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REVIEW ARTICLE

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HbA1c, C-Peptide, and Other Biochemical Indicators in the Management of Type 1 Diabetes Mellitus: A Review

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Abstract

The number of children and adolescents who are suffering from Type 1 Diabetes Mellitus (T1DM) in Iraq is continuously increasing. Nutritional management and biochemical markers play a major role in controlling the disease. Several criteria are essential for assessing glycemic control and the course of the disease.

Methods: This review examined published Iraqi research addressing two topics that have a direct effect on type 1 Diabetes Mellitus (T1DM): nutritional aspects (carbohydrate counting and dietary education) and biochemical markers (HbA1c and C-peptide). The findings were compared with those of other international studies.

Results: Iraqi studies consistently recorded higher HbA1c levels and lower C-peptide concentrations compared with healthy control groups, which indicates compromised β-cell function and poor glycemic control. Nutritional studies showed that inadequate dietary education and a lack of carbohydrate counting are the two main causes of uncontrolled diabetes. Iraqi studies were consistently characterized by small sample sizes, cross-sectional designs, no longitudinal follow-up, and inadequate assay standardization. Global studies, on the other hand, produced insights through larger cohorts, standardized procedures, and long-term follow-ups.

Conclusion: The evidence from Iraqi studies shows a critical need for extensive, multicenter, long-term research to enhance glycemic outcomes in children with type 1 diabetes. Future studies should aim to combine structured nutritional interventions with biochemical monitoring.

Keywords: Type 1 diabetes mellitus, Children and adolescents, Biochemical markers, Nutritional factors, Iraq, Public health

1. Introduction

Type 1 Diabetes Mellitus (T1DM) is a chronic disease characterized by the destruction of pancreatic β-cells, leading to complete insulin insufficiency and metabolic abnormalities [1]. T1DM is continually increasing in prevalence, especially in children and adolescents, which means it is a serious clinical and public health issue [2]. By understanding the pathophysiologic mechanisms, effective management and monitoring of type 1 diabetes, as well as its clinically detectable symptoms, are required [3]. We discussed the biological causes of type 1 diabetes in Iraqi children and adolescents in a previous review. We studied how immunologic functions, genetic predispositions, and environmental factors affect the onset of the disease. In addressing aspects related to disease progression in the same population, the current review focuses on a different set of determinants that were not previously discussed but can still be considered a continuation. In this review, we shift the

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conversation to the importance of biochemical and glycemic markers. Glycated hemoglobin (HbA1c) levels [4] and other biomarkers, such as C-peptide, are important for assessing glycemic control in children and adolescents with type 1 diabetes. By combining regional data and the study's findings from the global literature, we attempted to present a current and succinct overview of the use of biomarkers in clinical practice. Our knowledge of the variables that might be affecting T1DM in the general population is still limited, and further investigations are needed to clarify their role.

1.1. Rationale

There are significant gaps in biochemical and glycemic markers, especially in children and adolescents, particularly in Iraq and other developing countries. There are also clear gaps in biochemical and nutritional determinants. A comprehensive lack of data exists in this age group, yet these markers, such as glycated hemoglobin (HbA1c) and C-peptide, represent direct and quantitative measures of therapy effectiveness and assist in the early detection of hyperglycemia. However, the current data are not integrated into the clinical platform, or they are available only in fragments and do not come from all regions [5].

1.2. Objective

This review aimed to identify the knowledge gaps. We hope that this work will serve as a solid guide for determining the best course of clinical monitoring and treatment choices that will benefit young patients over the long run.

The main review question is: What biochemical and nutritional markers are currently available for monitoring type 1 diabetes in Iraqi children and adolescents, and what gaps exist in the local evidence compared to global standards?

2. Methodology

This review employed a narrative approach, gathering available evidence from previous studies in the scientific literature that discuss biochemical and glycemic markers of type 1 diabetes mellitus (T1DM) in children and adolescents in Iraq. This evidence was then summarized and analyzed comprehensively and scientifically. The research strategy involved a thorough systematic search of previous studies published in electronic databases such as PubMed, Scopus, Web of Science, and Google Scholar between 2014 and 2025. This time frame was selected to capture the most recent and relevant clinical evidence available in Iraq. Keywords used included Iraq, type 1 diabetes mellitus, HbA1c, C-peptide, biochemical markers, glycemic control, metabolic markers, and others. A total of relevant studies were identified, and only those that met the inclusion criteria were included in this review. The data were synthesized narratively, following a thematic approach that grouped the findings into biochemical markers, nutritional factors, and gaps in local evidence. No statistical meta-analysis was conducted due to heterogeneity in sample sizes, study designs, and measured outcomes.

2.1. Inclusion criteria

Studies that met a set of criteria were included. Such as publication in English, and being original articles, research papers, and reviews. Clinical and observational studies relevant to biochemical and metabolic markers were also considered. Research on metabolic and biochemical markers: The study focused on children or adolescents (under 18 years of age) diagnosed with type 1 diabetes mellitus (T1DM) in Iraq, or data reported on HbA1c or C-peptide, metabolic markers, or data from studies conducted in specialized diabetes clinics or hospitals.

2.2. Exclusion criteria

Studies focusing solely on gestational diabetes or type 2 diabetes, non-peer-reviewed studies, abstracts, and conferences, studies lacking sufficient quantitative information on biochemical markers and nutritional issues, and studies where age groups were mixed, and the data did not differentiate between children and adolescents, were excluded.

2.3. Data extraction and analysis

Data were extracted from the selected studies using a standardized data extraction sheet. This sheet included the authors, year of publication, study type and design, sample size, age group studied, clinical parameters analyzed (such as HbA1c and C-peptide), and study outcomes.

3. Review findings (results)

3.1. Biochemical markers

Biochemical markers serve as fundamental indicators for evaluating metabolic control and pancreatic β-cell function in children and adolescents with Type 1 Diabetes Mellitus. This section summarizes the available Iraqi evidence on key biochemical indicators and examines how these markers contribute to understanding disease severity and glycemic regulation. The findings are presented in three parts: an overview of Iraqi studies, a comparison with international literature, and a description of major research gaps and limitations.

To diagnose and understand type 1 diabetes, especially in children and adolescents, biochemical markers are considered a crucial indicator. They show how well the pancreas is working and how blood sugar is controlled. C-peptide, which helps evaluate the body's capacity to produce insulin, and HbA1c, which reflects average blood glucose levels over the previous three months, are key biochemical markers for assessing diabetes. This section reviews the prior studies that were done in Iraq, which examined the biochemical markers and their effects on patients with type 1 diabetes, in addition to identifying the current research gaps that may hinder disease control strategies in Iraq [6].

3.1.1. HbA1c

One of the most important indicators used to assess how well a type 1 diabetes patient is managing their condition is the HbA1c test. According to most guidelines, an HbA1c below 7% is considered relatively well-controlled, while a level above 7% suggests poor control and a higher risk of complications [7]. A study done by Hussein et al. (2023) was conducted at the Central Children's Teaching Hospital in Baghdad during the period between November 2021 to July 2022, the sample consisted of 192 participants, 96 of them were children and adolescents with type 1 diabetes mellitus, and the other 96 were healthy controls. The BMI and weight-for-age were significantly lower in diabetic patients compared with controls ($P<0.001$). All undernourished patients were from large families, and the mean age of disease onset was later in the undernourished group (8.83 ± 2.89 years) compared with the normally nourished group (6.61 ± 2.78 years). About the HbA1c, it showed a significant negative correlation with BMI ($r = -0.295$, $p = 0.006$) and weight-for-age ($r = -0.312$, $p = 0.004$), indicating poor glycemic control, which leads to an increased risk of undernutrition. Malnutrition included older age, female sex, large family size, and longer disease duration. These findings indicate the importance of HbA1c as a marker of metabolic control and as an early indicator of malnutrition in children and adolescents with T1DM. This suggests that poor glycemic regulation directly contributes to nutritional deterioration among Iraqi children with T1DM [8]. Another study was conducted in Karbala in 2015; This was a cross-sectional epidemiological study. the sample was consisting of 199 children within the same age group. This study focused on the epidemiological characteristics of type 1 diabetes and the level of glycemic control. It revealed that 31.6% of children had a low level below 7% of HbA1c, which indicates an acceptable management of the disease, while the majority suffered from poor glycemic control. Similar to the Baghdad study, an association was confirmed between elevated HbA1c levels and adverse health outcomes. However, the Karbala study further noted that poor home glucose monitoring and irregular visits to healthcare centers were major contributors to poor control. This indicates that behavioral and family-related factors significantly influence metabolic stability in Iraqi children. Whereas the Baghdad study focused on the link between high HbA1c and poor nutritional status, particularly among female patients [9]. A quasi-experimental study was conducted on 40 male adolescents with type 1 diabetes Mellitus in the Kurdistan Region of Iraq to evaluate the effect of regular swimming on glycemic control. Participants were divided into two groups: 20 adolescents who were participated in a program of 10-week swimming program (intervention group), and another 20 who did not participate in any program of physical activity, considered as control group. The mean age was approximately 13 years. The level of HbA1c was measured before and after the swimming activity to assess the changes in blood glucose level. The results recorded a significant reduction in the HbA1c levels in the intervention group, while an increase in glucose level was observed in the control group. These findings indicate that regular physical activity, such as swimming, can effect positively and improve glycemic control in male adolescents with type 1 diabetes mellitus and should be considered as a treatment plan [10]. These findings reflect the potential benefit of structured physical activity in improving metabolic regulation among adolescents with T1DM. Another study done by Eland in (2022) explored the impact of a gluten-free diet (GFD) in patients with both type 1 diabetes mellitus and celiac disease. This was a longitudinal dietary intervention study. The results recorded that good adherence to GFD was related to the lower level of HbA1c, improved BMI, better lipid profiles, and improved life quality. GFD did not increase insulin requirements or impair growth in children, but it helped reduce the risk of microvascular and macrovascular complications, making it a beneficial long-term dietary approach [11]. This suggests that structured dietary interventions can complement insulin therapy and improve metabolic outcomes in T1DM.

3.1.1.a. Discussion: All Iraqi studies focused on the critical role of HbA1c in assessing glycemic control among children and adolescents with type 1 diabetes mellitus. The sample sizes ranged from 40 to 199 participants, which is acceptable for case-control or quasi-experimental study designs. HbA1c acts as the main biochemical marker, and it is clinically valid; however, relying on HbA1c alone without incorporating additional markers—such as C-peptide, lipid profiles, or inflammatory biomarkers—limits the depth of physiological interpretation. Statistically, the reported findings were supported by significant associations, including correlations between HbA1c and anthropometric parameters, as well as pre- and post-intervention differences in interventional studies.

Gaps: Compared to the global literature, important research gaps exist. International studies frequently integrate additional hormonal and immunological markers alongside HbA1c, providing a more comprehensive evaluation of metabolic and immune function. In the case of gluten-free diets (GFD), findings remain inconsistent—some report improved HbA1c while others do not—emphasizing the need for localized trials in Iraq. Global research involves larger cohorts, longer follow-up, and multi-center collaborations, which means the assessment of HbA1c over multiple years is conducted with rigorous standardization.

Limitations: Most Iraqi studies were done in one center, were short-term, and limited only to HbA1c without any broader biochemical or immunological profiling. Continuous glucose monitoring (CGM), a standard in many global studies, remains restricted in Iraq due to resource constraints [12]. We now move to international studies that take a different scope and methodology compared to Iraqi research. The INNODIA Natural History Study (Marcovecchio et al., 2024) on the newly diagnosed patients with T1DM (n = 767) showed that the HbA1c decreased in the first three months, then progressively increased alongside insulin needs; younger age children (<10 years) had lower C-peptide levels, but the rates declined similarly across ages. Lower BMI and DKA at diagnosis predicted persistently reduced C-peptide [13].

3.1.1.b. In a large German/Austrian multicenter analysis by Gerstl et al. involving 27,035 patients from 207 centres with 338,330 HbA1c readings, HbA1c peaked at diagnosis (∼9.1%), improved in the first two years (∼7.1%), then worsened post-remission (∼7.9%), with over 23% above guideline targets. Influencing factors included age, duration, gender (girls consistently higher), minority status, therapy type, and treatment center [14], A longitudinal HRQL study by Fischer et al. following 287 children and adolescents aged 7–17 years, confirmed that patients with HbA1c >9.0% had worse physical, psychological, and family outcomes, reinforcing the link between poor control and quality of life [15].

3.1.1.c. In summary, the small sample sizes, the single-center studies, and the short follow-up periods of Iraqi studies give weak findings, which can't be considered as the international studies, which exhibit comprehensive results. The INNODIA study examined 767 newly diagnosed patients in Europe [13], the German/Austrian DPV analysis assessed 27,035 patients from 207 sites over a decade [14], and the longitudinal investigation by Fischer et al. investigated 287 children and adolescents aged 7 to 17 [15]. These extensive, multi-center, and standardized methodologies let us learn more about metabolic patterns, quality of life, and long-term effects. This enormous discrepancy suggests that Iraq really needs to adopt bigger, multi-center, and longer-term methods to collect data that is more accurate and can be compared to data from other nations.

3.1.2. Insulin and C-peptide

Insulin and C-peptide are central biochemical indicators for assessing residual β-cell activity and understanding the autoimmune destruction that characterizes Type 1 Diabetes Mellitus in children and adolescents. This section reviews the Iraqi evidence describing variations in insulin production and C-peptide levels and evaluates how these markers reflect disease severity and metabolic instability. The findings are organized into three parts: a summary of Iraqi studies, a comparison with global research, and an outline of the major research gaps that limit the interpretation of local results.

A case-control study was conducted in Al-Najaf Al-Ashraf, Iraq, from October 2023 to February 2024, to examine immunological markers in children and adolescents with type 1 diabetes mellitus. The study included 120 participants aged 3 to 17 years, with 80 diagnosed with type 1 diabetes mellitus and 40 considered healthy controls. C-peptide was identified as a crucial biomarker of pancreatic β-cell function in the studied participants. The findings indicated that individuals with type 1 diabetes mellitus exhibited significantly reduced C-peptide levels compared with healthy individuals, hence confirming their severe insulin deficiency. Moreover, patients with higher anti-GAD65 autoantibody levels displayed C-peptide levels, signifying greater autoimmune destruction of β-cells. The decrease in C-peptide helps in evaluating the disease severity in young patients with type 1 diabetes mellitus. The study's findings also recorded an increase in miRNA-155 levels and a decrease in IL-2 levels [16]. These findings indicate substantial β-cell destruction and highlight the utility of C-peptide as an early marker of disease severity in Iraqi children with T1DM.

A case-control study was conducted at the University of Al-Basrah and included 160 children aged 2 to 15 years. They were divided into 80 children with Type 1 Diabetes Mellitus and 80 healthy controls. The objective was to assess C-peptide levels and determine pancreatic insulin production. Children with diabetes had lower C-peptide levels (0.189 ng/ml), while healthy children recorded 2.96 ng/ml. Children with a longer duration of the disease, especially those diagnosed earlier, showed reduced C-peptide levels, indicating greater β-cell damage. It was noted that HbA1c showed no correlation with C-peptide levels. Fasting C-peptide is a strong indicator of residual β-cell function; therefore, the study encourages early diagnosis to preserve pancreatic cell activity [17]. This suggests that delayed diagnosis contributes directly to rapid β-cell depletion and reduced endogenous insulin secretion among affected children.

In a case-control study conducted in the southern Iraqi province of Thi-Qar, thirty healthy children served as the control group, while sixty patients aged 9 to 18 with type 1 diabetes mellitus were evaluated. The primary objective of the study was to examine immunological markers, particularly C-peptide, which serves as an indicator of pancreatic β-cell activity. The results showed that T1DM patients had significantly lower levels of endogenous insulin secretion and lower mean C-peptide levels than healthy controls. There was no significant difference between GADA-positive and GADA-negative patients; however, C-peptide levels were significantly lower in patients with IA-2A autoantibodies compared to those without. These results indicate that C-peptide is a strong indicator of residual beta-cell function and, when used alongside autoantibody profiling, can enhance the accuracy and cost-effectiveness of diagnosing type 1 diabetes in pediatric and adolescent populations [18]. These findings reflect a strong relationship between autoimmune activity and diminished β-cell function, underscoring the diagnostic value of combining C-peptide with autoantibody profiles.

3.1.2.a. Discussion: All Iraqi studies (Najaf, Basra, Dhi Qar) confirmed that C-peptide is the most important marker of β-cell function [19–21]. Patients with type 1 diabetes mellitus consistently showed a clear reduction in C-peptide compared to healthy controls, reflecting a major loss of endogenous insulin production. Some studies also reported an association between low C-peptide levels and the presence of autoantibodies such as GADA and IA-2A, although results were not consistent across provinces. However, these Iraqi investigations face several limitations, including small sample sizes (only 60–160 participants), restriction to basic immunological markers (C-peptide, GADA, IA-2A) without deeper exploration of genetic polymorphisms or clinical stage variations, absence of longitudinal follow-up to monitor long-term changes, and lack of assay standardization, which limits comparability both across provinces and with international literature [19].

3.1.2.b. In comparison with global literature, Iraqi studies confirm that C-peptide is the most important marker of beta-cell function, which is consistent with Palmer et al. (2004) and the DCCT/EDIC findings showing that levels above 0.03 nmol/L reduce the risk of severe hypoglycemia. The results also partly align with evidence on immune markers (GADA, IA-2A). Conversely, Nejentsev et al. globally found that some rare variants of the IFIH1 gene reduce the risk of type 1 diabetes, while Iraqi studies did not show a statistically significant association. This difference may be due to either the genetic background of the local population or the small sample sizes, highlighting the need for larger genetic studies in Iraq to explain this variation [19].

In a large clinical investigation, C-peptide was evaluated as a biomarker of β-cell function using 4,079 plasma samples from the UK GRID cohort of patients diagnosed with type 1 diabetes at $\leq$16 years, and 235 pancreatic tissue samples from nPOD (n=111) and EADB (n=124) donors diagnosed before 18 years. The finding confirmed that C-peptide is measure and reflects the real insulin secretion, and that assists and distinguishing the diabetes types and guiding the therapy management [22]. In the DCCT/EDIC study of 944 participants with ~35 years of T1DM, residual β-cell function was tested by serum C-peptide. 117 patients (12.4%) had residual secretion: high (>0.2 nmol/L), intermediate (>0.03–0.2), or low (0.003–0.03). Residual C-peptide correlated with higher baseline stimulated C-peptide (p=0.0001), but not with HbA1c, HLA haplotypes, or autoantibodies. Severe hypoglycemia was less frequent with higher C-peptide (27% high, 48% intermediate) compared to low (74%) or none (70%). Microvascular complication rates were similar. Thus, β-cell function can persist for decades, and >0.03 nmol/L C-peptide protects against severe hypoglycemia [21]. In a study conducted by Cimbek et al., including 275 children (aged 1–18 years, median 7.9 years, 66% prepubertal) newly diagnosed with type 1 diabetes, fasting, prandial, and AUC C-peptide were measured. The median levels were 0.26 ng/mL (fasting) and 0.43 ng/mL (prandial). C-peptide levels were positively associated with age, BMI, and pubertal stage ($P < 0.001$). The study recorded that the stage of puberty is significantly and independently affected by C-peptide levels at diagnosis, which indicates the ability of provide an immunopathological endotype of typem1 diabetes mellitus [23]. In a study done by Boughton in 2022, within the CLOuD Consortium, this suggests that advanced technologies may offer measurable benefits in preserving β-cell function. about 133 children and adolescents (aged 10–16 years) with newly diagnosed type 1 diabetes participated in this study. The researchers compared the closed-loop insulin therapy and the standard insulin treatment. Findings recorded that the closed-loop therapy significantly preserves C-peptide secretion at 12 months after diagnosis, indicating better residual β-cell function. In contrast, the control group on standard therapy experienced a faster decline in C-peptide levels [24].

3.1.2.c. Iraqi studies: are limited due to their small sample sizes (only 60–160 participants) and their narrow focus on basic markers such as C-peptide, GADA, and IA-2A. They also lack large-scale or long-term genetic investigations and suffer from insufficient assay standardization, which restricts comparability across regions [19]. In contrast, global studies are more comprehensive, relying on very large cohorts (e.g., 4,079 patients in the UK GRID and hundreds of pancreatic tissue samples from nPOD/EADB) and addressing complex immune, genetic, and clinical markers such as IFIH1, HLA, and pubertal stage [22]. Furthermore, international investigations included extended follow-ups, such as the 35-year DCCT/EDIC study, which provided clinically relevant insights including the protective role of residual C-peptide against severe hypoglycemia and its utility in distinguishing diabetes types and guiding management strategies [24]. This indicates a critical research gap in Iraq, so the future studies should increase the sample size and expand participant recruitment in cross-sectional designs to cover different regions and adopt longitudinal studies that combine clinical, genetic, and biomarker data to achieve results comparable to international standards.

Table 1. Summary of Iraqi and international studies, which assess of HbA1c and C-peptide among children and adolescents with Type 1 Diabetes Mellitus (T1DM). The table focus on the sample sizes, biomarkers assessed, key findings, and the limitations of the comprehensive reported, major knowledge gaps in Iraqi research compared to comprehensive international studies.

4. Nutritional factors

Nutritional factors play a critical role in shaping glycemic stability and metabolic outcomes among children and adolescents with Type 1 Diabetes Mellitus. This section synthesizes the Iraqi evidence on how diet quality, meal patterns, micronutrient status, and environmental influences contribute to glycemic control and overall metabolic health. The findings are organized into three components: an overview of local studies, a comparison with global dietary evidence, and a summary of key research gaps that limit the interpretation of nutritional and lifestyle influences in the Iraqi context.

4.1. Factors associated with poor glycemic control

In Iraqi studies, poor glycemic control among children and adolescents with type 1 diabetes was related to several factors, including the patient's age, maternal illiteracy, recurrent episodes of diabetic ketoacidosis (DKA), lack of carbohydrate counting, and the presence of lipodystrophy at injection sites [25]. This was a cross-sectional observational study. No statistically significant difference in glycemic control was found between patients with and without celiac disease ($p = 0.619$) or according to BMI ($p = 0.063$) [26]. This was a cross-sectional clinical assessment. Adherence to blood glucose monitoring was generally poor; 69% of patients and caregivers reported never adjusting insulin doses based on diet, physical activity, or blood glucose readings, and more than 69% admitted they either never or rarely made such adjustments [27]. This was a questionnaire-based cross-sectional study. Older adolescents often have poorer glycemic control due to their nonstable lifestyle, Maternal illiteracy make it harder for mother's to manage the disease at home. The absence of carbohydrate counting resulted in mismatched insulin dosing, and lipodystrophy disrupted insulin absorption. The high p-values for celiac disease and BMI indicated no meaningful statistical association with glycemic control in this cohort. This indicates that not all comorbidities or anthropometric measures contribute equally to glycemic deterioration in this population. Overall, without carbohydrate counting, regular monitoring, and appropriate dose adjustments, achieving target HbA1c levels becomes difficult. Addressing lipodystrophy and enhancing family education—especially for mothers—can improve metabolic stability and reduce the incidence of DKA [27], A brief explanation is given to show how these factors affect the disease.

1. **Age and Puberty:** Adolescents experience worsening glycemic control due to hormonal changes that increase insulin resistance and lifestyle modifications such as irregular eating patterns or reduced parental supervision. HbA1c levels

Table 1. Summary of Iraqi and international studies on HbA1c and C-peptide in children and adolescents with type 1 diabetes mellitus (T1DM).

Study (Year, Place)	Origin	Sample Size	Biomarker(s) Assessed	Key Findings	Notes/ Limitations
Hussein et al. 2023, Baghdad	Iraq	192 (96 T1DM, 96 controls)	HbA1c, BMI, weight-for-age	HbA1c negatively correlated with BMI (r=-0.295, p=0.006). Undernutrition linked to poor control, females, large families, longer duration.	Single-center, short-term
Karbala 2015	Iraq	199 T1DM	HbA1c	31.6% had HbA1c <7% (acceptable control). Majority had poor control due to irregular monitoring and follow-up.	Limited to HbA1c
Kurdistan (Swimming, 2020)	Iraq	40 male adolescents	HbA1c	Swimming program reduced HbA1c vs control.	Small sample, short intervention
Eland et al. 2022 (Iraq, T1DM + Celiac)	Iraq	-	HbA1c, BMI, Lipid profile	Gluten-free diet improved HbA1c, BMI, lipid profile, QoL. Reduced risk of complications.	Focused on celiac overlap
Najaf 2023–2024	Iraq	120 (80 T1DM, 40 controls)	C-peptide, Anti-GAD65, miRNA-155, IL-2	T1DM patients had significantly reduced C-peptide. Lower with higher anti-GAD65. ↑miRNA-155, ↓IL-2.	Limited immunological profiling
Basrah (Case-control)	Iraq	160 (80 T1DM, 80 controls)	C-peptide	T1DM: 0.189 ng/ml vs controls: 2.96 ng/ml. Lower in longer duration/earlier diagnosis. No correlation with HbA1c.	No longitudinal follow-up
Thi-Qar (Case-control)	Iraq	90 (60 T1DM, 30 controls)	C-peptide, GADA, IA-2A	Lower C-peptide in T1DM vs controls. Lower in IA-2A+. No diff. with GADA.	Small sample, regional only
INNODIA (2024, Europe)	International	767 newly diagnosed	HbA1c, C-peptide	HbA1c ↓ first 3 months, then ↑. Younger children <10 yrs had lower C-peptide. BMI & DKA predicted lower secretion.	Multicenter, standardized
DPV (Germany/Austria, 2008)	International	27,035 patients, 207 centers	HbA1c	HbA1c ∼9.1% at diagnosis, improved 7.1%, then worsened post-remission. Influenced by age, gender, therapy type.	Large cohort, long-term
DCCT/EDIC (USA)	International	944 patients, 35 years follow-up	C-peptide, HbA1c	Residual C-peptide (>0.03 nmol/L) protected from severe hypoglycemia. Function persisted for decades.	Landmark global trial
CLOuD Consortium (2022, UK)	International	133 (10–16 yrs) newly diagnosed	C-peptide	Closed-loop insulin therapy preserved C-peptide at 12 months vs standard therapy.	RCT, advanced design

were significantly higher among adolescents, confirming age as an independent risk factor [28].

2. **Maternal Education:** Low maternal education (maternal illiteracy) has been consistently linked with poor glycemic outcomes. Mothers lack the awareness about carbohydrate counting, the proper amount of insulin, and how to monitor a good diet [29].
3. **Recurrent DKA Episodes:** The recurrence of diabetic ketoacidosis (DKA) happened due to the poor monitoring of insulin [30].
4. **Lipodystrophy at Injection Sites:** Insulin lipodystrophy was another factor that contributed to the instability of glycemic control. It leads to reduced insulin absorption. Iraqi studies recorded that improper injection techniques and the repetition in use of the same injection site were major causes of lipodystrophy, leading to significantly higher HbA1c values among affected patients [25].

4.2. Dietary habits

In Iraq, 73.5% of children and adolescents had normal diets, while 25.9% ate sugar-rich foods and 0.6% ate high-fat foods. This reflects suboptimal dietary awareness among families and indicates a tendency toward sugar-dense diets in this population. Promoting healthy eating for mothers and giving families basic education were suggested to increase awareness of routine diabetes screening in children [31].

This was a community-based cross-sectional study. Another study found that a low-carbohydrate diet is a practical lifestyle option for adults with type 1 diabetes who fail to achieve glycemic control despite proper carbohydrate counting, adequate self-monitoring, and medical supervision [32]. This was a dietary intervention study. This dietary approach was useful for those people who are aiming to lose weight. This approach helps to improve glycemic control, reduces the dose of daily insulin, helps to lower the risk of hypoglycemia as well, it also supports weight and body fat management, and improves the serum of lipid profiles. Overall, a healthy diet was found to be associated with higher antioxidant vitamin levels and improved glycemic and lipid profiles in both healthy individuals and those with type 2 diabetes [33]. In children and adolescents with type 1 diabetes, Dietary habits are influenced by how many meals they take a day (meal frequency), the type of food (fast food intake), micronutrient status, and cultural habits, This indicates that dietary behaviors in Iraq are shaped not only by individual choices but also by family customs and cultural eating patterns.

1. **Meal frequency and snacking behavior**: Irregular meals and sweet snacks lead to poor insulin adherence and unstable glucose in blood [34]. Children who don't take breakfast or who consumed frequent sweets or snacks were more likely to have uncontrolled glycemia.
2. **Fast food and processed food consumption:** A local study recorded that High consumption of fried foods, sugary sweets and drinks, and snacks in general leads to elevated HbA1c, resulting in poor diabetes control [35]. This was a local cross-sectional assessment.
3. **Micronutrient intake (zinc, iron, vitamin D)**: deficiencies in vitamin D, iron, and zinc are common and observed among Iraqi children who are infected with type 1 diabetes, which means poor glycemic control and complications. A study done in an Iraqi hospital revealed that 60% of participants were diagnosed with vitamin D deficiency, they had poor glycemic control, and they had higher rates of insulin resistance [36]. This hospital-based study assessed micronutrient deficiencies.
4. **Cultural food practices in Iraq:** culture and habits play a major role in the management of diabetes. in Iraq, people traditionally depend on carbohydrates almost such as rice and bread. A survey done in Baghdad showed that people are rarely on a carbohydrate usually, its be worse in Ramadan due to the social habits at Iftar [37]. This survey-based study evaluated cultural dietary patterns.

4.3. Anthropometry

BMI has a negative effect on glycemic control; higher BMI means poor control [38].This suggests that obesity-related insulin resistance contributes significantly to unstable glycemia. Other indicators such as fat mass, muscle mass, waist-to-hip ratio, height-for-age, and overall nutritional status provide additional insight into the metabolic profile of children with T1DM and help explain the relationship between physical growth and metabolic control in Iraqi children and adolescents with type 1 diabetes.

1. **Body composition (fat mass vs. muscle mass):** Excess of fat, even if BMI is normal, reduces insulin sensitivity, while the muscle mass improves the metabolism of patients [39].
2. **Waist-to-hip ratio as an indicator:** Iraqi evidence recorded that central obesity, which is measured by waist-to-hip ratio, is more sensitive to poor glycemic control than BMI. Adolescents who had higher ratios demonstrated a greater risk of insulin resistance and recurrent DKA [40]. This indicates that central adiposity is a stronger predictor of metabolic instability than overall body weight.
3. **Height-for-age Z-score**: Children with lower height-for-age *Z*-scores have worse glycemic control, and they may have delayed puberty [38]. This reflects the role of chronic hyperglycemia in impairing normal growth progression.
4. **Malnutrition (undernutrition vs. overnutrition):** Iraqi studies recorded that malnutrition and overnutrition have a negative effect on glycemic control. Children had weakened immune systems and higher complication risks, while over nourishment in children leads them to obesity-related insulin resistance [41]. This highlights the dual burden of undernutrition and overnutrition in influencing diabetes outcomes in Iraqi children.

4.4. Surrounding environment

Environmental and socioeconomic factors also played a significant role in glycemic control. Maternal illiteracy was identified as one of the major contributing factors. Higher HbA1c levels were significantly associated with puberty, rural residency, and poor socioeconomic status [25]. This suggests that lower socioeconomic conditions create barriers to consistent diabetes management. The proportion of controlled disease was significantly higher among children aged ≤8 years, those with educated mothers and fathers, children of employed fathers, and those with a disease duration of less than 6 years [9]. A significant difference was also noted in adherence to insulin therapy and glucose monitoring according to caregiver education; children with illiterate caregivers had much lower commitment to insulin and glucose monitoring compared to those whose caregivers had at least a primary school education [27]. This reflects the strong influence of caregiver education on adherence behaviors. Due to financial constraints, low-income individuals often face greater challenges in accessing health care services. While financial pressure sometimes increased their motivation to adhere to insulin treatment, the study still reported poor adherence to insulin self-administration among children and adolescents with type 1 diabetes in Iraq [27]. This indicates that economic stress can both hinder and motivate treatment adherence depending on household circumstances. Additionally, early childhood was found to be a critical period for increasing the risk of developing type 1 diabetes. Maternal diseases such as gestational diabetes, pre-eclampsia, and prenatal infections during pregnancy, along with maternal habits such as tea drinking during pregnancy, were also identified as significant contributors. Furthermore, a higher percentage of type 1 diabetes was observed among children with a family history of thyroid disease or type 2 diabetes in first- and second-degree relatives, which represented an important confounding risk factor [31]. This suggests that genetic and prenatal influences may interact with environmental exposures to increase disease susceptibility. Limited knowledge about the benefit of specialized diabetes clinics, financial barriers, and environmental exposures affect the disease.

1. Access to specialized diabetes clinics: Iraqi studies recorded that children who regularly attended diabetes centers [42] recorded significant control of glycemic level [43]
2. Availability of health insurance or subsidies: financially supported families adhered better to insulin and monitoring [44]
3. Environmental pollution and toxins: Pollutant exposure may raise T1DM risk in predisposed children [45].
4. Urban vs. rural lifestyle differences Rural children had poorer glycemic control due to regulations affecting their attendance at diabetes centers: [46]

4.5. Diabetes management

Controlled diabetes was significantly higher among patients who regularly attended diabetes centers, practiced blood glucose self-monitoring, adhered to insulin treatment, and had parental control over dietary intake. This reflects the central role of family involvement in maintaining glycemic stability. Statistically significant factors included self-monitoring of blood glucose, irregular attendance at diabetes centers, and family history of diabetes mellitus [9]. One study demonstrated that a low-carbohydrate diet is a feasible lifestyle option for adults with type 1 diabetes who fail to achieve glycemic control despite proper carbohydrate counting, adequate self-monitoring, and medical supervision. This diet was found to positively impact type 1 diabetes patients by improving glycemic control, reducing the total daily insulin dose, lowering the risk of hypoglycemia, aiding in weight management, decreasing body fat, and improving serum lipids with a good safety profile [32]. Another study reported that the majority of diabetic secondary school students exhibited either moderate or low levels of self-care in all aspects of diabetes management, including insulin administration, blood glucose monitoring, diet, exercise, and follow-up. Moreover, a significant relationship was found between self-care practices and demographic data such as age and school grade, while other demographic data were not statistically significant [47].

1. **Use of insulin pumps or continuous glucose monitoring (CGM):** In Iraq, the use of insulin pumps and CGM devices remains very limited due to high costs and lack of availability in most centers. Iraqi studies revealed that the majority of children still rely on conventional insulin injections (NPH and Regular), which were associated with higher HbA1c and challenges in achieving optimal glycemic control [48].
2. **School support for diabetic children:** An Iraqi study among secondary school students with diabetes showed that most exhibited either moderate or low levels of self-care across all aspects of management, including blood glucose monitoring, dietary control, and physical activity. Insufficient school support and lack of structured health education were identified as major contributing factors [49, 50].
3. **Role of pharmacists and primary care:** The pharmacists in Iraq have a role to limit the disease, but they have to do their best to educate the patient to help them improve diabetes control [51].
4. **Impact of mobile apps and telemedicine:** There aren't enough studies yet, but Iraqi research showed that after COVID, apps and digital tools can help patients to follow up and adjust the doses of insulin more easily [52].

4.6. Growth parameters

In Iraq, several studies have looked at growth and nutrition in children and adolescents with type 1 diabetes, A study done by Dohan in 2021 in Basra reported that weight, height, and BMI were below the 5th percentile, showing a high rate of malnutrition. This indicates that nutritional deficiencies remain a major contributor to poor growth outcomes in Iraqi children with T1DM. Main reasons were low family income, poor diet, and short treatment duration [53]. Similarly, Abdoun study in 2021, in Babylon, reported that longer diabetes duration was inversely correlated with height, indicating impaired growth despite some overall improvements; growth parameters remained abnormal particularly with prolonged disease duration [53]. More recently, Hussein's study (2023) in Baghdad recorded that children with type 1 diabetes had significantly lower anthropometric measures compared with healthy control children. Independent predictors of malnutrition included older age of the patient, female gender, large family size, and longer disease duration. Moreover, BMI and the ratio of weight-for-age have negative correlation with HbA1c, This suggests that chronic hyperglycemia impairs normal growth trajectories. and that suggest that poor nutritional status was directly linked to worse glycemic control [8].

Parameters: Growth in children with type 1 diabetes is not only influenced by nutritional status but also by puberty-related development, bone health, and hormonal interactions. Several Iraqi studies have highlighted these aspects:

1. **Pubertal development and delayed growth:** An Iraqi study done in Al Basra by Dohan in 2021 reported that the delayed in pubertal development was more common in children who had long disease duration and their poor glycemic control, both of which affected overall growth [53]. This reflects the strong interplay between glycemic control and pubertal development.
2. **Bone mineral density:** Hussein et al. (2023) in Baghdad confirmed that children with type 1 diabetes had significantly lower bone mineral density scores compared to healthy peers, with poor glycemic control and female gender as independent risk factors [54]. This indicates that sex-specific vulnerabilities may influence bone health in T1DM.
3. **Growth hormone and insulin interaction: study done by** Abdoun in Babylon showed abnormal growth parameters in children with diabetes were explained partly through the growth hormone and insulin pathways. especially children who consider prolonged disease duration [28].
4. **Catch-up growth after treatment initiation:** However, direct Iraqi evidence specifically documenting "catch-up growth" after insulin initiation is limited. However, local studies from Baghdad and Babylon show that better metabolic control, shorter disease duration, and moving away from conventional insulin regimens are associated with more favorable height-for-age and pubertal progression. These findings imply that early, intensive management and improved glycemic control may allow partial recovery of linear growth trajectories in Iraqi children with T1DM [55]. This suggests that early and intensive metabolic control can mitigate long-term growth impairment.

Table 2 summarizes Iraqi and international studies on nutritional factors in children and adolescents with Type 1 Diabetes Mellitus (T1DM). The table highlights carbohydrate counting, maternal education, dietary habits, micronutrient intake, cultural practices, and modern dietary interventions. Iraqi studies reveal consistent gaps such as small sample sizes, lack of structured education, and limited long-term follow-up compared to international research.

4.7. Discussion

Older age, maternal illiteracy, recurrent episodes of diabetic ketoacidosis (DKA), lack of carbohydrate counting, and lipodystrophy at injection sites were all significantly associated with poor glycemic control in Iraqi children and adolescents with type 1 diabetes. People who were starting puberty, lived in rural areas, or were from lower socioeconomic groups had significantly higher HbA1c levels. With only 27.1% of patients achieving ≤7.5% and a mean HbA1c of 9.43 ± 2.56…the use of Regular + NPH insulin regimens further worsened glycemic control. Children under the age of eight, those with parents who were educated and employed, children who attended diabetes centers regularly, and children under strict parental supervision all showed better control [25] Lipodystrophy hampered insulin absorption, This suggests that both behavioral factors and clinical complications directly impair metabolic control in Iraqi children with T1DM. frequent DKA was a sign of inadequate prior control, and the lack of carbohydrate counting resulted in incorrect insulin dosage. Glycemic control did not significantly correlate with either BMI (p=0.063) or celiac disease (p=0.619) [26], The majority of Iraqi children and teenagers (73.5%) ate a typical diet, whereas 25.9% ate diets high in sugar and just 0.6% ate diets high in fat. Low-carb diets have been shown in international studies to enhance weight and lipid management, lower insulin needs, and improve glycemic control. Better diet quality (higher UKDDQ and CNHI scores) was associated with lower FBG,

Table 2. Summary of Iraqi and international studies on nutritional factors in children and adolescents with type 1 diabetes mellitus (T1DM).

Study (Year, Place)	Origin	Sample Size	Nutritional Factors Assessed	Key Findings	Notes / Limitations
Baghdad survey (2018)	Iraq	150 T1DM	Carbohydrate counting, family education	Families rarely practiced carb counting; most children had poor glycemic control and irregular insulin adjustment	Cross-sectional, self-reported data
Karbala (2017)	Iraq	199 T1DM	Dietary habits, maternal education	Poor maternal education linked with poor HbA1c; adolescents had worse control; frequent DKA episodes in low-educated families	No intervention; limited to HbA1c
Basra (2019)	Iraq	120 T1DM	Lipodystrophy, insulin absorption	Lipodystrophy at injection sites linked to poor control and high HbA1c	Focused only on injection practices
Baghdad (2020)	Iraq	73 children & adolescents	Meal frequency, fast food intake	Skipping breakfast and frequent snacks worsened glycemic control; fast food intake associated with higher HbA1c	Small sample, no biochemical follow-up
Iraqi hospital study (2021)	Iraq	100 T1DM	Micronutrients (Vit D, Zn, Fe)	>60% had Vit D deficiency → poor control & insulin resistance; low Zn & Fe linked with complications	Single center, no long-term monitoring
Baghdad survey (2016)	Iraq	134 T1DM	Cultural diet, Ramadan fasting	Heavy reliance on rice & bread made insulin adjustment difficult; Ramadan led to skipped meals or overeating at iftar → unstable glucose	Self-reported, no intervention design
International (Low-carb diet, 2022)	International	Adults (n=120)	Low-carb diet, weight control	Low-carb diet improved HbA1c, lowered insulin dose, reduced hypoglycemia, improved lipid profile	Adults only; not pediatric focused
Global micronutrient studies (2015–2020)	International	Multi-country	Vit D, Zn, antioxidants	Higher antioxidant vitamin levels and adequate Vit D/Zn improved metabolic stability and reduced complications	Not Iraq-specific; highlights global standards

HbA1c, TC, TG, and higher levels of antioxidant vitamins in people with type 2 diabetes [31]. High consumption of fried foods, sugary drinks, and processed snacks was associated with elevated HbA1c, while irregular meal frequency and frequent sweet snacking worsened glycemic control locally. Deficits in micronutrients, particularly zinc, iron, and vitamin D (>60% prevalence), were linked to poor glycemic control, insulin resistance, slowed wound healing, and an increased risk of infection. Additional obstacles to insulin adjustment and stable glycemia were presented by cultural dietary practices, such as the consumption of bread and rice, large family meals, and fasting during Ramadan [56], Anthropometric indicators had a significant impact on metabolic outcomes. Poorer glycemic control was linked to higher BMI, but insulin sensitivity was hampered by excessive body fat even at normal BMI, while stability was linked to lean muscle mass [38]. Compared to BMI alone, central obesity (waist-to-hip ratio) was a more sensitive indicator of poor control and recurrent DKA. Chronic malnutrition was noted by patients who considered low height-for-age (Z-scores), which were also noted that they delayed in puberty, and they have poorer glycemic control [57]. Results were recorded that patients with malnutrition had weak immunity and they exposure to more complications, while children who considered as obese, they displayed insulin resistance [57].

Glycemic results were also influenced by environmental and socioeconomic factors. other factor like Low income and maternal illiteracy were significant determinants of poor glycemic control [44]. Due to limited access to healthcare and lower parental education, living in a rural area was associated with a higher HbA1c [25]. Regular attendance at specialized diabetes clinics was associated with better outcomes for children than sporadic visits. Families with subsidies adhered better to insulin and monitoring, whereas those without health insurance had less continuity of care [44]. Although there is a dearth of data from Iraq, there is broader evidence that environmental pollutants and toxins may increase the risk of type 1 diabetes [45]. Contributing factors were found to be early-life exposures, such as preeclampsia, infections, maternal gestational diabetes, and tea consumption during pregnancy. Susceptibility was further increased by a positive family history of type 2 diabetes or thyroid disease [31].

Regular center attendance, self-monitoring, insulin adherence, and parental dietary supervision were associated with better glycemic outcomes [25]. Nonetheless, the majority of teenagers reported moderate to low levels of self-care, which included follow-up, diet, exercise, and insulin use [48]. CGM and insulin pumps were rarely used because of their high cost and limited availability, while conventional insulin (NPH + Regular) remained the primary treatment and was linked to higher HbA1c [48]. There was inadequate school support and inadequately structured diabetes management education [49]. Although their involvement in insulin education and DKA management could improve control, pharmacists and primary care physicians only had a minor role [52]. Despite worldwide evidence of the benefits of telemedicine and mobile apps following COVID-19, these technologies are still not well-known in Iraq.

Among Iraqi children with type 1 diabetes, growth impairment was consistently observed. Weight, height, and BMI were often below the 5th percentile in Basra [53], whereas in Babylon, a longer duration of the disease was associated with stunted growth. had significantly lower anthropometric measures compared with healthy control children; independent predictors included female sex, older age, larger family size, and length of stay. Poorer growth outcomes were directly associated with high HbA1c and poor nutrition [53].

Despite the breadth of findings summarized above, most Iraqi studies remain limited by small sample sizes, single-center recruitment, and cross-sectional designs, which restrict the generalizability of the results and reduce the ability to establish long-term causal relationships. These limitations highlight the need for larger, multi-center, and longitudinal studies in Iraq to generate more robust, generalizable, and clinically informative evidence.

4.8. Gaps and limitations

1. Nutrition: Limited qualitative and quantitative evaluation of macronutrients and micronutrients, no long-term assessment of the impact of family education programs on glycemic control, and a lack of research on contemporary dietary interventions in Iraqi children with T1DM (such as ketogenic diets and carbohydrate cycling).
2. Psychosocial Factors: Inadequate evaluation of the role of schools and pharmacists in diabetes care, and insufficient assessment of psychological stress, depression, diabetes burnout, family support, and quality of life among children and adolescents.
3. Technology and Healthcare Services: Research on advanced tools (such as CGM, insulin pumps, mobile apps, and telemedicine) is scarce. Diabetes center services—including staffing, visit frequency, nutritional education, and access to monitoring devices—are not well evaluated, and there is little data on how financial assistance or health insurance affects treatment adherence.
4. Environmental and Genetic Factors: Research on the effects of environmental pollutants and toxins is lacking, and little is known about how genetic predisposition (non-HLA polymorphisms) affects glycemic control among Iraqi children with T1DM.
5. Long-term Complications: A large number of Iraqi studies have focused mainly on growth and bone fragility, while only a few studies have examined early complications such as neuropathy, retinopathy, and nephropathy.
6. Growth and Anthropometry: The assessment of bone health among Iraqi children with type 1 diabetes is inadequate, with limited integration of indicators such as BMI, WHR, Z-score, and body composition. In addition, there is little data on growth improvement after achieving better glycemic control.

5. Conclusion

The results that were extracted and analyzed from previous Iraqi studies indicated that children and adolescents under 18 years of age who are suffering from type 1 diabetes experience a clear weakness in controlling blood sugar levels and a noticeable decline in beta-cell function. These findings summarize the biochemical, nutritional, environmental, and growth-related aspects discussed throughout this review and ensure internal consistency across all sections. which are mainly responsible for controlling sugar in the human body. These findings summarize the biochemical, nutritional, environmental, and growth-related aspects discussed throughout this review and ensure internal consistency between all sections. In addition, they face major nutritional challenges. Although the main indicators, namely HbA1c and C peptide, were addressed in the studies, most of the Iraqi studies were limited by several limitations, such as the small sample size or reliance on data from single centers, and also the absence of long-term follow-up. This limits the possibility of comparison or building strong conclusions. From a nutritional standpoint, children face significant challenges, including inadequate nutritional education for parents and the community at large, and poor dietary habits that contribute significantly to disease progression.

This review integrated all major domains examined in Iraqi literature, including biochemical markers (HbA1c, insulin, C-peptide, and autoantibodies), nutritional behaviors, anthropometric and growth indicators, and environmental and socioeconomic determinants of glycemic control. The synthesis of these sections demonstrated that poor metabolic control in Iraqi children arises from overlapping biological, nutritional, social, and health-service-related factors, not from a single cause. This comprehensive picture highlights the need for multidisciplinary management rather than focusing on HbA1c alone.

A comparison of Iraqi and international studies reveals a substantial and tangible gap. International studies rely on very large sample sizes, utilize data from multicenter designs, and employ comprehensive analyses of biochemical, genetic, nutritional, and psychological indicators, along with long-term follow-ups spanning several years.

In conclusion, the final message of this review is that we must work to improve the clinical outcomes for Iraqi children with type 1 diabetes. The central conclusion is that improving outcomes requires a unified national strategy that integrates nutrition, clinical monitoring, and long-term research. This requires developing a comprehensive care model that integrates nutritional education for all segments of society, provides and facilitates healthcare services that support regular biochemical monitoring, and relies on more comprehensive and long-term studies. Future studies should also expand to include broader indicators such as biochemical, metabolic, and immunological markers, and leverage modern technologies like continuous glucose monitoring systems. Only through this integrated approach can Iraq build a reliable database, improve treatment decisions, and enhance growth, health, and quality of life outcomes for children and adolescents with type 1 diabetes.

Ethical approval

Not Applicable.

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