Review article
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A Comprehensive Review on the Micronutrient Deficiencies of Vitamin D and Calcium Among Children and Adolescents with Type 1 Diabetes Mellitus

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Abstract
Type 1 diabetes mellitus (T1DM) is a chronic autoimmune disease characterized by insulin deficiency resulting from the destruction of pancreatic β-cells. In addition to poor glucose metabolism, individuals with T1DM often experience micronutrient deficiencies, particularly in calcium and vitamin D, which can exacerbate metabolic dysregulation and increase the risk of long-term complications. This review aimed to provide an overview of available data on the prevalence, underlying mechanisms, and clinical consequences of vitamin D and calcium deficiencies in children and adolescents with type 1 diabetes, as well as their potential effects on bone health, glycemic control, and disease management. A literature review was conducted using published research on the anthropometric profiles and biochemical status of children and teenagers with type 1 diabetes. This review highlights data extracted from peer-reviewed research studies conducted between 2010 and 2025, encompassing a combined sample of approximately 824 children and adolescents diagnosed with Type 1 Diabetes Mellitus (T1DM). Data were compiled into Tables summarizing study characteristics, anthropometric measurements, and biochemical parameters from 11 relevant studies. Vitamin D deficiency and low bone mineral density were consistently observed among pediatric patients with type 1 diabetes. The results showed that the prevalence of deficiency was less than 20 ng/mL, which was as high as 55%, and the mean serum 25-hydroxyvitamin D [25(OH)D] levels varied from 18.5 ± 6.4 ng/mL to 23.7 ± 8.1 ng/mL among 40–65% of participants. Several studies have reported that calcium intakes are below from the recommended dietary allowances (RDAs). Compared with healthy individuals, youth with type 1 diabetes mellitus (T1DM) exhibit significantly lower bone mineral density (BMD) Z-scores, particularly in the lower lumbar spine. This reduction in BMD may result from the combined effects of metabolic dysregulation and inadequate intake of essential micronutrients. Poor glycemic control, as indicated by an HbA1c level greater than 9%, was often associated with lower 25(OH)D levels and decreased bone mineral density. In conclusion, vitamin D and calcium deficiencies are common yet often overlooked in children and adolescents with type 1 diabetes mellitus (T1DM). Early detection, consistent monitoring, and appropriate supplementation can enhance metabolic control, thereby reducing the risk of skeletal and autoimmune complications. Further longitudinal studies are essential to establish optimal intake levels and confirm the long-term benefits of these corrective interventions.

Keywords: Type 1 Diabetes, Micronutrient Deficiencies, Calcium, Vitamin D, Adolescent, Children.

Highlights:

- Vitamin D and calcium deficiencies affect up to 65% of children and adolescents with Type 1 Diabetes Mellitus (T1DM).
- Vitamin D deficiency impairs insulin secretion, while calcium deficiency increases bone resorption and lowers bone density.
- Combined deficiencies, particularly those associated with poor glycemic control, accelerate metabolic acidosis and bone fragility.
- Regular screening and supplementation can enhance metabolic and skeletal health in pediatric type 1 diabetes mellitus (T1DM).

1. Introduction

Diabetes mellitus is a long-term metabolic disease marked by elevated blood glucose levels and complications with protein and fat metabolism. Either the pancreas is not producing enough insulin, or the body's cells are not utilizing the available insulin efficiently, resulting in hyperglycemia. Clinical symptoms typically begin in childhood or adolescence, but in some instances, they can also emerge in adulthood (Katsarou et al., 2017). There are three primary types of diabetes: (1) Type 1 diabetes, which is characterized by a lack of insulin production; (2) Type 2 diabetes, which is characterized by insulin resistance and a gradual decrease in insulin secretion; and (3) gestational diabetes, which arises during pregnancy and can cause complications for both the mother and the unborn child, such as a higher chance of type 2 diabetes in the mother (Roglic, 2016).

Type 1 diabetes is an autoimmune disorder that destroys pancreatic β-cells, leading to insulin deficiency. It is most commonly diagnosed in childhood or adolescence and characterized by hyperglycemia. Exogenous insulin therapy must be initiated immediately to prevent metabolic decompensation and ensure survival (Haller et al., 2005). This type of diabetes accounts for 5–10% of all diabetes cases worldwide. In people with type 1 diabetes, the pancreas fails to release insulin fully, necessitating lifelong insulin therapy for survival and metabolic control (Mobasseri et al., 2020).

More broadly, diabetes mellitus represents a group of metabolic disorders characterized by chronic hyperglycemia resulting from defects in insulin secretion, insulin action, or both. These abnormalities in glucose regulation, whether due to autoimmune β-cell destruction in type 1 diabetes or insulin resistance in type 2 diabetes, progressively affect multiple organ systems and contribute to acute and long-term complications, including bone fragility, osteoporosis, nephropathy, retinopathy, and neuropathy (Blair, 2016).

Type 1 diabetes (T1D) in children and adolescents is increasing worldwide, posing a growing public health challenge. Type 1 Diabetes (T1D) affects approximately 9 million people worldwide, including over 1.5 million children. In addition to those with symptoms, many children and adults may unknowingly have early-stage type 1 diabetes (T1D) (Bell & Lain, 2025). According to the *International Diabetes Federation (IDF)* 2021, there are an estimated 1.21 million prevalent cases of T1D among individuals aged 0–19 years globally, with approximately 149,500 new (incident) cases diagnosed each year in this age group (IDF Diabetes Atlas, 2021).

More recent global estimates from 2022 indicate that approximately 530,000 new cases of T1D occur annually across all age groups, with about 201,000 diagnoses in individuals younger than 20 years (Diabetes and the Environment Database, 2022). The number of children diagnosed with type 1 diabetes is increasing in many countries. Although the trend varies by region, the global rate of new cases grows by approximately 3% per year. Every year, an estimated 79,000 children worldwide develop type 1 diabetes. In some European countries where the disease was previously less common, it is spreading more quickly, particularly among young children (Patterson et al., 2014).

In Pakistan, a nationwide cross-sectional survey conducted across all four provinces revealed a substantial burden of diabetes mellitus (DM) and impaired glucose tolerance (IGT) among both urban and rural populations. Among 5,433 participants, the combined prevalence of glucose intolerance (DM + IGT) was higher in urban areas (22%) than in rural areas (17%), with women showing greater susceptibility than men. The study identified age, central obesity, and family history of diabetes as the primary risk factors contributing to this trend (Shera et al., 2007).

Vitamin D plays a crucial role in maintaining bone health. Severe vitamin D deficiency can cause rickets in children, which affects the developing skeleton, as well as osteomalacia in adults. Additionally, low serum vitamin D levels have been associated with an increased risk of fractures in older adults. Notably, children with type 1 diabetes mellitus (T1D) have an exceptionally high and variable prevalence of vitamin D deficiency, ranging from 15% to 65% by the end of winter (Arteaga, 2009).

This review article presents a narrative aimed at exploring micronutrient deficiencies of vitamin D and calcium in children and adolescents with type 1 diabetes mellitus (T1DM), highlighting the evidence on prevalence, biochemical and anthropometric alterations, and possible physiological mechanisms linking these deficiencies to diabetes-related complications. Moreover, this review includes the relevant literature, which was searched from 2010 to 2025 across online databases such as PubMed, ScienceDirect, Web of Science, and Google Scholar. The main keywords used were: "Type 1 Diabetes Mellitus", "vitamin D deficiency", "calcium deficiency", "micronutrients", "children", "adolescents", "bone health", and "metabolic control". A combined sample of approximately 824 children and adolescents diagnosed with Type 1 Diabetes Mellitus (T1DM) was reported in Table 1. The data from these studies were systematically compiled and analyzed to identify trends and associations between micronutrient status, metabolic control, and bone health outcomes in pediatric populations with type 1 diabetes mellitus (T1DM).

1.1. Inclusion Criteria

Studies were included if they:

- Focused on children or adolescents (<19 years) diagnosed with T1DM.
- Reported data on serum vitamin D and calcium levels, biochemical findings, or bone health indicators.
- Eleven studies of peer-reviewed and published in English between 2010 to 2025 were added.

1.2. Exclusion Criteria

Studies were excluded if they

- Focused on Type 2 or any other form of diabetes,
- Lacked clear diagnostic criteria for T1DM or relevant micronutrient measurements.

1.3. Data Extraction

From each eligible study, information was collected on:

i) Author and year of publication, ii) Country and population studied, iii) Anthropometric data (age, height, weight, iv) BMI, and growth indicators. v) Serum vitamin D, vi) calcium, vii) HbA1c, and viii) other biochemical parameters (phosphorus, magnesium, and Iron).

Data from all the studies were carefully compared and summarized in tables for easier interpretation.
All data were organized into three main themes:

1.4. Anthropometric Outcomes: Growth, BMI, and Body Composition Trends in T1DM Youth

1.4.1. Biochemical findings: serum levels of Vitamin D, calcium, HbA1c, and related micronutrients, and their association with glycemic markers.

1.4.2. Mechanistic and Clinical Interpretation: physiological pathways, explaining how vitamin D and calcium deficiencies affect insulin secretion, bone remodeling, and overall metabolic control (Table 1).

Table 1: Summary of studies investigating the anthropometric, biochemical, and metabolic aspects in children and adolescents with T1DM across different countries.

Country	Age group	Sample Size	Key focus	Author (Year)
Brazil	Children & adolescents	54	Relationship between anthropometric and biochemical profiles in T1DM	Teles & Fornés (2012)
India	Children & adolescents	20	Serum micronutrient levels in T1DM	Chaithanya et al., (2022)
Israel	Adolescents	20	Impact of low-carbohydrate diet on micronutrient intake and status in T1DM	Levran et al., (2023)
Turkey	Adolescents	110	Diet quality, nutritional status, and biochemical parameters in T1DM	Şahin Bodur et al., (2021)
Turkey	Children	52	Effects of carbohydrate counting on metabolic control in T1DM	Gökşen et al., (2014)
Italy	Children & adolescents	180	Adiposity, diet composition, and cardiovascular risk in T1DM	Maffeis et al., (2017)
Turkey	Children & adolescents	53	Effect of adherence to carbohydrate counting on metabolic control in T1DM	Bayram et al., (2020)
Turkey	Children & adolescents	150	Assessment of energy, macro-, and micronutrient intakes in T1DM	Ozkaya & Ozkaya (2023)
India	Children & adolescents	125	Growth status in T1DM	Khadilkar et al., (2013)
Poland	Adolescents	60	Skeletal status, body composition, and glycemic control in T1DM	Wierzbicka et al., (2018)
Egypt	Children	50	Serum magnesium levels and correlation with glycaemic control in T1DM	Abd-Alraouf et al., (2018)
Total Sample Size		824		

1.5. Anthropometric Analysis

The anthropometric profile refers to the measurement and evaluation of physical parameters, including height, weight, body mass index (BMI), waist circumference, and growth Z-scores, which are essential indicators of nutritional and growth status in children and adolescents (Table 2) (WHO, 1995). In the context of Type 1 Diabetes Mellitus (T1DM), these parameters provide valuable insights into the impact of chronic metabolic dysregulation on physical development. Deviations from standard growth patterns, such as reduced height-for-age or altered BMI Z-scores, can indicate underlying nutritional deficiencies or poor metabolic control (Kumar et al., 2022). In this review, anthropometric findings were analyzed to assess how vitamin D and calcium insufficiencies may influence growth, body composition, and overall physical development in pediatric T1DM populations. Regular anthropometric assessment thus serves as an essential tool for identifying subtle growth impairments related to micronutrient deficiencies and long-term glycemic instability (Ozer et al., 2024).

Table 2: Summary of Anthropometric characteristics and growth indicators among children and adolescents with T1DM reported in previous studies.

#	Parameters (Units)	Results (Mean± S.D)	Interpretation	Authors
1	Age (years)	10.4 ± 3.5	The sample's mean BMI is within the normal range, indicating adequate growth and nutritional status; there is no clear evidence of underweight or overweight.	Teles & Fornes et al., (2012)
	Weight (Kg)	45.6 ± 15.6		
	Height (cm)	150.6 ± 15.4		
	BMI (kg/m^2)	19.6±3.5		
	Diabetes Duration (years)	5.2±3.3		
2	Age (years)	12.35±4.73	A slight departure from growth norms is indicated by slightly negative height and weight z-scores, which may reflect metabolic or nutritional effects of type 1 diabetes.	Chaithanya et al., (2022)
	Height -Z-score	-0.5±1.07		
	Weight Z score	-0.34 ± 1.06		
	BMI			

3	BMI z-score	1.30±1.64	The benefits of glycemic status, an elevated BMI z-score, and a high waist circumference percentile indicate increased adiposity and possible early cardiometabolic risk.	Levran et al., (2023)
	Waist circumference percentile	76.50±20.74		
4	Body weight (kg)	54.7 ± 14.36	Higher body fat percentage and waist circumference indicate central fat accumulation, which may increase metabolic risk even though the mean BMI is within normal limits.	Şahin Bodur et al., (2021)
	Body mass index (kg/m²)	21.0 ± 3.46		
	Waist circumference (cm)	72.0(median)		
	Waist/height ratio	0.44(median)		
	Body fat percentage (%)	22.5 ± 6.94		
5	Age	17.09±5.01	Despite having diabetes for a long time, the BMI is within the healthy range, suggesting that growth status has been largely maintained.	Gökşen et al., (2014)
	Diabetes duration (years)	8.97±4.42		
	BMI (kg/m^2)	20.89±3.31		
6	Age (years)	12.7	Mean height, weight, and BMI values closely match reference norms; minimal deviation from expected growth patterns for age and sex.	Maffeis et al., (2017)
	Height (cm)	153.1		
	Weight (kg)	47.2		
	BMI (kg/m^2)	19.5		
	BMI z-score	0.01		
7	Age	10.64±4.40	Above-average growth is indicated by slightly positive z-scores for BMI, height, and weight, which may be related to proper dietary intake and glycemic control.	Bayram et al., (2020)
	Diabetes Duration	24.59±5.71		
	BMI z score	0.49±0.93		
	Height z score	0.31±0.8		
	Weight z score	0.21±0.90		
8	Height (cm)	148.4±16.6	There is no indication of growth retardation or excessive obesity, and anthropometric values are within normal ranges.	Ozkaya et al., (2023)
	Body Weight (kg)	46.2±15.1		
	BMI (kg/m^2)	20.3±3.4		
	BMI Z-score	0.41±0.92		
	Age	6.9±3.3		
	Duration of Type 1 DM (years)	5.3±3.3		
9	Age (years)	9.7	Mild stunting and underweight tendencies are indicated by negative height and weight z-scores, which may be a sign of glycemic instability or chronic nutritional inadequacy.	Khadilkar et al., (2013)
	Height (cm)	128.2		
	HAZ (Height for Age score)	-1.1		
	Weight (kg)	29.3		
	WAZ (Weight for Age score)	-1.1		
	BMI	16.4		
	BAZ (BMI for age Z score)	-0.6		
10	Age (y)	9.9 ± 3.9	Normal growth patterns are indicated by height and weight SDS values near zero, which are consistent with proper diabetes management and nutrition.	Wierzbicka et al., (2018)
	Diabetes duration (y)	5.1 ± 3.9		
	Body height (cm)	166.5 ± 11.5		
	Body height (SD score)/2	0.07 ± 1.12		
	Body weight (kg)	58.9 ± 11.9		
	Body weight (SD score)/2	0.29 ± 1.16		

Children and adolescents with type 1 diabetes mellitus (T1DM) have an uncertain assessment of their growth and nutritional status, as indicated by anthropometric data from the reviewed studies summarized in Table 1. Mean BMI values, height, and weight were near population reference norms in several cohorts, including those examined by Teles & Fornés et al. (2012), Ozkaya et al. (2023), Maffeis et al. (2017), and Wierzbicka et al. (2018). This suggests that, even though type 1 diabetes is a chronic condition, growth trajectories can be sustained with proper metabolic control and a healthy diet. These results suggest that a proper diet and adherence to treatment plans may help mitigate the potential growth impairments commonly associated with the disease.

However, there were also minor deviations: Chaithanya et al. (2022) reported slightly negative height and weight z-scores, while Khadilkar et al. (2013) found more severe deficits, with both height-for-age (HAZ) and weight-for-age (WAZ) z-scores at -1.1 and a BMI-for-age (BAZ) of -0.6. These patterns indicate mild stunting and underweight tendencies that may be caused by chronic undernutrition, poor glycemic control, or increased metabolic demands; in these situations, growth faltering may be a result of a cumulative burden of suboptimal dietary intake, recurrent glycemic fluctuations, or untreated micronutrient deficiencies, like calcium and vitamin D, which are crucial for bone health and growth.

Several studies found evidence of increased adiposity at the other end of the spectrum, despite having BMIs within the "normal" range. Şahin Bodur et al. (2021) found higher body fat percentages and waist measurements. Levran et al. (2023) reported a high mean BMI z-score of 1.30 and a waist circumference percentile of 76.5. Central fat accumulation, a phenotype linked to increased cardiometabolic risk, is indicated by these findings. The impact of decreased physical activity, dietary imbalances, and excessive caloric intake, particularly in the context of flexible insulin regimens, is a potential explanation. Because they may increase patients' risk of insulin resistance and metabolic syndrome in later life, even slight increases in central adiposity in T1DM should be treated clinically.

The BMI, height, and weight z-scores reported by Bayram et al. (2020) were slightly positive (0.49, 0.31, and 0.21, respectively), indicating above-average growth in their sample. This could be attributed to a healthy diet, effective metabolic management, and access to comprehensive diabetes care, all of which promote healthy growth. Gökşen et al. (2014) reported healthy-range BMI values despite having diabetes for a comparatively long time (8.97 years), lending further credence to the notion that, with proper management, chronic illness need not necessarily affect anthropometric outcomes.

Combined results showed that growth outcomes in people with type 1 diabetes are highly diverse and represent the intricate interactions among metabolic control, dietary sufficiency, disease duration, and lifestyle factors. The coexistence of mild undernutrition and early central adiposity in the same population underscores the importance of routine anthropometric monitoring, despite the majority of studies indicating standard growth patterns. To enable early detection of deviations in either direction, assessments should include measurements of body composition, waist circumference, and z-scores, in addition to tracking BMI. By combining these measurements with dietary and biochemical assessments, it may be possible to identify individuals at risk, deliver targeted interventions, and promote long-term metabolic health and optimal growth in this susceptible group.

1.6. Biochemical Profile

The biochemical profile encompasses laboratory-based measurements of blood parameters that reflect an individual's internal metabolic and nutritional status. In this study, key biochemical indicators included serum levels of 25-hydroxyvitamin D, calcium, phosphorus, magnesium, and glycated hemoglobin (HbA1c) (Table 3) (Marshall et al, 2020). These biomarkers help determine the presence and severity of micronutrient deficiencies, as well as their association with glycemic regulation and bone metabolism, in children with type 1 diabetes mellitus (T1DM). Low serum vitamin D and calcium levels have been linked to impaired insulin secretion, poor glycemic control, and decreased bone mineral density, underscoring their dual role in maintaining metabolic and skeletal health (Mondkar et al., 2024).

Table 3: Summary of biochemical profile micronutrient status (vitamin D and Calcium), glycemic control (HbA1c), and bone health indicators in children and adolescents with T1DM.

#	Parameters	Results (Mean±S.D)	Interpretation	Authors
1	Calcium	9.6 ± 0.5 mg/dL	Although overt calcium/Vitamin D deficiency was rare, poor glycemic control was associated with central adiposity and unfavorable lipid profiles, which may affect bone health.	Teles & Fornes et al., (2012)
	25-Hydroxyvitamin D	27.9 ± 9.1 ng/mL		
	Phosphorus	4.5 ± 0.8 mg/dL		
	HbA1c	9.4 ± 2.1%		
2	Calcium	9.68±0.64	The prevalence of vitamin D deficiency or insufficiency in Indian children with type 1 diabetes suggests that specific monitoring and supplementation are necessary.	Chaithanya et al., (2022)
	25-Hydroxyvitamin D	19.98±4.86		
	Iron	62.79±26.56		
	Mg	1.97±0.15		
	phosphorus	5.30±0.79		
3	Magnesium (mg/dL)	1.90±0.15	In adolescents with type 1 diabetes, limiting carbohydrates can help with glycemic control. However, it may also reduce intake of calcium and other micronutrients, necessitating supplementation and monitoring to preserve bone health.	Levran et al., (2023)
	Phosphorus (mg/dL)	4.10±0.44		
	Calcium (mg/dL)	9.7±0.37		
	HbA1c %	8.1±1.41		
4	HbA1c %	9.2±1.92	Teenagers with type 1 diabetes may have poorer body composition and metabolic risk due to suboptimal diet quality and poor glycemic control. If dairy or vitamin D sources are not available, they may also have inadequate calcium/vitamin D status.	Şahin Bodur et al., (2021)
5	HbA1c (%)	8.43±1.52	For young people with type 1 diabetes, carbohydrate counting can help improve glycemic control and possibly improve bone health. However, calcium and vitamin D intake should be tracked and supplemented if necessary.	Gökşen et al., (2014)

6	HbA1c (%)	8.09	Regardless of glycemic control, obesity and poor diet increase cardiovascular risk in young people with type 1 diabetes, thereby bolstering calcium/vitamin D monitoring as a component of overall risk assessment.	Maffeis et al., (2017)
7	HbA1c (%)	7.85±1.53	Improved dietary adherence reduces bone/mineral risk and improves glycaemia in people with type 1 diabetes; however, rigorous meal planning is necessary to ensure adequate calcium and vitamin D intake.	Bayram et al., (2020)
8	HbA1c (%)	9.5±1.8	Regular dietary screening and supplementation are recommended because many children and adolescents with type 1 diabetes do not consume enough calcium and vitamin D.	Ozkaya et al., (2023)
9	HbA1c (%)	9.1 ± 2.0%	Micronutrient and bone health assessments are necessary because impaired growth in Indian children with type 1 diabetes may be caused by poor calcium/vitamin D status or glycemic control.	Khadilkar et al., (2013)
10	HbA1c (%)	7.9 ± 1.4	The association between vitamin D deficiency, poor calcium handling, and long-term skeletal risk is supported by lower bone mass and lower vitamin D levels observed in adolescents with type 1 diabetes.	Wierzbicka et al., (2018)
	Serum 25(OH)D (ng/mL)	15.3 ± 7.0		
	Serum iPTH (pg/mL)	30.4 ± 16.4		
	Serum Ca (mmol/L)	2.44 ± 0.09		
	Serum P (mmol/L)	1.39 ± 0.19		
11	Age	9.68 ± 3.99	Along with vitamin D and calcium, mineral screening is recommended because low magnesium is common in children with type 1 diabetes and is associated with poor glycemic control.	M Abd-Alraouf et al., (2018)
	HbA1c% hypomagnesemic diabetic group	11.93 ± 3.17%		
	HbA1c% normomagnesemia diabetic group	8.92 ± .93%		
	Serum Magnesium	1.83 ± .27 mg/dL		

Several studies on calcium, vitamin D, and associated biochemical parameters in children and adolescents with type 1 diabetes have linked these micronutrients to long-term bone health outcomes and glycemic control. In Table 2, Teles & Fornés et al. (2012) reported a high HbA1c of 9.4 ± 2.1%. They also reported mean serum calcium levels of 9.6 ± 0.5 mg/dL, phosphorus levels of 4.5 ± 0.8 mg/dL, and 25-hydroxyvitamin D levels of 27.9 ± 9.1 ng/mL. While there were few cases of overt calcium or vitamin D deficiency in their cohort, poor glycemic control was associated with negative lipid profiles and central adiposity, which may indirectly impact bone health. Similar findings were made by Chaithanya et al. (2022), who discovered that the mean calcium was 9.68 ± 0.64 mg/dL, the phosphorus was 5.30 ± 0.79 mg/dL, the magnesium was 1.97 ± 0.15 mg/dL, the Iron was 62.79 ± 26.56 µg/dL, and the 25(OH)D was significantly lower at 19.98 ± 4.86 ng/mL. This suggests that vitamin D insufficiency or deficiency is common in Indian children with type 1 diabetes. In their report, Levran et al. (2023) found that HbA1c was 8.1 ± 1.41%, calcium was 9.7 ± 0.37 mg/dL, phosphorus was 4.10 ± 0.44 mg/dL, and magnesium was 1.90 ± 0.15 mg/dL. They also noted that although carbohydrate restriction may improve glycemic control, it can also lower calcium and other micronutrient intake, requiring dietary monitoring.

According to Şahin Bodur et al. (2021), adolescents with poor metabolic control (HbA1c = 9.2 ± 1.92%) may not be getti ng enough calcium and vitamin D due to a poor diet, particularly when dairy or fortified sources are not available.HbA1c was 8.43 ± 1.52% in Turkey, according to Gökşen et al. (2014), who emphasized the value of tracking calcium and vitami n D intake for bone health while also endorsing carbohydrate counting as a helpful glycemic control tactic.An HbA1c of 8. 09% was reported by Maffeis et al. (2017), highlighting the fact that obesity and dietary factors, in addition to glycemia, a ffect cardiovascular risk in young people with type 1 diabetes. This highlights the importance of calcium/vitamin D evalua tion in risk management. HbA1c was 7.85 ± 1.53%, according to Bayram et al. (2020), who also linked better dietary adherence to better glycemic and bone mineral status. However, they cautioned that structured meal planning is necessary to ensure adequate calcium and vitamin D.

With a HbA1c of 9.5 ± 1.8%, Ozkaya et al. (2023) suggested routine dietary screening and supplementation because many kids and teenagers don't get enough calcium and vitamin D. Khadilkar et al. (2013) reported a HbA1c of 9.1 ± 2.0% in India and proposed that poor calcium/vitamin D status or uncontrolled diabetes may be the cause of impaired growth in T1DM, necessitating evaluations of bone health and micronutrients. With HbA1c at 7.9 ± 1.4%, serum 25(OH)D at 15.3 ± 7.0 ng/mL, iPTH at 30.4 ± 16.4 pg/mL, calcium at 2.44 ± 0.09 mmol/L, and phosphorus at 1.39 ± 0.19 mmol/L, Wierzbicka et al. (2018) presented a more thorough biochemical profile in adolescents. They connected decreased bone mass and elevated long-term skeletal risk to inadequate calcium handling and low vitamin D. The significance of magnesium was finally emphasized by M. Abd-Alraouf et al. (2018), who found that children with hypomagnesemia had a mean magnesium level of 1.83 ± 0.27 mg/dL and a significantly worse glycemic control (HbA1c = $11.93 \pm 3.17\%$) than their peers with normal magnesemia status ($8.92 \pm 0.93\%$). Their results support the use of magnesium in combination with calcium and vitamin D for routine biochemical monitoring in the management of type 1 diabetes.

Findings from other pediatric T1DM cohorts align with the anthropometric and biochemical trends observed in the current dataset, particularly the high prevalence of suboptimal vitamin D status and signs of decreased bone mineral health. According to Bae et al. (2018), mean serum 25-hydroxyvitamin D levels were insufficient in the current analysis. They found that Korean children and adolescents with type 1 diabetes had significantly lower mean 25(OH)D concentrations (21.6 ± 8.5 ng/mL) than healthy controls (28.0 ± 12.0 ng/mL), as well as a significantly higher prevalence of vitamin D deficiency (48% vs. 26%). In a meta-analysis of 46 studies, Loxton et al. (2021) confirmed that children and adolescents with type 1 diabetes consistently had lower bone mineral density across multiple sites, including the lumbar spine, femoral neck, and entire body, compared to their peers without the disease. This deficiency risk translates into long-term skeletal implications. The relationship between metabolic regulation and skeletal health was also highlighted by Loureiro et al. (2014), who found a significant correlation between poor glycemic control, increased osteoprotegerin expression, and decreased bone mineral density in Brazilian youth with type 1 diabetes. When combined, these studies support the current understanding that children with type 1 diabetes frequently have both vitamin D deficiency and poor bone health. This suggests that routine screening and early nutritional or treatment interventions are necessary to prevent long-term skeletal complications.

1.7. Pathophysiological Mechanisms Linking Vitamin D and Calcium Deficiencies with T1DM and Bone Fragility

Several studies have reported an association between vitamin D deficiency and the development of type 1 diabetes mellitus (T1DM) (de Oliveira & Dominguetti, 2018). Epidemiological evidence further suggests that vitamin D deficiency during early life may increase the risk of developing type 1 diabetes mellitus (T1DM) later in childhood (Bener et al., 2009).

Vitamin D regulates immune function in a variety of ways, including innate immunity, antigen presentation, and adaptive immune responses. Vitamin D receptors (VDRs) are found in both pancreatic islet β-cells and immune cells, including activated T cells. Vitamin D regulates islet β-cell activity, improves insulin sensitivity, and protects β-cells by reducing inflammation and apoptosis. A vitamin D deficiency can impair glucose tolerance, disrupt the expression of genes required for islet cell function, and increase the risk of both type 1 and 2 diabetes. Vitamin D modulates immune responses by binding to its receptors, potentially reducing autoimmune damage associated with type 1 diabetes (He, Song, Zhu, Gu, and Liu, 2022) (Fig. 1).

Vitamin D and calcium deficiencies may contribute to metabolic dysregulation and impaired bone remodeling through multiple interrelated pathways. Vitamin D plays a crucial role in pancreatic β-cell function by enhancing calcium-dependent insulin secretion and modulating inflammatory cytokines that are involved in autoimmunity. Its deficiency disrupts calcium homeostasis within β-cells, reducing insulin release and worsening hyperglycemia (Klec et al., 2019). Additionally, insufficient vitamin D reduces insulin receptor expression and impairs glucose uptake in peripheral tissues, further aggravating glycemic instability. Calcium, on the other hand, is essential for both insulin exocytosis and bone mineralization. Chronic calcium insufficiency stimulates parathyroid hormone (PTH) secretion, which, in turn, increases bone resorption and decreases bone mineral density (Cipponeri et al., 2025). The combination of metabolic acidosis from poor glycemic control and vitamin D/calcium deficiency accelerates bone turnover, resulting in compromised skeletal integrity and a higher risk of fractures in children and adolescents with T1DM (Argano et al, 2023).

It has been documented that 1,25-dihydroxyvitamin D_3 [1,25$(OH)_2D_3$] can affect the way that pancreatic β-cells secrete insulin. Because insulin is released when intracellular calcium levels rise rapidly, this hormone significantly affects the dynamics of calcium (Ca^{2+}) within cells. 1,25$(OH)_2D_3$ specifically promotes calcium buffering, increases calcium mobilization from internal stores, and facilitates calcium entry into the β-cells. These processes cause rapid, regular calcium oscillations in the cells, which occur regardless of glucose levels. Although organelles have little effect on lowering excess calcium, the plasma membrane and endoplasmic reticulum (ER) actively remove calcium through specialized transporters, such as calcium exchangers and the SERCA pump (Szymczak-Pajor et al., 2020). Additionally, 1,25$(OH)_2D_3$ mobilizes calcium from the ER via ryanodine receptors, but not via IP_3 receptors, and stimulates calcium influx through both voltage-sensitive and voltage-insensitive channels. Vitamin D receptors on the ER and plasma membranes are implicated in these effects. Crucially, the pattern of calcium oscillations, which correlates with 1,25-$(OH)_2D_3$ concentration, is followed by insulin secretion (Al-Shoumer & Al-Essa, 2015). According to Ahn, Kang, and

Jeung (2017), this suggests that $1,25(OH)_2D_3$ may help regulate insulin release when glucose levels are stable, such as during fasting. The whole pathological pathway is summarized in Figure (1).

Vitamin D and calcium deficiencies in children and adolescents with type 1 diabetes mellitus (T1DM) contribute to both metabolic and skeletal dysfunction. Optimizing these micronutrients may help restore β-cell function, stabilize blood glucose levels, and enhance bone health.

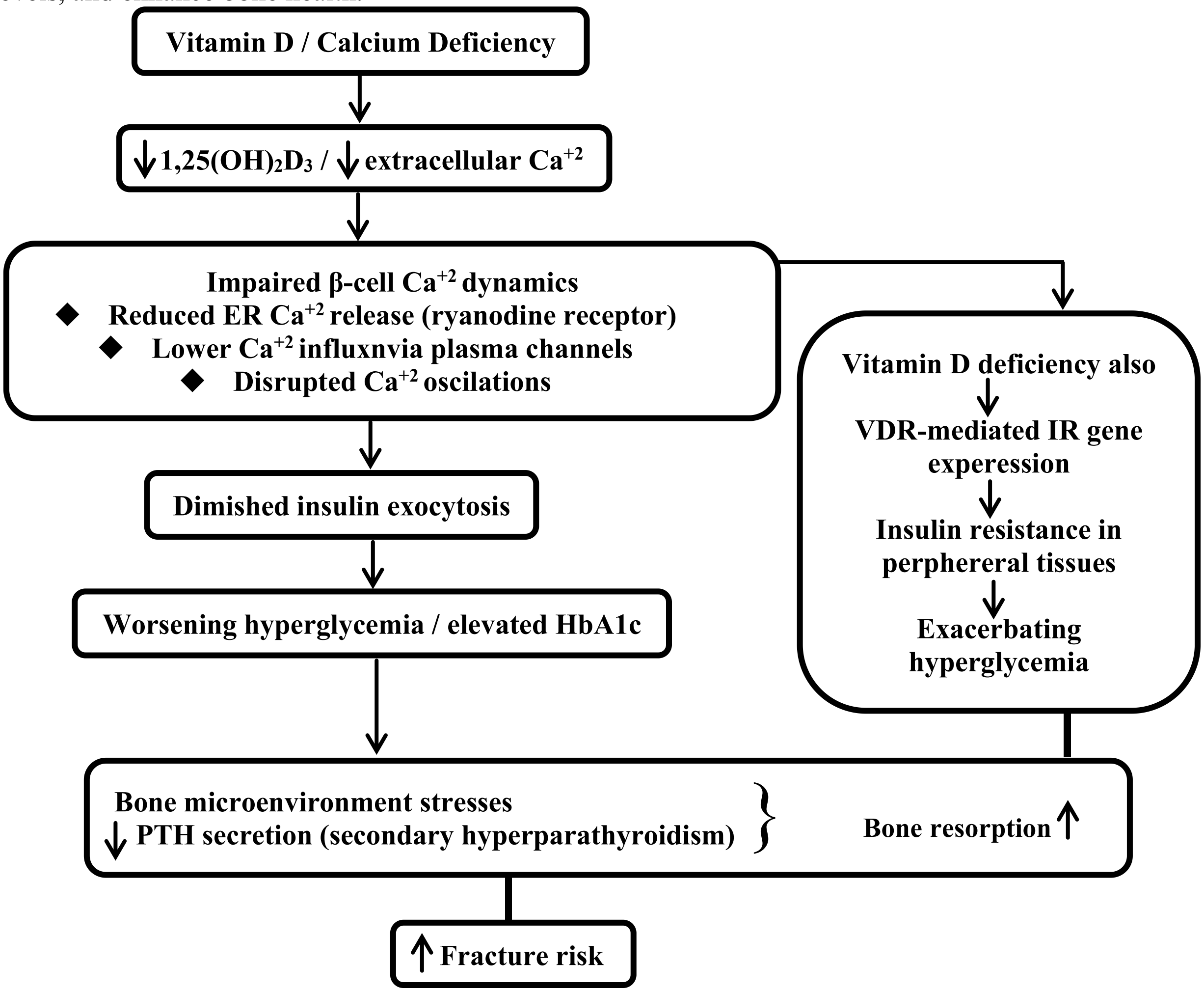

Figure 1: Pathophysiological Mechanisms Linking Vitamin D and Calcium Deficiencies with T1DM and Bone Fragility

1.8. Theoretical Hypothesis

Vitamin D and calcium deficiencies in children and adolescents with Type 1 Diabetes Mellitus impair calcium-dependent β-cell insulin secretion and bone mineralization through dysregulated calcium homeostasis, enhanced parathyroid activity, and increased metabolic acidosis. Correction of these deficiencies may restore β-cell functionality, improve insulin sensitivity, and reduce skeletal fragility—thereby serving as an adjunct therapeutic target alongside insulin therapy.

1.9. Therapeutic Strategies

The management of vitamin D and calcium insufficiency in children and adolescents with type 1 diabetes should be targeted and multimodal: screening and biochemical testing (serum 25-hydroxyvitamin D, calcium, phosphorus, magnesium, PTH) is appropriate for high-risk patients (poor glycemic control, malabsorption, limited sun exposure) rather than as an unconditional universal test for all patients, and treatment should be reserved for documented deficiency with individualized follow-up (Mahmud et al., 2018).

Vitamin D repletion aims to restore 25(OH)D (maintenance intakes ~600 IU/day for children with higher supervised dosing or loading regimens used for confirmed deficiency); randomized trials in youth with T1DM reliably increase 25(OH)D but show mixed evidence for improvements in HbA1c or β-cell preservation, so repletion must be individualized and monitored _including checking calcium to avoid hypercalcemia_ Ensure age-appropriate calcium intake (≈1,000 mg/day for children 4–8 years; ≈1,300 mg/day for 9–18 years) primarily from diet, using supplements only when dietary sources are inadequate and under medical supervision(Office of Dietary Supplements, 2022). Combine dietary counseling with weight-bearing exercise and safe sun exposure to maximize bone accrual and insulin sensitivity, and include multidisciplinary care (Davis et al., 2023). Finally, assessing and correcting magnesium levels were indicated because hypomagnesemia is common in T1DM and is associated with worse glycemic control (Dobrovolska et al., 2024).

Conclusion

Vitamin D and calcium deficiencies are common yet overlooked complications in children and adolescents with Type 1 Diabetes Mellitus. These deficiencies impair insulin secretion, worsen glycemic control, and weaken bone mineralization, increasing the risk of long-term skeletal fragility. Regular screening and timely correction through diet, supplementation, and lifestyle modification can enhance both metabolic stability and bone health. Integrating micronutrient management with insulin therapy offers a straightforward, cost-effective approach to improving outcomes in pediatric T1DM.

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Conflict of Interest.

The author declares no conflict of interest. This study received no external funding and was conducted purely for academic and research purposes.

References

Ahn, C., Kang, J. H., & Jeung, E. B. (2017). Calcium homeostasis in diabetes mellitus. *Journal of veterinary science*, *18*(3), 261-266.

Al-Shoumer, K. A., & Al-Essa, T. M. (2015). Is there a relationship between vitamin D with insulin resistance and diabetes mellitus?. *World journal of diabetes*, *6*(8), 1057.

Argano, C., Mirarchi, L., Amodeo, S., Orlando, V., Torres, A., & Corrao, S. (2023). The role of vitamin D and its molecular bases in insulin resistance, diabetes, metabolic syndrome, and cardiovascular disease: state of the art. *International journal of molecular sciences*, *24*(20), 15485.

Arteaga, E. (2009). High prevalence of vitamin D deficiency in children and adolescents with type 1 diabetes. *Bone*.

Bae, K. N., Nam, H. K., Rhie, Y. J., Song, D. J., & Lee, K. H. (2018). Low levels of 25-hydroxyvitamin D in children and adolescents with type 1 diabetes mellitus: a single center experience. *Annals of pediatric endocrinology & metabolism*, *23*(1), 21-27.

Bayram, S., Kızıltan, G., & Akın, O. (2020). Effect of adherence to carbohydrate counting on metabolic control in children and adolescents with type 1 diabetes mellitus. *Annals of pediatric endocrinology & metabolism*, *25*(3), 156-162.

Bell, K. J., & Lain, S. J. (2025). The Changing Epidemiology of Type 1 Diabetes: A Global Perspective. *Diabetes, obesity & metabolism*, *27 Suppl 6*(Suppl 6), 3–14.

Bener, A., Alsaied, A., Al-Ali, M., Al-Kubaisi, A., Basha, B., Abraham, A., ... & Mian, M. (2009). High prevalence of vitamin D deficiency in type 1 diabetes mellitus and healthy children. *Acta diabetologica*, *46*, 183-189.

Blair, M. (2016). Diabetes mellitus review. *Urologic nursing*, *36*(1). +

Chaithanya, H. B., Rallapalli, S. S., Sabinkar, G., Tirupati, S., Jumkhawala, K., & Sarathi, V. (2022). Serum micronutrient levels in children and adolescents with type 1 diabetes mellitus. *Romanian Journal of Diabetes Nutrition and Metabolic Diseases*, *29*(3), 368-373.

Cipponeri, E., Tarsitano, M. G., Falbo, E., & Conte, C. (2025). Insulin resistance in type 1 diabetes: is there a role for vitamin D? A systematic review of the evidence. *Discover Endocrinology and Metabolism*, *1*(1), 7.

Davis, E. A., Shetty, V. B., Teo, S. Y., Lim, R. J., Patton, S. R., & Taplin, C. E. (2023). Physical activity management for youth with type 1 diabetes: Supporting active and inactive children. *Diabetes spectrum*, *36*(2), 137-145.

de Oliveira, V. R. L. S., & Domingueti, C. P. (2018). Association of vitamin D deficiency and type 1 diabetes mellitus: a systematic review and meta-analysis. *International Journal of Diabetes in Developing Countries*, *38*, 280-288.

Diabetes and the Environment Database. (2022). *Diabetes incidence and historical trends*. https://www.diabetesandenvironment.org/home/diabetes-incidence-and-historical-trends

Dobrovolska, L., & Boyarchuk, O. (2024). Magnesium intake and serum magnesium concentration in children with type 1 diabetes mellitus: association with glycemic control and clinical symptoms. *Frontiers in Nutrition*, *11*, 1477814.

Gökşen, D., Altınok, Y. A., Özen, S., Demir, G., & Darcan, Ş. (2014). Effects of carbohydrate counting method on metabolic control in children with type 1 diabetes mellitus. *Journal of clinical research in pediatric endocrinology*, *6*(2), 74.

Haller, M. J., Atkinson, M. A., & Schatz, D. (2005). Type 1 diabetes mellitus: etiology, presentation, and management. *Pediatric Clinics*, *52*(6), 1553-1578. +

He, L. P., Song, Y. X., Zhu, T., Gu, W., & Liu, C. W. (2022). Progress in the relationship between vitamin D deficiency and the incidence of type 1 diabetes mellitus in children. *Journal of Diabetes Research*, *2022*(1), 5953562.

International Diabetes Federation (2021). *IDF Diabetes Atlas*, 10th Edition. Brussels, Belgium. https://diabetesatlas.org/

Katsarou, A., Gudbjörnsdottir, S., Rawshani, A., Dabelea, D., Bonifacio, E., Anderson, B. J., ... & Lernmark, Å. (2017). Type 1 diabetes mellitus. *Nature reviews Disease primers*, *3*(1), 1-17. +

Khadilkar, V. V., Parthasarathy, L. S., Mallade, B. B., Khadilkar, A. V., Chiplonkar, S. A., & Borade, A. B. (2013). Growth status of children and adolescents with type 1 diabetes mellitus. *Indian journal of endocrinology and metabolism*, *17*(6), 1057-1060.

Klec, C., Ziomek, G., Pichler, M., Malli, R., & Graier, W. F. (2019). Calcium signaling in ß-cell physiology and pathology: a revisit. *International journal of molecular sciences*, *20*(24), 6110.

Levran, N., Levek, N., Sher, B., Gruber, N., Afek, A., Monsonego-Ornan, E., & Pinhas-Hamiel, O. (2023). The impact of a low-carbohydrate diet on micronutrient intake and status in adolescents with type 1 diabetes. *Nutrients*, *15*(6), 1418.

Loureiro, M. B., Ururahy, M. A., Freire-Neto, F. P., Oliveira, G. H., Duarte, V. M., Luchessi, A. D., ... & Rezende, A. A. (2014). Low bone mineral density is associated to poor glycemic control and increased OPG expression in children and adolescents with type 1 diabetes. *Diabetes research and clinical practice*, *103*(3), 452-457.

Loxton, P., Narayan, K., Munns, C. F., & Craig, M. E. (2021). Bone mineral density and type 1 diabetes in children and adolescents: a meta-analysis. *Diabetes Care*, *44*(8), 1898-1905.

M Abd-Alraouf, A. A., Ismail, N. Y., Ghanem, S. M., & Abd-Elaziz, A. F. (2018). SERUM MAGNESIUM IN CHILDREN WITH TYPE 1 DIABETES AND ITS CORRELATION TO GLYCEMIC CONTROL. *Al-Azhar Journal of Pediatrics*, *21*(1), 1846-1857.

Maffeis, C., Fornari, E., Morandi, A., Piona, C., Tomasselli, F., Tommasi, M., & Marigliano, M. (2017). Glucose-independent association of adiposity and diet composition with cardiovascular risk in children and adolescents with type 1 diabetes. *Acta Diabetologica*, *54*(6), 599-605.

Mahmud, F. H., Elbarbary, N. S., Fröhlich-Reiterer, E., Holl, R. W., Kordonouri, O., Knip, M., ... & Craig, M. E. (2018). ISPAD Clinical Practice Consensus Guidelines 2018: Other complications and associated conditions in children and adolescents with type 1 diabetes. *Pediatric diabetes*, *19*(Suppl 27), 275.

Mobasseri, M., Shirmohammadi, M., Amiri, T., Vahed, N., Fard, H. H., & Ghojazadeh, M. (2020). Prevalence and incidence of type 1 diabetes in the world: a systematic review and meta-analysis. *Health promotion perspectives*, *10*(2), 98. +

Office of Dietary Supplements. (2022, November 8). *Vitamin D fact sheet for consumers*. U.S. Department of Health & Human Services, National Institutes of Health. https://ods.od.nih.gov/factsheets/VitaminD-Consumer/

Ozkaya, V., & Ozkaya, S. O. (2023). Assessments of energy, macro and micronutrient intakes in children and adolescents with type 1 diabetes mellitus. *Marmara Medical Journal*, *36*(2), 235-241.

Patterson, C., Guariguata, L., Dahlquist, G., Soltész, G., Ogle, G., & Silink, M. (2014). Diabetes in the young–a global view and worldwide estimates of numbers of children with type 1 diabetes. *Diabetes research and clinical practice*, *103*(2), 161-175.

Roglic, G. (2016). WHO Global report on diabetes: A summary. *International Journal of Noncommunicable Diseases*, *1*(1), 3-8. +

Şahin Bodur, G., Keser, A., ŞIKLAR, Z., & Berberoğlu, M. (2021). The Relationship Between Diet Quality of Adolescents with Type 1 Diabetes and Nutritional Status and Biochemical Parameters. *Erciyes Medical Journal*, *43*(5).

Shera, A. S., Jawad, F., & Maqsood, A. (2007). Prevalence of diabetes in Pakistan. *Diabetes research and clinical practice*, *76*(2), 219-222.

Szymczak-Pajor, I., Drzewoski, J., & Śliwińska, A. (2020). The molecular mechanisms by which vitamin D prevents insulin resistance and associated disorders. *International journal of molecular sciences*, *21*(18), 6644.

Teles, S. A. S., & Fornés, N. S. (2012). Relationship between anthropometric and biochemical profiles in children and adolescents with type 1 diabetes. *Revista Paulista de Pediatria*, *30*, 65-71.

Wierzbicka, E., Swiercz, A., Pludowski, P., Jaworski, M., & Szalecki, M. (2018). Skeletal status, body composition, and glycaemic control in adolescents with type 1 diabetes mellitus. *Journal of diabetes research*, *2018*(1), 8121634.

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