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RESEARCH ARTICLE

Prediabetes and Associated Factors Among Young University Students in Lubumbashi, Democratic Republic of the Congo: A Cross-Sectional Study

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Abstract

Background: Prediabetes is an important early marker of dysglycaemia and an established risk state for the subsequent development of type 2 diabetes and cardiovascular disease. However, evidence on prediabetes among young adults in sub-Saharan Africa remains limited. This study aimed to estimate the prevalence of prediabetes and identify factors associated with prediabetes among university students in Lubumbashi, Democratic Republic of the Congo (DRC). **Methods:** We conducted a descriptive cross-sectional study among students aged 18–34 years enrolled at the University of Lubumbashi during the 2025–2026 academic year. Participants were selected using simple random sampling. Sociodemographic, behavioural, anthropometric and clinical data were collected using a structured questionnaire and standardised measurement procedures. Fasting plasma glucose, glycated haemoglobin (HbA1c), lipid profile and serum creatinine were measured. Prediabetes was defined as an HbA1c level of 5.7–6.4%, while values $\geq$ 6.5% were considered compatible with probable diabetes. Participants with probable diabetes were excluded from analyses of factors associated with prediabetes. Associations were assessed using bivariate and multivariable logistic regression models, with results expressed as odds ratios (ORs) and 95% confidence intervals (CIs). **Results:** Among 378 students sensitised to the study, 327 participated, corresponding to a participation rate of 86.5%. Of these, 202 (61.8%; 95% CI, 56.4–66.9) were normoglycaemic, 87 (26.6%; 95% CI, 22.1–31.7) had prediabetes, and 38 (11.6%; 95% CI, 8.6–15.6) had HbA1c values compatible with probable diabetes. Thus, 38.2% of participants had dysglycaemia. Among the 289 participants included in the comparative analysis of normoglycaemia versus prediabetes, the mean age was 22.96 $\pm$ 2.89 years, and the prevalence of prediabetes was 30.1%. Most sociodemographic, anthropometric, behavioural and clinical characteristics were not significantly associated with prediabetes. Prediabetic participants had lower mean HDL-cholesterol concentrations than normoglycaemic participants (42.92 $\pm$ 11.80 *vs* 49.82 $\pm$ 14.77 mg/dL; $p < 0.001$). In multivariable analysis, HDL-cholesterol remained independently associated with prediabetes (adjusted OR, 0.97; 95% CI, 0.94–0.99; $p = 0.012$), corresponding to approximately 3% lower odds of prediabetes per 1 mg/dL increase in HDL-cholesterol. **Conclusion:** Prediabetes was common among university students in Lubumbashi, affecting approximately one in four students overall and nearly one in three participants after exclusion of those with probable diabetes. HDL-cholesterol was the only factor independently associated with prediabetes. The high burden of dysglycaemia observed in this young population highlights the importance of early metabolic risk assessment and prevention strategies among young adults in the DRC.

Keywords: prediabetes, HbA1c, dysglycaemia, university students, HDL-cholesterol, DRC, sub-Saharan Africa

1 Introduction

Prediabetes is an intermediate state of dysglycaemia between normoglycaemia and type 2 diabetes (T2D), characterised by impaired fasting glucose (5.6–6.9 mmol/L), impaired glucose tolerance (7.8–11.0 mmol/L 2 hours after an oral glucose load), and/or glycated haemoglobin (HbA1c) levels of 5.7–6.4% [1]. It generally reflects a progressive combination of insulin resistance and impaired pancreatic β-cell function and is an important marker of subsequent risk of T2D [2]. However, progression is not inevitable, as lifestyle interventions can substantially reduce the risk of developing T2D [3,4].

Prediabetes is also associated with increased cardiometabolic risk. It has been linked to a higher risk of cardiovascular disease and all-cause mortality, suggesting that its adverse consequences may precede the onset of clinically overt diabetes [5, 6]. Its global burden is substantial. In 2021, an estimated 464 million adults had impaired glucose tolerance and 298 million had impaired fasting glucose; these numbers are projected to increase to 638 million and 414 million, respectively, by 2045 [7]. This increase is expected to be particularly pronounced in low- and middle-income countries, where urbanisation, nutritional transition and changing lifestyles are rapidly reshaping metabolic risk.

The emergence of prediabetes among adolescents and young adults is an increasing concern. In the United States, data from the National Health and Nutrition Examination Survey indicated that, between 2005 and 2016, approximately one in five adolescents and one in four young adults had dysglycaemia consistent with prediabetes [8]. Dysglycaemia developing early in life may result in prolonged exposure to cardiometabolic risk and contribute to an earlier onset of T2D. However, metabolic risk in young adults is not limited to general obesity. Abdominal adiposity, lipid abnormalities, hypertension and individual susceptibility may contribute to the early development of insulin resistance and prediabetes [9]. In some African populations, metabolic abnormalities may also occur in the absence of marked excess body weight, highlighting the importance of an integrated assessment incorporating anthropometric, clinical and biochemical measures.

This issue is particularly relevant in sub-Saharan Africa, where the epidemiological transition is accompanied by a rapidly increasing burden of cardiometabolic diseases. In 2021, approximately 95 million African adults were estimated to have impaired glucose tolerance, with this figure projected to reach 130 million by 2045; over the same period, the number of adults with impaired fasting glucose is projected to increase from 58 million to 83 million [7]. A meta-analysis from East Africa estimated the prevalence of prediabetes at 12.6% and identified associations with older age, hypertension and overweight or obesity [9]. However, these estimates should be interpreted in the context of substantial heterogeneity across populations and differences in diagnostic methods and study characteristics.

In the Democratic Republic of the Congo (DRC), data on dysglycaemia remain limited despite the growing burden of non-communicable diseases within a context of persistent infectious diseases and a broader double burden of disease. Available studies indicate substantial variability in the prevalence of diabetes mellitus (DM), with estimates ranging from 5.3% to 15.6% across different populations and study settings, partly reflecting differences in diagnostic approaches [10, 11]. In Lubumbashi, a major urban centre and university hub, rapid urbanisation and changes in dietary and physical activity patterns may contribute to the early emergence of cardiometabolic risk factors. The potential severity of T2D in this setting is illustrated by a recent study conducted in three hospitals in Lubumbashi, which reported a 60-day mortality of 12.7% among adults with diabetes; chronic kidney disease, sepsis, neurological complications and severe metabolic disturbances were among the factors associated with mortality [12].

Despite these trends, prediabetes remains poorly documented in the DRC, particularly among young adults. Data on its prevalence and determinants in university populations are especially scarce. This gap is important because identifying dysglycaemia early in adulthood may provide an opportunity to address modifiable risk factors before the development of T2D and its complications. Local evidence is therefore needed to quantify the burden of prediabetes and determine whether risk factors traditionally associated with prediabetes in older populations are similarly relevant among young African adults.

This study therefore aimed to estimate the prevalence of prediabetes and identify factors associated with prediabetes among university students aged 18–34 years in Lubumbashi, DRC.

2 Methods

2.1 Study design and setting

We conducted a descriptive analytical cross-sectional study among university students aged 18–34 years at the University of Lubumbashi (UNILU), located in Lubumbashi, Haut-Katanga Province, DRC. Data collection was conducted in 2026 among students enrolled during the 2025–2026 academic year.

The University of Lubumbashi is one of the major public universities in the DRC and enrols students from different municipalities of Lubumbashi and from several provinces of the country. This heterogeneous student population provided an appropriate setting for assessing the burden

of early abnormalities in glucose metabolism and exploring their associated factors among young adults.

The study was designed to estimate the prevalence of prediabetes and to identify sociodemographic, behavioural, anthropometric, clinical and biochemical factors associated with prediabetes in this young university population.

2.2 Study population and eligibility criteria

The source population consisted of all students enrolled at UNILU during the 2025–2026 academic year. The study population comprised students aged 18–34 years who were eligible for participation and who completed the study procedures.

Students were eligible if they were aged between 18 and 34 years, were officially registered at UNILU during the study period, were able to participate in the questionnaire interview and clinical assessments, and provided written informed consent.

Students were not eligible if they reported a previous diagnosis of diabetes mellitus, a known endocrine disorder or liver cirrhosis, or current use of medications or substances known to substantially affect glucose metabolism, including glucose-lowering agents, quinine or pentamidine. Pregnant students were also excluded. Students with a functional impairment of the upper limbs that could interfere with reliable blood pressure measurement were not enrolled.

Participants were subsequently excluded from the analytical population when the collected data were insufficient to determine their glycaemic status or when measurements did not meet predefined quality criteria. Participants with evidence of previously undiagnosed diabetes identified during the study were also excluded from the analysis of factors associated with prediabetes. Diabetes-compatible glycaemic status was defined as an HbA1c $> 6.5\%$, according to the American Diabetes Association (ADA) criteria [1].

Importantly, prediabetes was not used as an eligibility criterion. Glycaemic status was established after enrolment using laboratory measurements. Participants were initially classified as normoglycaemic, prediabetic or having values compatible with diabetes. The analysis of factors associated with prediabetes was subsequently restricted to participants classified as normoglycaemic or prediabetic.

2.3 Sample size and sampling procedure

The source population comprised 34,640 students enrolled at UNILU during the 2025–2026 academic year. The minimum sample size was estimated using the single-population proportion formula:

$$n_0 = \frac{Z^2 p(1-P)}{d^2} \tag{1}$$

Where n_0 represents the initial required sample size, Z is the standard normal deviate corresponding to a 95% confidence level (1.96), p is the expected prevalence of prediabetes, and d is the desired absolute precision (0.05). In the absence of a reliable local estimate of prediabetes prevalence among young adults in Lubumbashi, an expected prevalence of 17% was used based on available evidence from sub-Saharan African populations [13, 14]. Thus, with p=0.17, Z=1.96, and d=0.05.

$$n_0 = \frac{(1.96)^2 \times 0.17 \times (1-0.17)}{(0.05)^2} \tag{2}$$

$$n_0 = \frac{3.8416 \times 0.17 \times 0.83}{0.0025} \tag{3}$$

$$n_0 \approx 217 \tag{4}$$

Because the source population was finite (N = 34,640), a finite population correction was considered using:

$$n_f = \frac{n_0}{1 + \frac{n_0 - 1}{N}} \tag{5}$$

which resulted in a minimum sample size of approximately 216 participants. To account for an anticipated 20% proportion of non-response, incomplete information or unusable measurements, the target sample size was increased according to:

$$n_{\text{final}} = \frac{n_f}{1-r} \tag{6}$$

Where $r = 0.20$ represents the anticipated proportion of non-response or incomplete data. This yielded a target sample of approximately 270 participants.

Eligible students were selected by simple random sampling from the available enrolment lists of students in the participating faculties. Each eligible student had an equal probability of being selected. Recruitment continued until the required number of participants had been approached and the available sample had been constituted.

In total, 378 students were sensitised and invited to participate. Of these, 327 accepted participation and completed the required procedures, corresponding to a participation rate of 86.5%.

2.4 Study variables

The primary outcome was prediabetes, defined according to HbA1c concentration. The main explanatory variables comprised sociodemographic characteristics, behavioural factors, anthropometric characteristics, clinical parameters and biochemical measurements. Sociodemographic variables included age and sex. Behavioural variables included alcohol consumption, tobacco use and level of physical activity. Family history of diabetes mellitus was assessed as a potential non-modifiable risk factor.

Anthropometric variables included body weight, height, body mass index (BMI) and waist circumference. Clinical variables included systolic blood pressure (SBP), diastolic blood pressure (DBP) and hypertension status. Biochemical variables included fasting plasma glucose, HbA1c, total cholesterol, HDL-cholesterol, LDL-cholesterol and triglycerides.

2.4.1 Definition and classification of glycaemic status

Glycaemic status was determined primarily from HbA1c measurements. In accordance with ADA criteria, participants were classified as normoglycaemic when HbA1c was $<5.7\%$, prediabetic when HbA1c was between 5.7% and 6.4%, and as having values compatible with diabetes when HbA1c was $\geq 6.5\%$ [1].

The primary outcome was therefore a binary variable for the analytical models, coded as 0 for normoglycaemia and 1 for prediabetes. HbA1c was selected as the principal indicator of glycaemic status because it reflects average glycaemic exposure over approximately the preceding 2–3 months and is not substantially influenced by short-term variations in dietary intake or the timing of the last meal. Fasting plasma glucose was measured concurrently as an additional biochemical assessment and was used, together with HbA1c, to identify participants with diabetes-compatible values.

Participants with HbA1c values compatible with diabetes were not included in the comparison between normoglycaemia and prediabetes. These participants were considered separately in the descriptive analysis of the overall study population and were advised to undergo appropriate confirmatory clinical assessment.

2.4.2 Assessment of behavioural characteristics and family history

Behavioural characteristics were assessed using a structured questionnaire administered by trained investigators. Tobacco use was assessed according to self-reported current smoking status. For the analysis, participants were classified as smokers or non-smokers according to their reported tobacco use at the time of the study. Alcohol consumption was assessed by self-report and categorised as current consumption versus no reported consumption. Given the small number of participants reporting tobacco use, smoking status was retained as a binary variable in the statistical analysis rather than being subdivided into detailed categories.

Physical activity was assessed according to the reported frequency, duration and intensity of exercise. Participants were classified into three categories—low, moderate and high physical activity—according to the predefined study classification. These categories were subsequently used in the bivariate and stratified analyses. A family history of diabetes mellitus was recorded when the participant reported diabetes in at least one first-degree or other close family member, according to the information provided during the questionnaire interview. The variable was subsequently categorised as having or not having a reported family history of diabetes.

2.4.3 Anthropometric measurements

Anthropometric measurements were obtained using standardised procedures and calibrated equipment. Body weight was measured in kilograms using a calibrated electronic weighing scale. Participants were weighed without shoes and wearing light clothing. Height was measured

in centimetres using a stadiometer, with participants standing upright without shoes, with the head maintained in the Frankfurt horizontal plane.

BMI was calculated as body weight in kilograms divided by height in metres squared:

$$BMI = \frac{Weight\ (kg)}{Height^2(m^2)} \tag{7}$$

BMI was categorised according to World Health Organization criteria as normal weight (18.5–24.9 kg/m^2), overweight (25.0–29.9 kg/m^2) or obesity ($\geq$ 30.0 kg/m^2).

Waist circumference was measured to the nearest centimetre using a non-stretchable measuring tape positioned horizontally at the midpoint between the lowest palpable rib and the iliac crest, at the end of a normal expiration. Waist circumference was subsequently categorised as elevated or not elevated using sex-specific thresholds of $\geq$ 94 cm for men and $\geq$ 80 cm for women. All anthropometric measurements were performed by trained investigators following standardised procedures. Equipment was checked regularly to minimise measurement error.

2.4.4 Blood pressure measurement and definition of hypertension

Blood pressure was measured using a validated automated oscillometric device (Omron M7®). Participants were instructed to remain seated and relaxed for at least 5 minutes before measurement, with their back supported and feet resting on the floor. The appropriate cuff size was selected according to arm circumference.

Three consecutive blood pressure measurements were obtained at approximately one-minute intervals. The mean of the second and third measurements was used for statistical analysis to minimise the effect of the initial measurement and short-term variability.

Systolic and diastolic blood pressure were analysed as continuous variables. Hypertension was defined as an SBP $\geq$ 140 mmHg and/or DBP $\geq$ 90 mmHg, according to the blood pressure threshold adopted in the study protocol and based on contemporary European Society of Cardiology recommendations [15].

2.4.5 Laboratory procedures

Venous blood samples were collected in the morning after an overnight fast of at least 12 hours. Participants were instructed to avoid food and caloric beverages during the fasting period. Blood collection was performed under standard aseptic conditions by trained laboratory personnel.

Laboratory investigations included fasting plasma glucose, HbA1c, total cholesterol, HDL-cholesterol, LDL-cholesterol and triglycerides. Serum creatinine was also measured to assess renal function and identify participants with advanced renal impairment.

Fasting plasma glucose was expressed in mg/dL. HbA1c was expressed as a percentage. Lipid parameters were reported in mg/dL. Laboratory analyses were performed using standard laboratory procedures and quality-control measures. Samples were handled and processed according to the laboratory's standard operating procedures to minimise pre-analytical and analytical variability.

2.4.6 Definition of dyslipidaemia

Lipid parameters were assessed individually and, where relevant, used to define dyslipidaemia.Low HDL-cholesterol was defined as HDL-cholesterol <40 mg/dL in men or <50 mg/dL in women. Hypertriglyceridaemia was defined as triglyceride concentrations $\geq$ 150 mg/dL.

For the regression analyses, total cholesterol, HDL-cholesterol, LDL-cholesterol and triglycerides were primarily retained as continuous variables. This approach preserved information contained in the laboratory measurements and allowed estimation of the change in odds of prediabetes associated with a one-unit increase in each lipid parameter.

2.4.7 Renal function assessment

Serum creatinine was measured to assess renal function and to identify participants with advanced renal impairment that could potentially interfere with the interpretation of metabolic measurements.

Estimated glomerular filtration rate (eGFR) was calculated using the appropriate creatinine-based equation available in the laboratory protocol. Participants with severe renal impairment, defined as an eGFR <15 mL/min/1.73 m^2, were excluded from the analytical population.

2.5 Data collection and quality assurance

Data were collected using a structured and standardised questionnaire administered by trained investigators. The questionnaire was pre-tested among students who were not included in the final study population to assess clarity, comprehension and feasibility of administration.

Before data collection, investigators received training on participant recruitment, informed consent, questionnaire administration, anthropometric measurements, blood pressure measurement and biological sample collection. Standard operating procedures were used for clinical and anthropometric measurements.

Completed questionnaires were reviewed regularly for completeness and internal consistency. Anthropometric and clinical measurements were checked for implausible values, and laboratory results were verified against the corresponding laboratory records.

Participants with incomplete information, unusable measurements or inconsistencies that could not be resolved were excluded from the relevant analytical population. This quality-control process resulted in the exclusion of 12 participants because of incomplete data and four because of measurement errors. A further 35 participants were excluded because they did not meet the age criterion, resulting in 327 participants retained for the assessment of glycaemic status.

2.6 Statistical analysis

All statistical analyses were performed using Stata version 16 (StataCorp, College Station, TX, USA). The initial analysis included all participants with valid HbA1c measurements and was used to describe the distribution of glycaemic status in the study population. Participants were classified as normoglycaemic, prediabetic or having diabetes-compatible values.

The prevalence of prediabetes was calculated as the number of participants with HbA1c values between 5.7% and 6.4% divided by the total number of participants with valid HbA1c measurements. The corresponding 95% confidence interval (CI) was calculated using an appropriate binomial method.

For the analysis of factors associated with prediabetes, the 38 participants with diabetes-compatible HbA1c values were excluded. The analytical population therefore comprised 289 participants: 202 with normoglycaemia and 87 with prediabetes.

Continuous variables were summarised using means and standard deviations (SD), whereas categorical variables were presented as frequencies and percentages. The distribution of continuous variables was assessed before selecting the appropriate statistical tests.

Differences in continuous variables between normoglycaemic and prediabetic participants were assessed using the independent-samples Student's *t*-test when the distribution was compatible with the assumptions of the test. Categorical variables were compared using Pearson's chi-square test. Fisher's exact test was used when expected cell frequencies were insufficient for the chi-square approximation.

Bivariate logistic regression analyses were performed to estimate the crude association between each explanatory variable and prediabetes. Odds ratios (ORs) with corresponding 95% CIs and *p*-values were reported. For categorical variables, one category was designated as the reference category. Continuous lipid variables were entered into the models as continuous measures.

The binary outcome was defined as:

$$Y = \begin{cases} 1, & \text{prediabetes} \\ 0, & \text{normoglycaemia} \end{cases} \tag{8}$$

For each explanatory variable *X*, the logistic regression model was expressed as:

$$\log\left(\frac{P(Y=1)}{1-P(Y=1)}\right) = \beta_0 + \beta_1 X \tag{9}$$

where *P(Y=1)* represents the probability of prediabetes and β_1 represents the estimated association between the explanatory variable and the log-odds of prediabetes. The corresponding odds ratio was calculated as:

$$OR = e^{\beta_1} \tag{10}$$

Variables with a p-value < 0.20 in bivariate analysis were considered candidates for the multivariable model, together with variables considered clinically important based on established knowledge of prediabetes risk factors. This criterion was deliberately less stringent than the conventional 0.05 threshold to avoid excluding potentially important confounding variables at the screening stage.

A multivariable binary logistic regression model was then fitted to identify factors independently associated with prediabetes. The adjusted odds ratios (aORs), 95% CIs and p-values were reported. The final model included total cholesterol, HDL-cholesterol and triglycerides, corresponding to the variables retained according to the predefined modelling strategy.

For continuous lipid variables, the estimated OR represented the change in the odds of prediabetes associated with a one-unit increase in the corresponding lipid concentration. Potential multicollinearity between explanatory variables was assessed before interpretation of the multivariable model. Model adequacy was assessed using an appropriate goodness-of-fit test. A two-sided p-value < 0.05 was considered statistically significant.

Because sex may modify the relationship between anthropometric and metabolic factors and dysglycaemia, additional analyses were stratified by sex. Separate bivariate logistic regression models were fitted for male and female participants, and sex-specific ORs, 95% CIs and p-values were reported. These analyses were considered exploratory and were used to assess whether the observed associations differed between men and women.

2.7 Ethical considerations

The study was conducted in accordance with the principles of the Declaration of Helsinki and applicable national ethical requirements. Ethical approval was obtained from the Medical Ethics Committee of the University of Lubumbashi before commencement of data collection (approval no. UNILU/CEM/016/2026).

Participation was voluntary. Before enrolment, each participant received information about the objectives of the study, the procedures involved, potential benefits and constraints, and their right to decline participation or withdraw from the study at any time without penalty or consequences for their academic or healthcare status.

Written informed consent was obtained from all participants before any study-specific procedure was performed. Confidentiality was maintained throughout the study. Participants were assigned unique identification codes, and personal identifiers were not used in the analytical database. Electronic data were stored in a password-protected database accessible only to authorised members of the research team.

Participants were informed of clinically relevant abnormal results identified during the study. Those with HbA1c values compatible with diabetes or other findings requiring further evaluation were advised to seek confirmatory assessment and appropriate medical care. Participants requiring further clinical evaluation were referred to the Internal Medicine Department of the University Clinics of Lubumbashi.

3 Results

3.1 Participant selection and analytical sample

Figure 1 illustrates the participant recruitment process, exclusions, glycaemic classification, and derivation of the final analytical sample. A total of 378 students were approached and sensitised about the study, of whom 327 agreed to participate and provided the required information, corresponding to a participation rate of 86.5%.

Among the 327 enrolled participants, 202 (61.8%) were classified as normoglycaemic, 87 (26.6%) had prediabetes, and 38 (11.6%) had HbA1c values compatible with diabetes. Thus, 289 participants were included in the analysis of factors associated with prediabetes, comprising 202 normoglycaemic and 87 prediabetic participants. The 38 participants with HbA1c values compatible with diabetes were excluded from this analytical stage to avoid combining determinants of prediabetes with those of established diabetes.

3.2 Prevalence of prediabetes

Table 1 presents the distribution of participants according to glycaemic status based on HbA1c concentrations. Among the 327 students assessed, 202 (61.8%; 95% CI: 56.4–66.9)

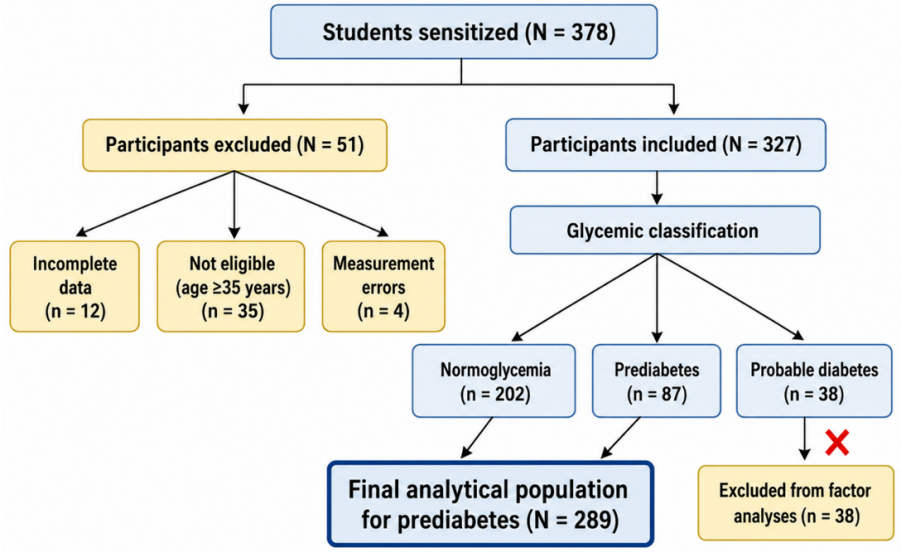

Figure 1 Flow diagram illustrating participant recruitment, exclusions, glycaemic classification, and the final analytical sample included in the analysis of factors associated with prediabetes.

were classified as normoglycaemic, whereas 87 (26.6%; 95% CI: 22.1–31.7) had prediabetes. In addition, 38 participants (11.6%; 95% CI: 8.6–15.6) had HbA1c values compatible with diabetes.

Table 1 Prevalence of prediabetes according to HbA1c among university students (N = 327)

Glycaemic status	Number	Percent (95% CI)
Normoglycaemia	202	61.8 (56.4–66.9)
Prediabetes	87	26.6 (22.1–31.7)
HbA1c values compatible with diabetes	38	11.6 (8.6–15.6)
Total	327	100.0

Overall, 38.2% of participants had dysglycaemia, defined as either prediabetes or HbA1c values compatible with diabetes. Prediabetes alone affected more than one-quarter of the study population, indicating a substantial burden of early glycaemic abnormalities in this young population. The proportion of participants with HbA1c values compatible with diabetes also suggests the presence of potentially previously undiagnosed diabetes requiring diagnostic confirmation and appropriate clinical evaluation.

3.3 Participant characteristics according to glycaemic status

Table 2 presents the sociodemographic, clinical and biochemical characteristics of the 289 participants included in the analysis of factors associated with prediabetes. The mean age was 22.96 ± 2.89 years, with no significant difference between normoglycaemic and prediabetic participants (23.06 ± 2.80 *vs* 22.74 ± 3.09 years, respectively; p = 0.394). More than half of the participants (53.6%) were aged 21–24 years. Women accounted for 50.2% of the analytical sample and men for 49.8%. The prevalence of prediabetes was higher among men than women (32.6% *vs* 27.6%, respectively), although the difference was not statistically significant (p = 0.349).

Regarding nutritional status, the mean BMI was 22.50 ± 3.27 kg/m^2, and 81.7% of participants had a normal BMI. No significant difference was observed between normoglycaemic and prediabetic participants in mean BMI (22.53 ± 3.38 *vs* 22.43 ± 3.00 kg/m^2; p = 0.807) or BMI categories (p = 0.964). Similarly, the prevalence of prediabetes did not differ according to the presence of an elevated waist circumference (30.8% *vs* 29.9%; p = 0.881).

Mean systolic blood pressure did not differ significantly between the two groups (p = 0.612). However, prediabetic participants had a significantly lower mean diastolic blood pressure than normoglycaemic participants (69.48 ± 8.42 vs 72.65 ± 8.78 mmHg, respectively; p = 0.005). Overall, hypertension was uncommon (6.6%) and was not significantly associated with prediabetes (p = 0.710).

Table 2 Sociodemographic, clinical and biochemical characteristics of participants according to prediabetes status (N = 289)

Variable	Total, n (%) / Mean ± SD	Normoglycaemia (n = 202)	Prediabetes (n = 87)	p-value
Age, years	22.96 ± 2.89	23.06 ± 2.80	22.74 ± 3.09	0.394[a]
Age group				0.286[b]
18–20 years	60 (20.8)	36 (60.0)	24 (40.0)	
21–24 years	155 (53.6)	114 (73.6)	41 (26.4)	
25–29 years	67 (23.2)	47 (70.2)	20 (29.8)	
30–34 years	7 (2.4)	5 (71.4)	2 (28.6)	
Sex				0.349[b]
Female	145 (50.2)	105 (72.4)	40 (27.6)	
Male	144 (49.8)	97 (67.4)	47 (32.6)	
BMI, kg/m^2	22.50 ± 3.27	22.53 ± 3.38	22.43 ± 3.00	0.807[a]
BMI category				0.964[b]
Normal weight	236 (81.7)	165 (69.9)	71 (30.1)	
Overweight	41 (14.2)	29 (70.7)	12 (29.3)	
Obesity	12 (4.1)	8 (66.7)	4 (33.3)	
Elevated waist circumference				0.881[b]
Yes	78 (27.0)	54 (69.2)	24 (30.8)	
No	211 (73.0)	148 (70.1)	63 (29.9)	
SBP, mmHg	117.12 ± 12.69	117.93 ± 12.38	117.12 ± 12.64	0.612[a]
DBP, mmHg	71.70 ± 8.78	72.65 ± 8.78	69.48 ± 8.42	0.005[a]
Hypertension				0.710[b]
Yes	19 (6.6)	14 (73.7)	5 (26.3)	
No	270 (93.4)	188 (69.6)	82 (30.4)	
Fasting plasma glucose, mg/dL	77.45 ± 11.02	77.65 ± 10.61	76.99 ± 11.97	0.643[a]
HbA1c, %	5.33 ± 0.58	5.00 ± 0.39	5.99 ± 0.19	< 0.001[a]
Total cholesterol, mg/dL	144.97 ± 27.17	146.32 ± 27.35	142.12 ± 26.70	0.237[a]
HDL-cholesterol, mg/dL	47.29 ± 14.13	49.82 ± 14.77	42.92 ± 11.80	< 0.001[a]
LDL-cholesterol, mg/dL	87.19 ± 26.58	88.46 ± 28.52	84.42 ± 21.62	0.243[a]
Triglycerides, mg/dL	65.32 ± 33.66	63.35 ± 29.07	69.50 ± 41.63	0.163[a]
eGFR, mL/min/1.73 m^2	109.74 ± 22.08	108.37 ± 22.28	112.93 ± 21.39	0.107[a]
Alcohol use				0.373[b]
Yes	89 (30.8)	59 (66.3)	30 (33.7)	
No	200 (69.2)	143 (71.5)	57 (28.5)	
Tobacco use				0.049[b]
Yes	4 (1.4)	1 (25.0)	3 (75.0)	
No	285 (98.6)	201 (70.5)	84 (29.5)	
Family history of diabetes				0.932[b]
Yes	49 (17.0)	34 (69.4)	15 (30.6)	
No	240 (83.0)	168 (70.0)	72 (30.0)	
Physical activity				0.584[b]
Low	209 (72.3)	145 (69.4)	64 (30.6)	
Moderate	68 (23.5)	47 (69.1)	21 (30.9)	
High	12 (4.2)	10 (83.3)	2 (16.7)	

Abbreviations: SD, standard deviation; BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; eGFR, estimated glomerular filtration rate; HbA1c, glycated haemoglobin; HDL, high-density lipoprotein; LDL, low-density lipoprotein. [a] Student's t-test; [b] Pearson's chi-square test.

As expected from the classification criteria, mean HbA1c was significantly higher among prediabetic participants than among normoglycaemic participants (5.99 ± 0.19% *vs* 5.00 ± 0.39%, respectively; $p < 0.001$). In contrast, mean fasting plasma glucose concentrations were similar between the two groups (77.65 ± 10.61 *vs* 76.99 ± 11.97 mg/dL; p = 0.643).

Among lipid parameters, only HDL-cholesterol differed significantly according to glycaemic status. Prediabetic participants had lower mean HDL-cholesterol concentrations than normoglycaemic participants (42.92 ± 11.80 *vs* 49.82 ± 14.77 mg/dL, respectively; $p < 0.001$). No significant differences were observed in total cholesterol (p = 0.237), LDL-cholesterol (p = 0.243), or triglycerides (p = 0.163). Estimated glomerular filtration rate (eGFR) also did not differ significantly between the two groups (p = 0.107).

Regarding behavioural characteristics, 30.8% of participants reported alcohol consumption, with no significant association with prediabetes (p = 0.373). Tobacco use was uncommon (1.4%). Although the proportion of prediabetes was higher among smokers than non-smokers (75.0% *vs* 29.5%, respectively), this finding should be interpreted cautiously given the very small number of smokers. The Pearson's chi-square test yielded p = 0.049, whereas the corresponding crude logistic regression estimate was not statistically significant (p = 0.090).

A family history of diabetes was reported by 17.0% of participants and was not associated with prediabetes (p = 0.932). Similarly, no significant association was observed between physical activity level and glycaemic status (p = 0.584).

3.4 Factors associated with prediabetes

In the bivariate analysis (Table 3), most sociodemographic, behavioural, clinical and anthropometric characteristics were not significantly associated with prediabetes. No statistically significant associations were observed for age, sex, BMI, physical activity, alcohol consumption, family history of diabetes, hypertension, or elevated waist circumference ($p > 0.05$ for all variables).

Table 3 Factors associated with prediabetes: crude and multivariable logistic regression analysis (N = 289)

Variable	Crude OR	95% CI	*p*-value	Adjusted OR	95% CI	*p*-value
Age group						
18–20 years	1.00	–	–	–	–	–
21–24 years	0.54	0.29–1.01	0.054	–	–	–
25–29 years	0.64	0.31–1.33	0.231	–	–	–
30–34 years	0.60	0.11–3.35	0.560	–	–	–
Sex						
Male	1.27	0.77–2.11	0.350	–	–	–
Female	1.00	–	–	–	–	–
BMI						
Normal weight	1.00	–	–	–	–	–
Overweight	0.96	0.46–1.99	0.916	–	–	–
Obesity	1.16	0.34–3.98	0.811	–	–	–
Physical activity						
Low	2.21	0.47–10.36	0.316	–	–	–
Moderate	2.23	0.45–11.10	0.326	–	–	–
High	1.00	–	–	–	–	–
Alcohol use						
Yes	1.28	0.75–2.18	0.373	–	–	–
No	1.00	–	–	–	–	–
Tobacco use						
Yes	7.18	0.74–70.00	0.090	–	–	–
No	1.00	–	–	–	–	–
Family history of diabetes						
Yes	1.03	0.53–2.01	0.932	–	–	–
No	1.00	–	–	–	–	–
Hypertension						
Yes	0.82	0.29–2.35	0.710	–	–	–
No	1.00	–	–	–	–	–
Elevated waist circumference						
Yes	1.04	0.59–1.84	0.881	–	–	–
No	1.00	–	–	–	–	–
Total cholesterol, mg/dL	0.99	0.98–1.00	0.237	0.99	0.98–1.00	0.153
HDL-cholesterol, mg/dL	0.96	0.94–0.98	0.001	0.97	0.94–0.99	0.012
LDL-cholesterol, mg/dL	0.99	0.98–1.00	0.253	–	–	–
Triglycerides, mg/dL	1.00	0.99–1.01	0.167	1.00	0.99–1.02	0.068
eGFR, mL/min/1.73 m^2	1.01	0.99–1.02	0.108	1.00	0.98–1.01	0.946

Tobacco use was associated with substantially higher odds of prediabetes in the crude logistic regression analysis (OR = 7.18, 95% CI: 0.74–70.00), although the association did not reach statistical significance (p = 0.090). The wide confidence interval reflects the very small number of participants who reported tobacco use.

Among biochemical parameters, higher HDL-cholesterol concentrations were significantly associated with lower odds of prediabetes (crude OR = 0.96, 95% CI: 0.94–0.98; p = 0.001). In contrast, total cholesterol, LDL-cholesterol, triglycerides and eGFR were not significantly associated with prediabetes in the crude analyses.

After adjustment for the variables included in the multivariable model, HDL-cholesterol remained independently and inversely associated with prediabetes (adjusted OR = 0.97, 95% CI: 0.94–0.99; p = 0.012). Thus, each 1-mg/dL increase in HDL-cholesterol was associated with approximately 3% lower odds of prediabetes. The associations between total cholesterol, triglycerides, eGFR, and prediabetes were not statistically significant after adjustment (Table 3).

3.5 Sex-stratified analysis

Table 4 presents the sex-stratified analysis of factors associated with prediabetes. Overall, the analysis suggested some differences in the pattern of associations between men and women, although most associations were not statistically significant within either subgroup.

Table 4 Sex-stratified analysis of factors associated with prediabetes among participants (N = 289)

Variable	Male (n = 144)					Female (n = 145)				
	Prediabetes		OR	95% CI	*p*-value	Prediabetes		OR	95% CI	*p*-value
	Yes (n = 97)	No (n = 47)				Yes (n = 105)	No (n = 40)			
Age										
18-20 years	10	10	1.00			26	14	1.00		
21–24 years	53	21	0.40	0.14–1.09	0.073	61	20	0.61	0.27–1.39	0.237
25–29 years	30	14	0.47	0.16–1.38	0.167	17	6	0.66	0.21–2.04	0.466
30–34 years	4	2	0.50	0.07–3.38	0.477	1	0	–	–	–
BMI										
Normal	90	41	1.00	–	–	75	30	1.00	–	–
Overweight	5	5	2.19	0.60–8.00	0.233	24	7	0.73	0.28–1.87	0.511
Obesity	2	1	1.10	0.10–12.45	0.940	6	3	1.25	0.29–5.32	0.763
Physical activity										
Low	74	35	0.79	0.35–1.79	0.570	71	29	1.43	0.28–7.29	0.667
Moderate	20	12	1.00	–	–	27	9	1.17	0.20–6.67	0.862
High	3	0	–	–	–	7	2	1.00	–	–
Alcohol use										
Yes	34	17	1.05	0.51–2.17	0.895	25	13	1.54	0.69–3.43	0.289
No	63	30	1.00	–	–	80	27	1.00	–	–
Tobacco use										
Yes	1	1	2.09	0.13–34.11	0.606	0	2	–	–	–
No	96	46	1.00	–	–	105	38	–	–	–
Family history of diabetes										
Yes	15	8	1.12	0.44–2.87	0.811	19	7	0.96	0.37–2.50	0.933
No	82	39	1.00	–	–	86	33	1.00	–	–
Hypertension										
Yes	12	4	0.66	0.20–2.16	0.492	2	1	1.32	0.12–14.98	0.822
No	85	43	1.00	–	–	103	39	1.00	–	–
Elevated waist circumference										
Yes	84	34	2.47	1.04–5.87	0.041	41	11	0.59	0.27-1.31	0.198
No	13	13	1.00	–	–	64	29	1.00	–	–
Total cholesterol, mg/dL	–	–	1.00	0.98–1.01	0.984	–	–	0.99	0.98–1.00	0.141
HDL-cholesterol, mg/dL	–	–	0.96	0.93–0.99	0.031	–	–	0.96	0.93–0.99	0.014
LDL-cholesterol, mg/dL	–	–	1.00	0.98–1.01	0.591	–	–	0.99	0.98–1.05	0.271
Triglycerides, mg/dL	–	–	1.01	0.99–1.02	0.236	–	–	1.00	0.99–1.02	0.517
eGFR, mL/min/1.73 m^2	–	–	1.01	0.99–1.03	0.238			1.02	0.99–1.04	0.128

Among men, elevated waist circumference was the only anthropometric characteristic significantly associated with prediabetes in the bivariate analysis (OR = 2.47, 95% CI: 1.04–5.87; p = 0.041). This finding suggests an association between abdominal adiposity and prediabetes among male participants. In contrast, no significant association was observed among women (OR = 0.59, 95% CI: 0.27–1.31; p = 0.198). Age, BMI, physical activity, alcohol consumption, tobacco use, family history of diabetes and hypertension were not significantly associated with prediabetes in either sex. Some non-significant trends were observed, including lower odds of prediabetes among older age groups in men, although these estimates were imprecise.

For lipid parameters, HDL-cholesterol was inversely associated with prediabetes in both men (OR = 0.96, 95% CI: 0.93–0.99; p = 0.031) and women (OR = 0.96, 95% CI: 0.93–0.99; p = 0.014). These findings indicate a consistent inverse association between HDL-cholesterol concentration and prediabetes across both sexes. However, they should not be interpreted as evidence of a causal or protective effect of HDL-cholesterol. No statistically significant associations were observed for total cholesterol, LDL-cholesterol, triglycerides or eGFR in either sex.

4 Discussion

This study found a high burden of dysglycaemia among young university students in Lubumbashi. More than one-quarter of participants had prediabetes (26.6%), while 11.6% had HbA1c

levels compatible with probable diabetes. Overall, 38.2% had abnormal glycaemic regulation despite a mean age below 23 years. Among the factors examined, low HDL cholesterol was the only factor independently associated with prediabetes after adjustment.

The 26.6% prevalence observed in Lubumbashi is high compared with several African estimates. A meta-analysis from East Africa reported a pooled prediabetes prevalence of 21.45% according to American Diabetes Association (ADA) criteria [9]. Lower prevalences have been reported among university students in Uganda (3.3%) [16], in a rural Ugandan community (9.19%) [17], and in Nigeria (21.5%) [18]. In Cameroon, a meta-analysis estimated the prevalence at 7.1% [19]. In contrast, a nationally representative analysis of the 2016 South African Demographic and Health Survey reported a markedly higher prevalence of prediabetes (67%) among individuals aged $\geq$ 15 years, with a substantial proportion of affected individuals remaining undiagnosed [20]. Among university students, estimates have ranged from 1.0% in Nigeria [21] to 16.3% in India [22], 18.8% in Saudi Arabia [23], 27% among medical students in Saudi Arabia [24], and 21.1% among Romanian university students [25]. In the United States, prediabetes affected 24.0% of young adults aged 19–34 years [**?**]. In England, Mainous et al. [26] reported an increase in prediabetes prevalence from 11.6% to 35.3% between 2003 and 2011 among adults aged $\geq$ 16 years. In Iran, the prevalence was 18.22% among adults aged 35–70 years [27], whereas a meta-analysis from Malaysia estimated a pooled prevalence of 11.62% [28].

These differences should be interpreted in light of variations in age, socioeconomic and nutritional context, urbanisation, and, importantly, diagnostic methods. HbA1c may identify glycaemic abnormalities that are not detected by fasting plasma glucose alone. In our study, fasting glucose levels were similar between normoglycaemic and prediabetic participants, whereas HbA1c differed substantially. The high prevalence observed may also reflect rapid changes in the urban environment, including dietary transitions and sedentary behaviours, which are important determinants of cardiometabolic risk in low- and middle-income countries.

The proportion of participants with HbA1c levels compatible with probable diabetes (11.6%) is also noteworthy. Although confirmatory testing is required before diagnosing diabetes, this finding suggests that undiagnosed diabetes may already be present in a substantial proportion of young adults. This is particularly concerning in African settings, where a large proportion of diabetes remains undiagnosed. Overall, these findings suggest that abnormalities of glucose metabolism may emerge relatively early in adulthood and could contribute to the future burden of type 2 diabetes in the DRC.

The main finding of our analysis was the inverse association between HDL cholesterol and prediabetes. After adjustment, each 1 mg/dL increase in HDL cholesterol was associated with approximately a 3% reduction in the odds of prediabetes. This finding suggests that lipid abnormalities may be detectable before the emergence of more conventional cardiometabolic risk factors in young adults. This association is biologically plausible. Beyond its role in reverse cholesterol transport, HDL is involved in glucose homeostasis through effects on skeletal muscle glucose uptake, insulin secretion, and β-cell function [29, 30]. The anti-inflammatory and antioxidant properties of HDL may also mitigate mechanisms involved in insulin resistance [31]. A large prospective study reported an association between low HDL concentrations and increased risk of incident diabetes; however, genetic analyses did not support a direct causal relationship, suggesting that HDL may also act as a marker of an adverse metabolic environment [32].

Our findings should therefore be interpreted as an association rather than evidence of a causal effect of HDL. Recent evidence further suggests that the relationship between HDL and diabetes risk may be modified by genetic factors, including variants involved in β-cell function and lipid metabolism [33]. Similarly, adverse lipid profiles have been associated with prediabetes in Chinese adults, including young and non-obese individuals [34]. These findings support the potential value of lipid parameters as markers of early metabolic vulnerability.

In contrast to HDL cholesterol, BMI was not associated with prediabetes. This may partly reflect the fact that 81.7% of participants had a normal BMI, thereby limiting exposure variability. It also highlights the limitations of BMI as a stand-alone marker of metabolic risk. BMI does not capture body composition or fat distribution, whereas visceral adiposity is strongly implicated in insulin resistance [35].

This interpretation is supported by the association observed among men between increased waist circumference and prediabetes. Waist circumference is an indirect marker of abdominal adiposity, which is metabolically more active than subcutaneous fat and promotes increased free fatty acid flux, inflammation, and insulin resistance [35, 36]. In a Chinese cohort, waist

circumference and its change over time were more strongly associated with incident diabetes than BMI or changes in body weight [37]. Similarly, the EPIC-InterAct study showed that waist circumference provided additional predictive information beyond BMI [38].

The sex-specific association may reflect differences in fat distribution, with men generally having a greater proportion of visceral adipose tissue than premenopausal women [39]. However, given the sample size and cross-sectional design, this interpretation remains exploratory. Larger studies incorporating more precise measures of body composition are needed to confirm this association among young African adults.

Age was not associated with prediabetes, in contrast to findings from general adult populations in which older age is an established risk factor [9, 17]. This difference is likely attributable to the relative homogeneity of our population, which was restricted to individuals aged 18–34 years, resulting in limited age-related exposure variability.

Similarly, no significant association was observed between family history of diabetes and prediabetes. This may reflect both the young age of participants and under-reporting due to limited awareness of relatives' diabetes status in a setting where diagnosis remains inadequate. Thus, the absence of an observed association does not exclude a contribution of genetic susceptibility to metabolic risk.

Physical activity and alcohol consumption were also not associated with prediabetes. These findings should be interpreted cautiously because both exposures were self-reported, and the assessment did not adequately capture physical activity intensity, sedentary time, or detailed drinking patterns. The absence of observed associations may therefore partly reflect exposure misclassification.

Smoking warrants particular consideration. An association was observed in the bivariate analysis, but smoking was reported by only 1.4% of participants and was no longer significant after logistic regression. The large odds ratio and wide confidence interval primarily suggest limited statistical power. Nevertheless, an association between smoking and dysglycaemia has been reported in other young populations [23].

Finally, total cholesterol, LDL cholesterol, and triglycerides were not significantly associated with prediabetes. The association restricted to HDL cholesterol may indicate that some disturbances in lipid metabolism emerge before more conventional quantitative lipid abnormalities. Studies using composite indices combining lipid and glycaemic parameters, such as the cholesterol-HDL-glucose index, further support an integrated approach to metabolic risk assessment [40, 41].

These findings have important implications for diabetes prevention in the DRC. The high prevalence of prediabetes among university students suggests that universities could provide suitable platforms for early prevention. Interventions could combine cardiometabolic risk assessment, simple anthropometric measurements, nutritional education, and promotion of physical activity. Given resource constraints, universal HbA1c screening may not be immediately feasible on a large scale. A risk-based approach targeting individuals with recognised cardiometabolic risk factors could therefore be considered, while taking into account the high prevalence observed in this population. The identification of 11.6% of participants with HbA1c levels compatible with probable diabetes also highlights the need to strengthen early detection and diagnostic confirmation of glycaemic abnormalities. Prevention should, however, extend beyond an exclusively individual-level approach. Improving the food environment on university campuses, creating supportive environments for physical activity, and integrating nutrition education and non-communicable disease prevention into university programmes could help reduce exposure to metabolic risk factors from early adulthood.

This study has several strengths, including its focus on a young population that remains understudied in sub-Saharan Africa, the use of HbA1c according to ADA criteria, the availability of biochemical and anthropometric measurements, and multivariable analysis of associated factors. The high participation rate (86.5%) also supports the quality and completeness of the study data.

Several limitations should nevertheless be considered. First, the cross-sectional design precludes assessment of temporality or causality, particularly regarding the association between low HDL cholesterol and prediabetes. Second, because the study was restricted to students at the University of Lubumbashi, generalisation to young adults across the DRC should be made with caution. Third, some behavioural exposures were self-reported and may have been affected by misclassification. Fourth, the absence of measurements of fasting insulin, Homeostatic

Model Assessment of Insulin Resistance (HOMA-IR), body composition, visceral adiposity, and dietary quality limited assessment of the underlying mechanisms. Finally, the small number of smokers and limited sample sizes in some sex-stratified analyses reduced statistical power to detect certain associations.

Although HbA1c was a major strength of the study, its interpretation may be affected by haematological abnormalities and haemoglobinopathies. These factors were not specifically assessed in our study and should be considered in future research involving African populations.

5 Conclusion

This study identified a substantial burden of dysglycaemia among young university students in Lubumbashi, with 26.6% meeting HbA1c-based criteria for prediabetes and a further 11.6% having HbA1c values compatible with probable diabetes. Traditional cardiometabolic risk factors, including BMI and hypertension, were not significantly associated with prediabetes in this young population. In contrast, lower HDL-cholesterol was independently associated with prediabetes, while higher waist circumference was associated with prediabetes among men, suggesting that early metabolic abnormalities and abdominal adiposity may identify vulnerability before overt obesity develops.

These findings highlight the need to consider young adults as an important target population for diabetes prevention in the DRC, rather than focusing exclusively on older or overweight individuals. Universities may provide a practical setting for integrated prevention strategies combining risk assessment, appropriate glycaemic screening, healthy nutrition, physical activity and reduction of sedentary behaviours. Given the cross-sectional design and the limited generalisability of a university-based sample, longitudinal and multicentre studies are needed to determine whether low HDL-cholesterol and abdominal adiposity predict progression to type 2 diabetes and to evaluate context-specific prevention strategies for young African populations.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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