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ORIGINAL ARTICLE

Observational Study

Visceral adiposity index, cardiorespiratory fitness, and fasting plasma glucose associations in adolescents

Danladi Ibrahim Musa, Rafiu O Okuneye, Joseph Ibrahim Momoh, Musa Haladu Darma, Mary O Onoja-Alexander, Francis M Mwangi

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Abstract

BACKGROUND
The global rise in the prevalence of type 2 diabetes mellitus (T2DM) in children and adolescents is partly linked to the increasing rates of childhood obesity and physical inactivity.

AIM
To explore the independent relationships of visceral adiposity index (VAI) and cardiorespiratory fitness (CRF) with fasting plasma glucose (FPG) in adolescents.

METHODS
This descriptive cross-sectional study included 403 adolescents (202 boys and 201 girls) aged 11-19 years. Participants were evaluated for VAI, CRF, and FPG. Regression models, adjusted for age and maturity status, were used to assess the associations between VAI, CRF, and FPG.

RESULTS
The prevalence of T2DM risk was 15.3% (girls = 7.4%; boys = 7.9%). In boys, high VAI was positively associated with FPG (β = 0.190, P = 0.009), while low CRF was negatively associated with FPG (β = -0.206, P = 0.010). These associations persisted even after adjusting for CRF and VAI. However, no significant associations between VAI, CRF, and FPG were observed in girls (P > 0.05). Adolescents with high VAI and low fitness levels demonstrated poorer glycemic profiles.

CONCLUSION
Among boys, both VAI and CRF were independently associated with T2DM risk, with CRF showing a stronger association. These associations were not observed in girls. Promoting regular aerobic exercise and healthy diets may serve as essential public health promotion strategies in preventing and managing T2DM risk in adolescents.

Key Words: Adolescents; Abdominal adiposity; Fitness; Metabolic health; Primary prevention

Core Tip: The recent global rise in the prevalence of type 2 diabetes mellitus (T2DM) in children and adolescents has been linked partly with the universal increase in childhood obesity and physical inactivity. There is paucity of information on the association of visceral adiposity index and cardiorespiratory fitness with risk of T2DM in Nigerian adolescents. This study unveiled the independent and joint associations of visceral adiposity index and cardiorespiratory fitness with the risk of T2DM in boys but not girls. It was recommended that health-promoting strategies that focus on favorable blood glucose levels, including healthy eating and aerobic-type activities should be encouraged among adolescents.

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INTRODUCTION

Type 2 diabetes mellitus (T2DM) is a chronic metabolic disorder characterized by elevated blood glucose levels, which is associated with significant complications and comorbidities, such as metabolic syndrome, cardiovascular disease, end-stage kidney disease, retinopathy, and limb amputation[1]. Globally, diabetes mellitus ranks as the 9th leading cause of death, with reports indicating that one in 11 adults worldwide is diagnosed with diabetes, with approximately 90% of these cases being T2DM[2]. In recent years, the prevalence of T2DM has surged among children and adolescents[3]. Traditionally regarded as a disease of adults, T2DM is increasingly recognized as a pediatric health issue, a trend that parallels the rise in childhood obesity and physical inactivity worldwide[4,5]. Screening and developing targeted interventions for high-risk adolescents should be prioritized as a crucial public health goal. Behavioral modifications, particularly those that promote increased physical activity and healthier eating habits, are essential strategies for combating this growing problem.

Impaired fasting plasma glucose (FPG) is an established biomarker for T2DM. Along with insulin resistance and impaired glucose tolerance, it is closely linked to obesity, particularly android obesity, in adolescents[6]. Waist circumference (WC) is commonly used to estimate visceral adipose tissue (VAT) in cardiometabolic disease (CMD) risk assessments; however, its limitation lies in the inability to differentiate subcutaneous from visceral fat. Recently, the visceral adiposity index (VAI), a novel sex-specific mathematical model based on anthropometric measures [body mass index (BMI) and WC] and blood lipid parameters [triglycerides (TG) and high-density lipoprotein cholesterol (HDL-C)], has been linked to VAT, adipokine levels, insulin resistance, and glucose disturbances in adults[7,8], and it was developed to estimate VAT dysfunction[9]. This method is gaining traction in public health research and clinical practice, with multiple studies identifying VAI as a predictor of CMD, including T2DM[2,10].

While several studies in the Caucasian population have demonstrated the detrimental health effects of VAI on T2DM risk in both adults[10,11] and youth[12,13], no study has explored the relationship between VAI and diabetes risk in African youth. Cardiorespiratory fitness (CRF), an objective measure of habitual physical activity, is considered a risk factor for T2DM and insulin resistance[11] and has been shown to positively impact CMD risk[14,15]. Recent reviews have also highlighted the efficacy of physical activity and CRF in managing T2DM in the general population[16]. However, it remains unclear whether the relationships among VAI, CRF, and diabetes risk in adolescents are independent or confounded by other factors. Furthermore, to our knowledge, no study has yet examined the combined association of VAI and CRF with diabetes risk in adolescents.

Adolescence is a critical developmental stage, often marked by unhealthy behavioral shifts such as increased social media use, smoking, drug and alcohol abuse, and other risky behaviors, which, if unchecked, can lead to pediatric non-communicable lifestyle diseases[17]. Both pediatric obesity and low physical fitness significantly increase the risk of CMD in youth[14,18], with many of these risks persisting into adulthood[19].

This study aimed to investigate the association of VAI and CRF with FPG in Nigerian adolescents aged 11 years to 19 years. Specifically, the study examined the independent relationships of VAI and CRF with FPG among participants. The study identified the cardiometabolic risk factors most strongly associated with FPG. Additionally, the T2DM risk profiles of the participants were characterized. It was hypothesized that adolescents with high VAI and low CRF would be at greater risk of T2DM. This information could be crucial for developing effective primary prevention strategies.

MATERIALS AND METHODS

Study design and sample

This study utilized a descriptive observational cross-sectional design involving apparently healthy school boys and girls aged 11-19 years from secondary schools in Kogi East, North Central Nigeria. A total of 418 adolescents were selected using a multistage cluster and random sampling method across four secondary schools in the study area, applying the adjusted Taro Yamane sample size determination formula with 5% error rate[20].

$n = N/1 + (N \times e^2)$: $n = 125910/1 + (125910 \times 0.05^2) = 398.73$

Where: n = sample size; N = population; e = margin of error

In 2019, the population of secondary school students in Kogi East Senatorial District was 125910 (National Bureau of Statistics, 2022). The minimum sample size determined was 399 participants; however, the sample was increased to 418 to account for participant dropout and ensure representativeness. Detailed descriptions of the sampling procedure, inclusion criteria, study setting, and pilot tests have been previously published[14]. The purpose and test procedures were explained to participants after obtaining permission from the school heads. Data collection involved two visits: The first to familiarize participants with the test protocols and measure physical characteristics, and the second for clinical and biochemical measurements.

Data collection

Anthropometric characteristics were assessed using standardized methods[21]. The procedures for measuring physical characteristics, including stature, body mass, percent body fat, WC, BMI, and classifying participants into healthy weight and overweight categories based on the updated FitnessGram data[22], have been previously detailed[14]. Sexual maturity [maturity offset (MO)] was estimated using chronological age and stature based on the prediction equation by Moore *et al*[23]. Age-at-peak-height-velocity was estimated as the difference between MO and age.

CRF was assessed using the 20-meter shuttle run test (20-MST), a multistage-progressive aerobic capacity test used globally in schools to evaluate CRF in children and adolescents. Participants ran back and forth between two lines set 20 meters apart, following an audio signal from a pre-recorded compact disc. The initial running speed was 8.5 km/hour, increasing by 0.5 km/hour every minute (level). The test is considered an accurate predictor of peak oxygen uptake in children and adolescents[24]. Participants who failed to complete two successive shuttles were withdrawn from the test. The number of completed laps or shuttles was used to estimate CRF[25]. Procedures for administering the test and classifying participants as high or low fitness have been documented[22].

Resting systolic blood pressure (SBP) and diastolic blood pressure were measured using an automated device (HEM-705 CP; Omron, Tokyo, Japan) after participants had rested for 10 minutes. Details of the protocol have been published elsewhere[14]. Hypertension was determined based on standard benchmarks[26].

FPG, HDL-C, and TG were collected after a 12-hour overnight fast between 9: 00 and 11: 00 a.m. using a Cardio-Check Plus Analyzer (CCPA) (PTS Diagnostics, Indianapolis, IN, United States). The tests were administered by two certified nurses and a laboratory technologist. Participants rested for 10 minutes before taking the tests. Test administration procedure details have been previously described[14]. The CCPA is a validated and reliable instrument for analyzing blood glucose and lipids[27].

VAI was calculated using the gender-specific equations provided by Amato and Giordano[7]:

$$\text{VAI (Girls)}: \left(\frac{\text{WC}}{39.58 + (1.89 \times \text{BMI})}\right) \times \left(\frac{\text{TG}}{0.81}\right) \times \left(\frac{1.52}{\text{HDL-C}}\right)$$

$$\text{VAI (Boys)}: \left(\frac{\text{WC}}{39.68 + (1.88 \times \text{BMI})}\right) \times \left(\frac{\text{TG}}{1.03}\right) \times \left(\frac{1.31}{\text{HDL-C}}\right)$$

In these formulas, WC is in centimeters, BMI in kg/m^2, and HDL-C and TG in mmol/L.

VAI has been used in earlier studies in both adults[8,10] and youths[12,13].

T2DM and cardiometabolic risk abnormalities were assessed using the International Diabetes Federation (IDF) standards[28]: FPG (≥ 5.6 mmol/L), TG (≥ 1.7 mmol/L), and HDL-C (≤ 1.04 mmol/L). Participants were classified as "healthy FPG" or "unhealthy FPG" based on their FPG levels. Since there is no established VAI threshold for the pediatric population, the minimum value of the highest tertile (1.1 for boys, 1.35 for girls) was used as the cut-off, following accepted methods[7,29].

A clustered metabolic risk score (MRS) was calculated by adding the z-scores of individual risk factors, including FPG, SBP, WC, HDL-C (inverted), and TG. A lower MRS indicated a more favorable metabolic risk profile[30].

Statistical analysis

Continuous variables were reported as means and standard deviations, while categorical variables were expressed as frequencies and percentages. The Kolmogorov-Smirnov test assessed the normality of variable distributions. Due to participant dropout and incomplete data, complete datasets for all variables were available for 403 out of the 418 participants, resulting in a compliance rate of 96%. Gender differences were evaluated using independent samples *t*-tests or Mann-Whitney *U* tests as appropriate. Partial correlation analysis, adjusted for age and MO, examined the relationships between dependent and independent variables. The associations of VAI and CRF with FPG and their relative importance were explored using multivariate regression models, also adjusted for age and sexual maturation. Statistical analysis was conducted using IBM SPSS (Version 20, IBM Corporation, Armonk, NY, United States), with significance set at $P \leq 0.05$.

Ethical clearance

Ethical approval was obtained from the Ethical Review Committee of the College of Health Sciences, Kogi State University, Nigeria (No. COHS/02/25/2020). Written informed consent was obtained from parents/guardians, and participants provided assent before data collection. All test administration procedures complied with the ethical standards of the Helsinki Declaration. Data collection occurred between 9: 00 a.m. and 12: 00 p.m.

RESULTS

Table 1 outlines the demographic, anthropometric, performance, and biochemical characteristics of the participants, categorized by glycemic profile and fitness. The average prevalence of FPG abnormalities, indicating risk of T2DM, was 15.3% (girls = 7.4%; boys = 7.9%). When the high-risk or unhealthy category was further stratified by fitness status, T2DM risk prevalence was found to be 27.4% in the high fitness group and 72.6% in the low fitness group (Figure 1). Adolescents with healthy or normal FPG were significantly younger ($P < 0.001$), had lower WC ($P < 0.001$), and better run performance ($P = 0.001$) than those at risk of T2DM. Similarly, participants with higher fitness levels had more favorable health profiles across other indices compared to their low fitness peers, regardless of glycemic status.

Table 2 presents the characteristics of participants, stratified by glycemic profile and VAI. When stratified by VAI, the prevalence of T2DM risk was 71% in the elevated VAI group and 29% in the low VAI group (Figure 1). As anticipated, adolescents in the low VAI group exhibited healthier profiles than those in the high VAI group, irrespective of glycemic status. Overall, these findings suggest that participants with elevated VAI and low CRF exhibited significantly poorer glycemic profiles and other cardiometabolic health markers, particularly in boys.

The results of the partial correlations (after controlling for age and sexual maturity) between the dependent variable (FPG) and independent variables (CRF, VAI, BMI, WC, HDL-C, TG, and MRS) showed generally non-significant associations ($P > 0.05$), except for a significant correlation between MRS and FPG ($P < 0.001$) in girls. In boys, weak to moderate but mostly significant correlations were observed between FPG and CRF ($P = 0.010$), VAI ($P = 0.009$), WC ($P < 0.001$), TG ($P = 0.011$), and MRS ($P < 0.001$). The strongest independent predictor of FPG was MRS in both sexes. Detailed results are provided in Table 3.

Regression analysis revealed that in girls, neither VAI ($P = 0.679$) nor CRF ($P = 0.704$) were significantly associated with FPG. However, in boys, VAI was positively associated with FPG ($\beta = 0.190$, $P = 0.009$). This association remained significant albeit weaker ($\beta = 0.165$, $P = 0.023$) after adjusting for CRF. The full model accounted for 16.5% of the variation in FPG, with age and MO contributing 13.7%. VAI explained only 2.8% of the variation in FPG. A unit increase of VAI resulted in a mean increase of 1.0 mmol/L in FPG. CRF was negatively associated with FPG ($\beta = -0.206$, $P = 0.010$) and remained significant after adjusting for VAI, though the relationship attenuated ($\beta = -0.178$, $P = 0.025$). CRF explained 2.9% of the variance in FPG, while the confounders explained 13.6%. Each unit (lap) increase in CRF was associated with an average decrease of 1.1 mmol/L in FPG. Overall, CRF had greater explanatory power than VAI. These results are detailed in Table 4.

DISCUSSION

VAI and CRF were scrutinized alongside FPG, a key metabolic health indicator. The findings suggest that the risk of T2DM is prevalent among participants, with a higher incidence in boys than girls. The prevalence of impaired FPG (15.3%: Girls = 7.4%, boys = 7.9%) is comparable to the 14.5% (girls = 7.4%; boys = 7.1%) reported among Ivorian adolescents[31], though lower than the 18.4% (girls = 5.4%; boys = 13.0%) reported for American adolescents[32] and the rates (girls = 8.4%; boys = 12.3%) documented in Indian adolescents[33]. These results indicate a higher T2DM risk among boys compared to girls.

A modest correlation between independent variables and FPG was observed after controlling for age and sexual maturity, with the MRS showing the strongest association in both sexes. This is consistent with the understanding that metabolic syndrome is a key marker of T2DM risk in the general population[1,4]. Both VAI and CRF were significantly associated with FPG in boys but not girls, aligning with earlier studies in adolescents[12,34]. These findings suggest that VAI and CRF are important determinants of T2DM risk in boys.

VAI and CRF were independently associated with FPG in boys, with fitness having a stronger impact. This result highlights the significant impact of both independent variables on glucose metabolism in boys even during adolescence. Together, VAI and CRF explained only 3% of FPG variation, while age and sexual maturity explained 13.5%. The implication of the significant joint association of VAI and CRF is that adolescents with both elevated VAI and low fitness tended to exhibit highest FPG levels, suggesting a synergistic effect where the negative impact of high VAT is exacerbated

Table 1 General characteristics of participants stratified by type 2 diabetes risk versus cardiorespiratory fitness status (*n* = 403)

Variable	Healthy FPG (*n* = 341)			Unhealthy FPG (*n* = 62)		
	Low fit (*n* = 153)	High fit (*n* = 188)	Total (*n* = 341)	Low fit (*n* = 45)	High fit (*n* = 17)	Total (*n* = 62)
Girls	74 (21.7)	97 (28.4)	171 (50.1)	22 (35.5)	8 (12.9)	30 (48.4)
Boys	79 (23.2)	91 (26.6)	170 (49.9)	23 (37.1)	9 (14.5)	32 (51.6)
Age (year)	15.7 ± 1.9	13.8 ± 2.1	14.5 ± 2.2	15.3 ± 2.2	14.6 ± 2.4	15.5 ± 2.3
Body mass (kg)	56.0 ± 12.6	51.9 ± 11.3	53.4 ± 12.0	46.7 ± 15.1	51.5 ± 11.6	52.0 ± 14.0
Stature (cm)	160.4 ± 9.5	161.6 ± 9.1	160.7 ± 9.3	152.8 ± 10.7	158.5 ± 11.9	158.7 ± 11.2
BMI (kg/m^2)	21.7 ± 3.5	19.7 ± 3.4	20.6 ± 3.5	20.3 ± 3.9	20.2 ± 2.3	20.3 ± 3.5
Fat (%)	16.6 ± 7.9	14.7 ± 5.6	15.6 ± 6.7	16.0 ± 8.7	14.1 ± 5.8	15.1 ± 8.2
WC (cm)	71.5 ± 8.8	60.6 ± 5.2	64.9 ± 8.7	67.6 ± 8.4	64.9 ± 7.4	69.2 ± 8.3
HDL-C (mmol)	1.3 ± 0.3	1.4 ± 0.4	1.3 ± 0.4	1.3 ± 0.3	1.1 ± 0.4	1.2 ± 0.4
TG (mmol)	1.2 ± 0.7	0.9 ± 0.6	1.0 ± 1.0	1.1 ± 0.4	0.9 ± 0.4	1.0 ± 0.4
FPG (mmol)	5.0 ± 0.4	4.7 ± 0.5	4.8 ± 0.5	6.2 ± 0.5	5.9 ± 0.8	6.1 ± 0.6
VAI	1.5 ± 0.5	1.0 ± 0.2	1.2 ± 2.2	1.4 ± 0.9	1.0 ± 0.5	1.3 ± 0.9
20-MST (lap)	20.8 ± 9.1	43.8 ± 13.6	33.6 ± 16.8	17.2 ± 7.0	50.6 ± 15.9	26.8 ± 15.0

BMI: Body mass index; WC: Waist circumference; HDL-C: High-density lipoprotein cholesterol; TG: Triglycerides; FPG: Fasting plasma glucose VAI: Visceral adiposity index; 20-MST: Multistage shuttle run test.

Table 2 General characteristics of participants stratified by type 2 diabetes risk versus visceral adiposity index status (*n* = 403)

Variable	Healthy FPG (*n* = 341)			Unhealthy FPG (*n* = 62)		
	Low VAI (*n* = 157)	High VAI (*n* = 184)	Total (*n* = 341)	Low VAI (*n* = 18)	High VAI (*n* = 44)	Total (*n* = 62)
Girls	60 (18.0)	111 (32.6)	171 (50.1)	10 (16.1)	20 (32.3)	30 (48.4)
Boys	97 (28.4)	73 (21.4)	170 (49.9)	8 (12.9)	24 (38.7)	32 (51.6)
Age (year)	13.9 ± 2.2	15.3 ± 2.1	14.5 ± 2.2	14.2 ± 2.0	15.0 ± 3.0	15.5 ± 2.3
Body mass (kg)	52.5 ± 12.2	54.8 ± 11.2	53.4 ± 12.0	51.4 ± 18.1	47.0 ± 12.1	52.0 ± 14.0
Stature (cm)	160.8 ± 10.5	161.2 ± 8.2	160.7 ± 9.3	155.3 ± 13.5	154.1 ± 8.3	158.7 ± 11.2
BMI (kg/m^2)	20.1 ± 3.5	21.0 ± 3.5	20.6 ± 3.5	20.7 ± 4.4	19.4 ± 3.0	20.3 ± 3.5
Fat (%)	15.0 ± 6.6	16.0 ± 6.8	15.6 ± 6.7	17.5 ± 10.9	14.6 ± 6.4	15.1 ± 8.2
WC (cm)	61.3 ± 6.1	69.1 ± 9.2	64.9 ± 8.7	62.6 ± 7.2	68.6 ± 7.9	69.2 ± 8.3
HDL-C (mmol)	1.5 ± 0.4	1.2 ± 0.4	1.3 ± 0.4	1.7 ± 0.3	1.1 ± 0.3	1.2 ± 0.4
TG (mmol)	0.7 ± 0.2	1.3 ± 0.3	1.0 ± 1.0	0.7 ± 0.4	1.2 ± 0.1	1.0 ± 0.4
FPG (mmol)	4.8 ± 0.4	4.9 ± 0.6	4.8 ± 0.5	6.1 ± 0.2	6.1 ± 0.3	6.1 ± 0.6
VAI	0.5 ± 0.1	1.8 ± 0.8	1.2 ± 2.2	0.5 ± 0.1	1.6 ± 0.9	1.3 ± 0.9
20-MST (lap)	41.0 ± 16.5	26.6 ± 13.1	33.6 ± 16.8	34.4 ± 23.1	23.0 ± 10.1	26.8 ± 16.9

BMI: Body mass index; WC: Waist circumference; HDL-C: High-density lipoprotein cholesterol; TG: Triglycerides; FPG: Fasting plasma glucose VAI: Visceral adiposity index; 20-MST: Multistage shuttle run test.

by poor fitness. Conversely, low VAI combined with high CRF is associated with the lowest FPG levels, highlighting the protective effect of good fitness levels against the adverse effects of VAT. This result is supported by previous research among Iranian and Saudi Arabian adolescents[12,13] but contrasts with that of Raheem and Co-workers[35]. Regarding CRF, our findings are supported by several studies in adolescents[36,37] but at variance with results from other studies [38,39]. Inconsistencies in results might be potentially due to disparity in measurement procedures, ethnicity, and age across studies. The small effect size of VAI and CRF suggests that these factors may not be major predictors of FPG in this cohort, with age and sexual maturity playing a larger role. Obesity, dyslipidemia and ethnicity are among other

Table 3 Partial correlation coefficients assessing the relationship among visceral adiposity index, cardiorespiratory fitness and fasting plasma glucose and other health indices after controlling for age and maturity status (*n* = 403)

Gender	VAI	CRF	BMI	WC	HDL-C	TG	MRS
Girls	0.031	-0.030	0.011	0.047	0.032	0.008	0.316[b]
Boys	0.185[a]	-0.183[a]	0.028	0.341[b]	-0.065	0.180[a]	0.640[b]

[a] $P < 0.05$.
[b] $P < 0.01$. VAI: Visceral adiposity index; CRF: Cardiorespiratory fitness; BMI: Body mass index; WC: Waist circumference; HDL-C: High-density lipoprotein cholesterol; TG: Triglycerides; MRS: Metabolic risk score.

Table 4 Standardized regression coefficients evaluating the relationship among visceral adiposity index, cardiorespiratory fitness and fasting plasma glucose after controlling for age and maturity status (*n* = 403)

Variable	Girls (*n* = 201)				Boys (*n* = 202)			
	Crude	*P* value	Adjusted	*P* value	Crude	*P* value	Adjusted	*P* value
VAI	0.031	0.655	0.029	0.679	0.190	0.009	0.165	0.023
CRF	-0.032	0.679	-.029	0.704	-0.206	0.010	-0.178	0.025

VAI: Visceral adiposity index; CRF: Cardiorespiratory fitness.

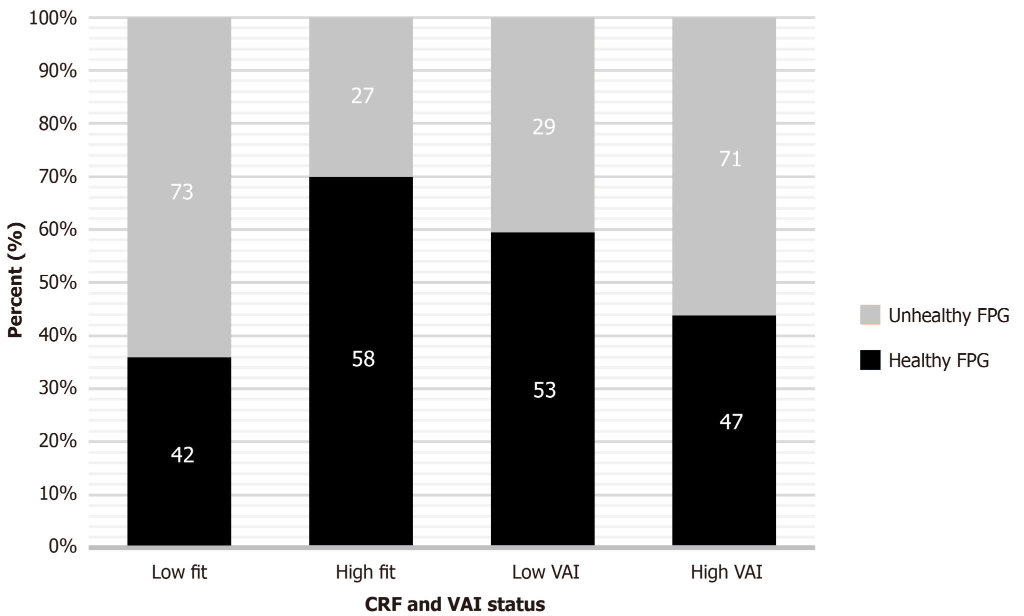

Figure 1 Glycemic profile of participants stratified by cardiorespiratory fitness and visceral adiposity index. FPG: Fasting plasma glucose; VAI: Visceral adiposity index; CRF: Cardiorespiratory fitness.

predictors of diabetes, not considered in this study[1,2]. However, longitudinal studies may better clarify the role of VAI and CRF in the development of T2DM in the pediatric population.

This study highlights that low VAI and high fitness levels are associated with better cardiometabolic health in adolescents, especially boys. Boys generally exhibited poorer glycemic profiles than girls, regardless of fitness or VAI levels (Table 1 and Table 2). VAI has been shown to be a strong correlate and independent predictor of FPG in boys[13] and in both sexes[12]. VAI serves as a surrogate for VAT, a metabolically active entity capable of secreting inflammatory cytokines and adipokines which promotes insulin resistance, dyslipidemia, impaired beta cell function and risk of diabetes[9,18]. Our findings regarding CRF are in conformity with previous studies in both youth and adults[15,39]. Regular physical activity or CRF, a well-known predictor of cardiovascular events, also plays a crucial role in insulin sensitivity, glucose metabolism, and overall metabolic health[40,41]. Prospective studies have shown that increased CRF is associated with a reduced risk of T2DM and cardiovascular disease[42]. Potential reasons for the lack of significant impact of the independent variables on risk of T2DM among girls in this study may be attributed to sexual dimorphism of fat distribution during adolescence. Boys generally accumulate more visceral fat, while girls tend to store more subcutaneous fat[43]. Additionally, the female hormone estrogen plays a role in reducing VAT accumulation and lowering insulin resistance in girls[13]. In this study, a larger proportion of girls demonstrated higher levels of CRF (Table 1), which is linked to improved metabolic health and better glucose regulation[15]. These factors help explain why the relationship between VAI, CRF, and FPG is more pronounced in boys.

Considering the cardiometabolic benefits of fitness, promoting aerobic physical activity in children and adolescents is vital. It is essential for stakeholders in adolescent health to utilize the current physical activity guidelines for youth to encourage regular participation in activities that enhance aerobic fitness[44]. The relationship between VAI, CRF, and the risk of T2DM may be influenced by unhealthy diets and sedentary lifestyles[11]. Addressing these lifestyle factors is critical to reducing the risk of T2DM in adolescents. Health promotion initiatives should therefore focus on encouraging both healthy eating habits and regular physical activity to mitigate T2DM risk.

Public health interventions should be gender-specific. Both school- and community-based health education programs in Nigeria must be tailored to address the distinct needs of boys and girls. For girls, programs should emphasize healthy lifestyle habits, such as maintaining a balanced diet and engaging in regular physical activity, without focusing on VAT. In contrast, boys' programs should additionally highlight activities that reduce the risk of VAT, such as aerobic exercises, both continuous and interval-based. Moreover, public health policies should include provisions for routine health screenings to detect metabolic risk factors, with particular attention to glucose levels among students. This approach aims to identify adolescents at risk, enabling early interventions to prevent the onset of T2DM and other metabolic disorders.

The findings of this study should be interpreted with certain limitations in mind. First, the cross-sectional design limits the ability to establish causality. Second, the study focused solely on school-going adolescents, excluding those without formal education. This sampling bias restricts the generalizability of the results to all adolescents in the study area. Third, CRF was estimated using a field method, which may be less precise than laboratory-based measurements of maximal oxygen consumption. Similarly, VAI is an indirect estimate of VAT, which may be less accurate than laboratory techniques such as magnetic resonance imaging or computed tomography. Despite these limitations, the study has several strengths. The direct measurement of participants provided more accurate data than relying on self-reported measures. Additionally, the use of the VAI as a surrogate for VAT offered a more detailed assessment compared to WC alone. Lastly, employing health-related CRF cut-points revealed that participants meeting health standards had a better glycemic profile.

CONCLUSION

The risk of T2DM exists among Nigerian adolescents, with both VAI and CRF independently associated with T2DM risk in boys. The combined contribution of VAI and CRF is small, but age and maturity status are stronger predictors of T2DM risk. Health-promoting strategies that focus on healthy glucose levels through diet and physical activity are crucial. Future longitudinal studies will provide deeper insights into the roles of VAI and CRF, and establish their predictive value in managing T2DM risk in adolescents.

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FOOTNOTES

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