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Non-Invasive Screening of Hormonal and Metabolic Risk for Type 2 Diabetes in Adolescents: A Cross-Sectional Study

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Abstract

Background: Type 2 diabetes (T2D) among adolescents is increasingly linked to early-onset obesity, hormonal dysregulation, and sedentary lifestyles. Early detection through non-invasive methods is crucial for preventing long-term complications. However, few studies have examined the combined influence of hormonal and lifestyle-related factors in obese adolescents. **Objective:** To identify key predictors of metabolic risk for T2D in obese adolescents using non-invasive screening approaches**. Methods:** A cross-sectional study was conducted involving obese adolescents aged 13–15 years. Non-invasive assessments included anthropometric measurements, dietary and physical activity questionnaires, and a hormonal imbalance questionnaire. Additional potential confounders considered were the participants sex and age. Multivariate logistic regression was used to analyses the association between risk factors and metabolic risk, with hormonal imbalance as a primary predictor. The model was adjusted for obesity severity, parental history of diabetes, physical activity, and dietary patterns. **Results:** Five significant predictors were identified: hormonal imbalance, obesity severity, parental history of diabetes, low physical activity, and poor dietary patterns. Hormonal imbalance was evaluated through a self-administered questionnaire., was the strongest predictor ($p < 0.05$). **Conclusion:** This study highlights the need for early screening strategies targeting hormonal and lifestyle factors. Non-invasive methods can be used to identify adolescents at risk for T2D.

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INTRODUCTION

Type 2 diabetes mellitus (T2DM), previously regarded as a condition predominantly affecting adults, is increasingly being diagnosed among adolescents worldwide.[1] This alarming trend is closely associated with the rising prevalence of adolescent obesity.[2] and has emerged as a critical global public health concern. Recent global estimates indicate that more than 14.6 million adolescents were affected by T2DM in 2021, with the prevalence more than doubling since 1990. In Indonesia, data from the 2018 Basic Health Research (Riskesdas) reported an increase in diabetes prevalence among individuals aged 15 years and older, from 6.9% in 2013 to 10.9% in 2018. The most recent findings from the 2023 Indonesian Health Survey (SKI) show that the prevalence of diabetes mellitus, based on blood glucose measurements in individuals aged ≥15 years, has further risen to 11.7%, reflecting a continued upward trajectory.[3] Although national data on adolescent T2DM remain limited, the sharp increase in adolescent obesity serves as a strong early indicator of metabolic health deterioration within this population.[4]

Adolescent obesity has been associated not only with long-term health risks such as cardiovascular disease[5] and cancer, but also with the early onset of metabolic disorders, including insulin resistance and diabetes.[6] However, current non-invasive diabetes screening methods for adolescents rarely incorporate hormonal indicators,[7] despite the fact that these signs may serve as important early warning markers. Hormonal imbalances, such as irregular menstruation or hirsutism in females—often indicative of polycystic ovary syndrome (PCOS)[8], or gynecomastia and delayed puberty in males, may reflect underlying metabolic dysfunction and insulin resistance.[9,10]

These clinical signs are frequently overlooked in conventional school-based health screenings. The novelty of this study lies in incorporating hormonal disorder indicators into a non-invasive screening model for T2DM risk among obese adolescents.[11,12] Most existing diabetes screening methods rely primarily on anthropometric or lifestyle-related indicators, while neglecting the hormonal dimension that can substantially contribute to diabetes risk.[13] By integrating hormonal indicators, this approach broadens the scope of conventional screening and provides a more comprehensive assessment of T2DM risk.[14] Notably, such clinical markers of hormonal imbalance, often indicative of early insulin resistance, are commonly underrecognized in standard screening practices.[15]

The integration of hormonal indicators into non-invasive screening models has the potential to enhance early identification and management of diabetes risk among obese adolescents. Accordingly, this study aimed to examine non-invasive risk factors, including hormonal disorders, associated with type 2 diabetes mellitus in obese adolescents aged 13–15 years in Karawang,

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Indonesia. This research is expected to contribute to the development of more comprehensive and holistic non-invasive screening tools for adolescents at risk of T2DM. By underscoring the role of hormonal indicators in early risk assessment, the study seeks to improve early detection strategies and inform adolescent-focused public health interventions. Furthermore, the findings may support policymakers and school health programs in developing targeted education and screening models that address both metabolic and hormonal dimensions of adolescent health.

METHODS

This study employed a quantitative cross-sectional design to examine non-invasive risk factors, including clinical signs of hormonal disorders, associated with the risk of type 2 diabetes mellitus (T2DM) among obese adolescents aged 13–15 years. The research was conducted between August and November 2024 in several junior high schools in Karawang Regency, West Java, Indonesia. A total of 296 participants were recruited using a multistage cluster random sampling technique. In the first stage, three junior high schools with comparable demographic and socioeconomic characteristics were randomly selected from the list of eligible schools in the regency. In the second stage, classes within each selected school were randomly chosen, and all students meeting the inclusion criteria were invited to participate. Adolescents with a previous diagnosis of diabetes or those undergoing hormonal therapy were excluded.

Data collection involved the use of structured questionnaires and non-invasive assessments, including anthropometric measurements (body mass index [BMI], waist circumference), clinical signs of hormonal imbalance (such as acanthosis nigricans, hirsutism, gynecomastia, or irregular menstruation), and self-reported lifestyle information. Hormonal imbalance indicators were identified through a combination of direct clinical observation and structured self-reports. Direct observations were conducted by trained healthcare professionals with expertise in paediatric and adolescent health assessments. No biochemical or hormonal laboratory testing was performed. Independent variables included demographic factors (age, sex), anthropometric indicators (BMI and waist circumference), lifestyle factors (physical activity and dietary habits), family history of diabetes, and clinical signs of hormonal imbalance. These variables were incorporated into a composite Type 2 Diabetes Mellitus (T2DM) risk score ranging from 0 to 10, with each component assigned a weighted point based on established risk assessment criteria. Risk levels were categorized as low (0–3), moderate (4–6), and high (7–10). For the purpose of statistical analysis, the risk score was dichotomized: participants with scores ≥7 were classified as high risk (coded as 1), whereas those with scores ≤6 were categorized as low-to-moderate risk (coded as 0).

Data were analyzed using SPSS version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were used to summarize participant characteristics. Associations between independent

variables and T2DM risk were initially assessed using chi-square tests. Variables with a p-value <0.25 in bivariate analysis were entered into a multivariate logistic regression model to identify independent predictors of high T2DM risk, with clinical signs of hormonal imbalance specified as the primary predictor. The regression model was adjusted for potential confounders, including age, sex, physical activity, dietary pattern, and family history of diabetes. Statistical significance was set at $p<0.05$.

Inclusion criteria were adolescents aged 13–15 years, classified as obese according to the World Health Organization (WHO) BMI-for-age z-score ≥+2 standard deviations (SD), and currently enrolled in school. Exclusion criteria were a prior diagnosis of diabetes or current hormonal therapy. Ethical approval was obtained from the Health Research Ethics Commission of Bani Saleh School of Health Sciences (EC.148/KEPK/STKBS/VIII/2024). Written informed consent was obtained from all participants and their parents/guardians prior to data collection.

RESULTS

Most participants were aged 13 years (57.9%), and the majority were female (n=178, 60.1%). A large proportion of respondents reported no parental history of diabetes (n=276, 93.2%). In terms of lifestyle, 172 adolescents (58.1%) engaged primarily in light physical activity. Regarding weight status, 124 respondents (78.7%) were classified as non-obese. Overall, 216 participants (73.0%) were categorized as not being at risk for type 2 diabetes mellitus (T2DM) based on the composite risk score (Table 1).

Table 1. Respondent Characteristics

Variable	N	%
Age		
13 years	170	57,4
14 years	105	3,5
15 years	21	7,1
Gender		
Male	118	39,9
Female	178	60,1
Parental History of Diabetes		
Yes	20	6,8
No	276	93,2
Physical Activity		
Light	175	59,1
Moderate	81	27,2
Vigorous	40	13,5
Dietary Pattern		
Poor	252	85,1
Good	44	14,9

Variable	N	%
Obesity		
Obese	82	27,7
Not Obese	214	72,3
Risk of Type 2 Diabetes Mellitus		
Yes	214	72,3
No	82	27,2
Hormonal Imbalance		
Yes	214	72,3
No	82	27,2
Total	296	100

The bivariate analysis identified several significant non-invasive risk factors associated with the risk of type 2 diabetes mellitus (T2DM) among obese adolescents. These included parental history of diabetes, low levels of physical activity, poor dietary patterns, obesity, and the presence of hormonal imbalance. Among these, obesity and hormonal disturbances demonstrated the strongest associations with T2DM risk. These findings underscore the importance of early identification and intervention strategies focused on lifestyle modification and the integration of hormonal indicators into screening practices for at-risk adolescent populations. In contrast, gender was not found to be significantly associated with T2DM risk in this study. The detailed results are presented in Table 2.

Table 2. Bivariate Analysis of Risk Factors for Type 2 Diabetes Mellitus (T2DM) Among Adolescents (N = 296)

Variable	T2DM Risk	No Risk	Total	OR (95% CI)	P-Value
Gender					
Male	38 (47.5%)	80 (37.0%)	118	1–.447 (0.864- 2.421)	0.134
Female	42 (52.5%)	136 (63.0%)	178		
Parental History of Diabetes					
Yes	20 (25.0%)	6 (3%)	26	6.23 (2.25–17.23)	0.000
No	60 (75.0%)	210 (97%)	270		
Physical Activity					
Light	62 (77.5%)	110 (50.9%)	172	3.51 (1.336–9.243)	0.000
Moderate	17 (21.3%)	67 (31.0%)	84		
Vigorous	1 (1.2%)	39 (18.1%)	40		
Dietary Pattern					
Poor	75 (93.8%)	175 (81.0%)	250	0.213 (0.139–0.324)	0.012
Good	5 (6.2%)	21 (19.0%)	46		
Obesity					
Obese	63 (78.8%)	5 (2.3%)	68	28.31(10.44-76.74)	0.000
Not Obese	17 (21.2%)	211 (97,7%)	228		

Variable	T2DM Risk	No Risk	Total	OR (95% CI)	P-Value
Hormonal Imbalance					
Yes	82 (98.8%)	6 (3%)	88	48.17 (17.21- 134.87)	0.000
No	1(1.2%)	207 (97%)	8		

The binary logistic regression analysis revealed that parental history of diabetes, hormonal imbalance, and obesity were significantly associated with the risk of developing type 2 diabetes mellitus (T2DM) among adolescents. Specifically, adolescents with a parental history of diabetes had 6.23 times greater odds of developing T2DM compared to those without such a history ($p < 0.001$, 95% CI: 2.25–17.23), indicating a strong and statistically significant association. Respondents with hormonal imbalance exhibited 48.17 times higher odds of developing T2DM than those without hormonal disturbances ($p < 0.001$, 95% CI: 17.21–134.87), representing a very strong and highly significant relationship. In addition, obese adolescents had 28.31 times higher odds of experiencing T2DM compared to their non-obese counterparts ($p < 0.001$, 95% CI: 10.44–76.74), demonstrating a substantial association between obesity and T2DM risk. These findings underscore the critical importance of incorporating screening and preventive strategies that target modifiable risk factors, particularly among adolescents with a family history of diabetes, hormonal abnormalities, or obesity. The detailed results are presented in Table 3.

Table 3. The Dominant Factor among Parental History of Diabetes, Physical Activity, Dietary Pattern, Obesity, Hormonal Imbalance in the Incidence of Metabolic Risk for Type 2 Diabetes

Variable	B	P-Value	Odd Ratio (Exp(B))	95% CI Exp (B)
Parental History of Diabetes	1.83	0.000	6.23	2.25 – 17.23
Hormonal Imbalance	3.87	0.000	48.17	17.21 – 134.87
Obesity	3.34	0.000	28.31	10.44 – 76.74
Physical Activity	-0.644	0.368	0.525	0.129 – 2.134
Dietary Pattern	1.329	0.509	3.779	0.073 – 195.141

DISCUSSION

This study identified parental history of diabetes, hormonal imbalance, and obesity as significant non-invasive risk factors associated with an increased likelihood of developing type 2 diabetes mellitus among obese adolescents, thereby directly addressing the research question on key predictors in this population.

Parenteral History: The study demonstrated a strong association between parental history of diabetes and the risk of developing T2DM among obese adolescents (OR = 6.23, $p < 0.001$). This

finding underscores the role of both genetic predisposition and shared familial environments in the early pathogenesis of T2DM. Adolescents with diabetic parents are not only genetically predisposed but are also more likely to adopt similar dietary habits, physical activity patterns, and other health-related behaviors that may further elevate their risk.[16] This intergenerational transmission of risk may begin as early as childhood and accumulate across the life course. From a reproductive health perspective, a family history of diabetes may also increase the likelihood of developing reproductive endocrine disorders, such as polycystic ovary syndrome (PCOS) in females, which has been shown to cluster within families affected by insulin resistance and type 2 diabetes. These findings highlight the importance of early screening and family-centered interventions to mitigate the cumulative risk of T2DM and its related complications.[17]

Hormonal imbalance emerged as a significant non-invasive indicator strongly associated with an increased risk of T2DM in this population. Clinical manifestations such as hirsutism, irregular menstruation, gynecomastia, and delayed puberty may reflect underlying insulin resistance—a key pathophysiological mechanism in both diabetes and reproductive dysfunction. In adolescent girls, features suggestive of polycystic ovary syndrome (PCOS) not only signal metabolic dysregulation but may also indicate impaired ovarian function, with implications for menstrual regularity and long-term fertility potential. In boys, hormonal disturbances such as gynecomastia or delayed sexual maturation may suggest impaired testicular function and hypogonadism, both of which have been linked to metabolic syndrome. These findings underscore the importance of incorporating reproductive health assessments into adolescent metabolic risk screening protocols. Moreover, the strong associations observed between hormonal imbalance (OR = 48.17) and obesity (OR = 28.31) with elevated diabetes risk reinforce existing evidence that endocrine and metabolic dysregulation jointly contribute to the pathogenesis of T2DM.[18] These results are consistent with the endocrine–metabolic theory, which posits that early disruptions in hormonal regulation—such as polycystic ovary syndrome (PCOS) in females or delayed puberty and gynecomastia in males—can precipitate chronic alterations in insulin sensitivity, lipid metabolism, and fat accumulation. Such disturbances in the hormonal milieu during critical developmental windows may accelerate the trajectory toward metabolic syndrome and type 2 diabetes mellitus in adolescence.[19,20] For example, hyperandrogenism commonly observed in PCOS has been shown to impair insulin signaling and promote visceral adiposity, thereby exacerbating metabolic dysfunction. Similarly, disturbances in the hypothalamic–pituitary–gonadal (HPG) axis in males may compromise glucose homeostasis and increase susceptibility to insulin resistance.[21]

Obesity: Obesity was significantly associated with an increased risk of diabetes, aligning with the extensive body of evidence linking excess adiposity—particularly central obesity—to insulin resistance and impaired glucose tolerance. Adolescents with elevated BMI and waist

circumference face a markedly higher risk of early-onset metabolic dysfunction. Beyond metabolic consequences, obesity during adolescence has been implicated in adverse reproductive outcomes, including menstrual irregularities and precocious puberty in girls, as well as reduced testosterone levels in boys. Such disturbances may persist into adulthood, compounding the risk for infertility, sexual dysfunction, and cardiometabolic disease. Therefore, interventions addressing obesity should be prioritized not only to mitigate metabolic risk but also to safeguard long-term reproductive health. Building on the role of hormonal disturbances, abdominal obesity constitutes a critical driver in the pathophysiological cascade toward T2DM, acting synergistically with endocrine dysregulation to accelerate metabolic deterioration.[22] Adipose tissue functions not only as an energy reservoir but also as an active endocrine organ, secreting pro-inflammatory cytokines and adipokines such as tumor necrosis factor-α (TNF-α), interleukin-6 (IL-6), and leptin that disrupt normal insulin signalling pathways.[23] The strong association observed between obesity and diabetes risk in this study is therefore both biologically plausible and consistent with evidence from previous research.

These findings highlight the urgent need for early detection and prevention strategies, particularly among adolescents who exhibit these risk characteristics. Routine non-invasive screening for hormonal irregularities using physical examinations and targeted questionnaires, combined with school- or community-based weight management programs, represents a feasible and impactful approach. In addition, incorporating family history into school health assessments may facilitate the identification of high-risk adolescents who require further evaluation or referral.

LIMITATIONS

This study provides valuable insights by highlighting non-invasive clinical indicators and underscoring the importance of integrating genetic, physiological, and lifestyle factors into adolescent diabetes risk assessments. Nevertheless, several limitations should be acknowledged. First, the study relied on self-reported lifestyle data and observational assessments of hormonal imbalance without biochemical validation, which may have introduced reporting and measurement biases. Second, the use of a composite risk score derived from five independent variables (IVs) as the dependent measure of T2DM risk could have introduced bias if the weighting or selection of these components was not fully validated, thereby affecting the accuracy of risk classification. Third, the cross-sectional design prevents the establishment of causal relationships between the identified risk factors and diabetes development. Finally, the findings may not be generalizable beyond the specific adolescent population studied. Future research should employ longitudinal designs, incorporate objective clinical and biochemical measures, and rigorously validate composite risk scores to enhance both the validity and generalizability of results.

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CONCLUSION

This study highlights the significant roles of parental history of diabetes, hormonal imbalance, and obesity as non-invasive predictors of increased risk for type 2 diabetes mellitus (T2DM) among obese adolescents. The findings emphasize the value of early identification of high-risk individuals through routine assessment of familial, anthropometric, and observable hormonal indicators. While lifestyle factors such as physical activity and diet were not significantly associated in this study, the integration of genetic and physiological markers provides an important framework for more targeted prevention. These results support the development of school- and community-based screening and intervention programs that address modifiable risk factors while acknowledging the influence of non-modifiable ones. Future studies should adopt longitudinal designs and incorporate biochemical validation to clarify causal pathways and strengthen strategies for early intervention.

RECOMMENDATION

It is recommended that national health policies integrate non-invasive screening for hormonal imbalances into routine school health programs to strengthen early detection of T2DM risk in adolescents. Strengthening intersectoral collaboration between the Ministry of Health, the Ministry of Education, and local authorities is essential to implement evidence-based lifestyle interventions that promote physical activity and balanced nutrition. These efforts align with Indonesia's National Strategy for Non-Communicable Disease Prevention and Control and the School Health Program (UKS), thereby supporting comprehensive and sustainable approaches to adolescent health.

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Declarations

Author contribution : All authors contributed significantly to the completion of this study. EE was responsible for the conceptualization, study design, and supervision. SS conducted the data collection and statistical analysis. TE contributed to the literature review and interpretation of the results. All authors participated in writing, critically reviewing, and approving the final manuscript.

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