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Original Article

Relationship between visceral fat and diabetes mellitus in the elderly: A cross-sectional study

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Abstract

Background: Diabetes mellitus and obesity are major public health concerns in older adults, and visceral adipose tissue (VAT) is suggested to play a critical role in the metabolic dysfunction observed in type 2 diabetes. This cross-sectional study investigated the relationship between VAT and other obesity-related indicators with type 2 diabetes mellitus in elderly adults in northern Iran.

Methods: Participants aged 60 years and older were included, comprising 300 individuals with diabetes and 600 controls for comparative analysis, matched by age and sex. Demographic characteristics, physical activity, anthropometric measures, fasting blood sugar (FBS), and lipid profile were assessed. VAT and other body fat parameters were measured using dual-energy x-ray absorptiometry (DXA). Statistical analyses including t-tests, Pearson correlation, and ROC curve analysis were performed.

Results: The diabetic group had a significantly higher VAT mass (954.54±319.82 vs. 831.95±323.20, p <0.001) and volume (1031.92±345.79 vs. 899.38±349.43, p <0.001) than controls, while total body fat mass and percentage were not significantly different in between groups (p = 0.052, 0.878; respectively). FBS showed positive correlation with VAT metrics (r = 0.127, p < 0.001). VAT mass and volume yielded the highest AUCs (0.605, 95% CI: 0.567–0.644, p < 0.001) for diabetes discrimination.

Conclusion: Our findings support the significant association of VAT and diabetes in older adults, in contrast to general fat measures. However, discriminatory power of VAT remained poor to inconclusive in our study, especially in older women. Further analysis is needed to clarify the clinical utility of VAT in screening and prevention.

Keywords: Diabetes, Elderly, Visceral fat mass, Visceral fat volume, Obesity, Body mass index, Waist circumference.

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Diabetes mellitus and obesity are major worldwide health concerns due to their rapid increase in prevalence and the consequential rise in other non-communicable diseases (1, 2). The population of adults aged 20-99 years living with diabetes worldwide is projected to reach 700 million by 2045 with the subpopulation aged 65-99 years reaching 276.2 million (2, 3). Concurrently, the elderly population, commonly representing people over the age of 60, is projected to reach 2.1 billion by 2050, with a large portion expected to live in developing countries (4, 5). Predictions in Iran specify that the rate of elderly population will increase from 8.2% in 2011 to 21.7% in 2050 (6). Obesity prevalence amongst adults in Iran is predicted to reach 52.84% for the female, and 33.40% for the male population in the next two decades, with even higher rates reported in Mazandaran Province where the city of Amirkola is located (7). Moreover, obesity has become prevalent in older populations regardless of sex, race, or academic degree, with a significant rising trend (1, 8). Adipose tissue is a dynamic system responsible for endocrine and immunological functions, majorly distributed throughout the body as subcutaneous (SAT) and visceral adipose tissue (VAT) (9).

This tissue undergoes functional and structural alterations with aging, contributing to the senescent pro-inflammatory status in the body (10). Cytokines produced in this inflammatory process induce direct interference with insulin signaling pathways, promoting insulin resistance and diabetes mellitus (11). Particularly, VAT has been positively linked to hepatic insulin resistance (11). VAT primarily accumulates in the mesentery and omentum of the abdomen (9). Elevated free fatty acid (FFA) release by this tissue inhibits insulin-mediated suppression of hepatic glycogenolysis, resulting in insulin resistance (10, 11). Obesity is usually determined by Body Mass Index (BMI) of over 30. This index however, cannot differentiate between muscle mass and adipose tissue (12). Moreover, body weight, muscular mass, and height go through physiological changes with aging, impacting BMI accuracy (13). Waist circumference is another tool used to assess central obesity, which is independently associated with cardiovascular risk as a stronger factor than BMI (14). However, this factor cannot differentiate between subcutaneous adipose tissue and visceral adipose tissue (15). Radiographic evaluation of body adipose tissue by CT scanning or MRI is the most accurate way to estimate adipose tissue distribution (15). However, these methods are not broadly feasible in clinical settings, and Dual-energy X-ray Absorptiometry (DXA) remains as the most practical precise tool for assessing body composition due to its accessibility (16). DXA is highly correlated to CT scanning and MRI as a direct measurer of VAT in the elderly, supporting its validity in this scope (17, 18).

Given the significant economic burden of diabetes and a rapidly growing aging demographic, this study aimed to investigate the relationship between visceral adipose tissue (VAT) alongside other obesity indicators and type 2 diabetes mellitus in the elderly population of northern Iran.

Methods

Study design and setting: This cross-sectional study was conducted on the population of 60 years and older living in Amirkola, a northern city in Iran, who participated in the second phase of Amirkola Health and Aging Cohort Project (AHAP) (19, 20). All participants provided informed consent before participation. Data was de-identified before analysis and reported in aggregate form to ensure confidentiality.

Study population: A minimum sample size of 250 per group was estimated to detect a 100 g visceral fat difference between diabetic and non-diabetic groups, assuming a standard deviation of 400 g in both groups, with a 95% confidence interval and an 80% statistical power (21-23).

A total of 2135 individuals participated in the second phase of AHAP cohort. After the exclusion of individuals with missing relevant medical information or a history of cancer, stratified random sampling was performed based on diabetes status; a total of 300 diabetic patients were randomly selected according to their unique identification numbers. For the sake of comparative analysis, a control group of 600 non-diabetic age-matched individuals was randomly selected from the remaining eligible participants. A 1:1 sex ratio was predefined for both groups.

Data collection: Demographic data, including age, sex, marital status, and history of chronic illness were collected through direct interviews conducted in the AHAP project. Physical activity was measured by the validated Persian version of the Physical Activity Scale for the Elderly (PASE) questionnaire (24).

Body mass index (BMI) was calculated as weight (in kilograms) divided by height squared (in meters) (12). Patients were divided into three groups based on BMI levels: BMI of less than 25, between 25 and 29.9, and above 30 (12). Waist circumference (WC) was measured with the measuring tape positioned at the midpoint between the rib cage's lower border and the iliac crest (15). Fasting blood sugar (FBS), Triglyceride (TG), and Cholesterol levels were measured in 15 ml of blood samples after at least 12 hours of overnight fasting via Pars-Azmoon kits (Tehran, Iran). Diabetes status was defined as an FBS of 126 and over on two separate occasions carried out during the cohort study or self-reported current use of glucose-lowering medications. Individuals with known type 1 diabetes mellitus were not included in this study.

All selected patients had gone through whole body dual energy X-ray absorptiometry (DXA) scanning as a part of the AHAP project, via Hologic Horizon-W1 densitometer (Hologic Inc., Waltham, MA, USA) according to the manufacturer protocols. The android region of interest was the area between the ribs and the pelvis, automatically defined by Hologic APEX software (version 4.0). Visceral Adipose Tissue (VAT) mass (g), volume (cm^3), total body fat mass (g) and total body fat percentage were obtained via the DXA scans.

Statistical analysis: All statistical data were analyzed using SPSS Version 25 (IBM Corp., Armonk, NY, USA). Two-tailed p-values < 0.05 were considered statistically significant. Descriptive statistics such as mean and standard deviation (SD) were utilized to describe numerical variables. Frequency and percentage indicators were reported for categorical variables. Normality of continuous

data was assessed using the Kolmogorov-Smirnov test. Independent t-test, chi-square, Pearson's correlation coefficient and ROC curve were utilized for data analysis and hypothesis assessment.

Results

900 individuals (300 diabetic and 600 non-diabetics as a control group) were included in this study. Participants aged 60 years or older, including 450 men and 450 women. Mean age of participants was 67.82±5.61 and 67.82±5.62 in the diabetic and non-diabetic groups respectively. Table 1 represents the baseline characteristics in the diabetic and non-diabetic groups. Individuals with diabetes had a significantly higher BMI in comparison to the control group (p = 0.001). Other characteristics were not significantly associated with diabetic status.

Elderly patients with diabetes had a mean FBS level of 173.66±54.66 compared to 89.37±9.68 in the control group. As presented in table 2, individuals with diabetes had a higher visceral adiposity compared to the control group, with a VAT mass of 954.54±319.82 vs. 831.95±323.20 (p <0.001) and a VAT volume of 1031.92±345.79 vs. 899.38±349.43 (p <0.001).

Table 1. Distribution of baseline characteristics of the elderly sample population across diabetic and non-diabetic groups

Characteristic	Non-diabetic (percentage)	Diabetic (percentage)	P-value*
Sex			
Male	300 (50.0)	150 (50.0)	0.999
Female	300 (50.0)	150 (50.0)	
Body mass index			
<25	154 (25.7)	44 (14.7)	0.001**
25-29.9	232 (63.4)	134 (44.7)	
≥30	214 (35.7)	122 (40.7)	
Marital Status			
Single	88 (14.7)	50 (16.7)	0.432
Married	512 (85.3)	250 (83.3)	
Physical Activity			
Insufficient	469 (78.2)	246 (82.0)	0.180
Sufficient	131 (21.8)	54 (18.0)	

* Calculated with chi square. ** Significant p value

Individuals with diabetes also had a significantly higher BMI (29.42±4.45 vs. 28.43±4.88, p = 0.003), WC (96.12±10.14 vs. 92.18±10.48, p <0.001), TG (178.96±100.51 vs. 137.50±75.88, p <0.001), cholesterol (194.31±49.75 vs. 184.44±46.02, p = 0.003), and number of accompanying chronic illnesses (4.73±2.32 vs. 3.26±2.14, p <0.001) compared to the control group. In contrast, total body fat mass and percentage were not significantly different in the diabetic and non-diabetic groups (p = 0.052, 0.878; respectively).

Table 2. Mean and standard deviation of quantity variables studied in the elderly individuals with and without diabetes

Parameters	Group	Diabetic (Mean±SD)	Non-diabetic (Mean±SD)	P-value*
VAT Mass (g)	Total	954.54±319.82	831.95±323.20	<0.001
	Male	928.93±286.795	773.43±323.868	<0.001
	Female	980.15±348.849	890.46±312.273	0.006
VAT Volume (cm3)	Total	1031.92±345.79	899.38±349.43	<0.001
	Male	1004.21±310.041	836.11±350.116	<0.001
	Female	1059.62±377.199	962.66±337.634	0.006

Parameters	Group	Diabetic (Mean±SD)	Non-diabetic (Mean±SD)	P-value*
Total body fat (g)	Total	28997.39±8152.02	27849.14±8443.78	0.052
	Male	26410.149±6962.5363	24004.325±7236.7980	**0.001**
	Female	31584.63±8450.0053	31693.965±7797.3005	0.892
Total body fat percentage (%)	Total	39.88±7.54	39.97±8.50	0.878
	Male	34.628±5.2320	33.576±6.0355	0.069
	Female	45.139±5.6029	46.369±5.1235	**0.021**
BMI (kg/m^2)	Total	29.42±4.45	28.43±4.88	**0.003**
	Male	28.1903±3.62040	26.9280±4.29842	**0.002**
	Female	30.655±4.86336	29.949±4.98056	0.154
WC (cm)	Total	96.12±10.14	92.18±10.48	**<0.001**
	Male	96.200±9.5128	91.800±10.4625	**0.001**
	Female	96.04±10.7712	92.563±10.5201	**0.001**
TG (mg/dl)	Total	178.96±100.51	137.50±75.88	**<0.001**
	Male	172.93±96.466	126.36±61.739	**0.001**
	Female	184.99±104.385	148.64±86.464	**<0.001**
Cholesterol (mg/dl)	Total	194.31±49.75	184.44±46.02	**0.003**
	Male	177.95±49.000	185.90±44.782	0.097
	Female	190.67±49.848	202.98±45.734	**0.009**
Number of chronic illnesses	Total	4.73±2.32	3.26±2.14	**<0.001**
	Male	3.9867±1.97972	2.4700±1.75290	**<0.001**
	Female	5.48±2.40447	4.0667±2.20266	**<0.001**

SD: standard deviation, VAT: visceral adipose tissue, BMI: body mass index, WC: waist circumference, TG: Triglyceride. Significant p values are formatted in bold.

* p-values were calculated with independent sample t-test.

In the male population, mean VAT mass and volume, total body fat, BMI, WC, TG, and the number of accompanying chronic disease were significantly greater in the diabetic group than the non-diabetic group (all p values < 0.05). Total body fat percentage and cholesterol were not significantly different in both groups (P-value= 0.069 and 0.097 respectively) (table 2). In the female population, VAT metrics and total body fat percentage, WC, TG, and cholesterol levels as well as accompanying chronic disease were significantly greater in the diabetic population compared to the non-diabetic group (all p-values <0.05). In contrast, total body fat and BMI were not significantly different (P-value = 0.892 and 0.154 respectively) (table 2). The correlation analysis showed that VAT mass and VAT volume were strongly and positively correlated with total body fat ($r = 0.778$, $p < 0.001$), BMI ($r = 0.755$, $p < 0.001$), and TG ($r = 0.194$, $p < 0.001$). Total body fat percentage was also positively associated with TG ($r = 0.067$, $p = 0.045$) and cholesterol ($r = 0.139$, $p < 0.001$). FBS demonstrated weak yet significant positive correlation with VAT mass and volume ($r = 0.127$, $p < 0.001$) and TG levels ($r = 0.265$, $p < 0.001$), yet did not correlate significantly with total body fat, BMI, or PASE score. PASE score was inversely associated with total body fat percentage ($r = –0.191$, $p < 0.001$), VAT measures ($r = –0.121$, $p < 0.001$), and age ($r = –0.288$, $p < 0.001$). Age showed small negative correlation with total body fat ($r = –0.113$, $p = 0.001$), but was not meaningfully associated with VAT measures, BMI, FBS, TG, or cholesterol (table 3). Sex-stratified correlation analysis was also performed (table 3).

Table 3. Pearson correlation coefficients between quantitative variables in the study population (total and grouped by sex) presented as: coefficient (p value)

Variables		VAT Mass (g)	VAT Volume (cm3)	Total body fat percentage (%)	Total body fat (g)	FBS (mg/dL)	TG (mg/dL)	Cholesterol (mg/dL)	Age	BMI (kg/m^2)
VAT Mass (g)	Total	1								
	Male	1								
	Female	1								
VAT Volume (cm3)	Total	1.000 **(<0.001)**	1							
	Male	1.000 **(<0.001)**	1							
	Female	1.000 **(<0.001)**	1							
Total body fat percentage (%)	Total	0.550 **(<0.001)**	0.550 **(<0.001)**	1						
	Male	0.711 **(<0.001)**	0.711 **(<0.001)**	1						
	Female	0.609 **(<0.001)**	0.609 **(<0.001)**	1						
Total body fat (g)	Total	0.778 **(<0.001)**	0.778 **(<0.001)**	0.834 **(<0.001)**	1					
	Male	0.826 **(<0.001)**	0.826 **(<0.001)**	0.895 **(<0.001)**	1					
	Female	0.771 **(<0.001)**	0.771 **(<0.001)**	0.853 **(<0.001)**	1					
FBS (mg/dL)	Total	0.127 **(<0.001)**	0.127 **(<0.001)**	-0.002 (0.956)	0.038 (0.258)	1				
	Male	0.205 **(<0.001)**	0.205 **(<0.001)**	0.111 **(0.018)**	0.149 **(0.002)**	1				
	Female	0.051 (0.284)	0.051 (0.285)	0.154 **(0.001)**	0.065 (0.169)	1				
TG (mg/dL)	Total	0.194 **(<0.001)**	0.194 **(<0.001)**	0.067 **(0.045)**	0.113 **(0.001)**	0.265 **(<0.001)**	1			
	Male	0.231 **(<0.001)**	0.231 **(<0.001)**	0.105 **(0.026)**	0.131 **(0.005)**	0.335 **(<0.001)**	1			
	Female	0.142 **(<0.001)**	0.142 **(0.002)**	0.131 **(0.005)**	0.034 (0.475)	0.210 **(<0.001)**	1			
Cholesterol (mg/dL)	Total	0.031 (0.345)	0.032 (0.345)	0.139 **(<0.001)**	0.062 (0.064)	0.020 (0.542)	0.405 **(<0.001)**	1		
	Male	0.014 (0.766)	0.014 (0.766)	0.064 (0.177)	-0.003 (0.946)	0.063 (0.179)	0.390 **(<0.001)**	1		
	Female	0.002 (0.971)	0.002 (0.971)	0.011 (0.813)	0.009 (0.844)	0.025 (0.600)	0.400 **(<0.001)**	1		
Age	Total	-0.008 (0.801)	-0.008 (0.803)	-0.025 (0.453)	-0.113 **(0.001)**	-0.027 (0.426)	-0.048 (0.148)	-0.052 (0.118)	1	
	Male	0.035 (0.465)	0.035 (0.464)	0.056 (0.239)	-0.039 (0.412)	-0.011 (0.815)	-0.105 **(0.025)**	-0.031 (0.507)	1	
	Female	-0.053 (0.262)	-0.053 (0.262)	-0.158 **(0.001)**	-0.208 **(<0.001)**	-0.042 (0.374)	-0.004 (0.933)	-0.077 (0.104)	1	

Variables		VAT Mass (g)	VAT Volume (cm3)	Total body fat percentage (%)	Total body fat (g)	FBS (mg/dL)	TG (mg/dL)	Cholesterol (mg/dL)	Age	BMI (kg/m^2)	
BMI (kg/m^2)	Total	0.755 **(<0.001)**	0.755 **(<0.001)**	0.666 **(<0.001)**	0.885 **(<0.001)**	0.059 (0.076)	0.157 **(<0.001)**	0.039 (0.243)	-0.100 **(0.003)**	1	
	Male	0.791 **(<0.001)**	0.791 **(<0.001)**	0.741 **(<0.001)**	0.883 **(<0.001)**	0.118 **(0.012)**	0.153 **(0.001)**	-0.036 (0.446)	-0.067 (0.157)	1	
	Female	0.727 **(<0.001)**	0.727 **(<0.001)**	0.657 **(<0.001)**	0.873 **(<0.001)**	0.009 (0.856)	0.116 **(0.013)**	-0.010 (0.833)	-0.142 **(0.003)**	1	
Total PASE score	Total	-0.121 **(<0.001)**	-0.121 **(<0.001)**	-0.191 **(<0.001)**	-0.127 **(<0.001)**	-0.029 (0.392)	-0.022 (0.518)	0.023 (0.492)	-0.288 **(<0.001)**	-0.109 **(0.001)**	1
	Male	-0.118 **(0.012)**	-0.118 **(0.012)**	-0.163 **(0.001)**	-0.107 **(0.024)**	-0.081 (0.087)	0.009 (0.847)	0.084 (0.075)	-0.281 **(<0.001)**	-0.053 (0.262)	1
	Female	-0.079 (0.093)	-0.079 (0.093)	-0.033 (0.484)	-0.026 (0.589)	-0.045 (0.341)	-0.020 (0.675)	0.008 (0.871)	-0.311 (<0.001)	-0.083 (0.079)	1

VAT: visceral adipose tissue, FBS: Fasting blood sugar, TG: Triglyceride, BMI: body mass index. Significant p values are formatted in bold.

Among the male population, VAT mass and volume, total body fat, and total body fat percentage significantly correlated with FBS as well as TG and PASE score, with no significant correlation to cholesterol. FBS and TG correlated positively with BMI, with no significant correlation with total PASE score. TG negatively correlated with age. In the female population, VAT mass and volume had a significant positive correlation with TG levels and no correlation with FBS and cholesterol. Total body fat percentage had a significant correlation with FBS and TG and age. FBS had no significant correlation with BMI or age.

TG had a positive correlation with BMI. Total PASE score was negatively correlated with BMI, otherwise having no significant correlation with other metrics. Sex-stratified scatter plots illustrating the association between VAT mass and FBS are presented in figure 1. Diagnostic accuracy of different adiposity indicators in the elderly population for diabetes was assessed using the ROC curve (figure 2), along with sex stratified analyses (figure 3a-b).

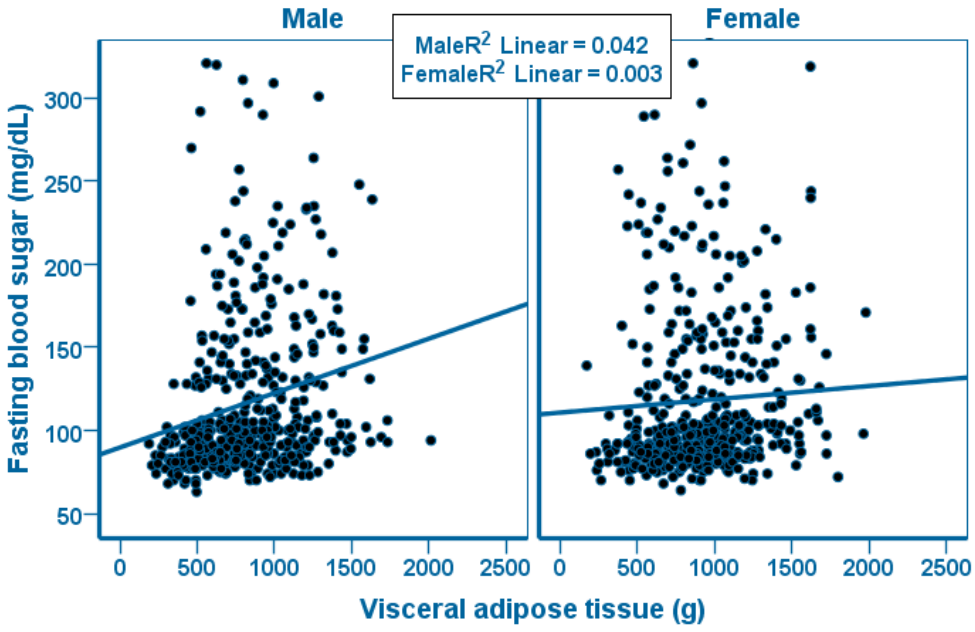

Figure 1. Scatter plots of visceral adipose tissue (VAT) mass and fasting blood sugar (FBS), with fitted linear regression lines in the male and female populations

Adiposity indicators showed modest discrimination power for diabetes, with VAT mass and VAT volume yielding the highest AUCs (AUC = 0.605, 95% CI: 0.567–0.644, p < 0.001). Waist circumference demonstrated similar values (AUC = 0.601, 95% CI: 0.563–0.639, p < 0.001). BMI showed a lower discrimination ability (AUC = 0.557, 95% CI: 0.519–0.596, p = 0.005), whereas total body fat mass and total body fat percentage were similar to chance (table 4). In our sex-stratified analyses, VAT mass and VAT volume showed the best discriminatory performance in men (AUC = 0.652, 95% CI: 0.60–0.70, p < 0.001), demonstrating a higher AUC than waist circumference (AUC = 0.613, 95% CI: 0.56–0.66, p < 0.001). BMI and total body fat also showed poor yet meaningful discrimination power (both AUCs = 0.586, p = 0.003) (table 4). The discriminatory ability of all adiposity indicators was even weaker in women, with VAT mass and volume showing only borderline performance (AUC = 0.566, 95% CI: 0.50–0.62, p = 0.022) and total fat mass and BMI performing at or below chance levels. Interestingly, total body fat percentage showed a meaningful yet poor negative discriminatory power (AUC = 0.439, 95% CI: 0.38–0.49, p = 0.034) (table 4, figure 3a-b).

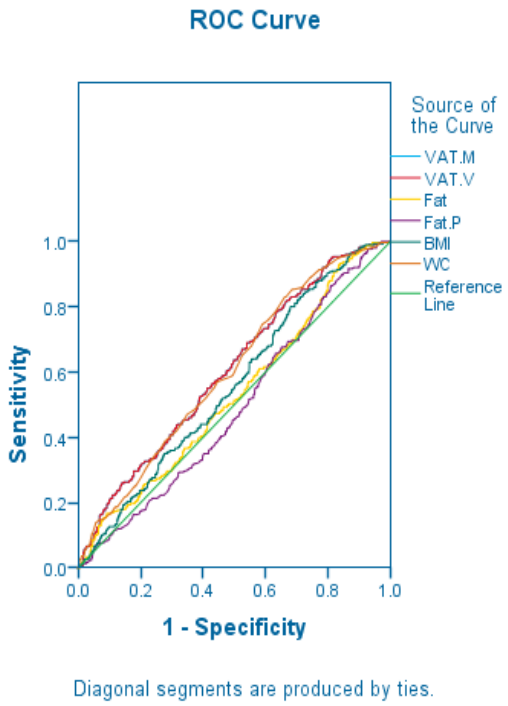

Figure 2. Receiver operating characteristics curve of adiposity indicators for evaluating diagnostic accuracy for diabetes

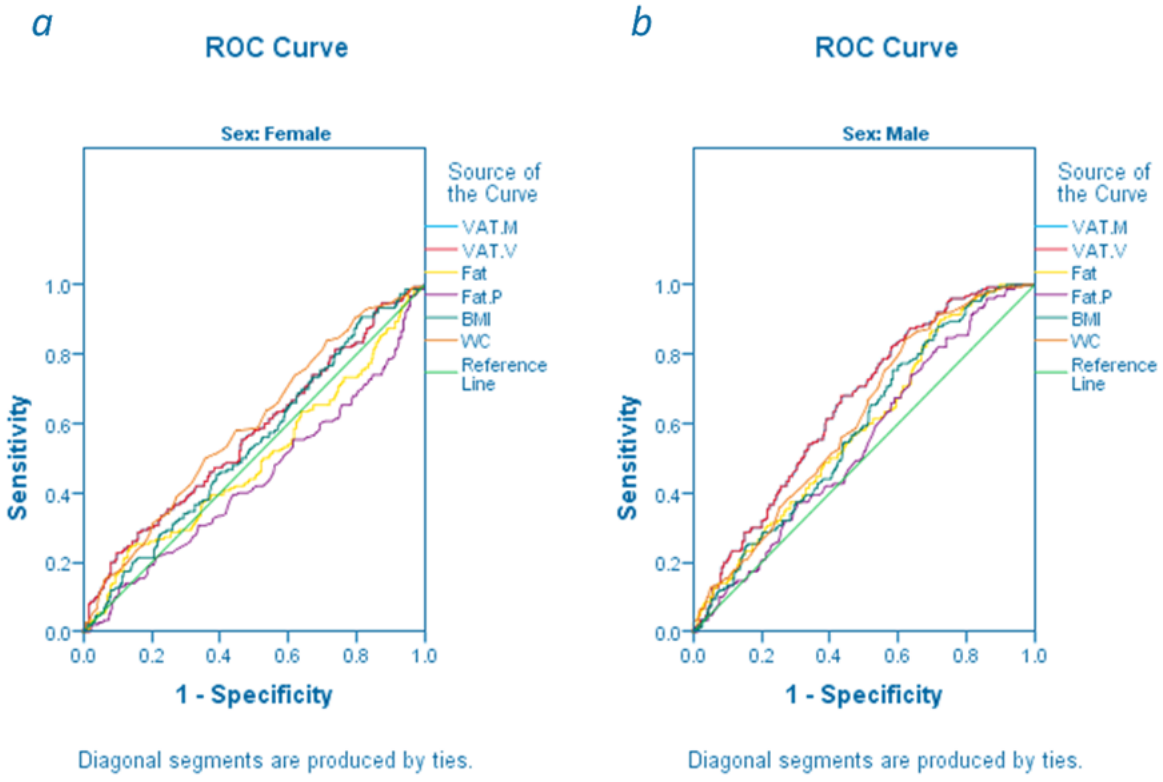

Figure 3. Receiver operating characteristics curve of adiposity indicators for evaluating diagnostic accuracy for diabetes in men (a), and women (b).

Table 4. Area under the curve of adiposity indicators for diabetes diagnostic accuracy

Parameters	Groups	AUC	CI 95%	P-value
VAT Mass (g)	Total	0.605	0.567-0.644	**<0.001**
	Male	0.652	0.60-0.70	**<0.001**
	Female	0.566	0.50-0.62	**0.022**
VAT Volume (cm3)	Total	0.605	0.567-0.644	**<0.001**
	Male	0.652	0.60-0.70	**<0.001**
	Female	0.566	0.50-0.62	**0.022**
Total body fat (g)	Total	0.530	0.490-0.569	0.146
	Male	0.586	0.53-0.64	**0.003**
	Female	0.491	0.43-0.55	0.765
Total body fat percentage (%)	Total	0.492	0.453-0.531	0.687
	Male	0.544	0.49-0.59	0.125
	Female	0.439	0.38-0.49	**0.034**
BMI (kg/m2)	Total	0.557	0.519-0.596	**0.005**
	Male	0.586	0.53-0.63	**0.003**
	Female	0.539	0.48-0.59	0.483
WC (cm)	Total	0.601	0.563-0.639	**<0.001**
	Male	0.613	0.56-0.66	**<0.001**
	Female	0.590	0.53-0.64	0.534

VAT: visceral adipose tissue, BMI: body mass index, WC: waist circumference, AUC: area under the curve, CI: confidence interval.

Discussion

This cross-sectional study assessed the relationship between different obesity metrics and diabetes in Iranian older adults. Our findings demonstrated that mean VAT mass and volume were significantly higher in individuals with diabetes compared to non-diabetics across both sexes. In contrast, total body fat mass and percentage were generally not significantly different between the two groups. These findings suggest that visceral fat accumulation is associated with diabetes in older adults, rather than general obesity.

Most epidemiologic studies use anthropometric metrics such as BMI or WC to define obesity. However, BMI cannot differentiate between body fat and lean mass, which are both prone to changes with aging (12). WC is a better metric for central obesity but also cannot differentiate between subcutaneous adipose tissue and VAT, unlike DXA or other radiologic methods (14). The relationship between visceral adipose tissue, calculated by a visceral adiposity index (VAI), and diabetes had been proposed in studies on the Chinese adult population by Han et al., Zhang et al., and Liu et al. (25-27). Nusrianto et al. conducted a systematic review, reporting VAI as a practical formula for estimation of visceral fat accumulation, making it a possible predictor for type 2 diabetes prediction in the Asian population (28). However, comparison of this index and actual measurements by DXA or CT scans have not been made in these studies. In a similar study to ours by Jung et al. on Korean adult population, visceral fat mass measured via DXA was associated with both diabetes and pre-diabetes, with an AUC of 0.69 (95% CI=0.64–0.73) in men and 0.70 (95% CI=0.67–0.74) in women. This association was closer than other obesity indicators such as waist circumference due to the differentiation of VAT and subcutaneous adipose tissue in DXA scans (22). The mechanism of the contribution of visceral fat to diabetes incidence is not completely clear, though it has been attributed to several underlying mechanisms; Accumulation of visceral fat increases abnormal adipocytokine secretion while reducing the secretion of anti-inflammatory

adiponectin (29, 30). This causes immune-activation and localized adipose inflammation which in turn elevates blood free fatty acids (FFAs) (11). FFAs subsequently cause inflammation in pancreatic islet cells and arteries (31, 32). Furthermore, they increase hepatic glucose production, inhibiting hepatic insulin extraction which exacerbates insulin resistance (11). FFAs also attenuates the protective glucose uptake capacity of skeletal muscle, particularly in older adults with lower lean mass, directly leading to glucose intolerance and type 2 diabetes (33).

Sex-specific differences were observed in our findings. In females, total body fat percentage was significantly higher among those with diabetes, whereas total body fat mass or BMI were not significantly different between groups. Waist circumference and VAT were both significantly higher in females. This pattern of higher body fat percentage without increased total fat mass suggests a possible reduction in lean mass or sarcopenia in older diabetic women, accompanied by central fat redistribution. Among males, total body fat mass, BMI and VAT were all higher in the diabetic group, indicating a more generalized increase in adiposity in this sex. ROC curve analysis demonstrated low to moderate VAT mass and volume discriminatory accuracy for diabetes in men (0.652, 95% CI: 0.60-0.70), whereas in women the value was closer to chance (AUC=0.566, 95% CI: 0.50-0.62). A weak yet significant negative relationship between diabetes and total body fat mass and percentage also persisted.

Prior studies were partially concordant with our findings; Chiba et al. reported that higher visceral fat accumulation (VFA), measured by abdominal bioelectrical impedance analysis, was associated with an increased risk of diabetes, similarly in men and women (33). In a study by Yokokawa et al., VFA, assessed via CT, was positively associated with diabetes in both sexes, whereas subcutaneous fat accumulation (SFA) was only positively associated with diabetes in women (34). In another study by Lv et al., VFA was found to be more strongly associated with type 2 diabetes in women than in men; among men, BMI seemed to be more important to diabetes risk than visceral adiposity (35). In contrast to these findings, our study found VAT to be associated with diabetes in both sexes, while having a stronger diagnostic accuracy in men.

Correlation analyses revealed that VAT mass and volume had a significant correlation with FBS, in contrast to BMI and total body fat mass. In the male sex, there were significant correlations between FBS and all adiposity indicators measured. Meanwhile in women, the only significant correlation observed was with body fat percentage. These correlations suggest that adiposity indicators, including VAT measures, relate more strongly to glycemic status among men. Nevertheless, diabetes classification in this cohort depended on both FBS and blood glucose-lowering medication use, which can modify FBS. Therefore, the observed correlations reflect relationships with poor glycemic control rather than diabetes per se. PASE score negatively correlated with both VAT (mass and volume) and BMI. However, it mostly showed no significant correlation with fasting glucose and lipid markers, which could be due to medication usage, dietary variability, differences in disease duration or the inherent limitations of the cross-sectional design of our study. Nevertheless, this does not diminish the importance of physical activity as a protective factor against obesity (36). Regular physical activity can support better adaptation in individuals with obesity and diabetes, improving overall disease management and quality of life (37).

Number of comorbid diseases was significantly higher among diabetic individuals in both men and women. This relationship could be bi-directional, as it is not truly clear which causes the other. Nevertheless, older adults frequently suffer from multiple chronic conditions that exert accumulative adverse effects on their well-being (38). The coexistence of these conditions often causes physical debility and lowered quality of life in the older population, as well as imposing psychological burden that can further exacerbate the overall impact of diabetes on these individuals (38, 39).

This study has several strengths; the major strength of our study was its relatively large sample of participants of older adults. Second, our study adds to the existing literature by focusing on the older population in which the relationship between visceral adiposity and diabetes remains understudied. Third, fat measurements were assessed using DXA, a valid radiologic method which provided a solid reference for comparison with other anthropometric measurements such as BMI and WC. In addition, our study compared VAT mass and volume with total body fat mass and body fat percentage, allowing for a better understanding of how VAT fits within overall body composition and fat. However, the present study has several limitations that should be taken into consideration. First, this was a cross-sectional study and causal relationships could not be inferred. The directionality of associations between visceral adiposity, glycemic measures, and diabetes status remains unclear. Longitudinal studies would be required to further clarify this relationship. Second, diabetes status was determined by only FBS levels and medication use; we did not include additional diagnostic indicators such as HbA1C or oral glucose tolerance testing (OGTT). As a result, individuals may have been misclassified. Furthermore, the use of glucose-lowering medications complicates the interpretations of blood glucose. Third, we did not account for differences in diabetes medications used. Various drugs have different effects on body weight and fat distribution, which may have influenced adiposity patterns observed in the diabetic group. Fourth, our assessment of adiposity focused solely on

visceral adipose tissue (VAT), as it was previously proposed to be more influential on the metabolic dysfunction in diabetes. Other adipose tissues, such as subcutaneous adipose tissue and intermuscular adipose tissue, were not included in our study, which could have provided a more comprehensive understanding of fat distribution differences in diabetes. Additionally, because the association between VAT and diabetes was assessed using univariable analyses, confounding factors such as BMI, WC, and physical activity cannot be excluded. Finally, although we adjusted for some relevant variables, we were unable to fully account for all potential confounding factors, including diet, specific comorbid conditions, and other lifestyle or metabolic variables.

Future research should explore the underlying biological mechanisms of the observed metabolic effects of visceral adiposity in older adults. Incorporating adiponectin levels in similar studies may help explain metabolic pathways. Observed sex differences need to be clarified; the role of androgens in influencing VAT accumulation in men and the impact of menopause-related hormonal decline in older women should be further investigated (40, 41). In addition, subcutaneous adipose tissue and intermuscular adipose tissue could be assessed along with VAT in individuals with type 2 diabetes. Future work could also take advantage of stratifying older adults into more refined age groups to provide a better understanding of how aging impacts diabetes and VAT relationship. The findings of this study can be used to improve targeted prevention strategies and monitoring of predisposing risk factors in older adults.

In conclusion, results demonstrated that VAT mass and volume were significantly higher in individuals over 60 with diabetes compared to non-diabetics across both sexes, whereas total body fat mass and percentage were not significantly different between groups. Our findings provide preliminary insights that may contribute to the development of future preventative strategies and identification of individuals at high risk for diabetes. However, the discriminatory power of VAT remained poor to inconclusive in the present study, especially in older women.

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