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ORIGINAL RESEARCH

Association of Conventional and Unconventional Lipid Profiles with Visceral Fat Area in Overweight/Obese Individuals with Type 2 Diabetes Mellitus

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Background: Several lipid metabolism-related profiles have been explored for their association with obesity, but no consensus has been reached. Therefore, this study aimed to comprehensively analyze the correlation between conventional and unconventional lipid profiles and visceral fat area (VFA) in overweight/obese patients with type 2 diabetes mellitus (T2DM). Emphasizing the overall relationship between lipid metabolism and visceral fat accumulation.

Methods: This cross-sectional study included 1288 overweight/obese T2DM patients, with VFA measured using bioelectrical impedance analysis and visceral fat obesity (VFO) was defined as VFA $\geq$ 100 cm². Both conventional lipid profiles include total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-c), high-density lipoprotein cholesterol (HDL-c), and lipoprotein(a), and unconventional lipid profiles include lipid composite index (LCI), platelet/ HDL-c ratio (PHR), remnant cholesterol (RC), TG/HDL-c, Castelli Risk Index I (CRI-I), Castelli Risk Index II (CRI-II), Non-HDL-c, atherogenic index of plasma (AIP) and atherogenic coefficient (AC) were analyzed. The study population was divided into non-VFO and VFO groups, The relationship between conventional and unconventional lipid profiles and VFO was evaluated.

Results: Compared to the non-VFO group, the VFO group exhibited significantly higher levels of TG, lipoprotein(a), LCI, RC, TG/HDL-c, CRI-I, CRI-II, AIP, and AC (all $P < 0.05$). Univariate analysis revealed that RC, TG, LCI, TG/HDL-c, CRI-I, CRI-II, AIP, and AC were positively correlated with VFA and VFO, while HDL-c and lipoprotein(a) were negatively correlated (all $P < 0.05$). Logistic regression identified RC as an independent risk factor for VFO (OR: 1.667, 95% CI: 1.216–2.285, $P = 0.001$).

Conclusion: Among lipid profiles, RC is independently and significantly associated with VFO, underscoring its role in lipid metabolism and abdominal obesity management, especially in overweight/obese T2DM patients.

Keywords: remnant cholesterol, type 2 diabetes mellitus, unconventional lipid profiles, visceral fat area, visceral fat obesity

Introduction

Diabetes is a major public health concern that is strongly associated with obesity, particularly abdominal obesity characterized by an increased visceral fat area (VFA), which plays a critical role in the development and progression of diabetes and its complications.[1,2] Dysregulation of visceral fat is closely associated with insulin resistance (IR), inflammation, and metabolic disorders.[3] In patients with type 2 diabetes mellitus (T2DM), excessive visceral fat further exacerbates the risk of diabetes-related complications.[4,5] Therefore, identifying risk factors associated with increased VFA in individuals with T2DM is essential for optimizing metabolic risk assessment and management.

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Research has confirmed that lipid metabolism abnormalities are closely associated with visceral fat accumulation.[6] Conventional lipid profiles, including total cholesterol (TC), triglycerides (TG), low-density lipoprotein cholesterol (LDL-c), high-density lipoprotein cholesterol (HDL-c), and lipoprotein(a), have been widely used to assess metabolic disorder risks and have been shown to be closely related to VFA.[7] However, the predictive ability of these profiles varies significantly across different populations, potentially influenced by factors such as gender, age, ethnicity, and metabolic status.[8,9] Furthermore, conventional lipid profiles are primarily based on single indicators, which fail to comprehensively reflect the complexity and dysregulation of lipid metabolism. This limitation somewhat restricts their application value in the identification of visceral fat abnormalities.

In recent years, a range of unconventional lipid profiles has been introduced to provide a more comprehensive assessment of lipid metabolic imbalances.[10] These include lipid composite index (LCI), platelet/HDL-c ratio (PHR), remnant cholesterol (RC), TG/HDL-c, Castelli risk index I (CRI-I), Castelli risk index II (CRI-II), Non-HDL-c, atherogenic index of plasma (AIP) and atherogenic coefficient (AC). Studies have demonstrated that these unconventional lipid profiles provide a broader view of lipid metabolism and are particularly useful in assessing the risks of metabolic and cardiovascular diseases (CVD).[11–13] Although the clinical utility of these unconventional lipid profiles is gaining attention, there is still no definitive research exploring their specific relationship with VFA.

Computed tomography (CT) and magnetic resonance imaging (MRI) are currently considered the gold standards for evaluating VFA.[14] However, recent studies have shown that bioelectrical impedance analysis (BIA), as a more accessible, convenient, and relatively cost-effective method, can effectively assess VFA.[15] Despite its limitations, such as being influenced by hydration status and individual variability, nevertheless, BIA has demonstrated good feasibility in diabetic populations.[16] Therefore, BIA was used in this study to assess VFA.

Although body mass index (BMI) is widely used internationally as a diagnostic tool for obesity, recent studies have shown that individuals with similar BMI levels can still demonstrate substantial variations in metabolic health and T2DM risk.[17,18] Consequently, this study employs BIA to assess VFA and investigates the association between conventional and unconventional lipid profiles and VFA in overweight/obese T2DM patients.

Methods

Study Participants

The study included 1288 T2DM patients aged 18 years and older who participated in diabetes treatment and prevention programs at People's Hospital of Linyi, Shandong Province, China, from January 2020 to March 2023. Inclusion criteria were as follows: (1) Diagnosis of T2DM based on the 1999 World Health Organization diagnostic criteria; (2) Age 18 years or older; (3) BMI $\geq$ 24 kg/m^2. Exclusion criteria were as follows: (1) Type 1 diabetes, acute diabetic complications, or other specific types of diabetes; (2) BMI < 24 kg/m^2; (3) Severe liver dysfunction (history of liver failure or current diagnosis) and severe kidney dysfunction (eGFR < 30 mL/min/1.73 m^2); (4) Incomplete clinical data on lipid metabolism profiles and VFA measurements.

Medical Data and Biochemical Measurements

According to medical records, participants' general data, including age, gender, height, weight, diabetes duration, smoking and drinking were collected. Participants rested for at least 5 minutes before blood pressure was measured using a standard electronic sphygmomanometer, and systolic and diastolic blood pressures (SBP and DBP) were recorded. After an overnight fast, venous blood samples were collected to measure alanine aminotransferase (ALT), aspartate aminotransferase (AST), serum creatinine (Scr), uric acid (UA), γ-glutamyl transferase (GGT), fasting plasma glucose (FPG), platelets, and lipid profile, including total cholesterol (TC), TG, LDL-c, HDL-c and lipoprotein(a). A biochemical analyzer (Cobas c 702, Roche, Germany) was also used to measure hemoglobin (Hb) and glycated hemoglobin (HbA1c) via high-performance liquid chromatography.

Calculation

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

Lipoprotein combine index (LCI) = TC (mmol/L) × TG (mmol/L) × LDL-c/HDL-c (mmol/L).[19]
PHR = platelet (10^9/L)/HDL-c (mmol/L).
RC = TC (mmol/L) − HDL-c (mmol/L) − LDL-c (mmol/L).[20]
TG/HDL-c = TG (mmol/l)/HDL-c (mmol/l).[10]
Castelli's risk index I (CRI-I) = TC/HDL-c (mmol/L).[21]
Castelli's risk index II (CRI-II) = LDL-c/HDL-c (mmol/L).[21]
Non-HDL-c = TC (mmol/L) − HDL-c (mmol/L).[22]
AIP = Log (TG/HDL-c) (mmol/L).[23]
AC = (TC - HDL-c) (mmol/L)/HDL-c (mmol/L).[24]

Visceral Fat Area

First, participants lay down and rested for at least 5 minutes to facilitate VFA measurement. The Omron dual-frequency scanning BIA device (Omron HDS-2000, Kyoto, Japan) was used, with the scanner positioned over the abdomen to measure the total abdominal fat tissue area. Next, participants wore an electrode belt with eight electrode pads positioned below the waist. Electrode plates were fastened securely onto both arms and legs to capture the subcutaneous fat area (SFA) while excluding the influence of visceral fat and muscle, to obtain accurate data on other fat areas. Finally, by subtracting the area of SFA and other fat regions from the total abdominal fat tissue area, the VFA value was calculated.

Statistical Analysis

Data analysis was performed using SPSS version 25.0 (SPSS Inc., Chicago, IL, USA). Normally distributed data are presented as mean ± standard deviation (SD), while non-normally distributed data are presented as median and interquartile ranges. Categorical variables are reported as frequency counts and percentages, with comparisons between groups conducted using independent sample *t*-tests (for normally distributed data) or Mann–Whitney *U*-tests (for non-normally distributed data). The chi-square test was used for comparisons of categorical variables. Pearson's correlation analysis was used to analyze normally distributed data. Log transformations were applied to variables such as diabetes duration, ALT, AST, GGT, TG, LCI, RC, TG/HDL-c, and SFA to examine their correlations with VFA and other assessment variables. Spearman correlation coefficient was used to analyze the correlation between VFO and related variables. For variables with significant differences between the VFO groups, binary logistic regression analysis was performed to identify independent predictors of VFO. A two-tailed P-value of < 0.05 was considered statistically significant.

Results

Clinical Characteristics of the Study Subjects

Table 1 presents the clinical characteristics of the participants. Compared with the non-VFO group (n = 555), the VFO group (n = 733) showed significantly higher rates of smoking and drinking, along with elevated levels of BMI, SBP,

Table 1 Comparison of Clinical and Biochemical Characteristics between Non-VFO and VFO Groups

Variables	Non-VFO Group	VFO Group	P value
Number (n)	555	733	
Age (years)	56.90 ± 11.51	56.79 ± 13.91	0.889
Diabetes duration (years)	8.00 (3.00 ~ 12.00)	8.00 (2.00 ~ 13.00)	0.918
Male (%)	158 (28.5%)	418 (57.0%)	<0.001
Smoking (%)	51 (9.2%)	190 (24.5%)	<0.001
Drinking (%)	51 (9.2%)	154 (21.0%)	<0.001
BMI (kg/m2)	26.18 ± 1.80	28.46 ± 3.03	<0.001

(*Continued*)

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Table 1 (Continued).

Variables	Non-VFO Group	VFO Group	P value
SBP (mmHg)	129.13 ± 17.54	134.35 ± 18.70	<0.001
DBP (mmHg)	79.94 ± 10.21	83.57 ± 11.85	<0.001
TC (mmol/L)	4.84 ± 1.22	4.83 ± 1.30	0.889
TG (mmol/L)	1.42 (1.04 ~ 1.99)	1.71 (1.22 ~ 2.58)	<0.001
LDL-c (mmol/L)	3.07 ± 1.03	3.03 ± 1.08	0.552
HDL-c (mmol/L)	1.18 ± 0.28	1.07 ± 0.26	<0.001
Lipoprotein(a) (mg/L)	95.3 (45.4 ~ 247.9)	132.55 (56.1 ~ 316.9)	0.005
LCI	17.73 (9.14 ~ 32.15)	23.71 (12.29 ~ 43.06)	<0.001
PHR	221.21 ± 87.74	229.07 ± 86.71	0.109
RC (mmol/L)	0.51 (0.28 ~ 0.75)	0.59 (0.35 ~ 0.93)	<0.001
TG/HDL-c	1.23 (0.82 ~ 1.88)	1.65 (1.07 ~ 2.54)	<0.001
CRI-I	4.28 ± 1.36	4.69 ± 1.52	<0.001
CRI-II	2.70 ± 1.02	2.92 ± 1.10	<0.001
Non-HDL-c	3.66 ± 1.18	3.76 ± 1.26	0.157
AIP	0.11 ± 0.29	0.24 ± 0.30	<0.001
AC	3.28 ± 1.36	3.69 ± 1.52	<0.001
ALT (U/L)	17.00 (13.10 ~ 24.50)	21.10 (14.90 ~ 34.40)	<0.001
AST (U/L)	16.80 (14.00 ~ 21.00)	18.50 (15.20 ~ 25.40)	<0.001
GGT (U/L)	20.00 (15.00 ~ 28.00)	28.00 (19.50 ~ 42.23)	<0.001
UA (μmolL)	273.63 ± 85.84	316.87 ± 95.05	<0.001
Scr (μmol/L)	61.85 ± 22.50	68.23 ± 23.66	<0.001
Hb (g/L)	139.55 ± 16.16	145.50 ± 18.11	<0.001
HbA1c (%)	9.23 ± 2.17	9.32 ± 3.32	0.565
FPG (mmol/L)	8.86 ± 3.23	9.32 ± 3.37	0.013
Platelet (109/L)	248.76 ± 65.62	236.59 ± 60.37	0.001
SFA	184.00 (158.00 ~ 217.00)	231.00 (195.50 ~ 272.00)	<0.001

Notes: Data were presented as mean ± SD for normally distributed variables, and median (interquartile ranges) for abnormal distributions. Independent-Samples *T* test and Mann–Whitney *U*-test were used for comparisons of normally and abnormally distributed continuous variables between on-VFO and VFO groups, respectively. VFO was defined as VFA ≥ 100 cm^2. Categorical variables were presented as percentage (%), and were compared by chi-square test. Statistical differences were defined by P (two-tailed) less than 0.05.

Abbreviations: BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; TG, triglyceride; LDL-c, low-density lipoprotein cholesterol; HDL-c, high-density lipoprotein cholesterol; LCI, lipoprotein combine index; PHR, platelet/HDL-ratio; RC, remnant cholesterol; TG/HDL-c, TG/HDL-c ratio; CRI-I, Castelli's risk index I; CRI-II, Castelli's risk index II; Non-HDL-c, Non-high-density lipoprotein cholesterol; AIP, atherogenic index of plasma; AC, Atherogenic Coefficient; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, γ-Glutamyl transpeptidase; UA, uric acid; Scr, serum creatinine; Hb, hemoglobin; HbA1c, glycated hemoglobin; FPG, fasting plasma glucose; SFA, subcutaneous fat area; VFA, visceral fat area; VFO, visceral Fat Obesity.

DBP, ALT, AST, GGT, UA, Scr, Hb, FPG, platelets, TG, lipoprotein(a), LCI, RC, TG/HDL-c, CRI-I, CRI-II, AIP, AC and SFA. HDL-c levels were also significantly lower in the VFO group (all $P < 0.05$). No statistically significant differences were found between the two groups in age, diabetes duration, TC, LDL-c, HbA1c, PHR and Non-HDL-c (all $P > 0.05$).

Univariate Analysis

As shown in Table 2, Pearson correlation analysis indicated that VFA was positively correlated with BMI, SBP, DBP, ALT, AST, GGT, UA, Scr, Hb, FPG, TG, LCI, PHR, RC, TG/HDL-c, CRI-I, CRI-II, AIP, AC and SFA, while being negatively correlated with HDL-c and lipoprotein(a) (all $P < 0.05$). No significant correlations were found between VFA and age, diabetes duration, HbA1c, platelets, TC, LDL-c or Non-HDL-c (all $P > 0.05$). Figure 1 displays the scatter plot of Pearson correlation coefficients between conventional and unconventional lipid profiles and VFA. (A) Conventional

Table 2 The Correlation between VFA or VFO by Univariate Analysis

Variables	For VFA		For VFO	
	Correlation Coefficient	P	Correlation Coefficient	P
Age	−0.020	0.484	0.015	0.598
Diabetes duration	0.017	0.563	0.003	0.918
Females			−0.284	<0.001
Smoking			0.196	<0.001
Drinking			0.160	<0.001
BMI	0.561	<0.001	0.422	<0.001
SBP	0.155	<0.001	0.142	<0.001
DBP	0.196	<0.001	0.156	<0.001
TC	−0.003	0.904	−0.005	0.849
TG	0.196	<0.001	0.182	<0.001
LDL-c	−0.022	0.426	−0.015	0.597
HDL-c	−0.252	<0.001	−0.201	<0.001
Lipoprotein(a)	−0.087	0.009	−0.107	0.001
LCI	0.147	<0.001	0.137	<0.001
PHR	0.104	<0.001	0.062	0.027
RC	0.150	<0.001	0.127	<0.001
TG/HDL-c	0.201	<0.001	0.209	<0.001
CRI-I	0.174	<0.001	0.150	<0.001
CRI-II	0.122	<0.001	0.107	<0.001
Non-HDL-c	0.052	0.061	0.039	0.159
AIP	0.293	<0.001	0.214	<0.001
AC	0.174	<0.001	0.150	<0.001
ALT	0.158	<0.001	0.206	<0.001
AST	0.131	<0.001	0.166	<0.001
GGT	0.214	<0.001	0.286	<0.001
UA	0.251	<0.001	0.244	<0.001
Scr	0.142	<0.001	0.214	<0.001
Hb	0.202	<0.001	0.191	<0.001
HbA1c	0.018	0.535	0.005	0.855
FPG	0.077	0.006	0.073	0.009

(*Continued*)

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Table 2 (Continued).

Variables	For VFA		For VFO	
	Correlation Coefficient	P	Correlation Coefficient	P
Platelet	−0.050	0.074	−0.097	0.001
SFA	0.511	<0.001	0.405	<0.001

Notes: VFO was defined as VFA ≥ 100 cm^2. Correlation coefficients between VFA, VFO and different variables were determined by Pearson correlation analysis and Spearman correlation analysis, respectively.

Abbreviations: BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; TC, total cholesterol; TG, triglyceride; LDL-c, low-density lipoprotein cholesterol; HDL-c, high-density lipoprotein cholesterol; LCI, lipoprotein combine index; PHR, platelet/HDL-c ratio; RC, remnant cholesterol; TG/HDL-c, TG/HDL-C ratio; CRI-I, Castelli's risk index I; CRI-II, Castelli's risk index II; Non-HDL-c, Non-high-density lipoprotein cholesterol; AIP, atherogenic index of plasma; AC, Atherogenic Coefficient; ALT, alanine aminotransferase; AST, aspartate aminotransferase; GGT, γ-Glutamyl transpeptidase; UA, uric acid; Scr, serum creatinine; Hb, hemoglobin; HbA1c, glycated hemoglobin; FPG, fasting plasma glucose; SFA, subcutaneous fat area; VFA, visceral fat area; VFO, visceral Fat Obesity.

lipid profiles; (B) Unconventional lipid profiles. Spearman correlation analysis showed that VFO correlated positively with smoking, drinking, BMI, SBP, DBP, ALT, AST, GGT, UA, Scr, Hb, FPG, TG, LCI, PHR, RC, TG/HDL-c, CRI-I, CRI-II, AIP, AC and SFA, and negatively with gender, platelets, HDL-c and lipoprotein(a) (all $P < 0.05$). No significant associations were observed between VFO and age, diabetes duration, HbA1c, TC, LDL-c or Non-HDL-c (all $P > 0.05$). Figure 2 illustrates the Spearman correlation coefficients among the variables, with coefficients ranging from −0.5 to 1.0, where 1.0 represents a fully positive correlation and −0.5 represents a moderately negative correlation.

Multivariate Analysis

In our analysis, we performed binary logistic regression analysis with VFO as the dependent variable and factors listed in Table 2 as independent variables. VFO was defined as VFA values ≥ 100 cm^2. After adjusting for gender, smoking, drinking, BMI, SBP, DBP, ALT, AST, GGT, UA, Scr, Hb, FPG, platelets, TG, HDL-c, LCI, PHR, RC, TG/HDL-c, CRI-I, CRI-II, AIP, AC and SFA, results (Table 3) indicated that RC (OR: 1.667, 95% CI 1.216–2.285), platelets (OR: 0.997, 95% CI 0.994–0.999), gender (females) (OR: 0.233, 95% CI 0.172–0.315), BMI (OR: 1.352, 95% CI 1.243–1.471), SBP

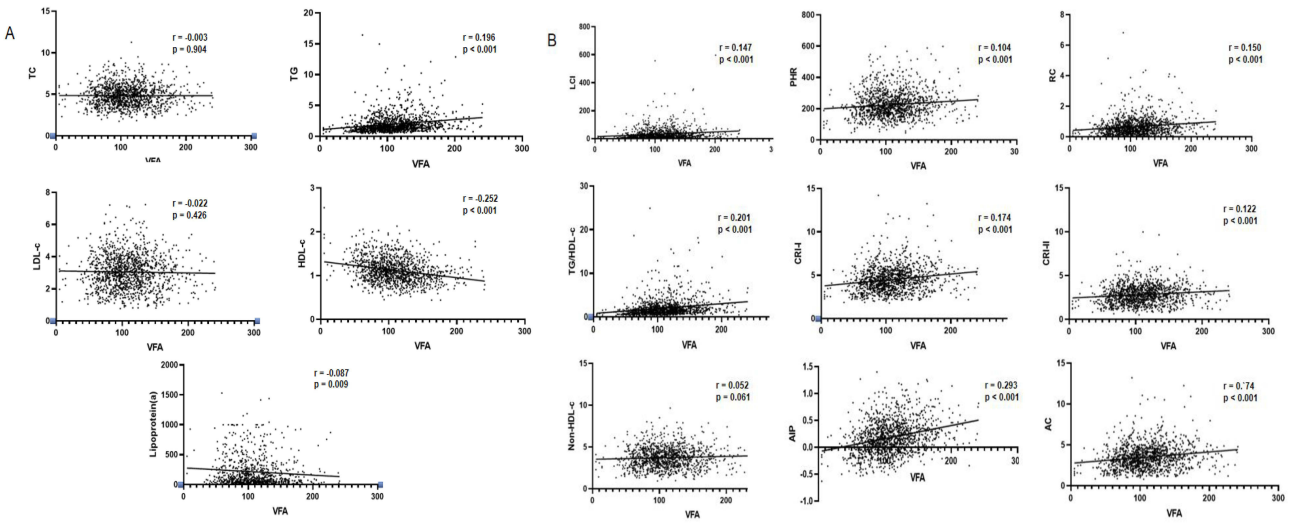

Figure 1 The scatter plot of Pearson correlation coefficients between conventional and unconventional lipid profiles and VFA. (**A**) Conventional lipid profiles (eg, LDL-c, HDL-c, TG) and their correlation with VFA. (**B**) Unconventional lipid profiles (eg, RC, TG/HDL-c ratio) and their correlation with VFA.

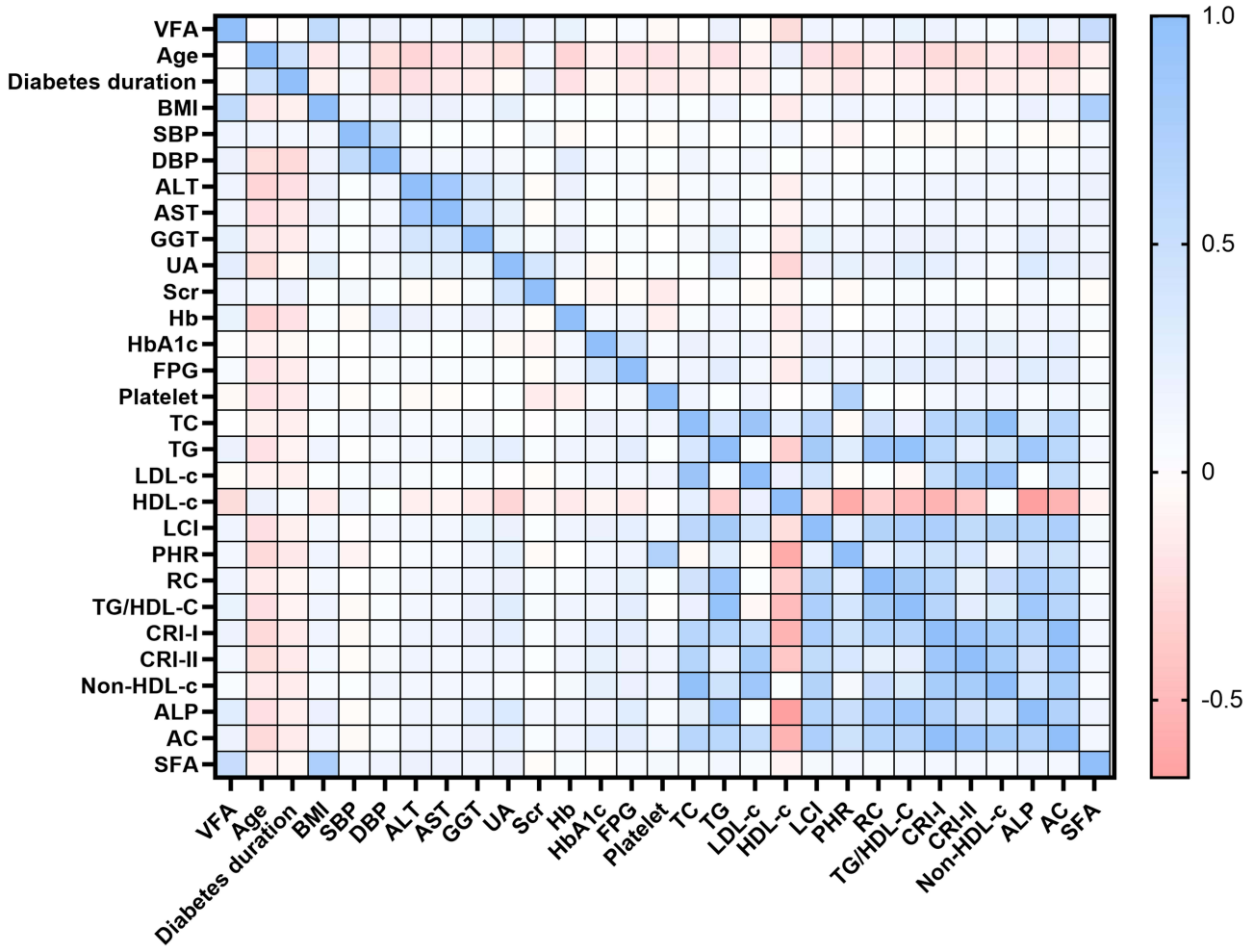

Figure 2 The heatmap shows the Spearman correlation coefficients among variables. Blue represents a strong positive correlation (close to +1), red represents a strong negative correlation (close to −1), and white indicates a weak or no correlation (close to 0).

(OR: 1.016, 95% CI 1.008–1.023), GGT (OR: 1.011, 95% CI 1.005–1.018) and SFA (OR: 1.010, 95% CI 1.007–1.014) were independently associated with VFO (all $P < 0.05$). Figure 3 displays a forest plot of the factors independently associated with VFO as identified by logistic regression analysis.

Table 3 The Relative Risk for VFO by Logistic Regression Analysis

Variables	B	SE	Wald	P	OR	95.0% CI for OR
RC	0.511	0.161	10.081	0.001	1.667	1.216–2.285
Platelet	−0.003	0.001	7.602	0.006	0.997	0.994–0.999
Gender (Females)	−1.457	0.155	88.726	<0.001	0.233	0.172–0.315
BMI	0.302	0.043	49.168	<0.001	1.352	1.243–1.471
SBP	0.015	0.004	15.083	<0.001	1.016	1.008–1.023
GGT	0.011	0.003	11.060	0.001	1.011	1.005–1.018
SFA	0.010	0.002	31.670	<0.001	1.010	1.007–1.014

Note: VFO was defined as VFA ≥ 100 cm^2.

Abbreviations: VFO, visceral Fat Obesity; RC, remnant cholesterol; HDL-c, high-density lipoprotein cholesterol; BMI, body mass index; SBP, systolic blood pressure; GGT, γ-Glutamyl transpeptidase; SFA, subcutaneous fat area; SE, standard error; CI, confidence interval; OR, odd ratio.

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Variables	P	OR	95.0 % CI for OR
RC	0.001	1.667	1.216 - 2.285
Platelet	0.006	0.997	0.994 - 0.999
Gender（Females）	<0.001	0.233	0.172 - 0.315
BMI	<0.001	1.352	1.243 - 1.471
SBP	<0.001	1.016	1.008 - 1.023
GGT	0.001	1.011	1.005 - 1.018
SFA	<0.001	1.01	1.007 - 1.014

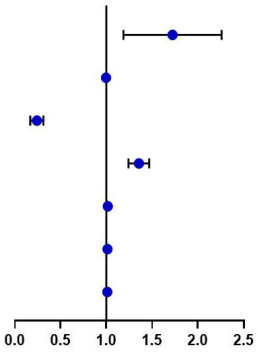

Figure 3 Forest plot of factors independently associated with VFO.

Discussion

In this study, we investigated the relationship between various lipid profiles and VFO. The results showed that the unconventional lipid profile RC exhibited significant independent associations in both univariate and multivariate analyses. After adjusting for confounding factors, RC remained independently associated with VFO, highlighting its potential as a reliable predictor.

Previous studies have confirmed a significant correlation between conventional lipid profiles and VFA.[7] However, in our study, although these conventional lipid profiles showed significant associations with VFA in univariate analysis, it was not included in the final regression model after adjusting for confounding factors. This finding suggests that single lipid profiles are limited in their ability to comprehensively reflect the complexity of lipid metabolism, especially in overweight/obese patients with T2DM. Furthermore, individual factors such as gender, age, ethnicity, and metabolic status may significantly influence the predictive ability of conventional lipid profiles.[8,9] Therefore, relying solely on conventional lipid profiles to predict visceral fat accumulation has certain limitations, and their clinical applicability may be restricted. Our study also included various unconventional lipid profiles, such as LCI, PHR, TG/HDL-c, TC/HDL-c, CRI-I, CRI-II, Non-HDL-c, AIP, and AC. The analysis showed that these profiles, including LCI, PHR, RC, TG/HDL-c, CRI-I, CRI-II, AIP, and AC, were positively correlated with VFA and independently associated with the prevalence of VFO after adjusting for confounders. Notably, RC remained in the regression model after adjusting for confounders, further emphasizing its significance as a predictive indicator for VFO.

RC, a triglyceride-rich lipoprotein remnant, reflects lipid metabolism imbalance and is a key risk factor for atherosclerosis and CVD.[25,26] Previous studies have demonstrated that RC contributes to the formation of atherogenic particles and foam cells, increasing endothelial cell susceptibility and exacerbating inflammatory responses and plaque formation.[27,28] These processes worsen the CVD risk and metabolic dysregulation within adipose tissue.[29] Additionally, RC influences genes related to lipogenesis and lipid oxidation, contributing to visceral fat accumulation, IR, and inflammation.[30–32] Therefore, RC may serve as a critical role in the onset and progression of VFO, and as a potential biomarker, it could become a key target for the management of atherosclerosis and metabolic disorders in the future.

Further analysis revealed that RC, along with other lipid profiles (such as TG/HDL-c, CRI-I, and AIP), was significantly elevated in the VFO group, indicating that these lipid profiles are closely related to visceral fat accumulation. RC may exacerbate fat accumulation by promoting lipogenesis, particularly in visceral adipocytes.[33,34] Compared to subcutaneous fat, visceral adipose tissue exhibits greater metabolic activity and is more susceptible to metabolic dysregulation, leading to the release of pro-inflammatory cytokines and the development of IR.[35] Elevated RC may contribute to VFO through its lipotoxic effects on visceral fat. Moreover, RC is closely associated with other lipid profiles, such as TG, LDL-c and lipoprotein(a),[26] suggesting a synergistic effect in promoting visceral fat accumulation.[36] In T2DM patients, elevated RC levels are typically accompanied by high TG and LDL-c levels, which may increase the transport of atherosclerotic particles, further raising the risk of CVD. The significant association between RC and VFO may, therefore, be driven by these interactions.

Apart from RC, our study also identified other factors independently associated with VFO, including platelet count, gender, BMI, and GGT. Platelet count was negatively correlated with VFO, suggesting that elevated platelet count may

serve as a marker of potential inflammatory responses or compensatory reactions in adipose tissue. The significant positive correlation between BMI and VFO further validates obesity as a major risk factor for VFO. Lastly, GGT, as a marker of liver function, showed a positive correlation with VFO, indicating that liver health may play a crucial role in the regulation of visceral fat accumulation and lipid metabolism.

Limitations

This study has several limitations to consider. First, due to its cross-sectional design, we cannot establish a causal relationship between RC levels and VFO. Second, the study did not account for the potential influence of lipid-lowering medications on the measured lipid profiles. Additionally, because the database did not include waist circumference as a key variable, we only adjusted for obesity-related profiles such as BMI and SFA. Furthermore, as a single-center study, the results may have limited generalizability. Finally, we could not rule out potential bias from medication use among T2DM patients or other confounding factors. Therefore, prospective, multi-center studies are needed for future validation of our findings.

Conclusion

In conclusion, among the various lipid profiles, the unconventional lipid profile RC is closely associated with VFA and serves as an independent risk factor for VFO in overweight/obese patients with T2DM. Given the critical role of VFO in the progression of T2DM and CVD, the independent association of RC makes it a potential target for early intervention and management. Future research should further explore the role of both conventional and unconventional lipid profiles, especially RC, in the monitoring and management of VFA in overweight/obese T2DM patients.

Ethics Approval and Consent to Participate

The study was reviewed and approved by the Human Ethics Committee of the People's Hospital of Linyi. This research was conducted in accordance with the ethical principles set forth in the Helsinki Declaration. Informed consent was obtained from all participants.

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Disclosure

The authors declare no competing interests in this study.

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