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Prevalence of and factors associated with pre-diabetes among adolescents in Eastern Sudan: a community-based cross-sectional study

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ABSTRACT

Objectives There is an increasing trend of pre-diabetes and diabetes mellitus (DM) among adolescents, and sub-Saharan Africa is no exception. However, few published data on pre-diabetes among adolescents in Sudan exist. We aimed to investigate the prevalence of and factors associated with pre-diabetes among adolescents in Eastern Sudan.

Design A community-based cross-sectional study was conducted from August to October 2023.

Settings This community-based study was conducted in Gadarif city, the capital of Gadarif state, Eastern Sudan.

Participants Adolescents (within the ages of 10–19 years).

Main outcome measures A questionnaire was used to collect socio-demographic information. Anthropometric and glycated haemoglobin (HbA1c) measurements were performed in accordance with standard procedures. Multivariate logistic regression analysis was performed.

Results Of the 387 enrolled adolescents, 207 (53.5%) were female and 180 (46.5%) were male. The median (IQR) age was 14.0 (12.0–16.0) years. 39.5% of the participants' fathers were employed. The median (IQR) HbA1c was 5.5% (5.2%–5.8%). One-third (32.6%) of the adolescents had pre-diabetes or DM. Of the participants, 67.4%, 30.0% and 2.6% had no DM, pre-diabetes or type 2 DM, respectively. In the univariate analysis, the father's employment (OR=1.60, 95% CI=1.03 to 2.50) was associated with increased odds of pre-diabetes; age, sex, parents' education, the mother's occupation, body mass index z-score, cigarette smoking and a family history of DM were not associated with pre-diabetes. In the multivariate analysis, the father's employment (adjusted OR=1.70, 95% CI=1.03 to 2.50) was associated with increased odds of pre-diabetes.

Conclusion Pre-diabetes is a significant public health problem among adolescents in Eastern Sudan. The introduction of early screening programmes for pre-diabetes at the community level is recommended to halt the progression of pre-diabetes to DM and to deal with existing DM among adolescents.

STRENGTHS AND LIMITATIONS OF THIS STUDY

⇒ The random sample selection and the study's community-based nature make it powerfully representative of the studied community (Gadarif locality).
⇒ Due to the nature of this study (a cross-sectional study), it could not establish a causality association between pre-diabetes among adolescents and the studied variables.
⇒ Conducting a longitudinal study will clarify the association between pre-diabetes and the studied variables among adolescents.
⇒ Dietary patterns, diversity or physical activity were not assessed; these could influence adolescents' vulnerability to pre-diabetes/diabetes mellitus.

INTRODUCTION

Globally, pre-diabetes and diabetes mellitus (DM) are increasing among adolescents, including in sub-Saharan Africa.[1–5] According to the International Diabetes Federation (IDF), pre-diabetes describes people with impaired glucose tolerance and/or impaired fasting glucose. It is an indicator of a higher risk of developing type 2 diabetes mellitus (T2DM) and its complications, such as diabetic nephropathy, microalbuminuria, diabetic ketoacidosis and diabetic retinopathy.[6–10] Recently, pre-diabetes among adolescents has received more attention; this could be attributed to several reasons. These include the global increase of T2DM among adolescents, including sub-Saharan Africa,[2–5] with its complications including cardiovascular diseases,[11] the high prevalence and incidence of youth-onset T2DM,[11 12] the heavy burden of pre-diabetes on health and the economy, especially in sub-Saharan Africa[4] and the possibility of slowing or halting the progression from pre-diabetes to T2DM,[13 14] or even reversing pre-diabetes.[4 15]

The prevalence of pre-diabetes among adolescents varies in different populations, including sub-Saharan Africa.[1 16] In Khartoum state, Central Sudan, a retrospective, hospital-based study found that out of 985 adolescent

patients, 38 (4%) had T2DM; most were diabetic, 35 (92.1%) had an onset of T2DM between 11 and 18 years of age and 3 patients (7.9%) were under 10 years.[2] A high prevalence of pre-diabetes among adolescents has been reported in India (16.2%)[17] and the USA 18%.[11] On the other hand, a low prevalence of pre-diabetes among adolescents has been reported in Nigeria, ranging from 4% to 9.4%.[5 18] Zuniga and DeBoer reported that 8.0% of adolescents with pre-diabetes were at risk of progression to T2DM over 3 years.[13] Weiner *et al* reported a similar progression rate of 2.5% from pre-diabetes to T2DM over 1 year.[14] In the USA, there is an increasing trend of pre-diabetes and DM among adolescents.[19]

Several factors, such as age,[5 11] sex,[11 20] low parental education level,[21] parental employment,[5 22] cigarette smoking,[23] a positive family history of DM[5 20] and an increased body mass index (BMI),[11 18 24] are associated with pre-diabetes among adolescents.

Early diagnosis and prompt intervention for pre-diabetes are crucial to control DM and its complications (morbidity and mortality). Three diagnostic criteria are used to diagnose pre-diabetes, these are glycated haemoglobin (HbA1c), 2-hour oral glucose tolerance tests (OGTT) and fasting plasma glucose.[25] The American Diabetes Association (ADA) and the National Institute for Health and Care Excellence have set differing levels of HbA1c to define pre-diabetes as levels ranging from 5.7% to 6.4%.[25 26] Investigating and introducing appropriate preventive measures for pre-diabetes cases can lead to the prevention and delay of DM among adolescents. A preventive approach should be followed, especially in limited-resource settings, to prevent DM and its related complications, which have been recognised as heavy burdens on the fragile health systems in sub-Saharan Africa, where most countries are low- and middle-income countries (LMICs).[4] Additionally, the IDF has estimated that approximately 90% of people with undiagnosed DM live in LMICs.[10] Based on WHO statistics, in Sudan, more than 20% of the population are adolescents.[27] Moreover, the present escalating war in Sudan is having a negative impact on children's and adolescents' health, especially those with DM, who require continuous medicine supplies and optimum insulin storage conditions.[28–30]

While the existing data focus more on pre-diabetes among Sudanese adults, pre-diabetes among adolescents has received less attention.[31 32] Moreover, the literature shows low awareness of pre-diabetes/DM among the public, among patients with pre-diabetes and even among healthcare professionals, including Sudanese professionals.[33–35] Our previous studies in Eastern Sudan reported a high prevalence of DM and its complications among adults.[36 37] To be more proactive, pre-diabetes and its associated factors need to be investigated among adolescents, especially at the community level. Therefore, the current study aimed to investigate the prevalence of and factors associated with pre-diabetes among adolescents in Gadarif state, Eastern Sudan.

METHODS

Study design and setting

This community-based cross-sectional study was conducted among 387 adolescents. This study was conducted in Gadarif city, the capital of Gadarif state, Eastern Sudan, from August to October 2023. Gadarif state is located in Eastern Sudan, which neighbours Ethiopia. According to the 2008 census, the total population of Gadarif state was 1 400 000 people.[38] Of the 11 localities in Gadarif state, the Gadarif locality (where Gadarif city is) is the most populated. Gadarif state has vast land suitable for agriculture and is home to Sudan's largest projects for rain-fed agriculture. It consists of ethnic groups representing different tribes (ie, a multiethnic society).[39] More details about the study area were given in our previous work.[40] The present study adhered to the Strengthening the Reporting of Observational Studies in Epidemiology guidelines.[41]

Sampling technique

The Gadarif locality was chosen from the 11 localities as it has a population mixture representative of the entire state. Gadarif city is divided into 4 squares (mouraba) comprising 13 blocks (hays). The total population numbers in each block were obtained from the local authorities. The percentage of 20% of adolescents from the total population in each block was chosen based on the WHO's estimation that more than 20% of the Sudanese population are adolescents.[27] A total of 387 adolescents (the desired sample size), including both males and females, were included. The number of adolescents from each block depended on the total estimated number of adolescents in the specific block (ie, proportional to the population size). Therefore, blocks with a larger population contributed more to the sample. In each block, the assigned sample size was selected using a simple random technique (lottery method) from the lists of households in the blocks. If there were no adolescents in the chosen household or if they refused to participate in the study or had one of the exclusion criteria of this study, the next household was chosen as a replacement.

Inclusion and exclusion criteria

The inclusion criteria were apparently healthy adolescents aged between 10 and 19 years residing in the study area (Gadarif city). In this study, an apparently healthy adolescent means an adolescent with no sickness during the time of data collection and or no apparent disability. Any participants younger than 10 or older than 19 years, participants who did not consent to participate in the study, those with known DM, those who were sick and pregnant or lactating girls were excluded.

Patient and public involvement

None.

Sample size calculation

OpenEpi Menu software was used to compute the desired sample size.[42] A sample of 387 adolescents was computed for the present study. Because there had been no previous

study in the study region, the maximum occurrence (50.0%) of the event (pre-diabetes) was assumed to be the optimum sample size, using the following equation: $(n=Z^2pq/d^2$, in which q=(1–p), Z1–α=CI interval (CI) of 95%=1.96, and d=margin of error of 5%=0.05). Thus, the type I α (alpha) error was set at 0.05 (5%), and the type 11 (1-beta) error was set at 0.20 (20%), power=1–β (80%).

Study variables and measures

The questionnaire was developed from previous similar studies.[5 11 18 20 24] The questionnaire collected data on socio-demographic characteristics, including age, sex, parental educational levels (<secondary or ≥secondary), mother's occupational status (housewife or employed), father's occupational status (employed or labourer), as well as cigarette smoking, a family history of DM, anthropometric measurements, such as weight and height (later expressed as a BMI z-score) and HbA1c. Five medical officers were trained by the investigators to collect the data.

After the participants and their guardians agreed to participate and signed an informed consent form, the selected adolescents were approached by the medical officers. The adolescents were informed about the study aims and all the necessary information, including their voluntary participation in the study, their right to withdraw from the study at any time without giving a reason and the preventive measures taken to ensure the privacy, confidentiality and safety of the participants, such as excluding personal identifiers during the data collection. Weight, height and HbA1c were measured using the following standard procedures. The socio-demographic data and BMI were secondary outcomes, and pre-diabetes was the primary outcome. A few cases of newly diagnosed T2DM (n=10) were excluded from the model.

Weight and height measurements

The adolescents' weights were measured in kilograms (kg) using standard procedures (ie, well-calibrated scales adjusted to zero before each measurement). Weight was measured to the nearest 100 grams (g). The adolescents stood with minimal movement, with their hands by their sides. In addition, shoes and excess clothing were removed. Height was measured to the nearest 0.1 cm, with the adolescents standing straight with their backs against the wall and their feet together. The BMI-for-age z-score was determined based on the WHO's standards.[43]

Blood sample processing

From each adolescent, 3 mL of blood was taken in an EDTA tube under aseptic conditions for HbA1c analysis. HbA1c was measured using an Ichroma machine as per the manufacturer's instructions (Republic of Korea), as described in our previous work.[36] Based on the ADA criteria of using HbA1c level, pre-diabetes was diagnosed as an HbA1c level ranging from 5.7% to 6.4% and T2DM was diagnosed as an HbA1c level ≥6.5%.[26] HbA1c has been used as a diagnostic tool for pre-diabetes/DM among children and adolescents in various studies.[21 44] Moreover, this ADA criteria of using HbA1c level is suitable in limited-resource settings such as Sudan, where it is difficult to perform OGTT and fasting plasma glucose in a survey.

Table 1 Socio-demographic characteristics of the studied adolescents in Eastern Sudan, 2023

Variable	Total (n=377)		Adolescents with pre-diabetes (n=116)	Adolescents without pre-diabetes (n=261)	P value
		Median (IQR)			
Age, years		14.0 (12.0 to 16.0)	13.8 (12.3 to 16.0)	14.0 (12.0 to 16.1)	0.896
Body mass index z–score		–0.97 (–1.97 to 0.23)	–0.98 (–1.87 to 0.36)	–95 (–1.98 to 0.16)	0.533
	Frequency (percentage)				
Sex	Female	207 (54.4)	58 (50)	147 (56.3)	
	Male	172 (45.6)	58 (50)	114 (43.7)	0.255
Mother's education	≥Secondary level	264 (70.0)	82 (70.7)	182 (69.7)	
	<Secondary level	113 (30.0)	34 (29.3)	79 (30.3)	0.851
Mother's occupation	Housewife	307 (81.4)	23 (19.8)	47 (18.0)	
	Employed	70 (18.6)	93 (80.2)	214 (82.0)	0.675
Father's education	≥Secondary level	283 (75.1)	86 (74.1)	197 (75.5)	
	<Secondary level	94 (24.9)	30 (15.9)	64 (24.5)	0.781
Father's occupation	Labourer	228 (60.5)	61 (52.6)	167 (64.0)	
	Employed	149 (39.5)	55 (47.4)	94 (36.0)	0.037
Family history of diabetes mellitus	No	270 (71.6)	86 (74.1)	184 (70.5)	
	Yes	107 (28.4)	30 (25.9)	77 (29.5)	0.469
Cigarette smoking	No	371 (98.4)	115 (99.1)	256 (98.1)	
	Yes	6 (1.6)	1 (0.9)	5 (1.9)	0.451

Statistical analysis

The collected data were entered into the SPSS for Windows (V.22.0; SPSS, New York, New York, USA) statistical software for analysis. Adolescents with HbA1c ranging from 5.7% to 6.4% were considered pre-diabetes and coded as (1), and adolescents with HbA1c of <5.7% were considered non-pre-diabetes (normal) and coded as (0). The continuous data (age and BMI) were evaluated for normality using the Kolmogorov-Smirnov test (a p value of <0.05) and found not normally distributed, and they were expressed as medians (IQRs). The median is better than the mean to measure the central tendency of the non-parametric (not normally distributed) group, as exceptionally high or low characteristic values do not skew it.

A univariate analysis was performed as pre-diabetes status was the dependent variable, and the socio-demographic data (age and sex), parents' education, parents' occupation, cigarette smoking and a family history of DM were the independent variables. All the variables in the univariate analysis were entered into a multivariate logistic regression to adjust for covariates regardless of their p values in univariate because these variables were shown to be predictors for pre-diabetes in previous studies, which is a statistical practice.[45] Adjusted ORs and 95% CIs were calculated as they were applied. A two-sided p value of <0.05 was considered statistically significant.

RESULTS

In the present study, 387 adolescents were enrolled, of whom 207 (53.45%) were female and 180 (46.5%) were male. The median (IQR) age was 14.0 (12.0–16.0) years. More than two-thirds (70.0%) of the mothers and three-quarters (75.1%) of the fathers had secondary school or higher education levels. Most of the mothers were housewives (81.4%), and almost two-fifths (39.5%) of the fathers were employed. The median (IQR) BMI z-score was 0.97 (−1.97 to 0.23). More than one-quarter (28.4%) of the participants had a family history of DM in a first-degree relative. The median (IQR) HbA1c was 5.5% (5.2%–5.8%) (table 1). One-third of the total enrolled adolescents (n=387) (32.6%) of these adolescents had pre-diabetes or T2DM. Among the 387 participants, 67.4%, 30.0% and 2.6% had no DM, pre-diabetes or DM, respectively.

In the univariate analysis, the father's employment (OR=1.60, 95% CI=1.03 to 2.50) was associated with increased odds of pre-diabetes; age, sex, parents' education, mother's occupation, the BMI z-score, cigarette smoking and a family history of DM were not associated with pre-diabetes (table 2). In the multivariate analysis, the father's employment (OR=1.70, 95% CI=1.03 to 2.50) was associated with increased odds of pre-diabetes (table 3).

DISCUSSION

The main finding of the present study was that one-third (30.0% with pre-diabetes and 2.6% with T2DM) of the adolescents had pre-diabetes or T2DM. This prevalence (30.0%) of pre-diabetes is higher than the previously reported prevalence in Nigeria, which ranged from 4% to 9.4%,[5 18] the United Arab Emirates (UAE) (21.9%),[22] Cote d'Ivoire (14.5%), India (16.2%),[17] China (8.7%)[46] and the USA (18%).[11] This high prevalence of pre-diabetes/T2DM confirms the increasing global trend of pre-diabetes and DM among adolescents, including

Table 2 Univariate analysis of the factors associated with pre-diabetes among adolescents in Eastern Sudan, 2023

Variable		OR	95% CI	P value
Age, years		1.01	0.92 to 1.10	0.854
Body mass index z–score		1.06	0.92 to 1.21	0.434
Sex	Female		Reference	
	Male	1.29	0.83 to 1.99	0.256
Mother's education	≥Secondary level		Reference	
	<Secondary level	0.96	0.59 to 1.54	0.851
Mother's occupation	Employed		Reference	
	Housewife	0.89	0.51 to 1.55	0.675
Father's education	≥Secondary level		Reference	
	<Secondary level	1.07	0.65 to 1.77	0.781
Father's occupation	Labourer		Reference	
	Employed	1.60	1.03 to 2.50	0.037
Family history of diabetes mellitus	No		Reference	
	Yes	0.83	0.51 to 1.37	0.470
Cigarette smoking	No		Reference	
	Yes	0.45	0.05 to 3.85	0.462

Table 3 Multivariate analysis of the factors associated with pre-diabetes among adolescents in Eastern Sudan, 2023

Variable		OR	95% CI	P value
Age, years		1.02	0.93 to 1.12	0.665
Body mass index z–score		1.056	0.92 to 1.22	0.462
Sex	Female	Reference		
	Male	1.42	0.90 to 2.23	0.134
Mother's education	≥Secondary level	Reference		
	<Secondary level	1.12	0.64 to 1.91	0.720
Mother's occupation	Employed	Reference		
	Housewife	0.88	0.49 to 1.56	0.654
Father's education	≥Secondary level	Reference		
	<Secondary level	1.12	0.64 to 1.97	0.700
Father's occupation	Labourer	Reference		
	Employed	1.70	1.06 to 2.67	0.026
Family history of diabetes mellitus	No	Reference		
	Yes	0.78	0.47 to 1.30	0.347
Cigarette smoking	No	Reference		
	Yes	0.46	0.05 to 4.10	0.484

in sub-Saharan Africa.[2–5] This high prevalence of pre-diabetes (30.0%) among adolescents could be attributed to several reasons. Unhealthy dietary habits, low physical activity and sedentary behaviours among Sudanese adolescents,[47] and lack of awareness about pre-diabetes/DM, even among Sudanese healthcare professionals, could lead to fewer preventive measures to combat pre-diabetes/DM among adolescents. In addition, this high level of HbA1c could be due to some haemoglobinopathies.[48] Concerning the urban residency of the studied adolescents (Gadarif city), a study conducted by Elfaki *et al* in Central Sudan revealed that adolescents residing in urban areas were at higher risk of metabolic syndrome, including fasting plasma glucose ≥100 mg/dL).[32] A recent systematic review and meta-analysis of 48 studies revealed that the prevalence of pre-diabetes among children and adolescents was higher in urban areas than in rural areas (6.78% vs 2.47%, p<0.01).[1] Moreover, the ongoing war in Sudan has impacted children's and adolescents' mental health (eg, depression and anxiety),[29] and this could lead to increasing pre-diabetes/DM.[37] Deschênes *et al* revealed that pre-diabetes, depression and anxiety interact synergistically as risk factors for developing T2DM.[49]

This high prevalence of pre-diabetes among adolescents could explain the high prevalence of T2DM among Sudanese children and adolescents[2] and among adults in different regions of Sudan, including Eastern Sudan.[31 36 37] In this study, the prevalence of T2DM among adolescents (2.6%) was high compared with other studies, such as in Cote d'Ivoire (0.4%),[3] the UAE (0.9%)[22] and the USA (1.1%).[19]

In this study, adolescents with employed fathers had odds of developing pre-diabetes that were 1.7 times higher than for the adolescents with unemployed fathers. Various studies have shown contradictory results regarding the association between parental employment and pre-diabetes among adolescents.[5 22] In Nigeria, a school-based cross-sectional study that included 405 adolescents showed that adolescents with employed parents were more likely to develop pre-diabetes compared with those with unemployed parents.[5] In contrast, in the UAE, Emirati adolescents with unemployed parents were at risk of pre-diabetes.[22] The association between the father's employment and pre-diabetes could be attributed to the influence of the father's employment on socioeconomic class. Another study in Nigeria reported that a higher socioeconomic class was significantly associated with pre-diabetes.[20] It seems that the influence of parents' employment on DM status can be attributed to family income, regardless of parents' employment status (ie, in some countries, such as the UAE, parental unemployment may indicate good socioeconomic status, unlike in sub-Saharan Africa). In our context, the influence of father employment on pre-diabetes compared with unemployed fathers (labourers) could be explained by the less time adolescents of employed fathers are involved in activities such as agricultural activity, which can provide some physical activity.[20]

Our results showed no association between age, sex, parents' education, mother's occupation, a family history of DM and BMI z-score and pre-diabetes. Similar to this study's results, in Eastern Sudan, our previous study found no significant association between education, BMI and adults' DM.[36] For example, the lack of association between BMI z-score and pre-diabetes in this study compared with other studies,[11 18 24] could raise the metabolic differences between obese and non-obese people regardless of anthropometric measurement (weight and

height).[50] Also, BMI cannot differentiate between muscle mass and fat mass.

In contrast, other studies have shown an association between adolescent age,[5 11] sex,[11 20] low parental education level,[21] cigarette smoking,[23] a family history of DM[5 20] and increased BMI[11 18 24] and pre-diabetes among adolescents. The results regarding the association between BMI and pre-diabetes among adolescents are contradictory: a study in Nigeria showed a positive association between normal BMI and pre-diabetes compared with adolescents with underweight,[5] and other studies found that an increased BMI increased the odds of pre-diabetes among adolescents,[11 18 24] and a study in China revealed a U-shaped curve association between pre-diabetes and BMI (ie, a high prevalence of pre-diabetes among underweight and obese adolescents).[46]

The lack of association between parents' education and mother's occupation and pre-diabetes could be attributed to the quality of education. Variations in the associated factors could have many explanations, including the low impact of education on health knowledge due to the poor quality of education provided to each parent, especially girls.[51] Variation in the influence of maternal education and occupation could also be explained by the low impact of education on the workforce (ie, in the present study, less than one-fifth of the adolescents' mothers were employed), and even employed women face a gender pay gap in sub-Saharan Africa, with a consequent impact on socioeconomic status.[51]

The lack of association between a positive family history of DM and pre-diabetes in this study might implicate environmental and lifestyle factors as risk factors rather than genetic ones; from a public health point of view, this is good since such factors can be modified.

Our results should be cautiously compared with the results of other studies. First, while the present study used the WHO's definition (ages 10–19 years) similar to previous studies,[5 20 24] other studies have included participants of different ages (early adolescents, late adolescents or both children and adolescents).[3 21 44] The WHO's cut-off ages of 10–19 years are recommended to tailor programmes that target adolescents precisely. Second, this study was community-based; other studies used different approaches (eg, school-based or hospital-based).[18 20] Third, definitions of pre-diabetes other than HbA1c, such as impaired fasting glucose (fasting blood glucose 110–125 mg/dL) and impaired glucose tolerance (2-hour glucose 140–199 mg/dL) according to the WHO's definition, have been used by various studies[3 20] for pre-diabetes based on the investigation tools.[52] Echouffo-Tcheugui and Selvin have called for a consensus definition of pre-diabetes to improve current screening and diagnostic practices.[52] In the present study, HbA1c was used since it is not influenced by the last meal, making it more suitable for surveys, especially in limited-resource settings and remote areas. Moreover, Ghaddar *et al* have reported that analyses including fasting plasma glucose and HbA1c yielded similar results in children and adolescents.[21]

Contradictory data on the prevalence of pre-diabetes and associated factors, such as age, sex, parental educational level and occupational status, have been documented on a global scale. Han *et al*, in their systematic review and meta-analysis, found that the prevalence of pre-diabetes varied according to the WHO and World Bank regions, and the European region and high-income countries had the lowest pooled prevalence ($p<0.01$).[1] Such contradictory data should prompt researchers to explore adolescents' DM status in their countries/regions and aim to address adolescents' pre-diabetes/DM with precise preventive approaches.

These study findings have implications for improving adolescents' health, since pre-diabetes is a preventable, treatable and revisable health condition, by introducing several preventive modalities, including lifestyle modification.[13] The present findings can act as a foundation for further studies; in particular, the present escalating war in Sudan is having severe negative impacts on population health and healthcare systems, especially among the most vulnerable groups, such as children and adolescents.[29] In Africa, where most conflicts exist, conflicts affect adolescents' health in various ways, such as the spread of diseases[53–55] and disturbing fragile healthcare systems.[53] For instance, the deadly impacts of conflicts on the lives of children and adolescents have been highlighted in our neighbouring country, Ethiopia; conflicts impact children and adolescents' health in various ways, including massive displacement, lack of meeting basic humanitarian needs, extreme levels of violence, hunger and malnutrition and lack of health services.[53] The authors of this study make certain recommendations, including interventional screening in community-based and school-based programmes for all adolescents to maintain adolescents' health in the present and future. The recommendations of Nwatu and Young, which include structured and intensive lifestyle modifications, such as weight loss, increased physical activity and healthy dietary habits, can be applied in our African context to halt or slow the progression to T2DM and even reverse pre-diabetes cases.[4] The 10 cases of T2DM found in this study were traced, and those adolescents and their families were advised to attend their nearest healthcare facility for further evaluation. Further high-quality research is needed with more patient and public involvement and engagement, including healthcare professionals, decision-makers and the community, to address adolescents' health, especially adolescents' pre-diabetes/DM, taking into account the present study limitations. The findings of this study and its recommendations will be shared with healthcare professionals and decision-makers for embedding in existing policies regarding adolescents' health.

Strengths and limitations

To the best of our knowledge, this is the first study that addressed pre-diabetes/DM among adolescents in Eastern Sudan. These data can add value to the limited data regarding pre-diabetes, especially among adolescents

in Sudan.[31 32] The results of this study can be used by healthcare professionals and decision-makers to improve children's and adolescent's health, especially during the current war in Sudan, which has negatively impacted the population's health, including adolescents. However, this study has some limitations that need to be mentioned. Due to the nature of this study (a cross-sectional study), it could not establish a causality association (ie, between different variables). Therefore, a further longitudinal study will clarify the association between pre-diabetes and the studied variables among adolescents. It is most important to take care of both the adolescents who already had T2DM (2.6%) and those with pre-diabetes (30.0%) from progressing to DM in a few years. This study was conducted in Eastern Sudan, which limits the generalisation of its results to adolescents in Sudan. Only HbA1c was used to diagnose pre-diabetes; further research is recommended to use OGTT and fasting plasma glucose. Moreover, in this study, no data were gathered regarding dietary patterns and diversity[5] or physical activity.[5 24] These data could influence the vulnerability of adolescents to pre-diabetes/DM.

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Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Consent obtained directly from patient(s).

Ethics approval The present study was conducted in accordance with the Declaration of Helsinki and good clinical research practices. This study received ethical approval from the Research Ethics Committee of the Faculty of Medicine, University of Gadarif, Gadarif, Sudan (Ref. #2023, 14). All the adolescents and their guardians signed a written informed consent form. The authors followed all measures to ensure the privacy and confidentiality of the participants, including excluding personal identifiers during data collection. All the methods and procedures of this study were carried out in accordance with appropriate guidelines and regulations.

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