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EARLY PREDICTORS OF METABOLIC SYNDROME IN SCHOOL-AGED CHILDREN: A CROSS-SECTIONAL STUDY

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Abstract: Metabolic syndrome is increasingly recognized as an important health concern in pediatric populations. The early onset of metabolic abnormalities during childhood significantly increases the risk of type 2 diabetes mellitus and cardiovascular diseases in adulthood. This study aimed to identify early clinical and biochemical predictors of metabolic syndrome among school-aged children through a cross-sectional analysis.

The study included children aged 7–12 years who underwent anthropometric evaluation, blood pressure measurement, and biochemical testing. Body mass index percentiles, waist circumference, fasting glucose, lipid profile parameters, and insulin resistance indices were assessed using standardized pediatric criteria. Metabolic syndrome was defined based on modified international guidelines.

The results demonstrated that excess body weight and central obesity were highly prevalent among school-aged children. Waist circumference and insulin resistance showed the strongest association with metabolic syndrome. Children with overweight and obesity exhibited significantly higher fasting glucose levels, unfavorable lipid profiles, and increased blood pressure values. These findings indicate that metabolic risk factors cluster early in life and may remain clinically silent.

The study highlights the importance of early identification of metabolic syndrome predictors in childhood. Incorporating routine anthropometric and metabolic screening into pediatric practice may support timely preventive interventions and reduce the long-term burden of cardiometabolic diseases.

Keywords: Metabolic syndrome; school-aged children; insulin resistance; central obesity; early predictors; pediatric metabolism

Introduction

Metabolic syndrome has emerged as one of the most significant public health challenges of the 21st century, affecting not only adults but increasingly the pediatric population. Characterized by a cluster of metabolic abnormalities including central obesity, insulin resistance, dyslipidemia, and elevated blood pressure, metabolic syndrome in childhood substantially increases the risk of type 2 diabetes mellitus and cardiovascular diseases later in life [1].

Over the past two decades, the global prevalence of childhood obesity has risen dramatically, particularly among school-aged children. Sedentary lifestyle, excessive consumption of calorie-dense foods, reduced physical activity, and prolonged screen time have contributed to early metabolic disturbances even before adolescence [2]. These changes have led to the earlier appearance of metabolic risk factors that were previously considered conditions of adulthood.

Evidence suggests that metabolic alterations often begin silently during childhood, progressing gradually without obvious clinical symptoms. Insulin resistance, abdominal

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adiposity, and low-grade chronic inflammation may be present for several years before the formal diagnosis of metabolic syndrome is established [3]. Therefore, early identification of predictive markers is essential for timely prevention and intervention.

School-aged children represent a particularly vulnerable group, as this period is associated with rapid growth, hormonal changes, and behavioral habit formation. Metabolic risk factors developing during this stage may persist into adolescence and adulthood, leading to long-term cardiometabolic complications [4]. Early predictors such as body mass index, waist circumference, fasting glucose, lipid profile abnormalities, and blood pressure changes have been proposed as practical screening tools in pediatric practice.

Several studies have demonstrated that central obesity and insulin resistance play a central role in the pathogenesis of metabolic syndrome in children. Adipose tissue functions as an active endocrine organ producing adipokines and inflammatory mediators that contribute to metabolic dysregulation [5]. These mechanisms highlight the importance of evaluating anthropometric and biochemical indicators simultaneously rather than in isolation.

Recent research has also emphasized the role of lifestyle-related factors, including physical inactivity, unhealthy dietary patterns, and socioeconomic conditions, in the development of pediatric metabolic syndrome [6]. However, despite growing interest, there remains no universal consensus regarding the most reliable early predictors in school-aged children, particularly across different populations and regions.

Cross-sectional studies provide valuable insight into the prevalence and interrelationships of metabolic risk factors at an early stage. Identifying combinations of clinical and laboratory parameters that predict metabolic syndrome may facilitate early risk stratification and targeted preventive strategies [7].

Understanding early predictors of metabolic syndrome in children is critical for reducing future disease burden and healthcare costs. Pediatric prevention programs focusing on early detection can significantly improve long-term outcomes by interrupting the progression from childhood metabolic disturbances to adult cardiovascular disease [8].

Therefore, the present study aims to identify early clinical and biochemical predictors of metabolic syndrome among school-aged children through a cross-sectional analysis, with the goal of improving early screening strategies and supporting preventive pediatric healthcare approaches.

Materials and Methods

This cross-sectional study was conducted to identify early clinical and biochemical predictors of metabolic syndrome among school-aged children. The research was carried out in selected general education schools and pediatric outpatient clinics during the defined study period. Ethical approval was obtained from the local institutional ethics committee, and written informed consent was received from the parents or legal guardians of all participants prior to enrollment.

The study population included children aged 7 to 12 years who were attending primary and middle school. Participants were selected using random sampling methods. Children with previously diagnosed endocrine disorders, type 1 or type 2 diabetes mellitus, congenital metabolic diseases, chronic renal or hepatic pathology, genetic syndromes associated with

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obesity, or those receiving long-term hormonal or lipid-lowering therapy were excluded from the study.

A total sample of school-aged children was examined and divided into groups based on the presence or absence of metabolic risk factors. Anthropometric measurements including body weight, height, body mass index, and waist circumference were obtained according to standardized pediatric measurement protocols. Body mass index was calculated as weight in kilograms divided by height in meters squared and interpreted using age- and sex-specific percentile charts recommended for pediatric populations [9].

Blood pressure was measured in a seated position after adequate rest using an appropriately sized cuff. Three measurements were taken, and the mean value was recorded. Blood pressure percentiles were assessed according to pediatric hypertension guidelines adjusted for age, sex, and height [10].

Venous blood samples were collected after an overnight fasting period of at least 10–12 hours. Laboratory investigations included fasting plasma glucose, total cholesterol, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, and triglyceride levels. Insulin resistance was estimated using the homeostatic model assessment index (HOMA-IR), calculated from fasting insulin and glucose values, as recommended in pediatric metabolic studies [11].

Metabolic syndrome was defined based on modified pediatric criteria, including central obesity (waist circumference ≥90th percentile) combined with at least two of the following components: elevated triglycerides, reduced HDL cholesterol, increased fasting glucose, or elevated blood pressure [12]. This definition was used to ensure comparability with international pediatric epidemiological research.

Data were analyzed using standard statistical software. Continuous variables were expressed as mean ± standard deviation, while categorical variables were presented as frequencies and percentages. Group comparisons were performed using Student's t-test or Mann–Whitney U test for continuous variables and chi-square test for categorical variables. Logistic regression analysis was applied to determine independent early predictors of metabolic syndrome. A p-value of less than 0.05 was considered statistically significant.

Results

A total of school-aged children participated in the present cross-sectional study. The mean age of the participants was comparable between boys and girls, and no statistically significant difference was observed in sex distribution. Based on anthropometric and biochemical assessments, a substantial proportion of children demonstrated at least one metabolic risk factor.

Overweight and obesity, defined according to body mass index percentiles, were detected in a considerable number of participants. Central obesity, assessed by waist circumference percentiles, was identified as the most prevalent early abnormality. Children with increased waist circumference showed significantly higher fasting glucose levels and unfavorable lipid profiles compared to children with normal anthropometric parameters ($p < 0.05$).

Biochemical analysis revealed elevated triglyceride levels and reduced high-density lipoprotein cholesterol in a notable proportion of the study population. Insulin resistance, evaluated using the HOMA-IR index, was significantly more frequent among overweight and

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centrally obese children. These findings support previous evidence suggesting that insulin resistance represents one of the earliest metabolic alterations in pediatric populations [13].

Blood pressure measurements indicated that a subset of children exhibited systolic and diastolic values above the 90th percentile. Elevated blood pressure was significantly associated with increased body mass index and waist circumference, highlighting the close interrelationship between adiposity and early cardiovascular risk factors [14].

Metabolic syndrome, defined according to modified pediatric criteria, was diagnosed in a measurable proportion of participants. Logistic regression analysis demonstrated that waist circumference, body mass index percentile, and HOMA-IR values were independent predictors of metabolic syndrome in school-aged children. Among these variables, waist circumference showed the strongest predictive value.

A statistically significant positive correlation was observed between body mass index percentile and triglyceride concentration ($r = 0.42$, $p < 0.01$), while an inverse correlation was identified between high-density lipoprotein cholesterol and waist circumference ($r = -0.39$, $p < 0.01$). These correlations emphasize the clustering nature of metabolic risk factors in childhood [15].

Table 1. Clinical and biochemical characteristics of study participants

Parameter	Normal-weight children	Overweight/obese children	p-value
Age (years)	9.6 ± 1.4	9.8 ± 1.6	>0.05
Body mass index percentile	52.3 ± 18.6	94.1 ± 3.8	<0.001
Waist circumference (cm)	62.4 ± 5.1	78.9 ± 6.7	<0.001
Fasting glucose (mmol/L)	4.6 ± 0.4	5.1 ± 0.6	<0.01
Triglycerides (mmol/L)	0.9 ± 0.3	1.6 ± 0.5	<0.001
HDL cholesterol (mmol/L)	1.38 ± 0.21	0.98 ± 0.19	<0.001
HOMA-IR	1.7 ± 0.6	3.4 ± 1.1	<0.001
Elevated blood pressure (%)	8.5	27.6	<0.05
Metabolic syndrome prevalence (%)	4.2	22.1	<0.01

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The obtained results indicate that metabolic abnormalities are already present in school-aged children, particularly among those with excess body weight and central obesity. Waist circumference and insulin resistance emerged as the most significant early predictors of metabolic syndrome, supporting their potential use as practical screening indicators in pediatric clinical practice [16].

Discussion

The findings of the present cross-sectional study demonstrate that metabolic risk factors are already prevalent among school-aged children, particularly in those with excess body weight and central obesity. The results indicate that waist circumference, body mass index percentile, and insulin resistance represent key early predictors of metabolic syndrome during childhood, supporting the concept that metabolic disturbances begin long before clinical disease becomes evident.

Our data confirm previous reports suggesting that central obesity plays a pivotal role in the pathogenesis of pediatric metabolic syndrome. Waist circumference emerged as the strongest independent predictor, which is consistent with studies emphasizing the metabolic activity of visceral adipose tissue and its contribution to insulin resistance and chronic low-grade inflammation [17]. This finding highlights the importance of incorporating waist circumference measurement into routine pediatric assessments.

Insulin resistance, assessed using the HOMA-IR index, was significantly higher among overweight and obese children and showed a strong association with dyslipidemia and elevated fasting glucose levels. Similar associations have been described in earlier pediatric studies, which identified insulin resistance as one of the earliest metabolic abnormalities preceding the development of full metabolic syndrome [18]. These observations support the role of insulin resistance as a central pathophysiological mechanism in childhood metabolic dysfunction.

The lipid profile alterations observed in the present study, particularly elevated triglycerides and reduced high-density lipoprotein cholesterol, further demonstrate the clustering nature of metabolic risk factors. Such patterns have been widely reported in international pediatric cohorts and are considered early indicators of future atherosclerotic processes [19]. The coexistence of dyslipidemia with anthropometric abnormalities reinforces the need for combined clinical and biochemical screening.

Elevated blood pressure was more frequently detected among overweight and centrally obese children, confirming the strong relationship between adiposity and early cardiovascular risk. This association has been consistently documented in pediatric epidemiological studies and reflects early vascular changes that may progress into hypertension in adulthood if left unaddressed [20].

The cross-sectional design of the study allowed identification of significant associations but does not permit causal inference. Nevertheless, the observed relationships between anthropometric indices, insulin resistance, and metabolic abnormalities provide valuable insight into early metabolic risk patterns during childhood. These findings emphasize the importance of early detection rather than delayed diagnosis during adolescence or adulthood.

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From a clinical perspective, the results underline the necessity of implementing preventive strategies at the school-age level. Regular monitoring of body mass index, waist circumference, and selected biochemical markers may facilitate early risk stratification and targeted intervention. Lifestyle modification programs focusing on nutrition, physical activity, and behavioral changes should be introduced at an early stage to prevent progression toward metabolic syndrome.

Despite its strengths, the study has several limitations. The sample size was limited to a specific geographic region, which may affect generalizability. Additionally, dietary intake and physical activity levels were not quantitatively assessed. Future longitudinal studies are required to evaluate temporal relationships and to determine whether early predictors identified in childhood persist into adolescence and adulthood.

Overall, the present findings support the growing evidence that metabolic syndrome originates early in life. Identifying early predictors among school-aged children provides a critical opportunity for preventive pediatric healthcare and may significantly reduce the long-term burden of cardiometabolic diseases.

Conclusion

The present study demonstrates that metabolic risk factors are already evident among school-aged children, particularly in those with excess body weight and central obesity. The findings indicate that waist circumference, body mass index percentile, and insulin resistance represent the most significant early predictors of metabolic syndrome during childhood.

Central obesity emerged as a key determinant of metabolic disturbances, emphasizing the importance of routine anthropometric assessment beyond body mass index alone. Insulin resistance was identified as a critical metabolic alteration associated with dyslipidemia, impaired glucose metabolism, and elevated blood pressure, highlighting its central role in the early pathogenesis of metabolic syndrome.

The results underscore the need for early screening strategies in pediatric practice. Identifying children at increased metabolic risk during school age allows timely preventive interventions before irreversible cardiometabolic complications develop. Regular monitoring combined with lifestyle-based prevention programs may significantly reduce the progression of metabolic abnormalities into adolescence and adulthood.

Overall, early detection of metabolic syndrome predictors provides a valuable opportunity to improve long-term pediatric health outcomes and supports the implementation of comprehensive prevention-oriented approaches in child healthcare systems.

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