



Growth Impairment and Nutritional Status among Children with Type 1 Diabetes at Edduiem Teaching Hospital, White Nile State, Sudan: A Cross-Sectional Study, 2024

Howida Mohammed Ibrahim¹, Mohammed Amer Ahmed², Weaam Elamin Dafa Alla¹

¹University of Bakht Alruda Faculty of Medicine and Health Sciences Department of Paediatrics

²University of Bakht Alruda Faculty of Education, Department of Geography

ABSTRACT

The study aimed to assess growth and nutritional status among children and adolescents with type 1 diabetes mellitus (T1DM) attending the pediatric diabetes clinic at Edduiem Teaching Hospital, and to examine associations with glycemic control parameters, duration of diabetes, sex, and number of daily meals: A descriptive cross-sectional study (January to December 2024). A simple random sample of 76 Sudanese children with T1DM was selected. Data were collected using a questionnaire alongside anthropometric measurements. Weight, height, and body mass index (BMI) were evaluated and converted to age- and sex-specific Z-scores according to World Health Organization (WHO) growth standards. Glycated hemoglobin (HbA1c) was measured using a Finecare™ fluorescence immunochemistry system. The chi-square test (χ^2) was used to evaluate statistical associations, with ($P < 0.05$) considered statistically significant. The study reached that the mean age was 12.16 years, and females accounted for 63.2% of participants. The mean age at diagnosis was 7.50 pm 4.14 years. Mean HbA1c was 10.30pm 2.58%; 59 out of 76 children (77.6%) had uncontrolled glycemic levels, whereas 17 children (22.4%) had controlled glycemic levels according to the study criteria, mild underweight was observed in 17.1%, moderate in 15.8%, and severe in 13.2%, mild stunting was present in 14.5%, moderate in 13.2%, and severe in 15.8%, 31.6% were classified as underweight, 6.6% as overweight, and 3.9% as obese, nutritional status was significantly associated with glycemic control across all metrics: weight-for-age ($P = 0.017$), height-for-age ($P = 0.014$), and BMI-for-age ($P = 0.021$). The detailed duration-of-diabetes table also showed statistically significant associations for weight-for-age ($P = 0.027$), height-for-age ($P = 0.031$), and BMI-for-age ($P = 0.025$), although the original narrative conclusion of the thesis described no overall significant differences between short- and long-duration groups and consuming one to two meals per day was associated with weight-for-age ($P = 0.016$) and height-for-age ($P = 0.024$), but not with BMI-for-age ($P = 0.062$). Severe underweight and severe stunting were significantly more frequent among males than females ($P < 0.05$), while age showed no statistically significant association with nutritional status.

Keywords: Type 1 diabetes mellitus; child growth; nutritional status; underweight; White Nile State; Sudan.

1. Introduction

Type 1 diabetes mellitus is a chronic metabolic disorder characterized by progressive loss of pancreatic beta-cell function and an absolute requirement for exogenous insulin. In children and adolescents, treatment extends beyond insulin administration and includes glucose monitoring, nutrition education, physical activity, psychosocial support, and continued supervision by a multidisciplinary diabetes team. Achieving satisfactory metabolic control during childhood is particularly important because childhood and adolescence are periods of rapid somatic growth, pubertal development, and changing nutritional requirements [1,7,13]. The global burden of childhood T1DM continues to increase. The thesis source cites estimates of approximately 1.21 million children and adolescents younger than 20 years living with T1DM worldwide, with more than 100,000 new diagnoses annually among those younger than 15 years [1,2]. Data from sub-Saharan Africa are comparatively sparse, and the burden is likely to be underestimated because of limited diagnostic capacity and incomplete disease registries [2,3]. In Sudan, published epidemiological studies have reported increasing incidence of childhood T1DM over time, but contemporary population-level evidence remains limited [4–6]. Growth impairment in children with diabetes may result from several interacting mechanisms. Persistent hyperglycemia and inadequate insulin availability can interfere with protein metabolism and the growth-hormone/IGF-1 axis. Inadequate energy intake, recurrent illness, psychosocial difficulties, treatment burden, and limited access to diabetes supplies may further contribute to poor growth. Conversely, intensified insulin treatment and changing dietary patterns may contribute to overweight and obesity in some children [9–12,28,43]. Thus, the nutritional challenge in childhood diabetes can be bidirectional: undernutrition and growth failure may coexist with excess weight in the same population. Anthropometric monitoring is therefore an essential component of pediatric diabetes care. Weight-for-age, height-for-age, and BMI-for-age provide complementary information. Weight-for-age can identify low body mass relative to age, height-for-age reflects linear growth and chronic growth restriction, and BMI-for-age helps identify thinness and excess weight. The WHO growth standards provide standardized age- and sex-specific references that facilitate comparison across populations [53]. Evidence from Sudan and neighboring countries suggests that growth impairment and poor glycemic control remain important challenges. A Sudanese study from Wad Medani reported stunting in 54% of children

with T1DM and poor glycemic control in 52.5%, with inadequate caloric intake also common [30]. Another Sudanese study reported poor glycemic control in approximately three quarters of children and highlighted socioeconomic influences [31]. Studies from Egypt, Iraq, Tanzania, Rwanda, Saudi Arabia, and India have similarly reported variable but substantial levels of stunting, underweight, and poor metabolic control [32,34,36–45]. Despite this evidence, there is little contemporary information on the growth and nutritional status of children with T1DM receiving care in White Nile State. Edduiem Teaching Hospital serves children from Edduiem and surrounding rural areas and therefore provides an opportunity to describe a population receiving specialist pediatric diabetes services in a resource-limited setting [source study]. The present study was designed to assess growth status and to examine its relationship with glycemic control, duration of diabetes, sex, and selected nutritional behaviors. The objectives were to: (1) measure growth parameters among children with T1DM attending the pediatric diabetes clinic; (2) assess the association between glycemic control and deviation from expected growth; (3) examine the relationship between duration of diabetes and growth status; and (4) assess the relationship between nutritional factors, particularly meal frequency, and growth.

2. Materials and Methods

Study design and setting

A descriptive, hospital-based cross-sectional study was conducted at the Diabetes Pediatric Clinic of Edduiem Teaching Hospital, White Nile State, Sudan, from January to December 2024. The hospital is described in the source thesis as a teaching hospital with 175 beds and multiple clinical departments. The pediatric diabetes clinic is staffed by pediatric clinicians, nurses, and a nutritionist and receives children with diabetes from Edduiem and surrounding rural areas.

Study population and eligibility

The study population comprised Sudanese children with T1DM attending the pediatric diabetes clinic during the study period. Eligible participants were Sudanese children with T1DM who attended the clinic during the study period and agreed to participate. Exclusion criteria were refusal to participate, age below one year, diabetes duration of less than one year, and known celiac disease, thyroid disease, or chronic kidney disease.

Sampling and sample size

Convenience non-probability sampling with total coverage of eligible pediatric clinic attendees was used. The final sample consisted of 76 participants. Because the sampling frame was clinic-based and non-probabilistic, the study should be considered descriptive of the participating clinical population rather than representative of all children with T1DM in White Nile State.

Data collection

Data were collected using a structured interviewer-administered questionnaire completed with caregivers after informed consent. The questionnaire covered demographic characteristics, clinical presentation, diabetes duration, hospitalization, diabetic ketoacidosis and hypoglycemia events, insulin regimen, treatment compliance, blood-glucose self-monitoring, meal frequency, snacks, dietary planning, sugary-food intake, physical activity, anxiety related to diabetes, parental education and occupation, family size, family history of T1DM, and parental consanguinity.

Anthropometric assessment

Weight was measured to the nearest 0.1 kg using a digital scale with the child standing motionless without shoes and wearing minimal clothing. Height was measured to the nearest 0.1 cm using a wall-mounted stadiometer, with the participant positioned according to the Frankfort horizontal plane. BMI was calculated as weight in kilograms divided by height in meters squared. Weight, height, and BMI were converted to age- and sex-specific Z-scores using WHO growth standards and an online WHO calculator [53]. The source study categorized weight-for-age as normal (>-1), mild underweight (-1 to -2), moderate underweight (<-2 to -3), and severe underweight (<-3). Height-for-age was categorized as normal (>-1), mild stunting (-1 to -2), moderate stunting (<-2 to -3), and severe stunting (<-3). BMI-for-age was categorized as underweight (<-2 SD), normal (-2 to $+2$ SD), overweight ($>+2$ to $+3$ SD), and obese ($>+3$ SD). These categories are reproduced from the source thesis and should be checked against the target journal's preferred WHO classification before submission.

Glycemic control

HbA1c was measured using capillary blood collected by finger prick and analyzed with the Finecare™ FIA Meter Plus fluorescence immunochromatography system. The source thesis applied age-related glycemic targets based on ADA recommendations and classified the most recent HbA1c measurement into controlled and uncontrolled categories. The present manuscript retains the study's original controlled/uncontrolled classification to preserve comparability with the reported results.

Duration of diabetes

Duration of diabetes was defined as the interval between diagnosis and assessment. The detailed results were presented in three categories: less than 5 years, 5–9 years, and more than 9 years. The methodology section also described a two-group analytical categorization of short duration (<5 years) versus long duration (≥ 5 years). Because the detailed results table uses three duration categories, this manuscript reports those three categories when presenting the available cross-tabulated results.

Statistical analysis

Data were entered, tabulated, and analyzed using the Statistical Package for the Social Sciences (SPSS). The chi-square test was used to assess associations between categorical variables. A 95% confidence level was specified, and $P < 0.05$ was considered statistically significant. The source thesis does not provide multivariable regression, effect sizes, or confidence intervals for the reported associations; therefore, this manuscript does not invent such estimates.

Ethical considerations

The study proposal was submitted for ethical review through the Sudan Medical Specialization Board, Council of Pediatrics and Child Health, and the Educational Development Centre. Permission to conduct the study was obtained from the relevant pediatric diabetes clinic and Edduiem Teaching Hospital. Written informed consent was obtained from caregivers. Questionnaires were coded and did not include names or addresses, participation was voluntary, participants could withdraw without affecting their care, and no change was made to routine hospital management.

Reporting considerations

The manuscript is based on a completed clinical MD thesis. The authors should verify the exact ethics approval number, institutional affiliation, author contributions, funding statement, conflict-of-interest statement, data-availability statement, and journal-specific reporting checklist before submission. Because this is a cross-sectional study, causal language is avoided.

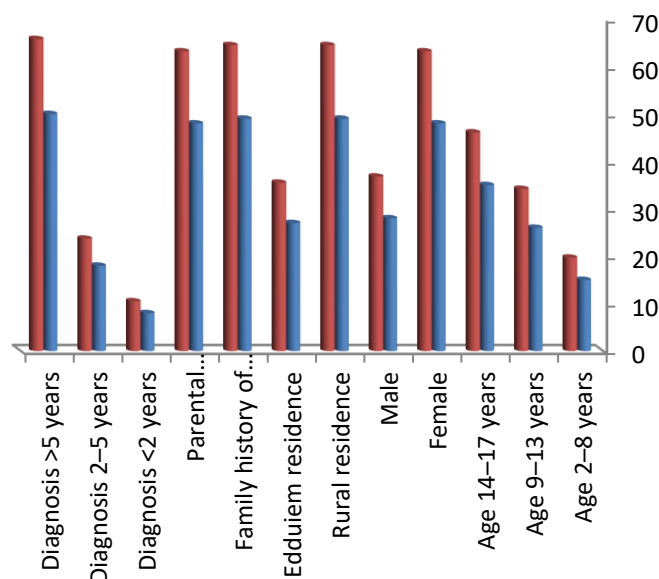
3. Results

3.1 Sociodemographic and clinical characteristics

Table (1) shows that A total of 76 children with T1DM were included. The mean age was 12.16 ± 3.96 years. The largest age group was 14–17 years (46.1%), followed by 9–13 years (34.2%) and 2–8 years (19.7%). Females accounted for 63.2% (48/76) and males for 36.8% (28/76). Rural residents represented 64.5%, while 35.5% were from Edduiem town. The mean age at diagnosis was 7.50 ± 4.14 years. Most children (65.8%) were diagnosed after the age of 5 years, 23.7% at 2–5 years, and 10.5% before 2 years. A family history of similar disease was reported in 64.5% of participants, and parental consanguinity was reported in 63.2%.

Table (1) Sociodemographic and clinical characteristics

Characteristic	n	%
Age 2–8 years	15	19.7
Age 9–13 years	26	34.2
Age 14–17 years	35	46.1
Female	48	63.2
Male	28	36.8
Rural residence	49	64.5
Edduiem residence	27	35.5
Family history of T1DM	49	64.5
Parental consanguinity	48	63.2
Diagnosis <2 years	8	10.5
Diagnosis 2–5 years	18	23.7
Diagnosis >5 years	50	65.8

Figure (1) Sociodemographic and clinical characteristics

3.2 Glycemic control and diabetes duration

Mean HbA1c was $10.30 \pm 2.58\%$. Fifty-nine children (77.6%) were classified as having uncontrolled glycemia and 17 (22.4%) as controlled. The mean duration of diabetes was 4.71 ± 2.71 years. Thirty-eight children (50.0%) had diabetes for less than 5 years, 33 (43.4%) had a duration of 5–9 years, and 5 (6.6%) had a duration greater than 9 years. The clinical burden of diabetes was substantial. During the preceding year, 44.7% had not been hospitalized because of diabetes, while 30.3% had one hospitalization and 24.9% had two or more. Thirty-nine point five percent reported no DKA episode in the preceding year; 34.2% reported one episode and 26.3% reported two or more. Hypoglycemia was reported in 53.9% at least once, including 28.9% reporting more than three episodes.

3.3 Treatment and lifestyle characteristics

Mixed insulin was the most commonly reported regimen (68.4%), followed by soluble insulin (21.1%), zinc insulin (6.6%), and premixed insulin (3.9%). More than half of participants received three injections per day (52.6%), while 47.4% received two. Treatment compliance was reported by caregivers for 93.4% of participants. Blood-glucose self-monitoring three times per week was reported by 57.9%; 11.8% reported no self-monitoring. Most children reported three meals per day (97.4%), while 2.6% reported one to two meals. Two snacks per day were reported by 69.7%. Only 3.9% reported following a specific dietary plan. Sugary foods were consumed sometimes by 56.5%, rarely by 22.4%, often by 6.6%, and not consumed by 14.5%. Physical activity for 1–3 hours was reported by 76.3%.

Growth and nutritional status

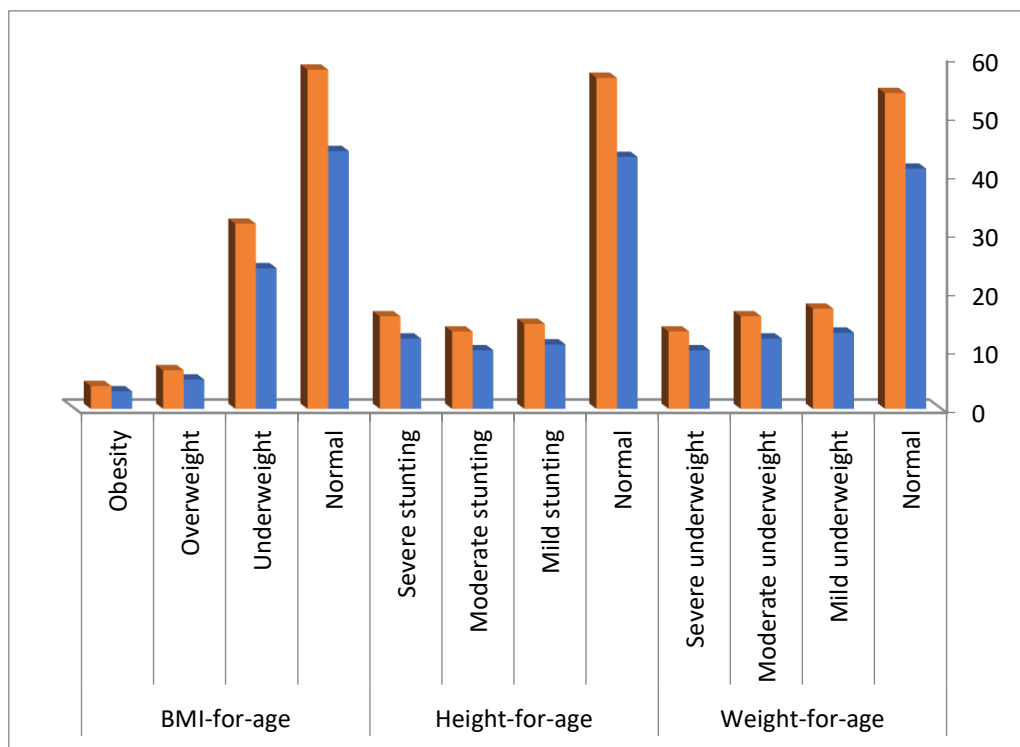
Using weight-for-age, 53.9% were categorized as normal, 17.1% mildly underweight, 15.8% moderately underweight, and 13.2% severely underweight. Using height-for-age, 56.5% were categorized as normal, 14.5% mildly stunted, 13.2% moderately stunted, and 15.8% severely stunted. For BMI-for-age, 57.9% were normal, 31.6% underweight, 6.6% overweight, and 3.9% obese.

Table (2) Growth and nutritional status

Anthropometric indicator	Category	n	%
Weight-for-age	Normal	41	53.9
	Mild underweight	13	17.1
	Moderate underweight	12	15.8
	Severe underweight	10	13.2
Height-for-age	Normal	43	56.5
	Mild stunting	11	14.5

Anthropometric indicator	Category	n	%
	Moderate stunting	10	13.2
	Severe stunting	12	15.8
BMI-for-age	Normal	44	57.9
	Underweight	24	31.6
	Overweight	5	6.6
	Obesity	3	3.9

Figure (2) Growth and nutritional status

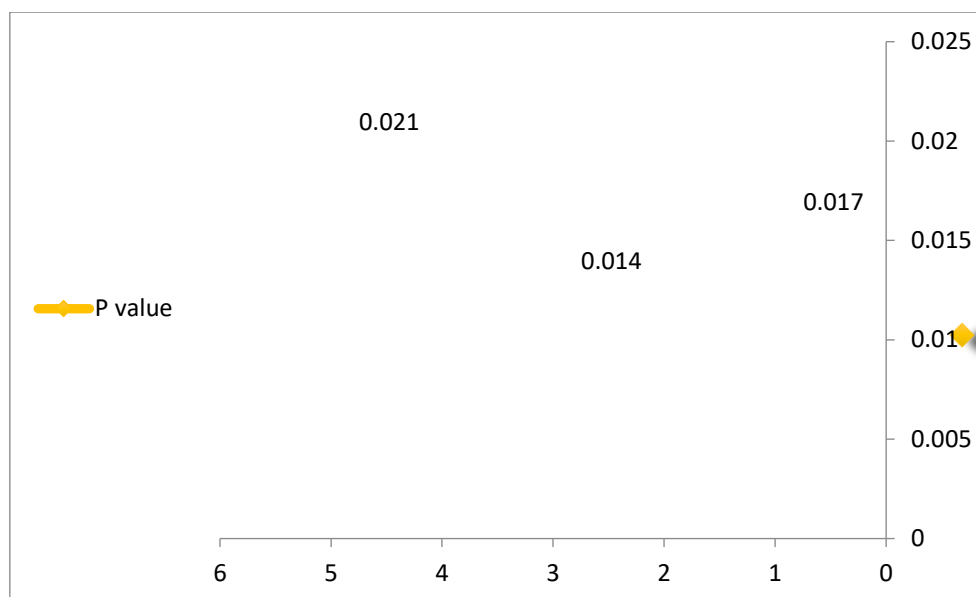


Association with glycemic control

Nutritional status differed significantly by glycemic-control category. For weight-for-age, the distribution differed between controlled and uncontrolled groups ($P=0.017$). Among controlled children, 70.6% were normal compared with 49.2% among uncontrolled children; severe underweight was 5.9% versus 15.3%, respectively. Height-for-age also differed significantly ($P=0.014$): 76.5% of controlled children were normal compared with 50.8% of uncontrolled children, while severe stunting was 5.9% and 18.6%, respectively. BMI-for-age differed significantly as well ($P=0.021$), with underweight present in 17.6% of controlled versus 35.6% of uncontrolled children.

Table (3) Association with glycemic control

Outcome	Controlled n (%)	Uncontrolled n (%)	P value
Normal weight-for-age	12 (70.6)	29 (49.2)	0.017
Severe underweight	1 (5.9)	9 (15.3)	
Normal height-for-age	13 (76.5)	30 (50.8)	0.014
Severe stunting	1 (5.9)	11 (18.6)	
BMI-for-age underweight	3 (17.6)	21 (35.6)	0.021

Figure (3) Association with glycemic control

Association with duration of diabetes

The detailed duration table showed statistically significant differences across the three duration categories. Weight-for-age was associated with duration category ($P=0.027$), height-for-age was associated with duration category ($P=0.031$), and BMI-for-age was associated with duration category ($P=0.025$). For example, the proportion with normal weight-for-age was 52.6% among those with duration <5 years, 57.6% among those with 5–9 years, and 40.0% among those with >9 years. Normal height-for-age was 55.3%, 54.5%, and 80.0%, respectively. Normal BMI-for-age was 47.4%, 66.7%, and 80.0%, respectively. These table-level findings differ from the narrative conclusion of the original thesis, which stated that there was no significant difference in growth between short- and long-duration groups. The discrepancy should be resolved from the original SPSS output before submission. In this manuscript, the exact P values in the source table are reported transparently rather than replacing them with the narrative conclusion.

Association with number of meals

Meal frequency was significantly associated with weight-for-age ($P=0.016$) and height-for-age ($P=0.024$). Only two participants reported one to two meals per day, compared with 74 reporting three meals, so the statistically significant comparisons should be interpreted with substantial caution because of the very small size of the one-to-two-meal group. BMI-for-age was not significantly associated with meal frequency ($P=0.062$).

Association with age and sex

Age was not significantly associated with nutritional status in the source analysis ($P>0.05$). However, severe underweight and severe stunting were reported to be significantly more frequent among males than females ($P<0.05$). The source thesis does not provide complete sex-by-category cross-tabulations and exact P values in the extracted tables, so no additional effect estimates are presented.

4. Discussion

This hospital-based study describes growth and nutritional status among children with T1DM receiving care in Elduiem, White Nile State. Three findings are particularly important. First, glycemic control was poor in most participants, with a mean HbA1c of 10.30% and 77.6% classified as uncontrolled. Second, clinically relevant underweight and stunting were common. Third, poorer nutritional status was significantly associated with poor glycemic control across weight-for-age, height-for-age, and BMI-for-age. The high HbA1c level observed in this study is consistent with the broader literature from resource-limited settings. In Sudan, Ali et al. reported poor glycemic control in 52.5% of children with T1DM, while Taha et al. reported poor control in approximately 76% [30,31]. The current prevalence of 77.6% therefore suggests that poor metabolic control remains a major challenge despite the reported high level of treatment compliance. This apparent discrepancy indicates that reported compliance alone may not capture the full range of determinants of glycemic control, including insulin availability, dosing adequacy, monitoring frequency, dietary consistency, illness, socioeconomic constraints, and health-system factors. Comparable metabolic patterns have been described outside Sudan. Gabri et al. reported a mean HbA1c of 10.85% and poor control in 75.5% of Egyptian children with T1DM [32]. Qadri reported a mean HbA1c of 9.9% with 73.8% poor control among Iraqi adolescents [37]. Mynepally et al. found a mean HbA1c of 10.33% in Indian children with T1DM [44]. These findings place the Elduiem population within a broader pattern of difficult glycemic management in settings where access to specialized diabetes technologies and comprehensive education may be constrained. The prevalence of undernutrition in the present study is also noteworthy. Approximately one third of participants were underweight by BMI-for-age,

while nearly one third had some degree of stunting by the source study's height-for-age categories. Severe underweight affected 13.2%, and severe stunting 15.8%. Previous Sudanese data reported a higher prevalence of stunting (54%) but a lower prevalence of underweight (18%) [30]. Differences may reflect variation in study populations, age distributions, treatment access, definitions, and timing. In Tanzania, Jumaan reported 51% stunting and 28% moderate or severe wasting among children and adolescents with T1DM [41], while Kayirangwa et al. reported 30.9% stunting in Rwanda [42]. The significant association between glycemic control and all three anthropometric indicators is biologically plausible. Insulin is an anabolic hormone and is essential for normal utilization of glucose, protein metabolism, and growth. Chronic insulin deficiency and hyperglycemia may therefore contribute to impaired weight gain and linear growth. Previous studies cited in the thesis similarly reported relationships between HbA1c and anthropometric outcomes. Gabri et al. found significant negative correlations between HbA1c and body weight and BMI [32], while Hussein et al. reported significant negative correlations between HbA1c and weight-for-age and BMI Z-scores [39]. Pavadigoudra et al. also found a significant relationship between poor HbA1c control and short stature [45]. Nevertheless, the cross-sectional design prevents determination of temporal direction. Poor glycemic control may contribute to impaired nutritional status, but undernutrition itself can complicate diabetes management and may be associated with illness, food insecurity, or inconsistent access to meals. Therefore, the observed associations should be interpreted as relationships rather than proof that hyperglycemia caused growth impairment.

The meal-frequency finding requires particularly cautious interpretation. Children reporting one to two meals per day had a higher frequency of low weight-for-age and impaired height-for-age, and the associations were statistically significant. However, only two children were in this category. A P value derived from such a small cell can be unstable, and the finding cannot be generalized without larger studies. Still, the direction of the observation is clinically important because children with T1DM require consistent nutritional intake to coordinate carbohydrate exposure with insulin therapy and support normal growth. The study population also had a high proportion of children from rural areas and large families, with more than half of families containing more than six members. These contextual characteristics may affect food availability, transport to specialist services, health education, and access to glucose-monitoring supplies. The present dataset did not contain sufficient multivariable analysis to determine whether socioeconomic factors independently predicted growth impairment. Future studies should include household food security, household income, distance to clinic, insulin affordability and availability, and access to glucose-monitoring equipment. The finding that severe underweight and severe stunting were more frequent among boys deserves further study. Sex differences in growth trajectories, pubertal timing, nutritional requirements, and care-seeking may contribute, but the present study was not designed to establish mechanisms. Other studies have reported sex-related differences, although the direction has not been consistent [37,39,41]. Duration of diabetes requires special consideration because the source thesis contains an internal inconsistency. The detailed cross-tabulation reports statistically significant associations between duration category and weight-for-age, height-for-age, and BMI-for-age, whereas the narrative discussion and conclusion state that no significant difference was observed between short and long duration. The discrepancy may reflect differences between the three-category and two-category analyses, a transcription error, or the original statistical output. A journal manuscript should not conceal this inconsistency. The present version therefore reports the detailed table results and explicitly flags the need to verify the original SPSS analysis before submission. The results are also relevant to the concept of growth monitoring as a clinical quality indicator. The literature summarized in the source thesis indicates that some children with T1DM can achieve near-normal final height when metabolic control is adequate, while growth deceleration may occur when control is persistently poor [29,43–52]. This suggests that routine plotting of height, weight, and BMI Z-scores may identify children at risk earlier than clinical symptoms alone. In settings with limited resources, anthropometric surveillance is inexpensive and can be incorporated into routine pediatric diabetes visits. The coexistence of undernutrition and a smaller proportion of overweight/obesity also illustrates the double burden of malnutrition. Although undernutrition was the dominant concern in this sample, 6.6% were overweight and 3.9% obese. This finding supports an individualized rather than uniform dietary strategy. Nutrition education should aim to provide adequate energy and micronutrients while promoting balanced carbohydrate intake and avoiding excessive intake of high-sugar foods. Overall, the study contributes locally relevant evidence from White Nile State, where published pediatric diabetes data are limited. Its main public-health implication is that improving metabolic control should be accompanied by systematic nutritional assessment rather than focusing on HbA1c alone. Children with persistent high HbA1c, low BMI-for-age, or reduced height-for-age should receive intensified clinical review and nutritional support.

Strengths and Limitations

Strengths include the inclusion of all eligible pediatric clinic attendees during the study period, direct anthropometric measurement using standardized procedures, assessment of three complementary growth indicators, measurement of HbA1c, and collection of information on dietary and diabetes-management characteristics. The study also addresses an under-researched population in White Nile State. Several limitations should be considered. First, the cross-sectional design precludes causal inference and does not measure growth velocity or final height. Second, the sample was small and recruited from a single hospital using convenience sampling, limiting generalizability. Third, the meal-frequency comparison contained only two children in the one-to-two-meal category, making that association particularly unstable. Fourth, the study did not include a healthy control group, preventing direct comparison with children without diabetes from the same population. Fifth, socioeconomic variables and food-security measures were limited. Sixth, the study relied partly on caregiver-reported information, which may introduce recall or reporting bias. Finally, the duration-of-diabetes analysis contains an inconsistency between the detailed table and the narrative conclusion that should be resolved using the original statistical output before journal submission.

Clinical and Public Health Implications

The findings support integration of growth and nutrition monitoring into routine pediatric diabetes care. At each clinic visit, children should have weight and height measured and interpreted using age- and sex-specific standards. Children with persistent hyperglycemia should receive review of insulin

regimen, glucose monitoring, dietary intake, and barriers to treatment. Nutrition counseling should emphasize adequate energy intake, balanced meals, appropriate carbohydrate distribution, and increased consumption of nutrient-dense foods. In resource-limited settings, practical counseling should be adapted to locally available foods and household economic realities. At the health-system level, pediatric diabetes services should strengthen access to HbA1c testing, insulin supplies, glucose-monitoring equipment, trained nutrition support, and structured diabetes education. Prospective multicenter studies are needed to evaluate growth velocity, pubertal development, food security, insulin dose, socioeconomic determinants, and long-term outcomes.

Results

1. Growth and nutritional abnormalities were common among children with T1DM attending the pediatric diabetes clinic at Edduiem Teaching Hospital.
2. The study population had a high prevalence of poor glycemic control, with a mean HbA1c of 10.30% and 77.6% classified as uncontrolled. Underweight and stunting were frequent, and nutritional status was significantly associated with glycemic-control category across weight-for-age, height-for-age, and BMI-for-age. Meal frequency was associated with weight-for-age and height-for-age, although the very small number of children reporting one to two meals limits interpretation.
3. The detailed duration-of-diabetes tables also showed statistically significant associations, but this conflicts with the original narrative conclusion and should be verified from the primary statistical output.
4. These findings support routine growth surveillance, individualized nutritional counseling, and stronger strategies to improve glycemic control in children with T1DM in resource-limited settings.

Recommendations

- 1) Strengthen regular HbA1c and blood-glucose monitoring and review treatment barriers among children with persistently poor control.
- 2) Measure weight and height routinely and plot age- and sex-specific growth indicators during pediatric diabetes follow-up.
- 3) Provide structured nutrition education for children and caregivers, emphasizing adequate and balanced meals, fiber-rich foods, fruits and vegetables, and moderation of high-sugar foods.
- 4) Pay particular attention to children with low BMI-for-age, low weight-for-age, or reduced height-for-age and assess dietary adequacy and treatment adherence.
- 5) Improve access to insulin, glucose-monitoring supplies, diabetes education, and pediatric nutrition services in rural and underserved communities.
- 6) Conduct larger prospective multicenter studies in Sudan to examine growth velocity, puberty, insulin dose, food security, socioeconomic factors, and long-term glycemic control.
- 7) Before submission of this manuscript, verify the duration-of-diabetes analysis against the original SPSS output and resolve the discrepancy between the detailed tables and the thesis narrative.

Declarations

1. Ethics approval: The source thesis reports ethical review through the Sudan Medical Specialization Board, Council of Pediatrics and Child Health, and the Educational Development 2. Centre. The exact approval/reference number should be inserted after verification.
3. Consent: Written informed consent was obtained from caregivers according to the source thesis.
4. Funding: Not reported in the source thesis; to be confirmed by the authors.
5. Conflict of interest: Not reported in the source thesis; to be completed by the authors.
6. Data availability: The underlying participant-level dataset was not provided with the thesis file. 7. A data-availability statement should therefore be finalized by the authors according to institutional and journal requirements.
8. Author contributions: To be completed by the authors according to the target journal's authorship requirements.

References

- Magliano DJ, Boyko EJ; IDF Diabetes Atlas 10th edition scientific committee. IDF Diabetes Atlas. 10th ed. Brussels: International Diabetes Federation; 2021.
- Tuomilehto J, Ogle GD, Lund-Blix N, Stene LC. Epidemiology of childhood type 1 diabetes. *Pediatr Endocrinol Rev.* 2020;17(Suppl 1):198–209.
- Manne-Goehler J, Geldsetzer P, Agoudavi K, et al. Health system performance for people with diabetes in 28 low- and middle-income countries: a cross-sectional study of nationally representative surveys. *PLoS Med.* 2019;16:e1002751.

- Elamin A, Omer MI, Zein K, Tuvemo T. Epidemiology of childhood type 1 diabetes in Sudan 1978–1990. *Diabetes Care*. 1992;15:1558–1559.
- Elamin A, Ghalib M, Eltayeb BTT. High incidence of type I diabetes mellitus in Sudanese children. *Ann Saudi Med*. 1997;17(4):478–480.
- Saad FM, Mahmoud LA, Ali AMM, Omer IM, Abdullah MA. Incidence and prevalence of type 1 diabetes mellitus in children and adolescents aged 6 months–19 years in Khartoum State, Sudan. *Sudan J Paediatr*. 2020;20(2):163–169.
- Sundberg F, de Beaufort C, Krogvold L, et al. ISPAD Clinical Practice Consensus Guidelines 2022: managing diabetes in preschoolers. *Pediatr Diabetes*. 2022;23:1496–1511.
- Dinleyici M, Çarman KB, Özdemir C, et al. Quality-of-life evaluation of healthy siblings of children with chronic illness. *Balkan Med J*. 2019;37:34–42.
- Hu K, Staiano AE. Trends in obesity prevalence among children and adolescents aged 2 to 19 years in the US from 2011 to 2020. *JAMA Pediatr*. 2022;176(10):1037–1039.
- Buzzetti R, Zampetti S, Pozzilli P. Impact of obesity on the increasing incidence of type 1 diabetes. *Diabetes Obes Metab*. 2020;22(7):1009–1013.
- de Ferranti SD, de Boer IH, Fonseca V, et al. Type 1 diabetes mellitus and cardiovascular disease: a scientific statement from the American Heart Association and American Diabetes Association. *Circulation*. 2014;130(13):1110–1130.
- Maffei C, Birkebaek NH, Konstantinova M, et al. Prevalence of underweight, overweight, and obesity in children and adolescents with type 1 diabetes: data from the international SWEET registry. *Pediatr Diabetes*. 2018;19(7):1211–1220.
- Chiang JL, Maahs DM, Garvey KC, et al. Type 1 diabetes in children and adolescents: a position statement by the American Diabetes Association. *Diabetes Care*. 2018;41(9):2026–2044.
- Los E, Wilt AS. Type 1 Diabetes in Children. In: *StatPearls*. Treasure Island, FL: StatPearls Publishing; 2025.
- American Diabetes Association. Children and adolescents: Standards of Medical Care in Diabetes—2019. *Diabetes Care*. 2019;42(Suppl 1):S148–S164.
- Wolfsdorf JL, Glaser N, Agus M, et al. ISPAD Clinical Practice Consensus Guidelines 2018: diabetic ketoacidosis and the hyperglycemic hyperosmolar state. *Pediatr Diabetes*. 2018;19(Suppl 27):155–177.
- Triolo TM, Fouts A, Pyle L, et al.; Type 1 Diabetes TrialNet Study Group. Identical and nonidentical twins: risk and factors involved in development of islet autoimmunity and type 1 diabetes. *Diabetes Care*. 2019;42(2):192–199.
- Diabetes Control and Complications Trial/Epidemiology of Diabetes Interventions and Complications Study Research Group. Intensive diabetes treatment and cardiovascular outcomes in type 1 diabetes: the DCCT/EDIC study 30-year follow-up. *Diabetes Care*. 2016;39(5):686–693.
- Libman I. ISPAD Clinical Practice Consensus Guidelines: definition, epidemiology, and classification of diabetes in children and adolescents. *Pediatr Diabetes*. 2022;23(8):1160–1174.
- Mehta NM. Defining pediatric malnutrition: a paradigm shift toward etiology-related definitions. *J Parent Enteral Nutr*. 2023;37(4):460–481.
- Uwaezuoke SN. Childhood diabetes mellitus and the double burden of malnutrition: an emerging public health challenge in developing countries. *J Diabetes Metab*. 2015;6:597.
- Baseer KA, Mohammed AE, Elwafa AM, Sakhr HM. Prevalence of celiac-related antibodies and its impact on metabolic control in Egyptian children with type 1 diabetes mellitus. *BMC Pediatr*. 2024;24:99.
- Bene J, Hadzsiev K, Melegh B. Role of carnitine and its derivatives in the development and management of type 2 diabetes. *Nutr Diabetes*. 2018;8:8.
- Bahendeka SK. Diabetes in sub-Saharan Africa: let us not forget type 1. *Lancet Diabetes Endocrinol*. 2017;5:575–577. Sandovici I, Smith NH, Nitert MD, et al. Maternal diet and aging alter the epigenetic control of a promoter-enhancer interaction at the *Hnf4a* gene in rat pancreatic islets. *Proc Natl Acad Sci U S A*. 2021;108(13):5449–5454.
- Park JH, Stoffers DA, Nicholls RD, Simmons RA. Development of type 2 diabetes following intrauterine growth retardation in rats is associated with progressive epigenetic silencing of *Pdx1*. *J Clin Invest*. 2018;118(6):2316–2324. Yajnik CS. Transmission of obesity-adiposity and related disorders from the mother to the baby. *Ann Nutr Metab*. 2014;64(Suppl 1):8–17.
- Braziuniene I, et al. Effect of insulin with oral nutrients on whole-body protein metabolism in growing pubertal children with type 1 diabetes. *Pediatr Res*. 2019;65(1):109–112.
- Elamin A, Hussein O, Tuvemo T. Growth, puberty, and final height in children with type 1 diabetes. *J Diabetes Complications*. 2006;20(4):252–256.
- Ali MOE, Abdullah MA. Growth and nutritional assessment of children with type 1 diabetes mellitus in Wadmedani Teaching Hospital, Gezira State. Thesis. Sudan Medical Specialization Board; 2018.
- Taha Z, Eltoum Z, Washi S. Predictors of glucose control in children and adolescents with type 1 diabetes: results of a cross-sectional study in Khartoum, Sudan. *Maced J Med Sci*. 2018;6(11):2035–2039.

- Gabri MF, Abdshaheed TS, Zaki EH, ElNakeeb IF, Aly HM. Growth disorders in children with type 1 diabetes in Aswan, Egypt. *Egypt J Hosp Med*. 2020;81(4):1726–1731.
- Sakhr HM, Hassan M, Ahmed AEA, et al. Nutritional status and extended metabolic screening in Egyptian children with uncomplicated type 1 diabetes. *Sci Rep*. 2024;14:21055.
- Al-Bahnasawy A-EF, El-Mougy MT, Farag IM, Yadak SES. Assessment of the nutritional status of children and adolescents with type 1 diabetes mellitus. *Al-Azhar Journal of Pediatrics*. 2023;26(3):3483–3498.
- Sherif EM, Adel Thabet R, Mahmoud RA, Abd El-aal AMA, et al. Assessment of anthropometric and pubertal growth of children and adolescents with type 1 diabetes mellitus. *QJM*. 2024;117(Suppl 1):070.519.
- Aljuhani FM, Al-Agha AE, Almunami BA, et al. Growth status of children and adolescents with type 1 diabetes mellitus in Jeddah, Saudi Arabia: a cross-sectional study. *Curr Pediatr Res*. 2018;22(3):249–254.
- Qadir KJ. Growth status of adolescents with diabetic type 1 and its associated factors. *Medical Research Archives*. 2023;11(7).
- Mousa WLA, Aitte SA, Qasim AK. Nutritional status of pediatric patients with type 1 diabetes mellitus in DhiQar Governorate. *Ann RSCB*. 2021;25(7):370–375.
- Hussein SA, Ibrahim BA, Abdullah WH. Nutritional status of children and adolescents with type 1 diabetes mellitus in Baghdad: a case-control study. *J Med Life*. 2023;16(2):254–260.
- Dohan BR, Habeeb SI, Abed Khazaal A. Nutritional status of children and adolescents with type 1 diabetes mellitus in Basrah. *Med J Basrah Univ*. 2021;39(1):54–60.
- Jumaan ZA. Nutritional status of children and adolescents with type one diabetes mellitus attending three diabetic clinics in Dar es Salaam, Tanzania. *HKMU*. 2021;4(7):12–17.
- Kayirangwa A, Rutagarama F, Stafford D, McCal N. Assessment of growth among children with type 1 diabetes mellitus: a cross-sectional study of factors contributing to stunting. *J Diabetes Metab*. 2018;9:793.
- Jadhav I, Chakole S. Effects of type 1 diabetes mellitus on linear growth: a comprehensive review. *Cureus*. 2023;15(9):e45428.
- Mynepally M, Yadav BR, Mythili A, Vivekananda B, Subrahmanyam KA. Study of growth parameters in children and adolescents with type 1 diabetes mellitus. *J Pediatr Endocrinol Diabetes*. 2023;3:58–62.
- Pavadigoudra MK, Sajjanar SB, Uday K, Ushakiran CB. Assessment of growth among children with type 1 diabetes mellitus. *Int J Contemp Pediatr*. 2024;11:1057–1060.
- Demir K, Altıncık A, Abacı A, Büyükgebiz A, Böber E. Growth of children with type 1 diabetes mellitus. *J Clin Res Pediatr Endocrinol*. 2019;2(2):72–77.
- Kim MS, Quintos JB. Mauriac syndrome: growth failure and type 1 diabetes mellitus. *Pediatr Endocrinol Rev*. 2019;5(Suppl 4):989–993.
- Lebl J, Schober E, Zidek T, et al. Growth data in large series of 587 children and adolescents with type 1 diabetes mellitus. *Endocr Regul*. 2021;37(3):153–161.
- Meira SO, Morcillo AM, Lemos-Marini SHV, et al. Pubertal growth and final height in 40 patients with type 1 diabetes mellitus. *Arq Bras Endocrinol Metabol*. 2019;49(3):396–402.
- Salerno M, Argenziano A, Di Maio S, et al. Pubertal growth, sexual maturation, and final height in children with IDDM: effects of age at onset and metabolic control. *Diabetes Care*. 2018;20(5):721–724.
- Choudhury S, Stutchfield P. Linear growth and weight gain in diabetic children: a cross-sectional and longitudinal evaluation. *J Pediatr Endocrinol Metab*. 2018;13(5):537–544.
- Kanumakala S, Dabadghao P, Carlin JB, Vidmar S, Cameron FJ. Linear growth and height outcomes in children with early onset type 1 diabetes mellitus—a 10-yr longitudinal study. *Pediatr Diabetes*. 2002;3:189–193.
- World Health Organization. WHO Child Growth Standards: Training Course on Child Growth Assessment. Geneva: WHO; 2008.
- American Diabetes Association. Standards of Care in Diabetes—2024. *Diabetes Care*. 2024;47(Suppl 1):S1–S321.
- Mustafa IO, Tanko Y, Yusuf R, Musa SA. The use of glycated haemoglobin (HbA1C) in determining glycemic control (and relevance of BMI) in diabetic patients in Ahmadu Bello University Teaching Hospital Zaria, Nigeria. *Diabetes Metab Syndr*. 2019;13(5):2967–2972.

Appendix (1) Key source-data tables retained for manuscript verification

Glycemic status	Weight-for-age normal	Severe underweight	Height-for-age normal	Severe stunting	BMI underweight
Controlled	70.6%	5.9%	76.5%	5.9%	17.6%
Uncontrolled	49.2%	15.3%	50.8%	18.6%	35.6%
Duration	Normal WAZ	Normal HAZ	Normal BMI-for-age	P values	
<5 years	52.6%	55.3%	47.4%	0.027 / 0.031 / 0.025	
5–9 years	57.6%	54.5%	66.7%		
>9 years	40.0%	80.0%	80.0%		
Meals/day	WAZ association	HAZ association	BMI association		
1–2 vs 3 meals	P=0.016	P=0.024	P=0.062		

Source note: All participant-level findings and numerical results in this manuscript were derived from the supplied thesis file. No participant data, statistical estimates, or effect sizes have been invented. Before submission, the authors should verify the statistical outputs, correct typographical inconsistencies in the original tables, confirm the exact WHO/ADA classification used, and update references where necessary.

