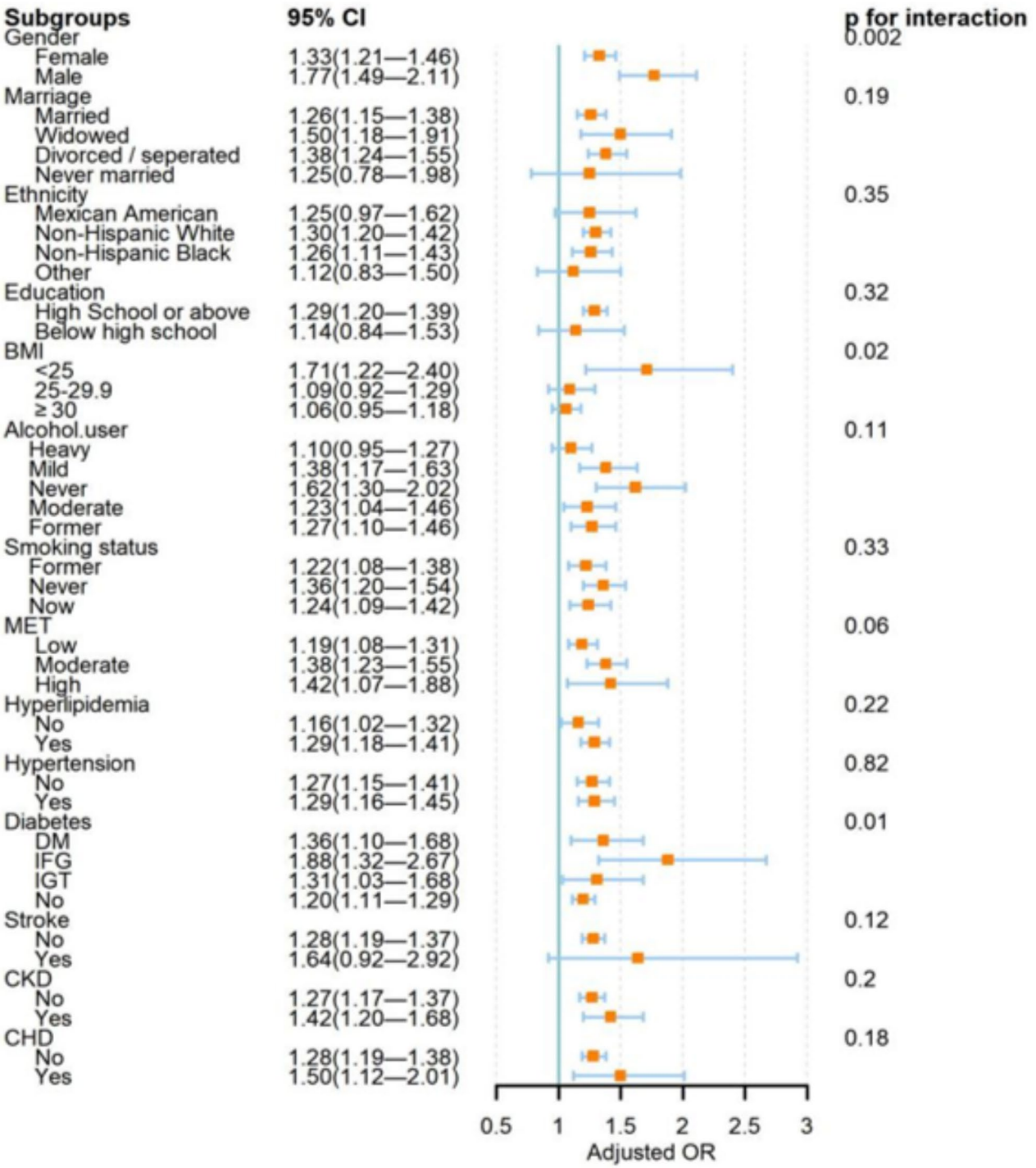

Fig. 3. Subgroup analysis of the association between FMI and MetS. and categorical variables (gender: Female/Male; ethnicity: Mexican American, Non-Hispanic Black, Non-Hispanic White, Others; marital status: Married/Cohabitant, Widowed, Divorced/Separated, Never married; educational level: Below high school, High school or above; alcohol intake: Never, Mild, Moderate, Heavy, Former; smoking habits: Never, Former, Current; BMI group: < 25 kg/m^2,25–29.9 kg/m^2, ≥ 30 kg/m^2;and the presence of hypertension, hyperlipidemia, diabetes, stroke, CKD, CHD: Yes/No).

inflammation, and dysregulation of adipokines. Visceral fat, an excessive adipose tissue type, actively secretes pro-inflammatory cytokines and adipokines that play a crucial role in the pathophysiology of MetS[18]. Furthermore, cancer therapies, including chemotherapy and hormonal treatment[19], can alter body composition by increasing fat mass and reducing lean mass[20]. The metabolic disruptions caused by cancer and its treatments might also

intensify the progression of MetS components[19]. Therefore, increased adiposity may lead to MetS through mechanisms such as inflammation, insulin resistance, and hormonal imbalances among cancer survivors.

This study has several strengths. Our findings underscore the critical need for consistent monitoring of metabolic health in cancer survivors, given their elevated risk of developing MetS. Incorporating FMI into standard follow-up protocols could significantly enhance the early identification of at-risk individuals, enabling timely interventions to mitigate these risks.Furthermore, this study highlights the importance of targeted intervention strategies aimed at reducing excess adiposity in cancer survivors. These strategies are directly tied to the observed associations in our findings, as excess adiposity represents a modifiable risk factor for MetS. By addressing this factor through comprehensive lifestyle interventions—such as dietary improvements, structured physical activity programs, and targeted healthcare measures—these strategies could not only lower the risk of MetS but also support better overall health outcomes. This aligns with the broader goal of improving long-term survivorship care and addressing the unique health challenges faced by cancer survivors.

However, this study has several limitations. First, its cross-sectional design prevents us from establishing a causal relationship between FMI and MetS. Second, despite adjusting for numerous relevant covariates, residual confounding factors may still influence the findings. Third, the absence of a formal sensitivity analysis limits the evaluation of the robustness of our results under different scenarios, such as excluding extreme values or employing alternative statistical models. Future research should include sensitivity analyses to validate findings across subgroups and assess the impact of potential biases or model assumptions.

Additionally, larger and more representative sample sizes will be essential to enhance the generalizability and statistical power of future studies. Longitudinal studies should also be conducted to validate these findings through objective measures of body composition and to monitor changes over time. Furthermore, specific subgroups, such as nonmelanoma skin cancer (NMSC) survivors, warrant further investigation due to their unique metabolic profiles and potential risks for MetS. These individuals may experience distinct pathways to metabolic dysfunction influenced by their disease characteristics and treatment modalities. Understanding these nuances will provide a more comprehensive perspective on MetS risks across diverse cancer survivor populations.

Conclusion

In conclusion, a higher FMI is significantly linked to an increased risk of MetS among cancer survivors. These results emphasize the necessity for comprehensive management strategies aimed at reducing body fat to enhance metabolic health in this vulnerable group. Further epidemiological studies and investigations into the pathological mechanisms linking FMI and MetS among cancer survivors are necessary. By exploring this relationship more thoroughly, we can more effectively identify cancer survivors at risk for MetS and develop targeted interventions to enhance their long-term health outcomes.

Data availability

NHANES data is accessible to the public and can be obtained through the website (www.cdc.gov/nchs/nhanes/).

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