

Original Article

Relationship between neck subcutaneous adipose tissue thickness and insulin resistance and related biomarker expression in overweight and obese patients

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Abstract: Objectives: This study aimed to investigate the association between neck subcutaneous adipose tissue (NSAT) thickness and insulin resistance (IR), and to evaluate the diagnostic value of NSAT for metabolic disorders. Methods: A total of 617 participants from Hongqiao Town were divided into two groups: an experimental group (EG) and a control group (CG). Ultrasonography (US) was adopted to measure NSAT thickness, and homeostatic model assessment-insulin resistance (HOMA-IR) was calculated to assess IR. Pearson correlation analysis was performed to analyze the correlation between NSAT and IR. Results: Male proportion (41.6% vs 24.7%), waist circumference (WC), hip circumference (HC), and body mass index (BMI) were significantly elevated in the EG compared to the CG (all $P < 0.05$). NSAT thickness was also markedly greater in the EG ($P < 0.05$). NSAT thickness was positively correlated with insulin and HOMA-IR, while no significant correlation was found between NSAT and fasting blood glucose (both $P > 0.05$). Subgroup analysis demonstrated that the correlation between NSAT and IR was more prominent in males and subjects aged over 60 years. Conclusion: NSAT thickness is significantly positively correlated with IR, independent of classic obesity indicators, indicating that neck subcutaneous fat can act as a new imaging biomarker for identifying metabolic abnormalities.

Keywords: Overweight/obesity, insulin resistance, neck subcutaneous adipose tissue

Introduction

The issue of being overweight and obese has become one of the most severe challenges in global public health. With lifestyle shifts, the widespread availability of high-calorie diets, and reduced physical activity, the number of overweight and obese individuals continues to grow, and the associated health risks have attracted widespread attention [1]. Epidemiological data show that the incidence of obesity is increasing annually, affecting people of all age groups and regions. With China's economic development and rising living standards, the number of obese individuals nationwide has gradually increased [2, 3].

Obesity is not merely an aesthetic concern; it is also related to hypertension and other diseases, placing a heavy burden on healthcare systems and resources. Further research has revealed that obesity and being overweight are primarily driven by metabolic dysregulation. A key manifestation of this disturbance is insulin resistance (IR), which refers to the reduced sensitivity of cells to insulin, impairing their ability to effectively lower blood glucose and leading to sustained hyperglycemia [4]. Over time, this process increases the risk of diabetes. The underlying mechanism involves complex changes in molecular signaling pathways, from abnormal phosphorylation of insulin receptor substrates to inhibition of key downstream kinases

such as PI3K, triggering a cascade of reactions that reduce cellular glucose uptake.

Neck subcutaneous adipose tissue (NSAT) is a distinct fat depot that has received increasing research attention in recent years. Most previous studies have focused on the link between abdominal or visceral adipose tissue and metabolic diseases, while NSAT remains relatively underexplored [5-7]. In fact, NSAT has unique structures and functions. It is close to the vascular and neural networks of the neck, and the adipokines it secretes may more directly affect systemic metabolic homeostasis through paracrine or endocrine pathways. Pro-inflammatory adipokines in this region can activate local immune cells, trigger chronic low-grade inflammation, interfere with insulin signaling, and thereby exacerbate IR [8].

As the concept of precision medicine advances, there is a growing need for markers that can precisely show the degree of metabolic abnormality and clinical risk in obese individuals. Traditional blood glucose and insulin tests can detect IR but have limitations; they cannot fully and dynamically reflect disease progression [9]. Emerging biomarkers, such as adiponectin and free fatty acids, play key roles in regulating adipose tissue metabolism. Changes in their expression are closely related to IR and hold potential as tools for early diagnosis, disease monitoring, and therapeutic target selection [10, 11].

This article innovatively focuses on NSAT thickness in overweight and obese patients, aiming to explore its intrinsic relationship with IR and the expression of related biomarkers. The findings may fill a research gap in this field, provide new insights, and offer a more precise and comprehensive theoretical basis to improve health outcomes in obese populations.

Materials and methods

Study design and subjects

This was a community-based cross-sectional observational study, and it was approved by the Ethics Committee of Hongqiao Community Health Service Center, Minhang District.

Participants were randomly selected from the diabetes screening population of Hongqiao

Town. A total of 617 participants were recruited and divided into an experimental group (EG, overweight/obese individuals) and a control group (CG, non-overweight individuals) based on BMI criteria: overweight ($24 \text{ kg/m}^2 \leq \text{BMI} < 28 \text{ kg/m}^2$) and obese ($\text{BMI} \geq 28 \text{ kg/m}^2$).

Inclusion criteria: (1) Aged 18 to 70 years. (2) Long-term residents of Hongqiao Town. (3) No history of psychiatric disorders, with the ability to fully understand and cooperate with various examination procedures, such as ultrasound and blood sampling. (4) Relatively stable life-style habits, with no major life events (e.g., unemployment) in the past 3 months that could drastically alter diet or exercise habits.

Exclusion criteria: (1) Patients with chronic diseases that severely affect metabolism or survival status, such as stroke, myocardial infarction, renal failure, or cancer. These conditions can cause complex metabolic disturbances that interfere with the study of IR and fat metabolism. (2) Pregnant and lactating women. (3) Individuals who have undergone bariatric surgery or liposuction, or who have taken drugs that significantly affect weight and blood glucose in the past six months (such as some antipsychotics and corticosteroids).

Sample size estimation

Based on a previously reported correlation coefficient of $r = 0.199$ between neck circumference-related adiposity indices and IR from a cross-sectional study [12], with a two-sided significance level of $\alpha = 0.05$ and a power of 0.80, the minimum required sample size was calculated as 246 participants using the correlation-based sample size formula. Considering that the present study involved an overweight/obese EG and a normal-weight CG, and accounting for an estimated 20% dropout rate, a total of 617 participants were eventually enrolled to ensure sufficient statistical power for between-group comparisons, correlation analyses, and stratified subgroup analyses.

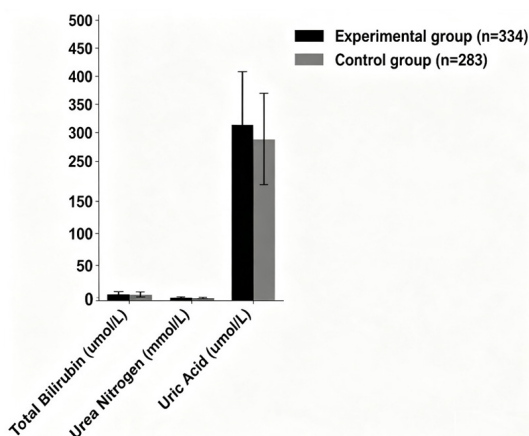
Ultrasound measurement of NSAT thickness

An ultrasonic instrument (Mindray Resonance 5s, Mindray Company) was used to measure NSAT thickness. Participants were seated with their heads slightly flexed forward to expose the neck area. A 3-10 MHz linear array trans-

Table 1. Comparison of baseline characteristics of subjects

Indicator	Experimental group (n = 334)	Control group (n = 283)	Statistical value	P value
Gender (Male/Female)	139/195	70/213	$\chi^2 = 19.12$	< 0.05
Age (years)	58.91±12.26	54.25±13.98	t = 1.89	> 0.05
Waist circumference (WC, cm)	91.70±6.37	76.93±6.98	t = 28.34	< 0.05
Hip circumference (HC, cm)	107.71±8.51	90.53±8.17	t = 25.67	< 0.05
Body mass index (BMI, kg/m ²)	26.18±1.58	21.68±1.62	t = 35.21	< 0.05

Note: Abbreviations: WC, waist circumference; HC, hip circumference; BMI, body mass index.

**Figure 1.** Comparison of liver and kidney function indicators in subjects.

ducer was used to scan vertically along the midline of the neck from top to bottom, and subcutaneous fat thickness was observed and recorded at the level of the 7th cervical vertebra. Three measurements were taken for each participant, and the average value was used as the final result.

Measurement of IR

IR was assessed using the HOMA-IR. The HOMA-IR equation is: fasting insulin ($\mu\text{U/mL}$) $\times$ FBG (mmol/L)/22.5. Higher HOMA-IR values indicate more severe IR. Participants fasted for at least 8 hours, and fasting venous blood was collected to measure insulin and glucose levels.

Clinical data collection

(1) Basic information of participants: gender, age, height, weight, WC, HC, etc. (2) Liver and kidney function indicators: total bilirubin ($\mu\text{mol/L}$), urea nitrogen (mmol/L), uric acid ($\mu\text{mol/L}$). (3) Complete blood count indicators: (A) White blood cell (WBC)-related: total WBC

count ($10^9/\text{L}$), lymphocyte ratio (%), neutrophil ratio (%), eosinophil absolute value ($10^9/\text{L}$), basophil absolute value ($10^9/\text{L}$), monocyte ratio (%), lymphocyte count ($10^9/\text{L}$), monocyte count ($10^9/\text{L}$), neutrophil count ($10^9/\text{L}$). (B) Red blood cell (RBC)-related: RBC count ($10^{12}/\text{L}$), hemoglobin (Hb) (g/L), hematocrit (%), mean corpuscular volume (MCV) (fL), mean Hb content (pg), mean Hb concentration (g/L), red cell distribution width (RDW) (%). (C) Platelet-related: platelet count ($10^9/\text{L}$), platelet distribution width (PDW) (fL), large platelet ratio (%), mean platelet volume (fL). (4) Insulin (pmol/L) and FBG data were collected to calculate the IR index (HOMA-IR).

Statistical methods

Data were analyzed using SPSS statistical software. Continuous data were represented as mean $\pm$ SD, and a t-test or analysis of variance was adopted. Categorical data were represented as percentages, and the χ^2 test or Fisher's exact test was used. Pearson correlation analysis was performed to explore the correlations between NSAT thickness and IR-related indicators (FBG, insulin, and HOMA-IR). A P -value ≤ 0.05 was considered statistically significant. Additionally, subgroup analysis was conducted to further investigate the relationship between NSAT thickness and IR. Participants were grouped based on BMI, and differences in NSAT thickness and IR levels were compared.

Results

Comparison of baseline characteristics

As is shown in **Table 1**, the EG had a significantly higher proportion of males (41.6% vs 24.7%), as well as higher WC, HC, and BMI compared with the CG (all $P < 0.05$). No significant difference was observed in age between the two groups ($P > 0.05$).

NSAT thickness and IR

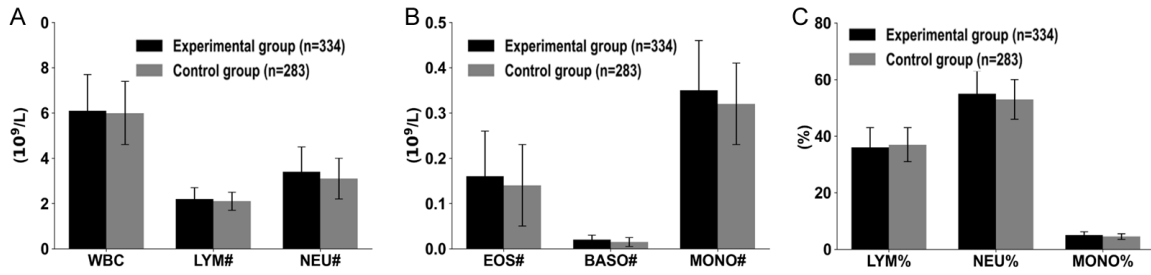


Figure 2. Comparison of WBC-related indicators in subjects. A. Total WBC count, lymphocyte count, and neutrophil count; B. Eosinophil absolute value, basophil absolute value, and monocyte count; C. Lymphocyte ratio, neutrophil ratio, and monocyte ratio. Note: Abbreviations: WBC, white blood cell; LYM#, absolute lymphocyte count; NEU#, absolute neutrophil count; EOS#, absolute eosinophil count; BASO#, absolute basophil count; MONO#, absolute monocyte count; LYM%, lymphocyte percentage; NEU%, neutrophil percentage; MONO%, monocyte percentage.

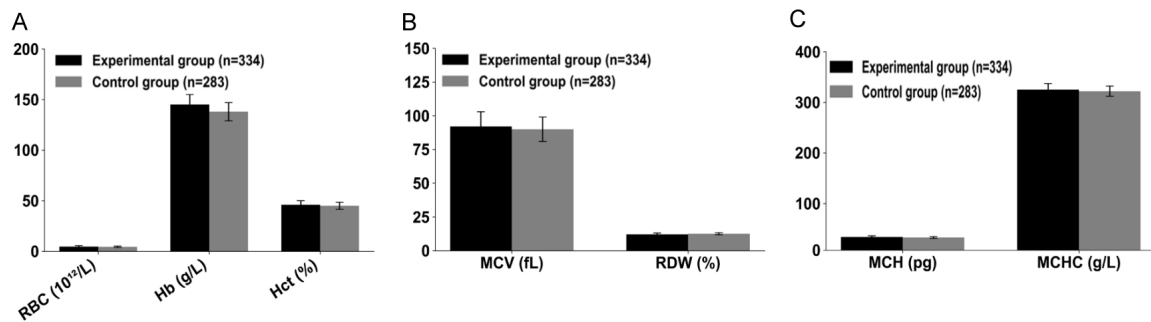


Figure 3. Comparison of RBC-related indicators in subjects. A. RBC count, Hb, hematocrit; B. MCV, RDW; C. mean Hb content, mean Hb concentration. Note: *as against the EG, $P < 0.05$. Note: Abbreviations: RBC, red blood cell; Hb, hemoglobin; Hct, hematocrit; MCV, mean corpuscular volume; RDW, red cell distribution width; MCH, mean corpuscular hemoglobin; MCHC, mean corpuscular hemoglobin concentration.

Comparison of liver and kidney function indicators

No significant differences in total bilirubin, urea nitrogen, or uric acid levels were found between the two groups (all $P > 0.05$, **Figure 1**).

Comparison of WBC-related indicators

There were no significant differences in terms of WBC-related indicators (all $P > 0.05$, **Figure 2**).

Comparison of RBC-related indicators

No significant differences were found in RBC count, Hb, MCV, or RDW between the two groups (all $P > 0.05$). However, the EG had a significantly higher hematocrit than the CG ($P < 0.05$, **Figure 3**).

Comparison of platelet-related indicators

No significant differences were found in platelet count, large platelet ratio, PDW, or mean

platelet volume between the two groups (all $P > 0.05$, **Figure 4**).

Comparison of IR-related data

The EG had significantly higher insulin levels and HOMA-IR index compared with the CG (both $P < 0.05$), while no significant difference was observed in FBG ($P > 0.05$, **Figure 5**).

Comparison of NSAT thickness

The NSAT thickness in the EG was significantly greater than that in the CG ($P < 0.05$, **Figure 6**).

Relationship between NSAT thickness and IR in overweight and obese patients

As shown in **Table 2** and **Figure 7**, NSAT thickness in overweight and obese patients was significantly and positively correlated with insulin levels and HOMA-IR index (both $P < 0.03$), but not significantly correlated with FBG levels ($P > 0.05$).

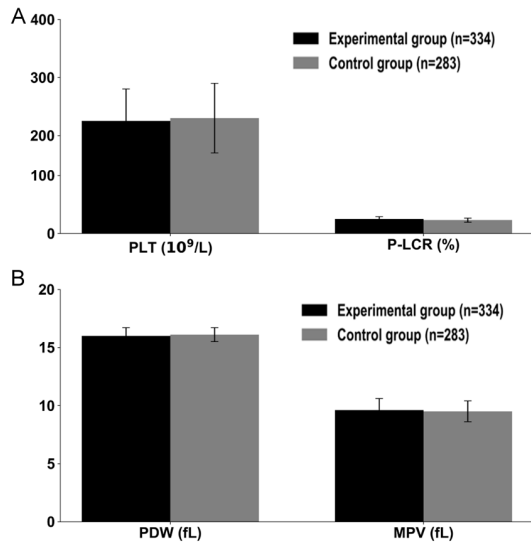


Figure 4. Comparison of platelet-related indicators in subjects. A. Platelet count, large platelet ratio; B. PDW, mean platelet volume. Note: Abbreviations: PLT, platelet count; P-LCR, platelet-large cell ratio; PDW, platelet distribution width; MPV, mean platelet volume.

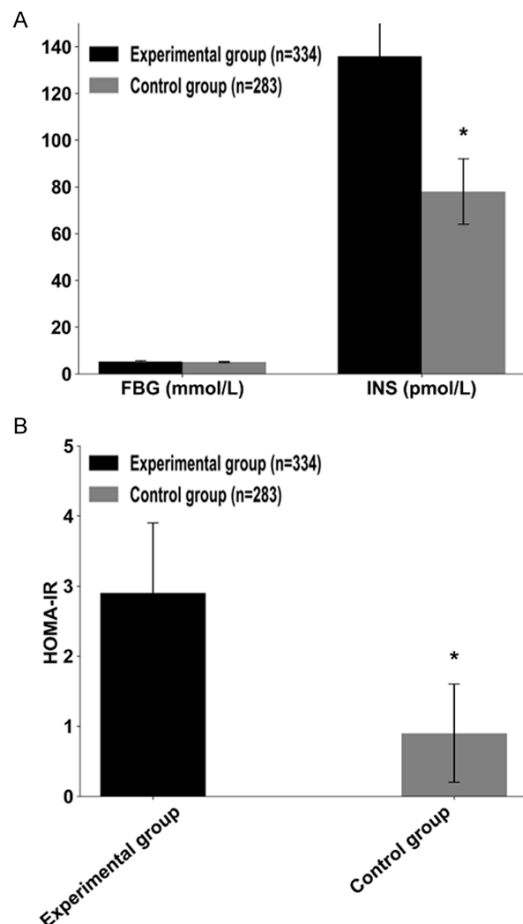


Figure 5. Comparison of IR-related data in subjects. A. FBG, insulin; B. IR index. Note: *as against the EG, $P < 0.05$. Note: Abbreviations: FBG, fasting blood glucose; INS, insulin; HOMA-IR, homeostatic model assessment-insulin resistance.

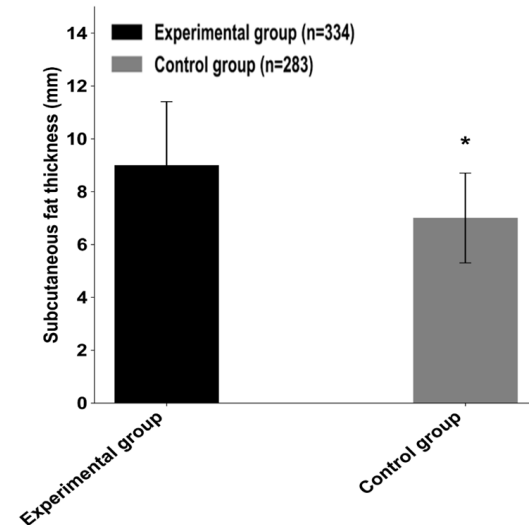


Figure 6. Comparison of NSAT thickness in subjects. Note: *as against the EG, $P < 0.05$.

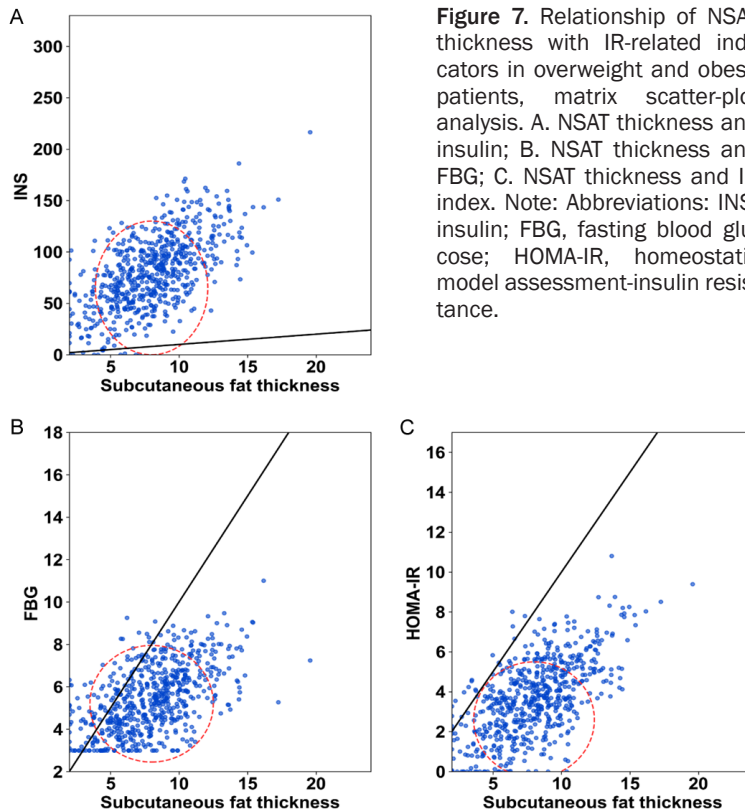
Table 2. Correlation of NSAT thickness with insulin-related indicators in overweight and obese patients, Pearson correlation analysis

Insulin-related indicators	Correlation coefficient	P-value
FBG	-0.026	0.632
Insulin	0.162	< 0.001
IR index	0.121	0.002

Note: Abbreviations: NSAT, subcutaneous adipose tissue; IR, insulin resistance; FBG, fasting blood glucose.

Discussion

With the continuous rise in global obesity rates, IR serves as a core pathological driver for metabolic syndrome, type 2 diabetes and cardiovascular diseases. Conventional anthropometric indices such as BMI can reflect overall adiposity yet fail to capture heterogeneity in body-fat distribution [13]. Growing research interest has focused on NSAT, owing to its unique anatomical features and metabolic activity. Beyond participating in local inflammatory responses, NSAT may modulate whole-body metabolic homeostasis via adipokine secretion.



In the current cohort, liver- and kidney-related biochemistry did not differ significantly between groups, implying that overweight-obesity status had not yet produced measurable organ dysfunction. Nevertheless, the overweight-obese subjects showed a non-significant trend toward higher serum uric acid, hinting at potential obesity-linked purine metabolic disturbance, which merits further validation in larger cohorts [14]. Most peripheral hematological parameters were comparable across groups; the elevated hematocrit observed in overweight-obese individuals may be attributed to hemoconcentration or low-grade chronic inflammation associated with excess adiposity.

Our key observation supports a positive association between NSAT and IR. Overweight and

The present community-based study from Hongqiao Town explored the relationship between NSAT and IR, aiming to validate NSAT as a potential imaging marker for early screening of obesity-related metabolic abnormalities. BMI-based baseline stratification effectively separated participants into overweight/obese and normal-weight subgroups. Gender discrepancy was observed between groups, which may reflect the known tendency for males to accumulate fat within visceral and neck adipose depots. Although age was comparable across groups, we noted a trend toward older age in the overweight-obese group. Age constitutes an important confounding variable for insulin sensitivity: advancing age lowers insulin secretion and peripheral insulin responsiveness, and comorbid conditions may further aggravate IR. By restricting participant age and excluding individuals with severe underlying metabolic disorders, our study partially mitigated such confounding effects. Moreover, subgroup analysis indicated a trend toward a more pronounced NSAT-IR association among participants aged over 60 years, suggesting that age stratification and comorbidity evaluation merit attention when interpreting clinical metabolic findings.

high BMI do not necessarily coincide with IR, as there are two special phenotypes: “metabolically healthy obesity” and “metabolically obese normal weight” individuals [15, 16]. Some participants with BMI above the normal range have predominantly benign subcutaneous fat without visceral adipose accumulation, accompanied by only mild inflammation and lipid disturbances, and their insulin sensitivity may remain normal. Conversely, some individuals with BMI within the normal range may still develop significant IR due to substantial accumulation of visceral and cervical ectopic fat. This phenotypic heterogeneity arises because BMI cannot distinguish between subcutaneous and visceral fat, while NSAT, as a regional fat indicator, more directly reflects the distribution of metabolically active fat [17]. We also found that the association between NSAT thickness and IR remained significant after accounting for BMI, suggesting that NSAT may capture metabolic risk information beyond overall adiposity. Therefore, relying solely on BMI to assess IR has clear limitations, and cervical subcutaneous fat thickness may serve as a complementary indicator to address this deficiency [18].

This study found a significant association between NSAT and insulin levels, but no association with FBG. This suggests that neck fat may influence insulin secretion rather than directly interfering with blood glucose regulation [19]. This pattern-elevated insulin with preserved fasting glucose-reflects a compensatory hyperinsulinemic state triggered by neck fat accumulation: β -cell secretion increases to overcome peripheral insulin resistance before overt hyperglycemia develops, in line with the “fat overload hypothesis” [20, 21].

Several potential pathways may explain how NSAT affects insulin sensitivity: (1) Adipokine imbalance: Decreased adiponectin and increased leptin secreted by neck fat directly promote IR. (2) Enhanced oxidative stress: Oxidative stress induced by fat tissue hypoxia can damage the insulin signaling pathway. (3) Dysbiosis of gut microbiota: Neck fat accumulation may affect gut microbiota composition through the neuro-immune axis, thereby interfering with metabolism.

Conclusion

This community-based cross-sectional study demonstrates that NSAT thickness is positively and independently associated with IR, indicating that neck subcutaneous fat may act as a novel imaging biomarker for metabolic abnormalities. NSAT accumulation appears to influence insulin secretion rather than directly alter blood glucose metabolism, and this association is more evident among older male subjects.

However, several limitations of this work should be noted. The cross-sectional design precludes causal inference. Visceral fat area and thyroid function were not evaluated in the present work. In addition, correlation analyses lacked comprehensive adjustment for multiple confounders, and the ultrasound measurement protocol for NSAT requires further standardization. Future prospective studies with multivariable adjustment and multimodal imaging are warranted to validate our findings and elucidate the metabolic mechanisms underlying NSAT. Our results provide preliminary evidence supporting the integration of neck fat evaluation into metabolic risk screening for high-risk populations in community settings.

Acknowledgements

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Disclosure of conflict of interest

None.

Abbreviations

IR, Insulin Resistance; NSAT, Neck Subcutaneous Adipose Tissue; BMI, Body Mass Index; HOMA-IR, Homeostasis Model Assessment of Insulin Resistance; FBG, Fasting Blood Glucose; PCA, Pearson Correlation Analysis; WC, Waist Circumference; HC, Hip Circumference; WBC, White Blood Cell; RBC, Red Blood Cell; Hb, Hemoglobin; MCV, Mean Corpuscular Volume; RDW, Red Cell Distribution Width; PDW, Platelet Distribution Width; PLT, Platelet Count; MPV, Mean Platelet Volume.

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