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Association Between Body Mass Index, Visceral Fat, and the Risk of Metabolic Syndrome Among Obese Adolescents

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Abstract

This study examined the association between Body Mass Index (BMI) and visceral fat with the risk of Metabolic Syndrome (MetS) among obese adolescents in Surabaya and Sidoarjo, Indonesia. The research addressed the increasing burden of cardiometabolic disorders in adolescents, focusing on the importance of early screening for central adiposity. A cross- sectional design was employed involving 72 obese adolescents from junior and senior high schools. BMI was measured using standard anthropometry, while visceral fat was assessed through Waist Circumference (WC)and Bioelectrical Impedance Analysis (BIA). MetS was identified based on established clinical criteria. The findings revealed that both BMI and visceral fat were significantly associated with MetS, with BIA-derived visceral fat demonstrating the strongest predictive value. Adolescents with high visceral fat exhibited substantially higher risks of dyslipidemia, hypertension, and overall metabolic abnormalities. These results highlight the limitations of BMI as a standalone indicator and reinforce the need for integrating visceral fat assessment in school-based screening programs. Early identification and targeted interventions are essential to mitigate the progression of MetS during adolescence.

Introduction

Metabolic Syndrome (MetS) has become an increasingly significant global health issue, affecting not only adults but also younger populations (Chong et al., 2023; Boddu et al., 2025). MetS refers to a constellation of interrelated cardiometabolic abnormalities including central obesity, dyslipidemia, hypertension, and impaired glucose regulation that collectively elevate the risk of cardiovascular disease, Type 2 Diabetes Mellitus (T2DM), and premature mortality (Alberti et al., 2005; Grundy et al., 2005). Although initially recognized as a condition prevalent in adulthood, epidemiological evidence now confirms that MetS is progressively emerging in children and adolescents. Data from the United States indicate that 8.4% of young individuals were classified as having MetS as early as 2010, while recent global estimates report prevalence rates ranging from 3% in children to 5% in adolescents (Noubiap et al., 2022). In Indonesia, the burden is considerably higher, with a national prevalence of 24.4% among individuals aged ≥15 years (Herningtyas & Ng, 2019) and a strikingly elevated rate of 45.8% reported among adolescents in East Java (Prihaningtyas et al., 2020). These findings collectively underscore the growing urgency of addressing MetS in younger age groups.

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The marked increase in MetS among adolescents is closely linked to the rapid rise in obesity. Obesity, defined by the World Health Organization (2007) as an excessive accumulation of body fat resulting from chronic energy imbalance, is commonly measured using Body Mass Index (BMI) as a practical anthropometric indicator. Although BMI remains widely used for population-level assessment, it does not differentiate between subcutaneous and visceral fat, limiting its ability to predict metabolic risks accurately (Kurniawan et al., 2018; Hamdy et al., 2006; Mathew et al., 2023). Of particular concern is visceral fat, an intra-abdominal fat depot that possesses a high degree of metabolic activity. Visceral adipose tissue secretes pro-inflammatory cytokines such as TNF-α and IL-6 that disrupt insulin signaling pathways and contribute to systemic inflammation, thereby initiating the pathophysiological processes underlying MetS and T2DM (Kataoka et al., 2023). Recent clinical evidence confirms that adolescents with a higher visceral fat burden exhibit significantly greater susceptibility to insulin resistance, hypertension, and dyslipidemia compared with peers who possess lower levels of visceral adiposity (Song et al., 2024; Musa et al., 2025; Balaji et al., 2025).

Accurate assessment of visceral fat has therefore become essential in adolescent health research, particularly in regions experiencing rapid nutritional and lifestyle transitions. Waist Circumference (WC) and Bioelectrical Impedance Analysis (BIA) are two accessible measurement tools widely used in clinical and epidemiological studies. WC provides a simple estimate of central obesity and correlates strongly with cardiometabolic risk, while BIA offers an indirect yet effective assessment of visceral adipose tissue through body composition analysis (Holmes & Racette, 2021; Bennett et al., 2025). However, despite the increasing relevance of central adiposity, empirical research examining the joint contribution of BMI and visceral fat to MetS risk among Indonesian adolescents remains limited. Most existing studies focus predominantly on adults or on isolated metabolic parameters, leaving a substantial gap in evidence specific to adolescent populations.

This gap is concerning in Indonesia, where urbanization, dietary changes, and sedentary lifestyles with little to no physical activities can increase the prevalence of MetS in obese adolescents. Latest international studies showed that excessive level of visceral adipose in children and adolescents is likely increasing the risk of metabolic diseases such as insulin resistent, dyslipidemia, and hypertension thus lead to MetS when they become adults (Marketou et al., 2023; Park et al., 2024). Furthermore, study on gene analysis showing strong association between excessive visceral fat level with the risk of Non-Alcoholic Fattly Liver Disease (NAFLD) (Tao et al., 2023; Njei et al., 2024; Chen et al., 2022). In addition to that, adolescents with excessive visceral fat showed aterogenic lipoprotein, a predictive factor for cardiovascular disease (S. T. Chung et al., 2023; Raitakari et al., 2023; Tragomalou et al., 2023). These findings highlight the importance of identifying an at-risk adolescent to prevent long term metabolic decline.

Given the growing prevalence of adolescent obesity in Surabaya and Sidoarjo and the critical metabolic implications of visceral fat, the present study aims to analyze the association between BMI, visceral adiposity, and the risk of MetS among obese junior and senior high school students in these regions. By addressing the scarcity of adolescent-focused data, this research seeks to strengthen early detection strategies and contribute to the development of more effective prevention programs targeting metabolic disorders in Indonesian youth.

Methods

This study applied an analytical cross-sectional design to examine the association between Body Mass Index (BMI), visceral adiposity, and the risk of Metabolic Syndrome (MetS) among obese adolescents in Surabaya and Sidoarjo. A cross-sectional approach was chosen because it allows simultaneous assessment of exposure and outcome variables within a defined population, making it suitable for determining prevalence and identifying correlations in

adolescent metabolic health research. The study utilized secondary data derived from a school-based anthropometric and metabolic screening conducted between September and October 2019. Such study designs are widely used in epidemiological investigations of pediatric metabolic disorders due to their practicality and capacity to generate baseline evidence efficiently.

The study population consisted of junior and senior high school students aged 13–18 years who met the criteria for obesity based on BMI-for-age Z-scores according to World Health Organization growth standards. Adolescents were excluded if they had consumed corticosteroids, hormonal therapy, or dyslipidemia medications within the previous three months, or if they reported smoking, alcohol consumption, recent infections, endocrine disorders, or immune-related diseases, as these conditions might influence metabolic parameters independently. After applying these inclusion and exclusion criteria, a total of 72 adolescents were eligible and included in the analysis. This sample size reflects the availability of complete anthropometric and biochemical records and aligns with typical sample ranges used in similar adolescent metabolic studies (Chung & Rhie, 2022).

A cluster random sampling technique was employed in which schools served as clusters. Selected schools were chosen randomly from a predefined sampling frame, and all obese students meeting eligibility criteria within each selected cluster were included. Cluster sampling is frequently used in school-based epidemiological studies because it enhances representativeness while maintaining logistical efficiency. The primary variables analyzed in this study included BMI and visceral fat as independent variables and MetS as the dependent variable. BMI was calculated by dividing body weight in kilograms by height in meters squared, and BMI-for-age Z-scores were used to categorize obesity status following WHO standards (World Health Organization, 2007). Visceral fat was assessed through two measurement techniques: waist circumference (WC), measured at the midpoint between the lower rib and iliac crest at the end of normal expiration, and Bioelectrical Impedance Analysis (BIA), conducted using a Tanita 953® device. BIA has been increasingly recognized as a practical and reliable method for estimating visceral adiposity in adolescents.

All anthropometric and biochemical measurements followed standardized clinical protocols. Body weight and height were recorded using calibrated instruments with high precision, while WC was measured with a non-elastic measuring tape according to internationally accepted anthropometric procedures. BIA assessments were performed with participants barefoot and following standard guidelines to reduce hydration-related variability. Fasting venous blood samples were collected to assess fasting plasma glucose, triglycerides, and HDL cholesterol, which were processed using routine clinical laboratory methods. Blood pressure was measured using a calibrated sphygmomanometer after participants had rested for at least five minutes in a seated position. These procedures conform to international recommendations for adolescent metabolic risk assessment (Abarca-Gómez et al., 2017).

Data collection for the original dataset was conducted by trained personnel who followed strict procedural guidelines to ensure measurement accuracy and consistency. Prior to analysis, the dataset underwent cleaning and verification to ensure completeness and reliability. Statistical analysis was performed using the Chi-square test to evaluate the associations between BMI and MetS, as well as between visceral fat and MetS. Relative prevalence (RP) values and 95% confidence intervals were calculated to estimate effect size and the strength of associations. A significance level of $p < 0.05$ was used for all statistical tests. The Chi-square test was selected due to its appropriateness for analyzing relationships between categorical variables in cross-sectional studies, and its application remains consistent with recent analytical approaches used in adolescent metabolic health research.

Ethical approval for the original data collection was granted by the Ethics Committee of the Faculty of Medicine, Airlangga University (Approval No. 254/EC/KEPK/FKUA/2025). All ethical principles concerning confidentiality, voluntary participation, and the protection of adolescent participants were strictly observed throughout the research process.

Result and Discussion

This study included seventy-two adolescent participants from junior and senior high schools in Surabaya and Sidoarjo who met the criteria for obesity. The analysis comprised demographic characteristics, clinical and metabolic profiles, and bivariate testing to examine the associations between body mass index (BMI), visceral fat, and the risk of metabolic syndrome. All analyses were conducted using the Chi-square test with a 95% confidence level, consistent with current recommendations for categorical metabolic risk assessment in adolescent populations (Herningtyas & Ng, 2019; Shi et al., 2022).

Characteristics of Study Participants

Demographic Characteristics

The participants were categorized into early adolescents (13–16 years) and late adolescents (17–18 years). Most respondents were late adolescents (n = 49; 68.06%), while early adolescents accounted for 23 participants (31.94%). The sex distribution indicated that male respondents represented 62.5% of the sample (n = 45), and females accounted for 37.5% (n = 27). The overall demographic distribution is summarized in Table 1 and Table 2.

Table 1. Distribution of Respondents by Age

Age Category	n	%
Early Adolescents (13–16)	23	31.94
Late Adolescents (17–18)	49	68.06
Total	72	100.0

Table 2. Distribution of Respondents by Sex

Sex	n	%
Male	45	62.5
Female	27	37.5
Total	72	100.0

Clinical and Metabolic Characteristics

BMI assessment using WHO standards revealed that most respondents were categorized as obese (n= 56; 77.78%), followed by 14 participants (19.44%) with normal BMI and 2 participants (2.78%) classified as overweight. Visceral fat assessed using waist circumference demonstrated that 53 adolescents (73.61%) met the criteria for central obesity. These findings were consistent with the BIA measurements, in which 52 adolescents (72.22%) exhibited elevated visceral fat levels.

Regarding metabolic parameters, 43 participants (59.72%) had HDL levels within the normal/high range, while 29 participants (40.28%) demonstrated low HDL levels. Most adolescents had normal triglyceride concentrations (n = 60; 83.34%), and only 12 participants (16.66%) had elevated triglycerides. Almost all respondents had normal fasting plasma glucose (n = 71; 98.61%), with only one participant (1.39%) meeting the diagnostic criteria for T2DM. Elevated blood pressure was highly prevalent, with 50 respondents (69.44%) categorized as hypertensive. The overall clinical and metabolic distribution is shown in Table 3.

Table 3. Clinical and Metabolic Characteristics of Respondents

Variable	Category	n	%
BMI	Obese	56	77.78
	Normal	14	19.44
	Overweight	2	2.78
Visceral Fat (WC)	Obese	53	73.61
	Normal	19	26.39
Visceral Fat (BIA)	Obese	52	72.22
	Normal	20	27.78
HDL	High	43	59.72
	Low	29	40.28
Triglycerides	High	12	16.66
	Normal	60	83.34
Plasma Glucose	T2DM	1	1.39
	Normal	71	98.61
Blood Pressure	Hypertension	50	69.44
	Normal	22	30.56
Metabolic Syndrome	MetS	31	43.06
	Non-MetS	41	56.94

The prevalence of metabolic syndrome, based on the IDF criteria for ages 10–16, was 43.06% a notably high proportion consistent with recent studies reporting an increasing burden of MetS in obese adolescents across Southeast Asia (Prihaningtyas et al., 2020).

Bivariate Analysis

Bivariate testing was conducted to examine the associations between BMI, visceral fat (WC and BIA), and metabolic syndrome.

Association Between BMI and Metabolic Syndrome

Table 4 shows that among adolescents categorized as obese, 31 individuals (55.4%) met the criteria for MetS. All participants with normal BMI (n = 14) and overweight status (n = 2) were free of MetS.

Table 4. Cross-tabulation of BMI and MetS

BMI Category	MetS n (%)	Non-MetS n (%)	Total (%)	p-value
Obese	31 (55.4)	25 (44.6)	56 (100.0)	0.000
Normal	0 (0.0)	14 (100.0)	14 (100.0)	
Overweight	0 (0.0)	2 (100.0)	2 (100.0)	
Total	31 (43.1)	41 (56.9)	72 (100.0)	

The Chi-square value ($\chi^2 = 15.554$; df = 2; $p < 0.001$) indicates a statistically significant relationship between BMI status and MetS.

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Association Between Visceral Fat and Metabolic Syndrome

Visceral fat was analyzed using both WC and BIA.

Waist Circumference

Among adolescents classified with central obesity, 58.5% had metabolic syndrome, whereas all individuals with normal WC were non-MetS.

Table 5. Cross-tabulation of Visceral Fat (WC) and MetS

WC Category	MetS n (%)	Non-MetS n (%)	Total (%)	RP	95% CI	p-value
Obese	31 (58.5)	22 (41.5)	53 (100.0)	0.415	0.302–0.571	0.000
Normal	0 (0.0)	19 (100.0)	19 (100.0)			
Total	31 (43.1)	41 (56.9)	72 (100.0)			

The Chi-square statistic ($\chi^2 = 19.516$; $p < 0.001$) confirms a strong association between visceral fat measured by WC and the occurrence of MetS.

BIA-Measured Visceral Fat

The association was even stronger for visceral fat measured using BIA. Of the adolescents categorized as having high visceral fat, 57.7% had MetS.

Table 6. Cross-tabulation of Visceral Fat (BIA) and MetS

BIA Category	MetS n (%)	Non-MetS n (%)	Total (%)	RP	95% CI	p-value
Obese	30 (57.7)	22 (42.3)	52 (100.0)	25.909	3.221–208.382	0.000
Normal	1 (5.0)	19 (95.0)	20 (100.0)			
Total	31 (43.1)	41 (56.9)	72 (100.0)			

These findings affirm that visceral fat particularly as measured by BIA serves as a far stronger predictor of MetS in adolescents than BMI alone, in line with emerging evidence highlighting visceral adiposity as a primary driver of cardiometabolic risk.

This study demonstrated that both BMI and visceral fat are significantly associated with the risk of metabolic syndrome among obese adolescents in Surabaya and Sidoarjo. The statistical findings strengthen the theoretical framework that general adiposity and central adiposity jointly contribute to metabolic disturbances in this age group. The significant association between BMI and metabolic syndrome ($p = 0.000$) aligns with previous evidence showing that adolescents with overweight or obesity have markedly higher risks of developing metabolic abnormalities compared with those in the normal-BMI range (Nehus & Mitsnefes, 2019). Although BMI does not differentiate between lean mass and fat mass or quantify fat distribution, adolescents with high BMI values typically exhibit higher visceral and ectopic fat deposits, which predispose them to insulin resistance and cardiometabolic dysfunction (Tran et al., 2023). The pathophysiological mechanisms underlying this relationship include adipocyte hypertrophy, elevated free fatty acid release, impaired insulin signalling, and chronic low-grade inflammation mediated by cytokines such as TNF-α and IL-6, alongside reduced adiponectin secretion (Kahn et al., 2006; Weihe & Weihrauch-Blüher, 2019). These processes collectively promote dyslipidaemia, hypertension, and disturbed glucose homeostasis, which form the clinical basis of metabolic syndrome.

Visceral fat, assessed using both waist circumference and BIA, also demonstrated a strong association with metabolic syndrome, with BIA showing a considerably higher risk estimate ($RP = 25.909$). This finding underscores the clinical importance of visceral adiposity as a more potent predictor of metabolic abnormalities compared with overall body size. Consistent with recent literature, visceral adipose tissue exhibits greater metabolic activity than subcutaneous fat and functions as an endocrine organ that releases pro-inflammatory mediators and free fatty acids, leading to insulin resistance and systemic metabolic imbalance (Krüger et al., 2024; Zatterale et al., 2020). The observed difference between waist circumference and BIA measurements suggests that direct body-composition assessment offers improved precision in estimating visceral fat, whereas waist circumference may capture mixed components of

abdominal fat. These findings support previous research indicating that body-composition based metrics outperform simple anthropometric measures when predicting metabolic risk (Lee et al., 2024), although waist circumference remains a cost-effective and feasible tool for routine adolescent screening (Holmes & Racette, 2021). Recent meta-analytic results involving Asian populations similarly reaffirm that visceral fat is an independent and powerful determinant of metabolic syndrome (Chen et al., 2010).

This study offers valuable insights by simultaneously examining BMI and visceral fat using two measurement approaches. The consistency of the findings with established physiological mechanisms and prior empirical evidence strengthens their clinical relevance. However, the study's cross-sectional design limits causal inference, and the sample size of 72 participants restricts generalisability. Additional confounding variables such as dietary intake, physical activity, socioeconomic factors, and genetic predisposition were not fully accounted for. Moreover, although BIA enhances accuracy compared with simple anthropometry, its precision remains inferior to advanced imaging modalities such as CT or MRI, which represent the gold standard for visceral fat assessment.

The findings carry important clinical and public health implications. Early identification of metabolic risk in obese adolescents should incorporate both BMI and visceral fat measurements to improve accuracy in detecting high-risk individuals. School-based screening programmes are strongly recommended to include waist circumference as a routine indicator alongside BMI. Adolescents identified as high risk should be prioritised for lifestyle interventions focusing on dietary improvement, increased physical activity, and behavioural guidance, given that reductions in visceral fat have been shown to significantly improve metabolic outcomes. Future research should employ longitudinal designs with larger and more diverse samples to clarify causal pathways and monitor the progression of metabolic syndrome over time. Interventional studies targeting visceral fat reduction are also needed to inform evidence-based clinical guidelines and community health strategies aimed at mitigating the rising burden of metabolic syndrome among Indonesian adolescents.

Conclusion

This study demonstrates that both general adiposity, as measured by BMI, and central adiposity, as assessed through waist circumference and BIA, are significantly associated with the presence of metabolic syndrome among obese adolescents in Surabaya and Sidoarjo. The prevalence of MetS reached 43.06%, a figure that mirrors the rising cardiometabolic burden in Indonesian youth and substantiates research showing that excessive visceral fat plays a decisive role in early metabolic deterioration. The findings confirm that adolescents with elevated visceral fat particularly those identified through BIA exhibit a substantially higher risk of meeting MetS criteria than those with normal visceral adiposity. These outcomes are consistent with current evidence emphasizing the metabolic activity of visceral fat and its contribution to systemic inflammation, insulin resistance, and dyslipidaemia.

The results also highlight the limitations of BMI as a standalone screening tool. Although BMI was significantly associated with MetS, it did not demonstrate the predictive strength observed in visceral fat measurements, reinforcing the importance of incorporating central adiposity indicators in adolescent health assessments. Given the practicality of waist circumference and the improved accuracy offered by BIA, school-based screening programmes should integrate both methods to enhance early identification of high-risk individuals. Such early detection is essential because lifestyle-based interventions targeting visceral fat reduction in adolescence have been shown to yield marked improvements in cardiometabolic markers.

Overall, this study underscores the urgent need for preventive strategies aimed at reducing visceral adiposity in Indonesian adolescents. Public health interventions should prioritise dietary quality, structured physical activity, and behavioural modification, particularly in

rapidly urbanising settings where sedentary lifestyles and obesogenic food environments are increasingly prevalent. Future research would benefit from longitudinal designs and larger samples to better elucidate causal pathways and monitor metabolic progression over time. Additionally, incorporating detailed behavioural and socioeconomic variables may refine risk prediction and strengthen policy recommendations tailored to adolescent health in Indonesia.

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