Lipids in Health and Disease

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Relative fat mass as a predictor of gallstones: insights from national health and nutrition examination survey data

Xiaochun Lin[1†], Hao Lin[2†], Jing Xu[3], Shouxing Yang[4] and Lei Miao[4*]

Abstract

Background Gallstones have been linked to obesity. Relative fat mass (RFM) has emerged as a novel obesity index that more precisely represents the body fat distribution. The correlation between RFM and the risk of developing gallstones remains unclear. This study aims to explore the correlation between RFM and the prevalence of gallstones.

Methods A cross-sectional analysis was conducted on the data from the NHANES 2017–2020. The correlation between RFM and the formation of gallstones was examined through multivariate logistic regression, receiver operating characteristic (ROC) curve, sensitivity analysis, subgroup analysis, and restricted cubic spline regression.

Results Among the 12,947 subjects, 1362 were categorized as having gallstones. It was observed that as the quartile range of RFM increased, with a notable rise in the prevalence of gallstones (3.7% vs. 7.5% vs. 9.8% vs. 21.1%, $P < 0.001$). Logistic and RCS regression analyses indicated a significantly positive linear correlation between RFM and the prevalence of gallstones, even after accounting for confounders potential (adjusted OR = 1.075, 95% CI: 1.050, 1.101). There is still a significant correlation between RFM and the prevalence of gallstones across both subgroup and sensitivity analyses. ROC analysis indicated that RFM (AUC = 0.696, 95%CI: 0.682, 0.711) can serve as a more robust identify for developing gallstones compared to traditional anthropometric indices.

Conclusion This study is the first to provide the evidence of a significantly positive correlation between RFM and the formation of gallstones. However, further prospective studies are needed to validate these findings.

Keywords Insulin resistance, Obesity, Relative fat mass, Gallstones, Body mass index

Introduction

Gallstone is one of the most prevalent digestive diseases worldwide, and the risk factors have been well established for gallbladder cancer as well. Gallstone represents a substantial healthcare burden in the United States, impacting up to 15% of its population [1, 2]. Epidemiological data indicate that the prevalence of gallstones ranges from 10 to 15% among Caucasian adults, which can be as high as 70% among American Indians [3, 4]. While gallstones are typically asymptomatic, 10–25% of affected individuals may experience specific symptoms such as acute cholecystitis and biliary pain. In these symptomatic cases,

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1–2% may develop complications [5–7], which can lead to severe pain and potentially life-threatening conditions. Although previous studies have identified risk factors correlated with the formation of gallstones, there is still a lack of reliable clinical indexes to prevent gallstones.

Numerous studies have identified obesity as a significant risk factor for developing of gallstones [8–10]. Obesity is typically characterized by the excessive accumulation of adipose tissues, which has a detrimental effect on physical health [11, 12]. Currently, the most commonly used criteria for obesity include waist-to-height ratio (WHtR), body mass index (BMI), waist-to-hip ratio (WHR), and waist circumference (WC). However, these traditional obesity indices primarily reflect the degree of overweight and abdominal obesity, without distinguishing between subcutaneous and visceral fat [13]. To address this limitation, researchers recently proposed and validated a simple and cost-effective method to estimate the whole-body fat percentage in adults: relative fat mass (RFM) [14]. RFM incorporates height, gender, and WC, and has been shown to better predict and estimate whole-body fat percentage than BMI among both females and males. Additionally, RFM demonstrated relatively good accuracy across diverse populations, including African-Americans, European-Americans, and Mexican-Americans [14]. Furthermore, RFM has been correlated with various diseases, including coronary heart disease [15], thromboembolism [16], type 2 diabetes [17], and hypertension [18].

However, the correlation between developing gallstones and RFM remains unclear. Additionally, it is still difficult to determine the best anthropometric index for gallstone screening. This study aims to explore the correlation between RFM and developing gallstones according to the data from NHANES. Additionally, it compared the correlations of BMI, WC, weight-adjusted waist circumference index (WWI), WHtR, and body roundness index (BRI) with the formation of gallstones, thereby evaluating the strength of the correlation between RFM and developing gallstones.

Methods

Research subjects

NHANES, conducted by NCHS [19], is a comprehensive study designed to assess the correlation between nutrition, health promotion, and disease prevention. The survey is conducted biennially on dietary, demographic, examination, and laboratory data by taking physical examinations, interviews, and various sections. Additional information regarding the NHANES database can be found at http://www.cdc.gov/nhanes.

The baseline clinical data analyzed in this study were derived from NHANES 2017–2020. Subjects aged 20 years old and older ($n = 14801$) were included in this study. And according to the exclusion criteria, subjects lacking data of RFM ($n = 1817$), those without questionnaire on gallstones ($n = 37$), were excluded. Consequently, 12,947 subjects were included in this study, of whom 1362 reported a history of developing gallstones by themselves (as shown in Fig. 1).

Measurement of covariates

According to previous studies [5, 14], potential confounding factors correlated with developing gallstones and RFM were incorporated into the final analysis. These factors included demographic variables (height, age, race, WC, gender, weight, educational attainment, and physical activities). Uric acid (UA), total cholesterol (TC), fasting plasma glucose (FPG), low-density lipoprotein cholesterol (LDL-C), albumin, triglycerides (TG), alanine aminotransferase (ALT), gamma-glutamyl transferase (GGT), creatinine, aspartate aminotransferase (AST), and high-density lipoprotein cholesterol (HDL-C) were collected in blood samples. Questionnaire surveys included hypertension, alcohol consumption, diabetes mellitus, dietary intake factors, encompassing energy, fat, sugar, and water. All the participants from 2017 to 2020 completed 24-hour dietary recalls on the mean consumption rates derived from these two recalls. Less than 3% of values missed in total. Multiple imputation was performed for missing values. Detailed measurement methodologies and data acquisition for each variable can be accessed at www.cdc.gov/nchs/nhanes.

Calculation formula of anthropometric index

Fundamental anthropometric parameters, including height, WC, and weight, were assessed through standardized methodologies and instruments at the mobile examination center. Subsequently, indices such as RFM, BMI, WtHR, BRI, and WWI, were calculated through established formulas as follows:

$RFM = 64 - (20 \times height/WC) + (12 \times gender)$, gender = 0 for male and 1 for female.

$BMI = weight\ (kg) / height^2(m)$.

$BRI = 364.2 - 365.5 \times (1 - [(WC\ (cm) / 2\pi) / (height(m) \times 0.5)]^2)^{0.5}$.

$WWI = WC\ (cm) / Weight^{0.5}(cm/kg^{0.5})$.

$WtHR = WC\ (cm) / Height(cm)$.

Statistical analysis

Subjects were categorized into quartiles (Q1:≤29.8; Q2: 29.8–35.6; Q3: 35.6–43.6; Q4:>43.6) according to RFM values. Continuous variables were compared through T-test and the Mann-Whitney U test (for non-normal distributed variables), and Categorical variables were compared through Chi-squared test. ORs and 95% CIs between RFM and developing gallstones were explored with multiple logistic regression models.

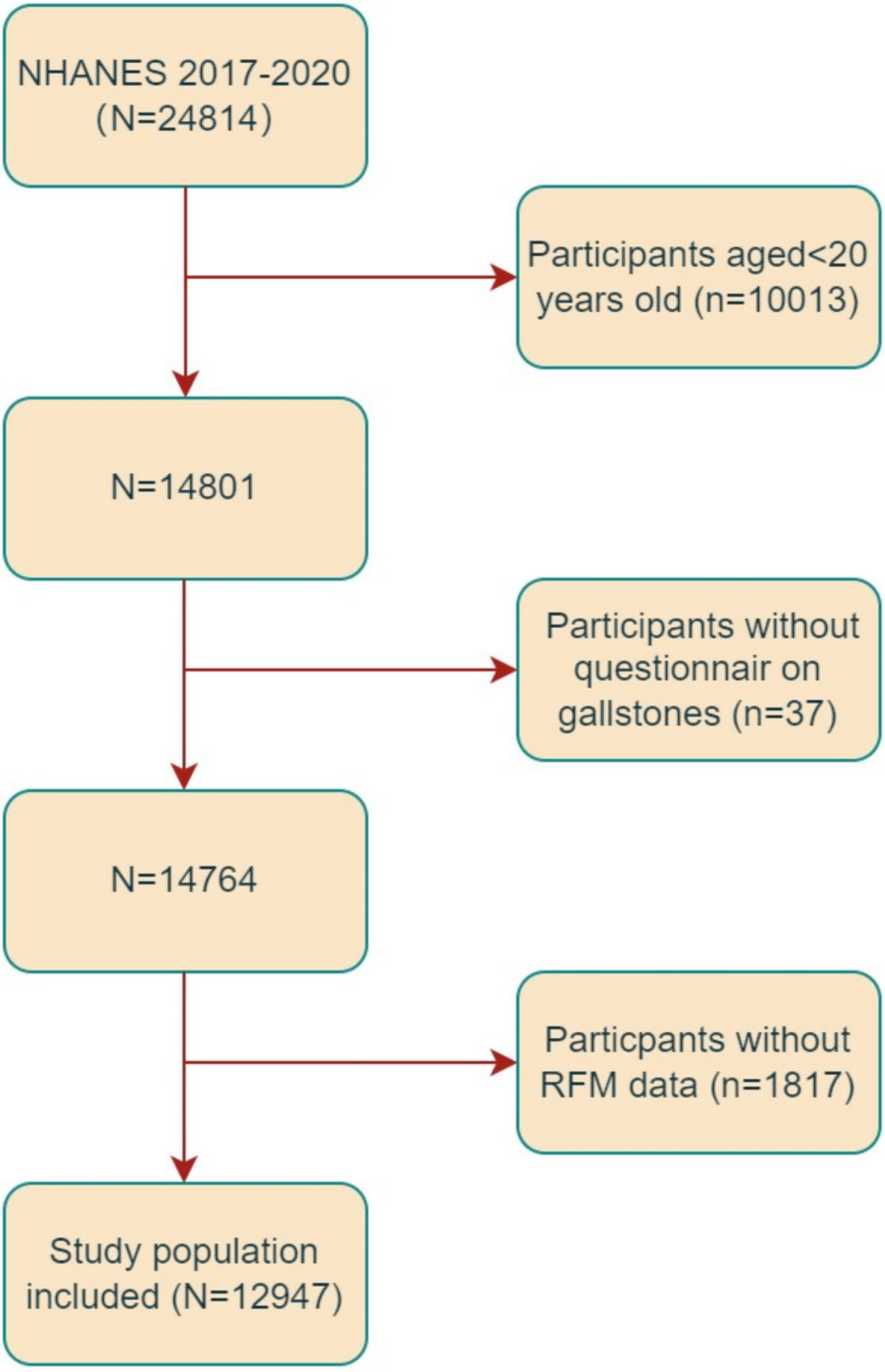

Fig. 1 Flowchart of the sample selection from the 2017–2020 NHANES

Table 1 Baseline characteristics of participants

Characteristic	Overall	Non-stone formers	Stone formers	*P* value
Number	12,947	11,585	1362	
Age, year	50.8 ± 17.4	49.9 ± 17.4	57.9 ± 15.8	< 0.001[a]
Male, n(%)	6323 (48.8%)	5927 (51.2%)	396 (29.1%)	< 0.001[c]
Race, n(%)				< 0.001[c]
Mexican American	1588 (12.3%)	1406 (12.1%)	182 (13.4%)	
Other Hispanic	1270 (9.8%)	1124 (9.7%)	146 (10.7%)	
Non-Hispanic White	4485 (34.6%)	3898 (33.6%)	587 (43.1%)	
Non-Hispanic Black	3298 (25.5%)	3032 (26.2%)	266 (19.5%)	
Other Race	2306 (17.8%)	2125 (18.3%)	181 (13.3%)	
Moderate activities, n(%)				< 0.001[c]
Yes	5310 (41.0%)	4814 (41.6%)	496 (36.4%)	
No	7635 (59.0%)	6770 (58.4%)	865 (63.6)	
Diabetes, n(%)				< 0.001[c]
Yes	1964 (15.2%)	1611 (13.9%)	353 (25.9%)	
No	10,983 (84.8%)	9674 (83.1%)	1009 (74.1%)	
Hypertension, n(%)				< 0.001[c]
Yes	4923 (38.1%)	4192 (36.2%)	731 (53.8%)	
No	8005 (61.9%)	7376 (63.8%)	629 (46.2%)	
Education level, n(%)				0.099[c]
Less than high school	2419 (18.7%)	2187 (18.9%)	232 (17.0%)	
High school or above	10,528 (81.3%)	9398 (81.1%)	1130 (83.0%)	
Drinking, n(%)				0.931[c]
Current or ever	11,150 (86.1%)	9976 (86.1%)	1174 (86.2%)	
Never	1797 (13.9%)	1609 (13.9%)	188 (13.8%)	
Smoking, n(%)				< 0.001[c]
Current or ever	5425 (41.9%)	4790 (41.4%)	635 (46.7%)	
Never	7519 (58.1%)	6794 (58.6%)	725 (53.3%)	
Weight, Kg	83.2 ± 22.5	82.5 ± 22.2	89.2 ± 24.3	< 0.001[a]
Body mass index, Kg/m^2	29.9 ± 7.3	29.5 ± 7.0	33.2 ± 8.4	< 0.001[a]
Waist circumference, cm	100.9 ± 17.1	100.0 ± 16.8	108.4 ± 17.2	< 0.001[a]
FPG, mmol/L	6.31 ± 2.11	6.26 ± 2.08	6.72 ± 2.31	< 0.001[a]
ALT, U/L	22.3 ± 17.8	22.4 ± 18.1	21.6 ± 14.4	0.137[a]
AST, U/L	21.9 ± 13.7	22.0 ± 13.8	21.5 ± 12.4	0.188
GGT, U/L	32.3 ± 49.5	32.0 ± 47.6	34.6 ± 62.8	0.078[a]
Albumin, g/dl	4.06 ± 0.34	4.07 ± 0.33	3.95 ± 0.36	< 0.001[a]
Creatinine, umol/L	74.3 (62.8, 89.3)	75.1 (62.8, 89.3)	71.6 (60.1, 87.5)	< 0.001[b]
Uric acid, umol/L	315.2 (261.7, 374.7)	315.2 (261.7, 374.7)	315.2 (267.7, 368.8)	0.175[b]
Total cholesterol, mmol/L	4.76 (4.11, 5.48)	4.76 (4.11, 5.51)	4.68 (4.03, 5.43)	0.007[b]
Triglycerides, mmol/L	1.30 (0.90, 1.90)	1.28 (0.89, 1.87)	1.46 (1.04, 1.98)	< 0.001[b]
HDL-cholesterol, mmol/L	1.32 (1.09, 1.60)	1.32 (1.09, 1.60)	1.29 (1.09, 1.55)	0.060[b]
LDL-cholesterol, mmol/L	2.74 (2.20, 3.39)	2.77 (2.20, 3.39)	2.66 (2.07, 3.39)	0.026[b]
PIR	2.59 ± 1.62	2.60 ± 1.63	2.56 ± 1.55	0.513[a]
Sugar intake, g/d	101.1 ± 63.7	100.9 ± 63.1	102.7 ± 68.3	0.375[a]
Energy intake, kcal/d	2032.4 ± 843.1	2047.5 ± 847.3	1908.6 ± 798.1	< 0.001[a]
Fat intake, g/d	82.6 ± 40.3	83.1 ± 40.5	78.8 ± 38.4	< 0.001[a]
Water intake, g/d	1163.3 ± 1033.1	1166.0 ± 1030.6	1141.1 ± 1054.0	0.444[a]
RFM	36.2 ± 8.8	35.6 ± 8.7	41.6 ± 8.0	< 0.001[a]

Values are mean±SD, median (IQR) or number (%). P values are for t test[a], Mann-Whitney U test[b] or χ^{2}[c] test. $P < 0.05$ was deemed significant. BMI, body mass index; FPG, fasting blood glucose; TC, total cholesterol; TG, triglyceride; HDL-c, High density lipoprotein cholesterol; LDL-c, Low density lipoprotein cholesterol; GGT, glutamyl transpeptidase; RFM, relative fat mass

Variables demonstrating clinical and statistical significance through univariate analyses ($p < 0.05$) were incorporated into multivariate analyses. Differences between subjects grouped by quartiles of RFM were compared in multivariable logistic regression, with Q1 as the reference group. The analysis incorporated three models:

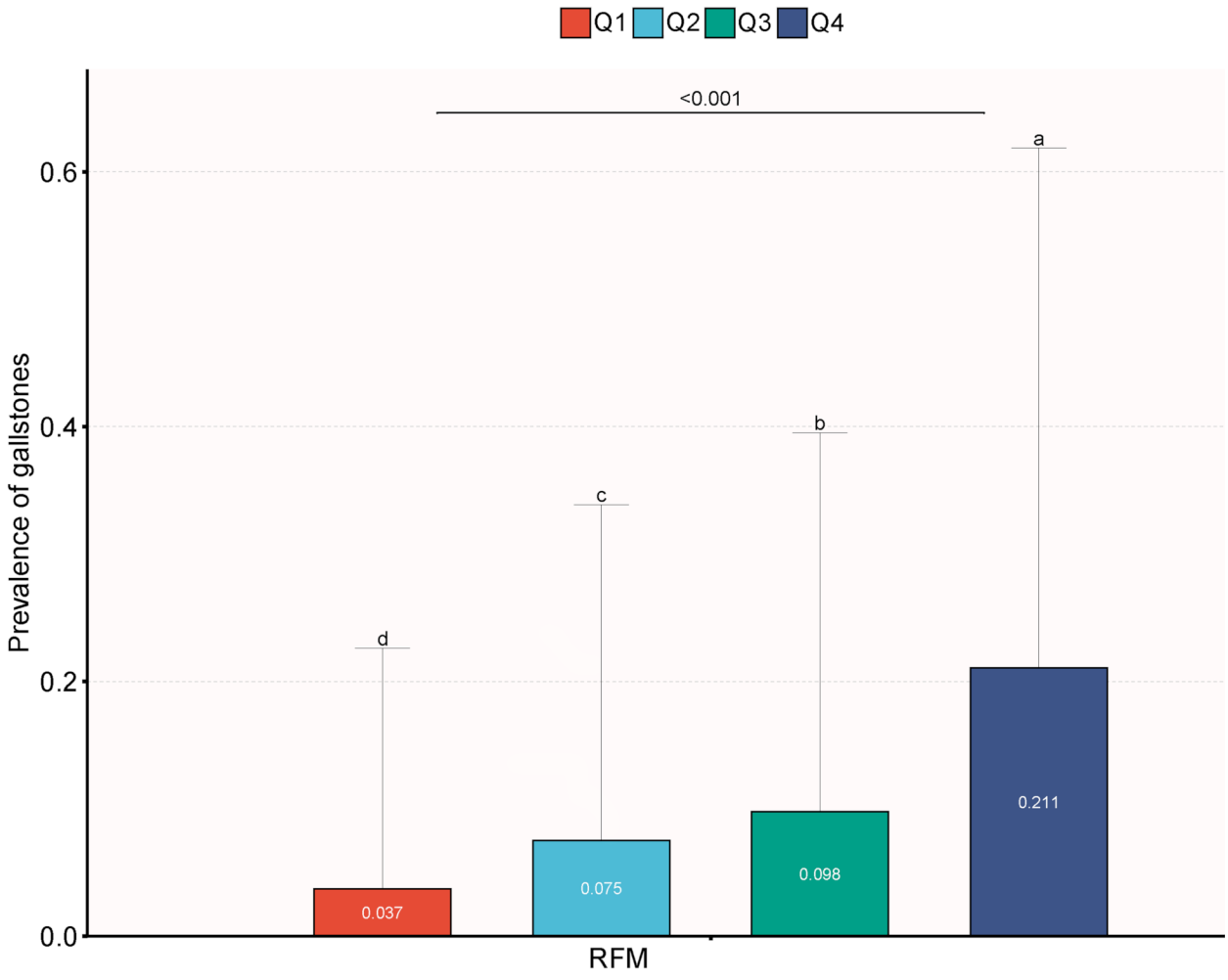

Fig. 2 The prevalence of gallstones across quartiles of RFM

Model 1 (unadjusted), Model 2 (adjusted for race, gender, and age), and Model 3 (further adjusted for BMI, alcohol abuse, education level, TC, moderate physical activities, diabetes mellitus, TG, albumin, PIR, hypertension, ALT, LDL-c, AST, creatinine, FPG, GGT, uric acid, total water, total energy, total sugar and total fat). The potential modification of covariates on correlation was explored through interaction tests and subgroup analyses. Furthermore, the non-linear correlation between RFM and developing gallstones was assessed through

Table 2 Logistic regression analysis between RFM with gallstones

subgroups	Model1		Model2		Model3	
	OR (95%CI)	*P*-value	OR (95%CI)	*P*-value	OR (95%CI)	*P*-value
RFM (continuous)	1.090 (1.082, 1.098)	< 0.001	1.108 (1.094, 1.122)	< 0.001	1.075 (1.050, 1.101)	< 0.001
RFM (category)						
Q1 (≤ 29.8)	1(Ref)		1(Ref)		1(Ref)	
Q2 (29.8–35.6)	2.110 (1.686, 2.640)	< 0.001	1.826 (1.452, 2.296)	< 0.001	1.683 (1.126, 2.518)	0.011
Q3 (35.6–43.6)	2.819 (2.271, 3.499)	< 0.001	2.581 (1.971, 3.380)	< 0.001	2.350 (1.458, 3.787)	< 0.001
Q4 (> 43.6)	6.933 (5.671, 8.477)	< 0.001	6.213 (4.628, 8.340)	< 0.001	4.125 (2.399, 7.094)	< 0.001
P for trend	1.880 (1.775, 1.991)	< 0.001	1.901 (1.731, 2.088)	< 0.001	1.614 (1.359, 1.917)	< 0.001

Model 1: None covariates were adjusted; Model 2: gender, age and race were adjusted; Model 3: gender, age, race, BMI, drinking, educational level, TC, moderate physical activities, diabetes, TG, PIR, albumin, hypertension, ALT, LDL-c, AST, creatinine, FPG, GGT, uric acid, total water, total energy, total sugar and total fat were adjusted

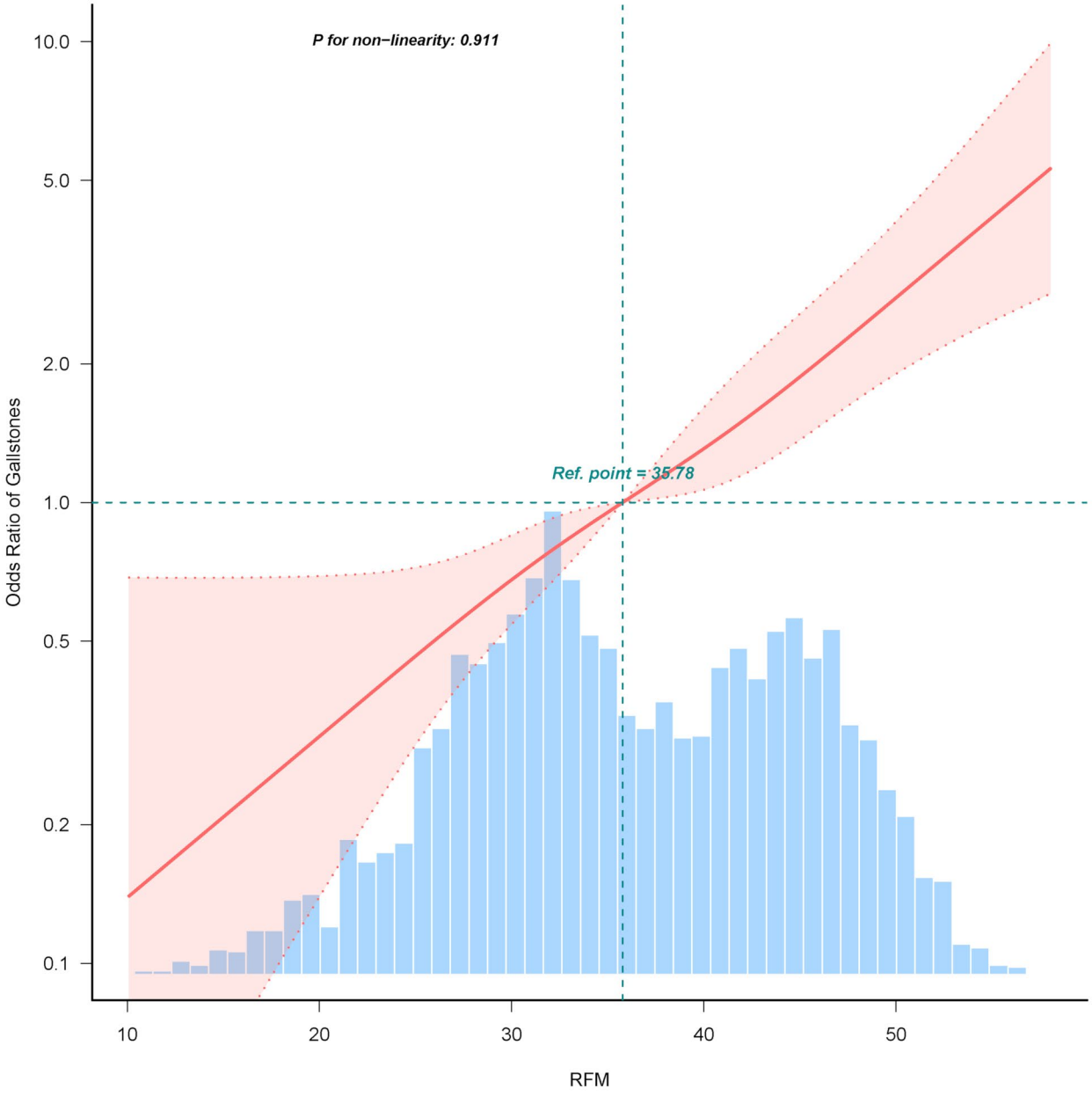

Fig. 3 Restricted cubic spline fitting for the association between RFM levels and gallstones

RCS analyses. Sensitivity analyses were performed after excluding individuals with extreme energy intake values (consuming more than 5000 kcal or less than 500 kcal per day). Additionally, Inverse Probability Weighting (IPW) regression analysis on the unweighted raw data was applied to address potential confounding variables. Finally, the diagnostic efficacy of RFM, WC, BMI, WHtR, WWI and BRI in detecting was evaluated through ROC curve analyses. The differences in AUC values were compared through the Delong test. Data analyses were performed with R software and Free Statistics software, with a significance threshold at $P < 0.05$ for all statistical tests.

Results

Clinical baseline features of subjects

Baseline demographic characteristics of enrolled subjects are detailed in Table 1, with attributes categorized according to gallstone status. Apart from alcohol intake, liver function, educational level, uric acid, HDL-C, PIR and dietary parameters (total water, sugar intake),

Table 3 Sensitivity analyses

	Adjusted OR (95CI%)	*P*
Excluding participants with extreme energy intake		
RFM (continuous)	1.075 (1.050, 1.101)	< 0.001
RFM		
Q1 (≤ 29.8)	1(Ref)	
Q2 (29.8–35.6)	1.780 (1.195, 2.650)	0.005
Q3 (35.6–43.6)	2.644 (1.640, 4.264)	< 0.001
Q4 (> 43.6)	4.768 (2.775, 8.190)	< 0.001
Inverse probability of weighting		
RFM (continuous)	1.073 (1.040, 1.070)	< 0.001
RFM		
Q1 (≤ 29.8)	1(Ref)	
Q2 (29.8–35.6)	1.053 (0.658, 1.687)	0.829
Q3 (35.6–43.6)	1.828 (1.042, 3.207)	0.035
Q4 (> 43.6)	2.275 (1.245, 4.157)	0.008

significant differences in baseline characteristics were identified between the two cohorts. Subjects with gallstones demonstrated higher values in age, BMI, TG, FPG, WC, and RFM. Additionally, the proportion of females was significantly higher, and the prevalence of hypertension and diabetes mellitus was also higher in this group. Conversely, subjects with gallstones showed lower levels of creatinine, albumin, TC, total energy and total fat intake.

Increase of RFM was positively correlated with the incidence of gallstones

As illustrated in Fig. 2, the quartile range of RFM increased, with a notable rise in the prevalence of gallstones (3.7% vs. 7.5% vs. 9.8% vs. 21.1%, $P < 0.001$). In the multiple logistic regression analysis, a significantly positive correlation was found between RFM and gallstones after adjusting Model 3 for confounders (OR = 1.075, 95% CI: 1.050, 1.101). According to the sensitivity analysis, RFM was categorized into quartiles, showing that in the fully adjusted Model 3, subjects in the second, third, and fourth quartiles exhibited a statistically significant increase in the risk of developing gallstones by 0.683, 1.350, and 3.125, respectively, compared to those in the lowest quartile (as shown in Table 2). RCS analyses demonstrated a linear association between RFM and developing gallstones (as shown in Fig. 3).

Subgroup analysis

A stratified multivariate logistic regression analysis was performed to explore the correlation between RFM and gallstones, across diverse population subgroups (Fig. 4).

The interaction test revealed no statistically significant differences in the correlation between RFM and gallstones with respect to education level, moderate physical activity, age, gender, BMI, and disease status (including hypertension and diabetes). These findings indicate that these variables did not significantly influence the observed positive correlation (all P for interaction > 0.05).

Sensitivity analyses

The results of sensitivity analysis are presented in Table 3. After excluding individuals with extreme energy intake, OR for the prevalence of gallstones was 1.075 (95% CI: 1.050, 1.101). After IPW, OR for the prevalence of gallstones was 1.073 (95% CI: 1.040, 1.070).

Predictive value of RFM for gallstones

ROC curve in Fig. 5 shows the diagnostic performance of RFM, WC, BMI, WHtR, WWI and BRI in identifying gallstones. As demonstrated in Table 4, RFM exhibited the highest diagnostic accuracy for gallstones, with an AUC value of 0.696 (95% CI: 0.682–0.711), significantly exceeding other anthropometric indexes ($P < 0.001$).

Discussion

This cross-sectional study was conducted on the data from NHANES to evaluate the correlation between RFM and the prevalence of gallstones, indicating a positive correlation between RFM and the prevalence of gallstones. Furthermore, this positive correlation was consistent with that from subgroup and sensitivity analyses. RCS analysis demonstrated a linear correlation between RFM and the prevalence of gallstones. Moreover, ROC analysis indicated that RFM exhibited superior identify ability for developing gallstones compared to WC, BMI, WHtR, BRI, and WWI, with statistical significance.

Obesity is widely recognized as a significant risk factor for developing gallstones, a correlation substantiated by numerous epidemiological studies [20, 21]. Among various indexes of obesity, BMI reflecting overall adiposity, has been the most commonly used index in recent years. Several studies have demonstrated a positive correlation between BMI and the risk of developing gallstones, which aligns with the findings of this study [22]. WWI, an obesity assessment metric proposed by Park et al., is considered as a more practical and reasonable measure compared to BMI alone [23]. Consistent with this, a cross-sectional study revealed a positive correlation between higher WWI and the prevalence of gallstones [24]. Additionally, other commonly used obesity metrics include WHtR, BRI, and WC. However, these traditional measures have certain limitations. For instance, BMI does not account for the specific distribution of body fat, while WHtR and WC fail to differentiate between subcutaneous and visceral fat. Consequently, RFM was developed to estimate body fat distribution by incorporating height, WC, and gender. Multiple studies have demonstrated that RFM can accurately estimate whole-body fat percentage [18, 25–27]. In extensive cohorts from

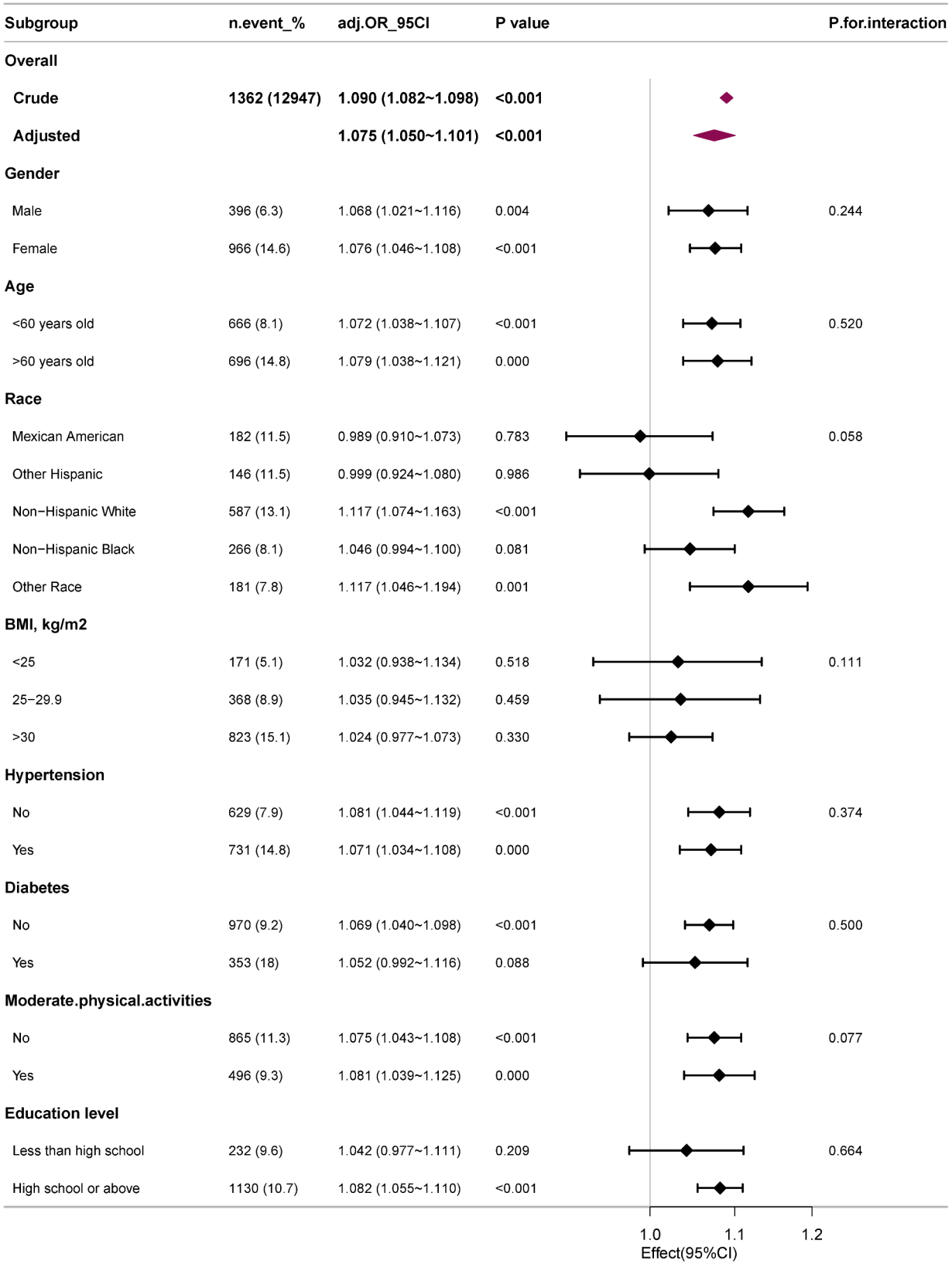

Fig. 4 Association between RFM and the risk of gallstones in various subgroups

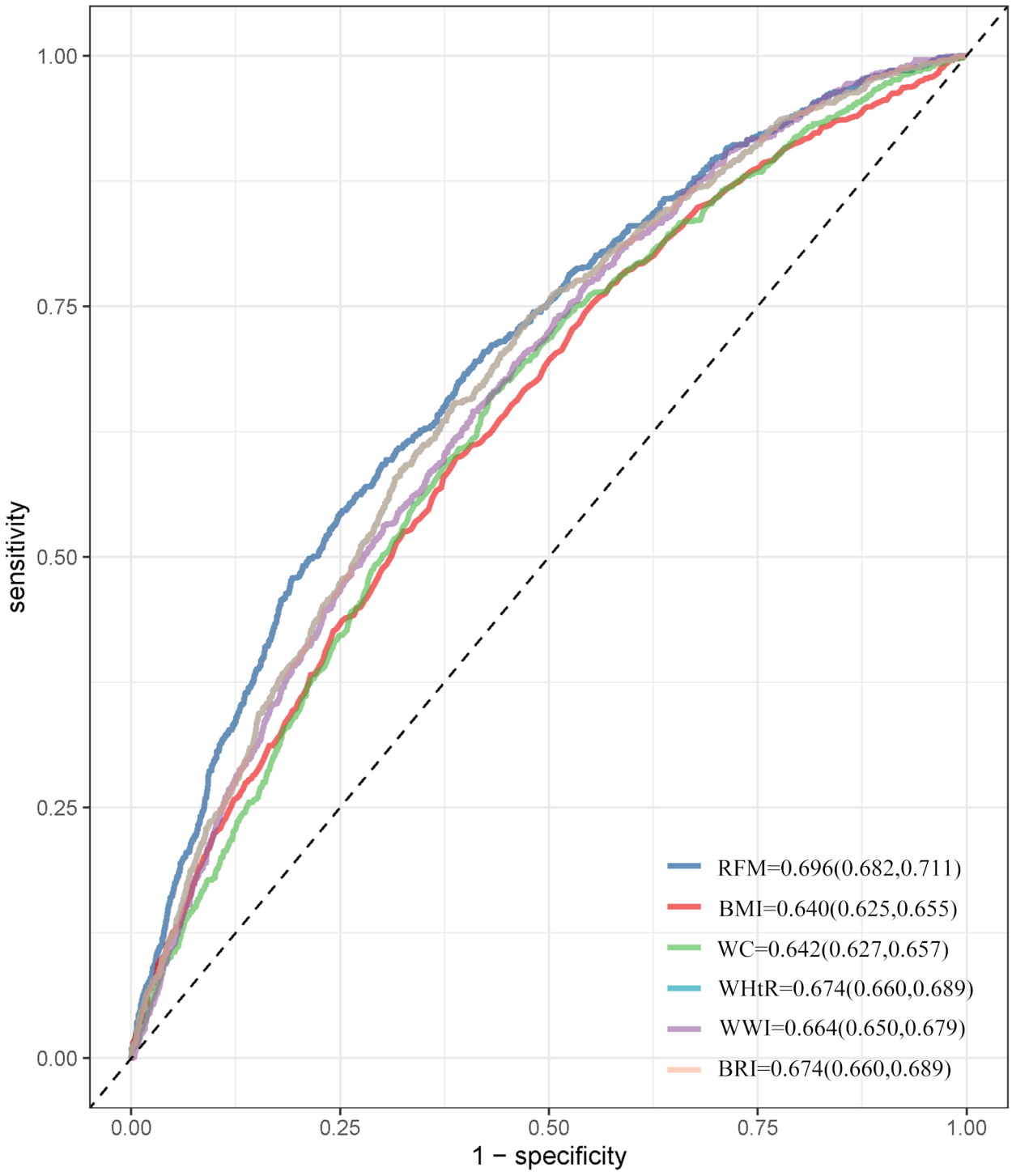

Fig. 5 ROC analysis of RFM, BMI, WC, WHtR, WWI, and BRI to gallstones among American adults

Brazil, United States, and Korea, adiposity measured by dual-energy X-ray absorptiometry (DXA) exhibited a stronger correlation with RFM than that with BMI [14, 26, 28]. Furthermore, RFM has been identified as a significant predictor in the evaluation of various health conditions, including diabetes [17], NAFLD [29], metabolic syndrome [30], hyperlipidemia [31], and heart failure [32]. In the alignment with prior research, the findings indicate that RFM can serve as a predictive tool for gallstones, demonstrating superior predictive capability compared to traditional anthropometric indices. Consequently, as a recently developed obesity metric, RFM

Table 4 The AUC for each index to discriminate gallbladder stone

	AUC	95%CI	Cutoff value	Sensitivity	Specificity	PPV	NPV	*P* for difference in AUC
RFM	0.696	0.682–0.711	42.7	0.543	0.729	0.204	0.933	Reference
BMI	0.640	0.625–0.655	30.2	0.599	0.611	0.153	0.928	< 0.001
WC	0.642	0.627–0.657	101.5	0.662	0.570	0.153	0.935	< 0.001
WHtR	0.674	0.660–0.689	0.622	0.651	0.616	0.166	0.938	< 0.001
WWI	0.664	0.650–0.679	11.3	0.645	0.591	0.157	0.934	< 0.001
BRI	0.674	0.660–0.689	5.93	0.651	0.616	0.834	0.006	< 0.001

RFM, relative fat mass; BMI, body mass index; WC, waist circumference; WHtR, waist-to-height ratio; WWI, weight-adjusted waist circumference index; BRI, body roundness index; PPV, positive predictive value; NPV, negative predictive value

holds considerable promise as a predictor for the occurrence of gallstones. Nevertheless, additional large-scale prospective cohort studies are necessary to validate these conclusions.

Obesity significantly increases the risk of developing gallstones through various pathophysiological mechanisms. Firstly, obesity contributes to heightened insulin resistance, which is correlated with a range of metabolic disorders elevating the incidence of gallstones [33]. Secondly, there is an overproduction of cholesterol resulting from the upregulation of 3-hydroxy-3-methylglutaryl coenzyme A (HMG-CoA) reductase activity in individuals with obesity, thereby facilitating the formation of cholesterol gallstones [34]. Lastly, leptin, a hormone secreted by adipocytes, has been implicated in this process. Studies with mouse models have demonstrated that bile cholesterol saturation diminishes when these mice exhibit resistance to leptin [35]. Obesity is correlated with elevated leptin secretion, which subsequently leads to an increased secretion of cholesterol into the bile, thereby heightening the risk of developing gallstones [36].

In this study, a robust positive correlation between RFM and the prevalence of gallstones across various stratifications, including disease status, gender, BMI, and race, was observed with all interaction *P*-values exceeding 0.05. Furthermore, previous research has indicated that a high energy intake is associated with an increased risk of gallstones [37]. After excluding individuals with extreme energy intake, sensitivity analyses demonstrated that the positive correlation remained significant. These findings underscore that RFM is a reliable metric for assessing body fat distribution, suggesting that effective management of adiposity may potentially mitigate the progression of gallstone development. It is important to note that rapid weight loss is correlated with an increased risk of developing gallstones [38, 39]. Consequently, it is imperative to emphasize strategies for weight reduction that incorporate personalized weight loss programs and dietary modifications [40].

Study strengths and limitations

This study possesses several notable strengths. Firstly, the samples employed in this study were derived from NHANES, which is characterized by its extensive sample size and high-quality data. Secondly, this study considered multiple confounding variables and subgroup and sensitivity analyses were conducted to ensure the generalizability of the findings across different populations. Thirdly, the comparatively good diagnostic efficacy of RFM for identifying gallstones underscores its potential for clinical application. However, large-scale prospective studies are still needed to verify the results due to slightly small AUCs. Additionally, this study is subject to several limitations. Firstly, this study does not establish a causal relationship between RFM and the development of gallstones. Secondly, it did not account for the potential influences of hormonal levels and medication usage. Thirdly, the determination of gallstone presence or absence relied on self-reported questionnaires, rather than objective imaging studies, which introduces the possibility of recall bias. Consequently, further validation of the findings through imaging modalities such as MRI and CT are warranted.

Conclusion

This study identified a positive correlation between RFM and the prevalence of gallstones within American adults. Furthermore, RFM demonstrated superior identify capability for the occurrence of gallstones when compared to traditional anthropometric indices. This study aims to enhance public awareness regarding the significance of RFM, a novel metric for assessing obesity, and to underscore that maintaining a moderate RFM may contribute to a reduction in the incidence of gallstones. However, more prospective studies are needed to validate these findings.

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Author contributions

LM designed the study; HL, SXY and JX collected biochemical data; XCL drafted the manuscript. All authors read and approved the final manuscript.

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Data availability
The datasets generated and analysis during the current study are available in the NHANES, www.cdc.gov/nchs/NHANEs/.

Declarations

Ethics approval and consent to participate
The National Center for Health Statistics Ethics Review Board has approved the implementation of NHANES.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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