

# Ultrasound-measured abdominal fat thickness: A diagnostic marker for metabolic syndrome and Metabolic Dysfunction-Associated Steatotic Liver Disease in children and adolescents with obesity

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## Research Article

**Keywords:** Metabolic syndrome, metabolic dysfunction-associated steatotic liver disease, pediatric obesity, ultrasonography, abdominal wall fat thickness

**Posted Date:** September 25th, 2026

**DOI:** <https://doi.org/10.21203/rs.3.rs-10905371/v1>

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**Additional Declarations:** No competing interests reported.

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# Abstract

## Objective

The increasing incidence of metabolic syndrome (MetS) and Metabolic Dysfunction-Associated Steatotic Liver Disease (MASLD) among children with obesity underscores the need to identify early, non-invasive biomarkers. Despite the extensive research on visceral fat, the predictive value of ultrasonographic subcutaneous adipose tissue (SAT) has received comparatively less attention. The present study evaluates the clinical utility of SAT as a diagnostic indicator in pediatric obesity.

## Methods

The study prospectively evaluated children aged 7–18 years, including 61 obese patients and 41 controls. The diagnosis of MetS was made using modified WHO criteria. Abdominal Wall Fat Thickness (AWFT) was measured by a linear probe at the umbilical level, and hepatic steatosis was graded semi-quantitatively. The diagnostic accuracy was evaluated using ROC curves and logistic regression.

## Results

This study demonstrated a significant correlation between AWFT and MetS as well as the severity of hepatic steatosis ( $p < 0.001$ ). The optimal AWFT threshold for discriminating MetS was established at  $> 2.7$  cm, which was associated with a 2.6-fold increased risk in the adjusted analysis (sensitivity: 75%, specificity: 66%, PPV: 60%, and NPV: 81%).

## Conclusion

AWFT is a non-invasive, readily accessible ultrasonographic biomarker for MetS in children with obesity. Our findings suggest that incorporating an AWFT threshold of  $> 2.7$  cm into routine pediatric obesity assessments could facilitate early identification of high-risk individuals and promote targeted intervention strategies.

## What is Known

Correlations have been demonstrated between abdominal subcutaneous fat thickness and individual metabolic components, including insulin resistance and dyslipidemia, in pediatric populations with obesity.

Waist circumference and waist-to-height ratio Z-scores have been demonstrated to be effective predictors of cardiometabolic risk.

Visceral adipose tissue has been identified as a significant contributor to metabolic risk, while the role of subcutaneous adipose tissue remains less well-defined.

### **What is New:**

This study is pioneering in its direct association between ultrasound-measured abdominal wall fat thickness (AWFT) and the presence of metabolic syndrome as a composite clinical entity in children and adolescents with obesity.

An AWFT threshold exceeding 2.7 cm has been identified as a potent independent predictor for MetS, associated with a 2.6-fold increase in risk.

Compared to traditional anthropometric measures, AWFT provides a sensitive and non-invasive method for the early detection of pediatric metabolic dysregulation and Metabolic Dysfunction-Associated Steatotic Liver Disease (MASLD).

## **INTRODUCTION**

Childhood obesity is intrinsically linked to a rising burden of cardiometabolic comorbidities, including metabolic syndrome (MetS) and Metabolic Dysfunction-Associated Steatotic Liver Disease (MASLD) [1]. Given the early onset and long-term health implications of these conditions, identifying reliable, non-invasive markers is essential for effective clinical risk assessment. Obesity has been identified as the primary etiological agent of pediatric MASLD. Meta-analytical data reveal that the prevalence of MASLD is substantially higher among children with obesity compared to the general pediatric population [2]. Furthermore, based on documented annual increase rates, it is projected that the global pediatric prevalence will significantly rise in the coming decades [3]. A similar trend is observed with MetS, affecting millions of children and adolescents worldwide and emerging as a critical public health concern across all socioeconomic levels [4].

Established anthropometric markers such as BMI, waist circumference (WC), and waist-to-height ratio (WHtR) are widely used for broad screening; however, they primarily reflect global or central adiposity and cannot differentiate between specific adipose tissue compartments. While visceral fat is a known driver of risk, the specific contribution of subcutaneous adipose tissue (SAT)—measured as Abdominal Wall Fat Thickness (AWFT)—remains poorly defined in pediatric populations [2, 6–10]. Existing literature presents inconsistent findings regarding the association of AWFT with individual components like insulin resistance and hepatic steatosis, and there is a distinct lack of evidence concerning its role in discriminating MetS as a composite clinical entity [2, 5–10].

We hypothesized that ultrasonographically measured AWFT would serve as a more precise and independent indicator of metabolic dysregulation and hepatic steatosis in children with obesity, offering superior specificity for risk stratification compared to traditional anthropometric measures. To test this hypothesis, the objective of this study was to evaluate the association between ultrasonographic AWFT,

MASLD, and MetS in children with obesity, and to investigate its potential as a practical, non-invasive early risk indicator in this population.

## **MATERIALS AND METHODS**

### **Patient Selection**

The present prospective study involved a total of 102 participants (61 children and adolescents with obesity and 41 healthy controls) aged 7–18 years, who were enrolled between October 2024 and April 2025. Participants were consecutively recruited from outpatient clinics to ensure a representative clinical sample. The group with obesity included children and adolescents with a Body Mass Index (BMI)  $\geq$  95th percentile for age and sex who were referred to the pediatric endocrinology unit. The healthy control group consisted of children with a BMI within the 5th–85th percentile range, consecutively selected from the general pediatric outpatient clinic during routine health assessments. All control subjects were confirmed to be free of any known chronic diseases or medication use that could affect growth or metabolic status. The calculation of BMI percentiles and standard deviation scores (SDS) for all participants was conducted in accordance with the World Health Organization (WHO) reference values [11].

### **Exclusion criteria**

To ensure a homogeneous cohort and minimize confounding effects on metabolic assessments, specific exclusion criteria were strictly applied. Excluded were patients with syndromic or monogenic obesity and obesity-related endocrine disorders (e.g., hypothyroidism), as these conditions are characterized by secondary obesity patterns. Children with chronic non-endocrine diseases, short stature, or those using medications known to affect body weight or metabolic parameters (e.g., steroids) were also excluded. Furthermore, to ensure accurate liver assessment, conditions that could alter hepatic echogenicity, including viral or idiopathic hepatitis, storage diseases, and hepatometabolic disorders, were ruled out. Participants with incomplete clinical or imaging data, or those already receiving lipid-lowering therapy, were excluded to ensure the validity of our risk assessments.

### **Anthropometric measurements**

Anthropometric measurements were performed following an overnight fast, with participants wearing light clothing. Height was measured using a Harpenden stadiometer (0.1 cm precision) and body weight with a SECA digital scale (0.1 kg sensitivity). BMI was calculated as  $\text{kg/m}^2$ . Waist circumference (WC) was measured at the umbilical level during normal expiration. WC and waist-to-height ratio (WHtR) z-scores were calculated based on reference standards [12]. Blood pressure was measured via the auscultatory method after a 20-minute rest. Values  $\geq$  95th percentile for age, sex, and height were defined as hypertension [13]. Pubertal maturity was assessed using the Tanner staging system [14].

# Biochemical Markers and Clinical Indices for the Assessment of Insulin Sensitivity

Plasma glucose, insulin, and lipid levels were measured after an overnight fast. Hyperinsulinemia was defined based on pubertal stage: fasting insulin > 15 mU/L in prepubertal children, > 30 mU/L during pubertal stages 2–4, and > 20 mU/L at stage 5 [15]. Insulin resistance (IR) was assessed using the homeostasis model assessment (HOMA-IR) formula: [fasting insulin (mU/L) × fasting glucose (mmol/L)] / 22.5 [16]. IR was defined as a HOMA-IR value > 2.5 in prepubertal and > 3.16 in pubertal children [17, 18]. Dyslipidemia was defined by meeting any of the following: (1) total cholesterol > 200 mg/dL, (2) triglycerides > 150 mg/dL, (3) LDL cholesterol > 130 mg/dL, or (4) HDL cholesterol < 40 mg/dL [19].

## Metabolic Syndrome (MetS)

MetS was diagnosed using modified WHO criteria adapted for children [20]. These criteria were specifically selected for this study because they prioritize impaired glucose regulation and hyperinsulinemia as central components, which aligns with our focus on AWFT as an early indicator of metabolic dysregulation. Participants meeting at least three of the following four criteria were classified with MetS:

1. **Obesity:** BMI  $\geq$  95th percentile for age and sex.
2. **Impaired Glucose Regulation:** Fasting hyperinsulinemia, impaired fasting glucose, or glucose intolerance.
3. **Hypertension:** Systolic blood pressure  $\geq$  95th percentile for age, sex, and height.
4. **Dyslipidemia:** Triglycerides > 105 mg/dL (age < 10) or > 136 mg/dL (age  $\geq$  10), and/or HDL cholesterol < 5th percentile.

## Ultrasound Examination

All ultrasonographic examinations were performed using a single ultrasound system (Resona I9, Mindray, Shenzhen, China) to ensure methodological consistency. All scans were conducted by the same radiologist, with participants in the supine position and during quiet respiration to minimize motion artifacts. To ensure reproducibility and minimize operator dependency, all measurements were performed by a single experienced radiologist following a strictly standardized protocol with minimal probe pressure. For hepatic evaluation, a convex transducer (SC6-1 MHz) was used. The liver was examined in standard longitudinal and transverse planes obtained from the right upper quadrant (Fig. 1). Hepatic steatosis was graded semiquantitatively on a 0–3 scale based on parenchymal echogenicity: grade 0 indicated normal echotexture with clear visualization of intrahepatic vessels and the diaphragm; grade 1 represented a mild diffuse increase in echogenicity with preserved vascular margins; grade 2 corresponded to a moderate increase in echogenicity with partial obscuration of intrahepatic structures; and grade 3 denoted marked echogenicity with poor visualization of vascular and diaphragmatic contours [21]. For the assessment of abdominal subcutaneous fat (Fig. 2), a linear probe (L14–3Ws) was

used. Measurements were obtained on the right side at the level of the umbilicus, where the anteroposterior diameter of the rectus abdominis muscle was maximal. At this level, subcutaneous adipose tissue thickness was measured as the distance between the skin surface and the anterior fascia of the rectus abdominis muscle. Care was taken to apply minimal probe pressure to avoid underestimation of tissue thickness. To ensure measurement reproducibility, intra-observer reliability was assessed in 20 randomly selected subjects, yielding an intra-class correlation coefficient (ICC) of 0.94, indicating excellent consistency.

## Group creation

Participants were stratified into subgroups to facilitate comparative analysis. The population was categorized based on BMI percentiles as follows: normal weight (5th–85th percentiles) or obese ( $\geq 95$ th percentile). According to the Tanner staging system, participants were divided into two groups: prepubertal (Stage 1) and pubertal (Stages  $\geq 2$ ). For the assessment of hepatic steatosis (HS), subjects were classified into three groups based on ultrasonographic findings: HS-0 indicates the absence of steatosis, HS-I indicates mild steatosis, and HS-II indicates moderate-to-severe steatosis. Furthermore, subjects were stratified into two distinct groups, contingent upon the presence or absence of MetS.

## Statistical Analysis

Statistical analyses were performed using SPSS version 22.0 (IBM Corp., Armonk, NY, USA). The study included 61 obese and 41 control participants. Continuous variables are expressed as mean  $\pm$  standard deviation or median (interquartile range [IQR]), and categorical variables as counts and percentages. The Kolmogorov-Smirnov test was used to evaluate the normality of continuous data. Group comparisons were conducted using Student's t-test or one-way ANOVA (with Scheffé's post-hoc test) for normally distributed variables, and the Mann-Whitney U or Kruskal-Wallis test for non-normally distributed variables. Receiver operating characteristic (ROC) curve analysis—along with 95% confidence intervals (CI)—was conducted to determine the optimal cutoff values for WHtR z-score, WC z-score, and AWFT in predicting and discriminating MetS in obese children. Using these cutoffs, univariate logistic regression was performed to assess the risk of MetS. Multivariate logistic regression models adjusted for age, sex, pubertal status (Tanner stage), and BMI z-score were then applied to calculate odds ratios (OR) and determine the independent predictive value of AWFT. Relationships between AWFT and MetS components were evaluated using Pearson or Spearman correlation analysis. Statistical significance was set at  $P < 0.05$ .

## RESULTS

The study population included 102 children, with 61 children classified as obese and 41 children classified as healthy controls. The study found no statistically significant differences between the groups in terms of age, sex, or pubertal status ( $P > 0.05$ ). The prevalence of clinical and metabolic complications—including hyperinsulinism, metabolic syndrome, dyslipidemia, hepatic steatosis, and dysglycemia—was

significantly higher in the group with obesity compared to the control group ( $P < 0.001$ ). Furthermore, acanthosis nigricans and striae were exclusively observed in children with obesity ( $P < 0.001$ ). The frequencies of these clinical characteristics are presented in Table 1.

Table 1  
Demographic and clinical characteristics of obese and control groups

|                                                                                                                                                                                                                                                      | <b>Group with Obesity (n = 61), n-%</b> | <b>Control Group (n = 41), n-%</b> | <b>P</b>          |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|------------------------------------|-------------------|
| Sex Female                                                                                                                                                                                                                                           | 37-60.7                                 | 24-39.3                            | 0.831             |
| Male                                                                                                                                                                                                                                                 | 24-58.5                                 | 17-41.5                            |                   |
| Puberty Prepubertal                                                                                                                                                                                                                                  | 14-23                                   | 14-34.1                            | 0.214             |
| Pubertal                                                                                                                                                                                                                                             | 47-77                                   | 27-65.9                            |                   |
| Subclinical hypothyroidism                                                                                                                                                                                                                           | 3-4.9                                   | 2-4.9                              | 0.993             |
| Hyperinsulinism                                                                                                                                                                                                                                      | 25-41                                   | 0-0                                | <b>&lt; 0.001</b> |
| Metabolic syndrome                                                                                                                                                                                                                                   | 24-39.3                                 | 0-0                                | <b>&lt; 0.001</b> |
| Dyslipidemia                                                                                                                                                                                                                                         | 26-42.6                                 | 0-0                                | <b>&lt; 0.001</b> |
| MASLD                                                                                                                                                                                                                                                | 33-54.1                                 | 0-0                                | <b>&lt; 0.001</b> |
| Dysglycemia*                                                                                                                                                                                                                                         | 23-37.7                                 | 0-0                                | <b>&lt; 0.001</b> |
| Acanthosis nigricans                                                                                                                                                                                                                                 | 24-39.3                                 | 0-0                                | <b>&lt; 0.001</b> |
| Striae                                                                                                                                                                                                                                               | 29-47.5                                 | 0-0                                | <b>&lt; 0.001</b> |
| Abbreviations MASLD; Metabolic Dysfunction-Associated Steatotic Liver Disease.                                                                                                                                                                       |                                         |                                    |                   |
| * A spectrum of metabolic disorders characterized by abnormal blood glucose levels that fall outside the normal homeostatic range. It encompasses prediabetes (Impaired Fasting Glucose and Impaired Glucose Tolerance) and overt diabetes mellitus. |                                         |                                    |                   |

A comparative analysis revealed no significant differences between the obese and control groups with respect to age, LDL-C, fasting glucose, liver enzymes (with the exception of ALT), thyroid functions, vitamin D levels, or DXA Z-scores ( $P > 0.05$ ). However, the group with obesity exhibited significantly higher values for all adiposity-related markers, including AWFT, BMI Z-score, WC Z-score, and WHtR Z-score ( $P < 0.001$ ). Concurrently, metabolic parameters such as fasting insulin, HOMA-IR, triglycerides, and uric acid were significantly elevated, while HDL-C levels were significantly lower in the children with obesity ( $P < 0.05$ ). A comprehensive array of these laboratory and anthropometric comparisons is delineated in Table 2.

Table 2  
Anthropometric and laboratory findings by obesity status

| Age                                                                                                                                                                                                                                                                                                                                                                                                                                                             | Group with Obesity (n = 61), mean ± SD | Control Group (n = 41), mean ± SD | p                 |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|-----------------------------------|-------------------|
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>12.76 ± 3.44</b>                    | <b>12.21 ± 3.31</b>               | <b>0.419</b>      |
| AWFT, cm                                                                                                                                                                                                                                                                                                                                                                                                                                                        | 3.15 ± 1.35                            | 1.44 ± 0.74                       | <b>&lt; 0.001</b> |
| Waist circumference, cm                                                                                                                                                                                                                                                                                                                                                                                                                                         | 96.51 ± 20.25                          | 63.30 ± 7.00                      | <b>&lt; 0.001</b> |
| Waist circumference Z-score                                                                                                                                                                                                                                                                                                                                                                                                                                     | 1.78 ± 0.53                            | -0.42 ± 0.39                      | <b>&lt; 0.001</b> |
| BMI Z-score                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 2.69 ± 0.77                            | 0.20 ± 0.67                       | <b>&lt; 0.001</b> |
| Triglycerides (mg/dL)                                                                                                                                                                                                                                                                                                                                                                                                                                           | 113.95 ± 47.41                         | 86.65 ± 19.85                     | <b>&lt; 0.001</b> |
| Total cholesterol (mg/dL)                                                                                                                                                                                                                                                                                                                                                                                                                                       | 156.55 ± 31.96                         | 142.26 ± 21.84                    | <b>0.009</b>      |
| LDL-C (mg/dL)                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 94.57 ± 29.11                          | 91.70 ± 31.16                     | 0.636             |
| HDL-C (mg/dL)                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 46.57 ± 10.58                          | 51.53 ± 7.05                      | <b>0.010</b>      |
| Fasting glucose (mg/dL)                                                                                                                                                                                                                                                                                                                                                                                                                                         | 84.03 ± 7.72                           | 83.83 ± 7.26                      | 0.894             |
| Fasting insulin (IU/mL)                                                                                                                                                                                                                                                                                                                                                                                                                                         | 21.56 ± 9.76                           | 6.10 ± 2.72                       | <b>&lt; 0.001</b> |
| HOMA-IR                                                                                                                                                                                                                                                                                                                                                                                                                                                         | 4.44 ± 2.15                            | 1.27 ± 0.60                       | <b>&lt; 0.001</b> |
| WHtR Z-score                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 1.74 ± 0.59                            | -0.59 ± 0.66                      | <b>&lt; 0.001</b> |
| Liver size, cm                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 14.77 ± 1.58                           | 11.69 ± 0.98                      | <b>&lt; 0.001</b> |
| Uric acid (mg/dL)                                                                                                                                                                                                                                                                                                                                                                                                                                               | 5.21 ± 1.11                            | 3.70 ± 1.05                       | <b>&lt; 0.001</b> |
| AST (U/L)                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 27.88 ± 16.46                          | 24.26 ± 7.92                      | 0.194             |
| ALT (U/L)                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 29.90 ± 21.33                          | 16.19 ± 7.11                      | <b>&lt; 0.001</b> |
| ft4 (ng/dL)                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 0.86 ± 0.16                            | 0.92 ± 0.16                       | 0.080             |
| TSH (mIU/mL)                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 2.84 ± 1.59                            | 2.30 ± 1.49                       | 0.091             |
| 25(OH)D ng/mL                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 16.98 ± 12.89                          | 17.60 ± 9.97                      | 0.795             |
| DXA Z-score                                                                                                                                                                                                                                                                                                                                                                                                                                                     | -0.04 ± 0.87                           | -0.39 ± 0.84                      | 0.274             |
| Abbreviations; AWFT: Abdominal Wall Fat Thickness, BMI: Body Mass Index, LDL-C: Low-Density Lipoprotein Cholesterol, HDL-C: High-Density Lipoprotein Cholesterol, HOMA-IR: Homeostasis Model Assessment of Insulin Resistance, WHtR: Waist-to-Height Ratio, AST: Aspartate Aminotransferase, ALT: Alanine Aminotransferase, ft4: Serum Free Thyroxine, TSH: Thyroid-Stimulating Hormone, 25(OH)D: 25-Hydroxyvitamin D, (DXA): Dual-Energy X-ray Absorptiometry. |                                        |                                   |                   |

To eliminate the confounding effect of obesity inherent in the MetS definition, ROC analyses were repeated strictly within the sub-cohort of participants with obesity (n = 61; MetS n = 24, non-MetS n = 37).

In this subgroup analysis, AWFT was the only variable that demonstrated statistically significant diagnostic discrimination for MetS (AUC = 0.743, 95% CI: 0.615–0.846,  $p < 0.001$ ). An AWFT cut-off point of  $> 2.7$  cm yielded a sensitivity of 75%, specificity of 66%, PPV of 60%, and NPV of 81%. Conversely, conventional metrics failed to achieve statistical significance for discriminating MetS within the cohort with obesity, including BMI z-score (AUC = 0.646,  $p = 0.073$ ), WC z-score (AUC = 0.631,  $p = 0.074$ ), and WHtR z-score (AUC = 0.639,  $p = 0.074$ ) Table 3 and Fig. 3.

Table 3  
Determining Optimal Cutoff Points for Metabolic Syndrome in Children with Obesity

| Test Result Variable(s)                                                                                                                                                                                                      | Best cut-off point for MetS | Area  | Sensitivity | Specificity | p            | PPV  | NPV  | Asymptotic 95% Confidence Interval |             |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|-------|-------------|-------------|--------------|------|------|------------------------------------|-------------|
|                                                                                                                                                                                                                              |                             |       |             |             |              |      |      | Lower Bound                        | Upper Bound |
| AWFT, cm                                                                                                                                                                                                                     | $> 2.7$                     | 0.743 | 0.75        | 0.66        | $< 0.001$    | 0.60 | 0.81 | 0.615                              | 0.846       |
| BMI Z-score                                                                                                                                                                                                                  | $> 2.48$                    | 0.646 | 0.67        | 0.62        | <b>0.073</b> | 0.53 | 0.74 | 0.513                              | 0.765       |
| WC Z-score                                                                                                                                                                                                                   | $> 1.85$                    | 0.631 | 0.63        | 0.65        | <b>0.074</b> | 0.54 | 0.73 | 0.498                              | 0.751       |
| WHtR Z-score                                                                                                                                                                                                                 | $> 1.87$                    | 0.639 | 0.63        | 0.68        | <b>0.074</b> | 0.56 | 0.74 | 0.505                              | 0.758       |
| Abbreviations; WC: Waist circumference, WHtR: Waist-to-Height Ratio, AWFT: Abdominal Wall Fat Thickness, MetS: Metabolic Syndrome, AUC: Area Under the Curve, PPV: Positive predictive value, NPV: Negative predictive value |                             |       |             |             |              |      |      |                                    |             |

In the multivariable binary logistic regression model restricted to children with obesity ( $n = 61$ ) and adjusted simultaneously for age, sex, pubertal status, and BMI z-score, AWFT ( $> 2.7$  cm) remained an independent significant factor associated with the presence of Metabolic Syndrome (OR = 2.604, 95% CI: 1.349–5.027,  $p = 0.004$ ). Higher BMI z-score was also independently associated with MetS (OR = 2.232, 95% CI: 1.090–4.573,  $p = 0.028$ ). However, WC z-score (OR = 2.844,  $p = 0.054$ ) and WHtR z-score (OR = 2.564,  $p = 0.055$ ) did not reach statistical significance in the fully adjusted model (Table 4).

Table 4  
Risk Estimates for Predictors of Metabolic Syndrome in Children with Obesity

| Test Result Variable(s)                                                                                                                            | best cut-off point for MetS | OR    | P            | Asymptotic 95% Confidence Interval |             |
|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|-------|--------------|------------------------------------|-------------|
|                                                                                                                                                    |                             |       |              | Lower Bound                        | Upper Bound |
| AWFT, cm                                                                                                                                           | > 2.7                       | 2.604 | <b>0.004</b> | 1.349                              | 5.027       |
| BMI Z-score                                                                                                                                        | > 2.48                      | 2.232 | <b>0.028</b> | 1.090                              | 4.573       |
| WC Z-score                                                                                                                                         | > 1.85                      | 2.844 | <b>0.054</b> | 0.981                              | 8.249       |
| WHtR Z-score                                                                                                                                       | > 1.87                      | 2.564 | <b>0.055</b> | 0.921                              | 6.704       |
| Gender                                                                                                                                             | Male vs. Female             | 1.073 | 0.365        | 0.921                              | 1.251       |
| Age                                                                                                                                                | Years                       | 1.053 | 0.405        | 0.547                              | 4.459       |
| Puberty                                                                                                                                            | Pubertal vs. Prepubertal    | 1.221 | 0.752        | 0.354                              | 4.216       |
| Abbreviations: AWFT: Abdominal Wall Fat Thickness; MetS: Metabolic Syndrome; OR: Odds Ratio; WC: Waist Circumference; WHtR: Waist-to-Height Ratio. |                             |       |              |                                    |             |

The associations between abdominal adiposity markers (AWFT, WC Z-score, and WHtR Z-score) and metabolic parameters were summarized in Table 5. A robust positive correlation was demonstrated between AWFT and BMI Z-score. Additionally, the study revealed a moderate positive correlation between the levels of the examined compounds and several metabolic indicators, including fasting insulin levels, HOMA-IR, and hepatic steatosis grade. Furthermore, a weak yet statistically significant positive correlation was identified with HbA1c levels. In a similar vein, WC Z-score demonstrated a significant positive correlation with BMI Z-score and a substantial positive correlation with fasting insulin levels. The study found moderate correlations between the variables under investigation and HOMA-IR, as well as hepatic steatosis grade. Despite the strong positive correlation between AWFT and BMI Z-score, the multivariate analysis confirmed that AWFT provides incremental predictive value for metabolic syndrome risk beyond overall obesity severity.

Table 5  
Relationship of AWFT (cm), WC Z-score, and WHtR Z-score with BMI Z-score, fasting insulin levels, HOMA-IR, hepatic steatosis grade

|                                                                                                                                                                                             |                     | AWFT (cm)         | WC Z-score        | WHtR Z-score      |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------|-------------------|-------------------|-------------------|
| BMI Z-score                                                                                                                                                                                 | Pearson Correlation | .735**            | .897**            | .852**            |
|                                                                                                                                                                                             | Sig. (2-tailed)     | <b>&lt; 0.001</b> | <b>&lt; 0.001</b> | <b>&lt; 0.001</b> |
|                                                                                                                                                                                             | n                   | 102               | 102               | 102               |
| Fasting insulin, (IU/mL)                                                                                                                                                                    | Pearson Correlation | .661**            | .709**            | .665**            |
|                                                                                                                                                                                             | Sig. (2-tailed)     | <b>&lt; 0.001</b> | <b>&lt; 0.001</b> | <b>&lt; 0.001</b> |
|                                                                                                                                                                                             | n                   | 102               | 102               | 102               |
| HOMA-IR                                                                                                                                                                                     | Pearson Correlation | .665**            | .679**            | .632**            |
|                                                                                                                                                                                             | Sig. (2-tailed)     | <b>&lt; 0.001</b> | <b>&lt; 0.001</b> | <b>&lt; 0.001</b> |
|                                                                                                                                                                                             | n                   | 102               | 102               | 102               |
| Hepatic steatosis                                                                                                                                                                           | Pearson Correlation | .632**            | .575**            | .557**            |
|                                                                                                                                                                                             | Sig. (2-tailed)     | <b>&lt; 0.001</b> | <b>&lt; 0.001</b> | <b>&lt; 0.001</b> |
|                                                                                                                                                                                             | n                   | 102               | 102               | 102               |
| Abbreviations: AWFT: Abdominal Wall Fat Thickness; BMI: Body Mass Index; HOMA-IR: Homeostasis Model Assessment of Insulin Resistance; WC: Waist Circumference; WHtR: Waist-to-Height Ratio. |                     |                   |                   |                   |

## DISCUSSION

This study demonstrates that ultrasonographically measured AWFT serves as a valuable marker for predicting the presence of metabolic syndrome and hepatic steatosis in children and adolescents with obesity. Our findings indicate that an AWFT threshold exceeding 2.7 cm is associated with a 2.6-fold increased risk of metabolic syndrome. Furthermore, compared to WC and WHtR Z-scores, AWFT has shown better diagnostic accuracy and specificity. These results suggest that SAT—specifically when evaluated via AWFT—is not merely a passive energy storage depot, but an active indicator of early metabolic dysregulation.

A substantial body of research has identified a strong correlation between SAT, as determined by diverse imaging techniques, and specific metabolic parameters in children—including hyperinsulinemia, insulin resistance, dyslipidemia, and MASLD [5, 6, 8, 22]. However, the majority of prior research has focused on these individual components rather than on MetS as a composite clinical entity. The present study makes a significant contribution to the existing literature by demonstrating a direct association between a specific ultrasonographic measurement of AWFT and the clinical diagnosis of MetS. Furthermore, the significant positive correlation observed between AWFT and MASLD grade underscores the clinical utility

of this parameter as a non-invasive tool for predicting pediatric MASLD risk and identifying early metabolic dysfunction [9, 10, 22–24].

The distribution and functional characteristics of adipose tissue are of critical importance in the pathophysiology of obesity-related metabolic disorders. Conventional wisdom has long posited that the accumulation of visceral fat serves as the primary catalyst for a range of complications, including but not limited to insulin resistance, dyslipidemia, hypertension, and MASLD [7, 8]. However, emerging evidence suggests that SAT may also exert an independent effect on metabolic health, separate from visceral fat. Indeed, an association has been demonstrated between increased subcutaneous fat thickness and metabolic dysfunction, even in the absence of marked visceral fat accumulation. The robust predictive value of AWFT can be explained by the 'lipid overflow' hypothesis, which suggests that metabolic complications arise when subcutaneous depots fail to sequester excess lipids [23, 24]. In the early stages of pediatric obesity, abdominal subcutaneous adipose tissue (SAT) functions as the primary metabolic buffer for excess energy storage [23, 24]. Unlike adults, where visceral fat (VAT) is often the dominant driver of metabolic risk, children frequently exhibit significant expansion of subcutaneous compartments before substantial VAT accumulation occurs [9–12]. When the storage capacity of abdominal SAT is exceeded or its metabolic function becomes impaired, lipids are shunted to ectopic sites, primarily the liver, leading to MASLD and systemic insulin resistance. Thus, increased AWFT serves as an early sentinel of this subcutaneous adipose tissue dysfunction [2, 5]. By specifically measuring the abdominal wall thickness via ultrasound, we capture a direct marker of early lipid partitioning failure, which may manifest before clinical metabolic syndrome is fully established.

Recent studies have indicated a significant correlation between abdominal SAT thickness and MASLD as well as dyslipidemia [5, 6, 22–25]. This study contributes to the advancement of this field by employing AWFT as a standardized ultrasonographic measure. To the best of our knowledge, no previous study has directly investigated the association between AWFT and the clinical presence of MetS, rendering this finding a novel and distinctive aspect of our research.

Previous research has demonstrated that WHtR is frequently a more effective indicator than BMI for defining the metabolic risk phenotype. There is a notable correlation between WHtR and insulin resistance, dyslipidemia, and hypertension [26–29]. Waist circumference (WC) has also been widely recognized for its strong association with visceral fat accumulation, cardiometabolic risk, and hepatic steatosis, leading to its recommendation as a practical risk assessment tool in childhood [25–27].

In our sub-analysis focused strictly on participants with obesity, AWFT was the sole variable that demonstrated statistically significant diagnostic discrimination for MetS (AUC = 0.743, 95% CI: 0.615–0.846,  $p < 0.001$ ), whereas WC and WHtR Z-scores failed to reach statistical significance. At an optimal cut-off point of  $> 2.7$  cm, AWFT yielded a sensitivity of 75%, a specificity of 66%, a positive predictive value (PPV) of 60%, and a negative predictive value (NPV) of 81%. Furthermore, in a multivariable logistic regression model adjusted for age, sex, pubertal status, and BMI Z-score, AWFT ( $> 2.7$  cm) remained an independent predictor of MetS (OR = 2.604, 95% CI: 1.349–5.027,  $p = 0.004$ ).

These findings indicate that AWFT serves as a robust and precise ultrasonographic tool for risk stratification, successfully identifying a high-risk phenotype characterized by severe metabolic dysregulation that warrants prioritized clinical intervention.

The findings of this study are consistent with extant literature and lend support to the clinical utility of WC and WHtR Z-scores in the early identification of metabolic syndrome and hepatic steatosis. However, the higher specificity observed for AWFT compared to these conventional metrics suggests that subcutaneous adipose tissue may more accurately reflect the initial stages of metabolic dysregulation. When interpreted in conjunction with existing research, these results suggest that AWFT may serve as a promising non-invasive biomarker for metabolic risk stratification in pediatric obesity. While AWFT may not possess the same degree of potency as visceral adipose tissue in determining these outcomes, its cost-effectiveness and ease of clinical application offer significant advantages for the pediatric population. This indicates that AWFT captures specific metabolic risks associated with subcutaneous adiposity that general measures of obesity might overlook.

The increasing global prevalence of pediatric MASLD has highlighted the need for reliable, non-invasive tools for evaluating body fat distribution and metabolic risk (1,30). In this context, several advanced imaging modalities have been explored (30). While magnetic resonance imaging (MRI) and MRI-proton density fat fraction (PDFF) remain the gold standard for direct quantification of visceral (VAT) and SAT without radiation, their clinical application is often limited by high costs and accessibility (3,7). Recent pediatric studies have established MRI-derived reference values for SAT and VAT, emphasizing that fat distribution patterns change significantly through puberty, which mirrors our findings regarding the relevance of AWFT in risk stratification (7–9). Furthermore, bioelectrical impedance analysis (BIA) has emerged as a practical alternative; recent evidence suggests that combining BIA parameters (such as percentage body fat) with anthropometric indices like waist-to-hip ratio (WHR) adds incremental value in identifying MASLD risk, even in youth with normal transaminase levels (26). This suggests that AWFT captures specific metabolic risks associated with subcutaneous adiposity that may not be fully reflected by conventional anthropometric measures. This observation is consistent with recent studies demonstrating the value of ultrasound-based fat assessment in improving the identification of pediatric metabolic risk (31). Importantly, although AWFT strongly correlates with BMI Z-score, our adjusted multivariate analysis confirmed that AWFT remains a significant independent predictor of MetS.

## Limitations

This study is not without its limitations. Primarily, the cross-sectional design precludes the establishment of causality between AWFT and metabolic dysfunction. The single-center recruitment and relatively small sample size ( $n = 61$ ) may limit the generalizability of the findings; therefore, the 2.7 cm threshold and associated risk estimates should be considered preliminary diagnostic suggestions.. Additionally, while our multivariate models were transparently adjusted for age, sex, and BMI Z-score to ensure the independence of AWFT, the stability of these risk estimates should be validated in larger cohorts. Furthermore, a significant limitation is that the diagnosis and grading of hepatic steatosis were based

solely on conventional ultrasound, without validation through gold-standard methods such as MRI-PDFF, CAP/FibroScan, or liver biopsy. Although measurements were performed by a single experienced radiologist following a standardized protocol to minimize operator dependency, further validation through larger, multicenter longitudinal studies are required to validate these findings and their long-term predictive value across broader populations.

## Conclusion

This study demonstrates that ultrasonographically assessed AWFT is a viable and practical clinical screening tool for children and adolescents with obesity. Specifically, an AWFT threshold exceeding 2.7 cm can serve as a non-invasive indicator for early risk stratification of MetS. Given its non-invasive nature, cost-effectiveness, and ease of application, AWFT represents a practical alternative to advanced imaging modalities in routine clinical practice. Although these findings are promising, prospective, large-scale multicenter studies are required to validate the long-term predictive value of AWFT.

## Declarations

## Ethics

**Ethics Committee Approval:** The study received approval from the Inonu University Medical Research Ethics Committee (approval number: 2024/6779, date: 03-12-2024) and was conducted in accordance with the principles of the Declaration of Helsinki.

## Informed Consent:

Informed consent and verbal assent were sought and obtained from all patients and their families.

## Conflict of interest:

None declared.

## Financial Disclosure

No grants or fellowships were provided to support the writing of this paper.

## Author Contribution

Concept: ID, ND; Design: ID, SG; Data Collection or Processing: ID, ND, RA, ST, EK, EC, SG, ZYY, EDG; Analysis or Interpretation: ID, ND, SG, EK, ZYY, EDG; Literature Search: ID, ND, SG; Writing: ID, ND, SG.

# Acknowledgement

Artificial intelligence tools (ChatGPT and Gemini) were used solely for language and style improvement. All scientific content and conclusions were determined by the authors.

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## Figures

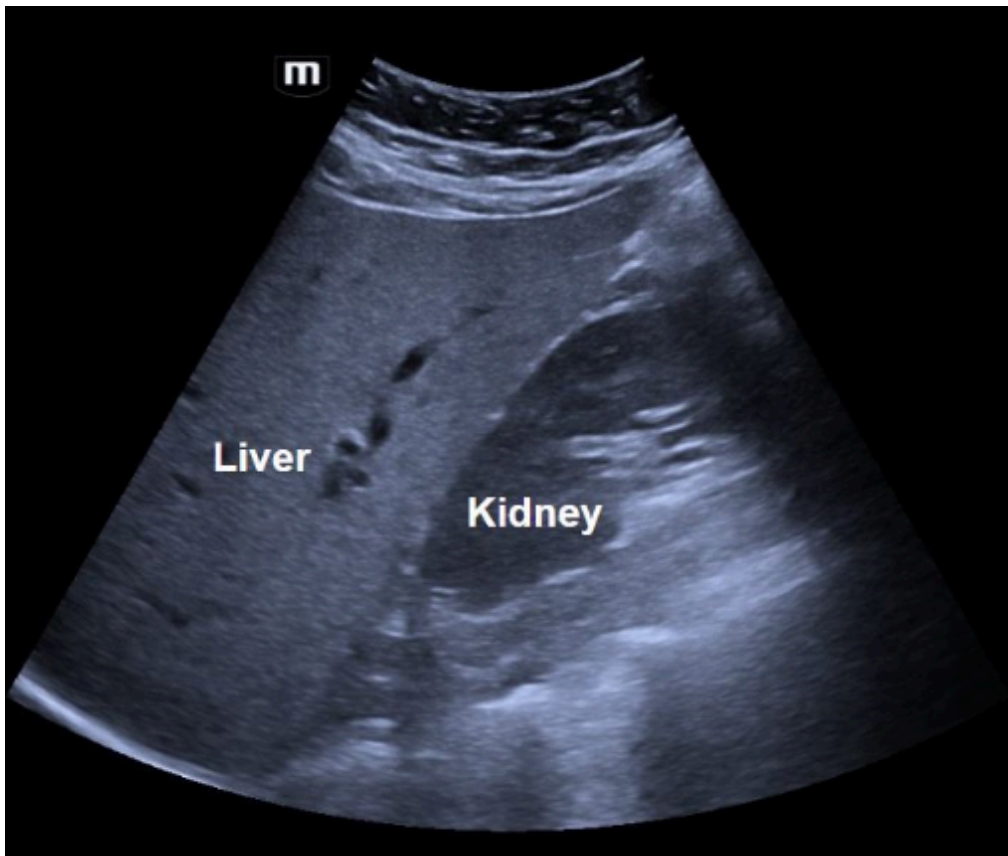


Figure 1

Gray-scale ultrasound image of the liver showing hepatic parenchymal echogenicity.

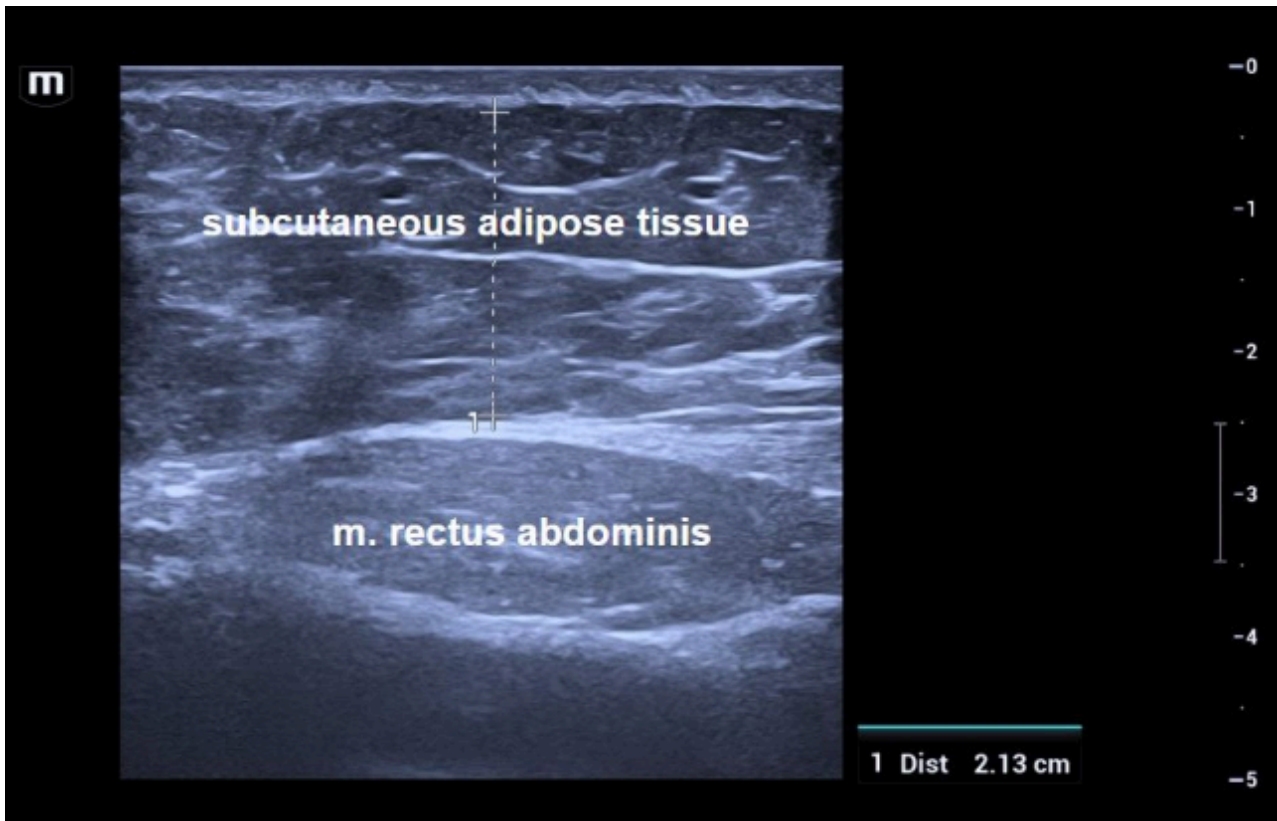


Figure 2

Measurement of abdominal wall fat thickness (AWFT) at the umbilical level using a linear transducer. The distance between the skin surface and the anterior fascia of the rectus abdominis muscle on the right side, where the anteroposterior diameter of the muscle is maximal, was recorded as the AWFT.

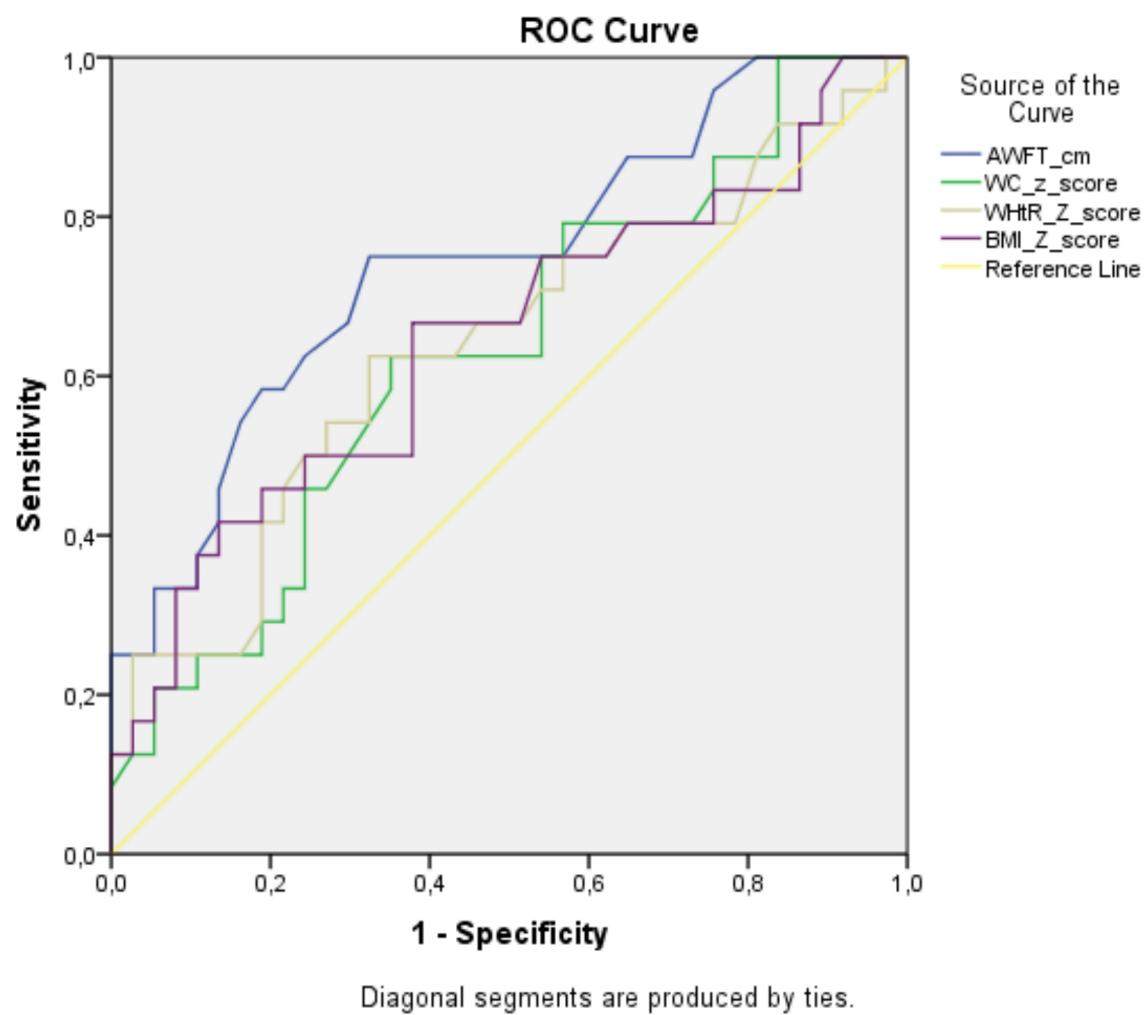


Figure 3

Receiver operating characteristic (ROC) curves of AWFT, BMI z-score, WC z-score, and WHtR z-score for discriminating metabolic syndrome strictly within the cohort of children with obesity (n=61).