World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(REVIEW ARTICLE)

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Factors that influence the physical development of children and adolescents with type 1 diabetes: A scoping review

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World Journal of Advanced Research and Reviews, 2025, 27(03), 1117-1126

Publication history: Received on 05 August 2025; revised on 14 September 2025; accepted on 16 September 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.27.3.3207

Abstract

Introduction: Type 1 diabetes mellitus is a chronic disease, with a high incidence, mainly in childhood. The disease can cause various complications, such as hypoglycemia or diabetic ketoacidosis, but it can also affect linear growth.

Purpose: The purpose of this scoping review is to investigate the relationship between type 1 diabetes mellitus and linear growth, as well as the effect of the disease on it.

Methods: This scoping review analyzed articles on type 1 diabetes and physical growth in children from PubMed and ScienceDirect databases. The key terms "T1D" and "linear growth" were combined with the terms "skeletal growth" and "height". The search was limited to English and criteria included articles published between 2018 and 2024, under 18-year-old participants, and research studies of any design. Exclusion criteria included growth hormone treatments, reviews, meta-analyses, case studies, risk of developing type 1 diabetes, muscle development, bone density association, and older subjects. The PRISMA-ScR methodology was applied for selection and analysis.

Results: A total of 98 articles were found, with 87 from PubMed and 11 from ScienceDirect. After applying selection criteria, 54 articles were rejected, leaving 13 to be reduced to 8 after reading the full text. These 8 articles involved 11,037 children from 6 countries, with 6 studies being observational, retrospective, prospective-longitudinal, or cross-sectional. The children's ages ranged from 3 to 18 years, and their heights were measured in centimeters.

Conclusions: The findings of the study show that the disease can affect the growth of children and adolescents, resulting in the final height differing from the target height. Regular monitoring and regulation of glucose levels also seems to be particularly important, to minimize the effects of the disease on linear growth.

Keywords: Type 1 Diabetes Mellitus; Linear Growth; Target Height; Final Height

1. Introduction

Type 1 diabetes mellitus is a chronic disease characterized by the destruction of pancreatic β-cells, leading to the inability to produce and release insulin. It is most commonly observed in children and adolescents, and its incidence increases every year [1]. The duration of diabetes, the frequency, and the quality of blood glucose control can affect the final height of children [5].

The impact of type 1 diabetes mellitus on the physical development of children and adolescents has not been studied extensively and is not particularly widespread among the variables related to the disease and examined in the

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international bibliography. Over time and with the increasing frequency of type 1 diabetes, complications are observed in the development of these children, compared to children who do not have diabetes.

The purpose of this scoping review is to find the correlation between the disease and physical growth, the effect of the disease on growth and the difference between the final height and the target height. Specifically, the goal of this specific limited review is to highlight the way in which type 1 diabetes is associated with physical development as well as the way it affects it. Therefore, the following research questions arise:

- How is type 1 diabetes mellitus related to physical development?
- How is the physical development of children and adolescents affected by type 1 diabetes mellitus?
- How does the final height differ from the target height of children and adolescents with type 1 diabetes?

2. Methods

This scoping review used articles from research studies found in the PubMed and ScienceDirect databases, within a three-week period. To find them, the key words and phrases "type 1 diabetes" and "T1D" were used in both databases in combination with the terms "linear growth", "skeletal growth" and "height". The BOOLEAN operator "AND" was used between them, in order to find as many articles with the desired topic as possible. In addition, the results of the articles were limited to the English language only.

Certain criteria were used to select eligible articles. These criteria were: 1) articles published from 2018 to 2024 (16/09/2024), in order to study more recent findings, 2) articles in the English language, as it is the most widely used language and the largest number of studies are conducted using it worldwide, 3) articles in which the participants were under 18 years of age, as childhood ranges from 1 to 13 years and adolescence from 13 to 18 years [4], 4) the articles selected were research studies of any design. At the same time, the exclusion criteria were: 1) articles that examined growth hormone treatments, 2) reviews of any kind, meta-analyses, and case studies, 3) articles that examined the risk of developing type 1 diabetes, 4) articles that focused on muscle development, 5) articles that examined the association of type 1 diabetes with bone density, and 6) articles whose study subjects were older than 18 years of age.

The PRISMA-ScR methodology, as modified for scoping reviews [8], was applied to select articles, which include identification, screening, eligibility, selection, and thematic analysis. The text content was coded, categories were created, and codes were grouped into headings to organize the data. In the final step, the results regarding type 1 diabetes mellitus and physical growth were reported. For each article, data was extracted from a pre-formatted spreadsheet. Data fields include authors, year of publication, country, research design/study type, purpose, instruments, results, and conclusions. The findings of the articles included in the study are summarized in the index table (Table 1).

3. Results

The selection criteria led to the finding of 98 articles, of which 87 articles were found in "PubMed" and 11 articles in "ScienceDirect". Out of these, 54 articles were published before 2018 and were rejected. After reading the abstracts of the 44 remaining articles, 31 articles that did not meet any of the selection criteria were rejected and of the 13 remaining, 5 reviews were rejected. Then, after reading the full text of the 8 remaining articles, 2 articles were rejected. Therefore, the search led to the selection of 6 articles for this limited review. The process of selecting and rejecting the articles is presented in detail in the flowchart below (Figure 1).

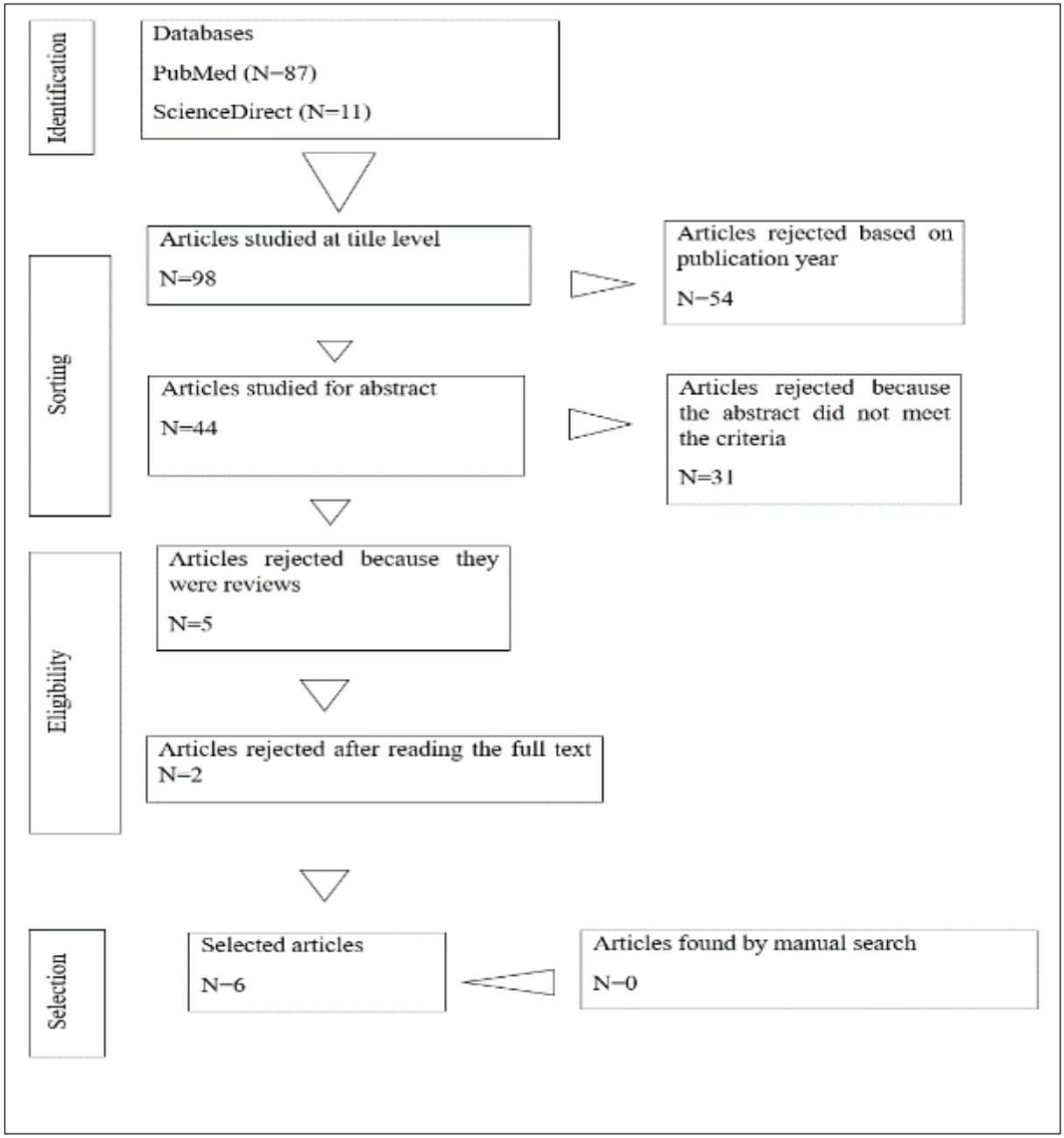

Figure 1 Flowchart according to the PRISMA-ScR proposed method

The 6 selected articles included a total of 11,037 children, specifically 5,729 boys and 5,308 girls. The studies were conducted in 6 different countries: one in Pakistan [6], two in Italy [2] [3], one in America [10], one in Germany and Austria [9], and one in China [7]. Of these, one was an observational study [6], one was a retrospective study [3], three were prospective–longitudinal studies [2] [9] [10] and one was a cross-sectional study [7].

The ages of the children ranged from 3 to 18 years. Consent from parents and/or children was requested for the participation of the children, however, in two studies it is not stated whether any kind of consent was given. The duration of the studies varied, with three lasting 2 years [3] [7] [10], one lasting 10 years [9], one lasting 20 years [6], while one did not state a specific duration [2]. In each of the studies, the height of the participants was measured at the beginning of the follow-up and was followed up every three to six months. In all studies, height was measured in centimeters (cm) and three studies, in order to compare the final height of the children with the target height, used the formula [(mother's height + father's height + 13)/2] for boys and [(mother's height + father's height - 13/2] for girls [2] [6] [7].

The study by Shaikh et al. (2022) included 66 children and adolescents (42 girls and 24 boys) with type 1 diabetes, with an average duration of diabetes of 0.5 years for boys and one year for girls. At the beginning of the study, the duration of diabetes and height were observed to be inversely related, as the longer the participants had the condition, the lower their height was, compared to the general population. At the end of the study, it was found that 85.7% of the girls reached the target height, while only 50% of the boys reached the target height. Another finding of the study was that the final height was also affected by glycosylated hemoglobin (HbA1c) levels. Irregular and inadequate glucose control and regulation contributed to reduced height, regardless of gender [6]. Blasetti et al. (2023) studied 144 children (76 boys and 68 girls). The study showed that children who showed greater increases in glucose variability during the two-year follow-up period tended to have less improvement in height. Conversely, lower glucose variability was associated with more favorable growth outcomes, highlighting the importance of stable glucose levels for normal growth in this population [3].

Bizzarri et al. (2018) studied 104 children (53 girls and 51 boys). The results of the study showed that the total height gain during puberty was 24.4 cm for boys and 19.0 cm for girls. The final height did not differ significantly from the target height, suggesting that children with type 1 diabetes who received intensive insulin therapy reached height as expected. The children were treated with either multiple daily injections or continuous subcutaneous insulin infusion, treatments that were associated with effective control of growth parameters. A positive correlation was found between the daily basal insulin dose during puberty and the adjusted target height, highlighting the importance of proper insulin intake for normal growth [2].

Zhu et al. (2018) studied 123 children (62 boys and 61 girls). The results showed that height was a reliable and practical biomarker for assessing the onset, progression, and status of puberty in youth with type 1 diabetes. The study confirmed that youth with diabetes who follow proper management of the condition can achieve adult height according to their genetic expectations, compared with the expected growth levels of the general population [10].

Vollbracht et al. (2021) studied 10,338 children (5,376 boys and 4,962 girls). The study revealed important evidence regarding the relationship between physical growth and basal insulin therapy in children and adolescents with type 1 diabetes. The findings highlighted that the use of long-acting insulin analogues was associated with more favorable height gain compared with intermediate-acting insulin therapies. Specifically, children taking long-acting insulin analogues demonstrated a closer alignment with normal growth trajectories, while children on intermediate-acting insulin showed slower growth, likely due to the less stable glycemic control provided by these therapies. Furthermore, the study highlighted the critical relationship between effective glycemic control and growth, as stable blood sugar levels achieved with long-acting insulin analogues had a positive impact on height. This finding highlights the importance of choosing the appropriate insulin regimen, not only for blood glucose management, but also for promoting healthy physical growth in pediatric patients with type 1 diabetes [9].

Song et al. (2018) studied 72 children (41 boys and 31 girls) with diabetes and 190 children (99 boys and 91 girls) without diabetes. The study examined the relationship between insulin-like growth factor-1 standard deviation score (IGF-1 SDS) and height in children with type 1 diabetes, revealing that physical growth in children with well-managed diabetes remains normal compared with that of healthy controls. Height standard deviation score (HSDS) was higher in children with diabetes compared with their healthy peers, and this difference was not statistically significant among those with good glycemic control. While IGF-1 SDS was strongly associated with HSDS in healthy controls, no such relationship was observed in children with diabetes, even among those with effective glycemic control, suggesting a dissociation of IGF-1 levels and height in this population. Poor glycemic control, as indicated by higher HbA1c levels, was associated with slightly reduced final height, while children with HbA1c below 7% had better height outcomes than those with HbA1c exceeding 8%. The study also highlighted the critical role of insulin in determining IGF-1 levels, as higher insulin doses were associated with higher IGF-1 levels and taller stature, underscoring the importance of appropriate insulin therapy to promote normal growth. In addition, girls with type 1 diabetes had higher HSDS and IGF-1 SDS compared with boys, possibly due to the effects of estrogen, which enhances hepatic insulin sensitivity and positively influences the growth hormone/IGF-1 axis. Finally, no significant differences in height or IGF-1 levels were observed between insulin delivery methods, such as multiple daily injections and continuous subcutaneous insulin infusion. Despite the impaired GH/IGF-1 axis commonly observed in diabetes, children without complications achieved normal height, with insulin levels playing a more decisive role than glycemic control in growth [7].

Table 1 Characteristics of the studies that fulfilled the inclusion criteria

Title	**Growth Trajectory in Children with Type 1 Diabetes Mellitus: The Impact of Insulin Treatment and Metabolic Control.**
Authors	Bizzarri, C., Timpanaro, T. A., Matteoli, M. C., Patera, I. P., Cappa, M., and Cianfarani, S. (2018).
Country	Italy
Study Type	Prospective-longitudinal study
Purpose	The study aimed to evaluate pubertal growth, final height, and metabolic profiles in children with type 1 diabetes mellitus undergoing intensive insulin therapy either through multiple daily injections or through continuous subcutaneous insulin infusion.
Tool	Researchers measured anthropometric data and monitored biochemical markers, such as HbA1c, and cholesterol levels. Insulin regimens were used to assess growth, pubertal development, and metabolic control.
Results	There was no discernible difference between final height and genetic target height. Higher doses of basal insulin positively affected height during adolescence. Improved metabolic profiles were associated with continued subcutaneous insulin therapy. HbA1c levels increased during adolescence but did not affect final height.
Conclusions	Modern intensive insulin therapies allow children with type 1 diabetes mellitus to achieve normal puberty and final height according to genetic expectations, despite disturbances in the growth process. Effective metabolic control, particularly through optimized basal insulin delivery, plays a critical role in normalizing growth outcomes.
Title	**The association of insulin-like growth factor-1 standard deviation score and height in Chinese children with type 1 diabetes mellitus.**
Authors	Song, W., Qiao, Y., Xue, J., Zhao, F., Yang, X., and Li, G. (2018)
Country	China
Study Type	Cross-sectional study
Purpose	The aim of the study was to evaluate the association between IGF-1 standard deviation score (IGF-1SDS) and height standard deviation score (HSDS) and to investigate whether either parameter influenced physical growth in children with type 1 diabetes mellitus.
Tool	The study used several tools to assess the association between IGF-1 SDS and HSDS in children with diabetes. Anthropometric measurements, including height, weight, body mass index, and HSDS, were calculated based on values for Chinese children, while target height was derived from parental heights. Glycemic control was categorized as good (HbA1c ≤7%) or poor (HbA1c >7%). Puberty stages were assessed using Tanner criteria.
Results	The study found that children with type 1 diabetes had higher height standard deviation scores (HSDS) compared with healthy controls, with girls showing a significant increase in HSDS. However, children with diabetes had lower IGF-1 levels and IGF-1 standard deviation scores (IGF-1SDS) than control group, suggesting reduced growth. Girls had higher HSDS and IGF-1 SDS compared with boys, likely due to higher insulin doses and the influence of estrogen. These findings suggest that while IGF-1 levels are affected in diabetes, height outcomes remain favorable, particularly when glycemic control and insulin dose are optimized.
Conclusions	While the growth hormone (GH)/IGF-1 axis is impaired in children with uncomplicated diabetes, these children generally maintain normal height. IGF-1 levels and height in these children do not improve with better glycemic control (i.e., reduced HbA1c), and neither C-peptide levels nor insulin types appear to affect height. However, high doses of insulin or estrogen use may contribute to higher IGF-1 levels and greater height, especially in girls with diabetes. Overall, C-peptide and insulin levels appear to play a key role in regulating IGF-1 levels in these children.
Title	**Determination of pubertal status in youths with Type 1 diabetes using height velocity and trajectories**
Authors	Zhu, J., Volkening, L. K., and Laffel, L. M. (2018)
Country	America

Study Type	Prospective-longitudinal study
Purpose	The goal was to create and validate a reliable and objective approach to assess the stage of puberty in young people with type 1 diabetes, using their growth patterns over time. This method aimed to use longitudinal growth data to accurately assess growth in puberty.
Tool	Participants were enrolled in a two-year study that focused on continuous glucose monitoring in young adults with type 1 diabetes. Puberty status at visit was determined using a stratified method that included clinical Tanner staging or, when available, pubertal growth indices from electronic health records. For additional visits, assessments of height growth rates and growth chart patterns were used.
Results	Adolescent status was assigned using three methods: 50% of children were assessed by clinical Tanner staging, 29% by health record review, and 22% by growth chart patterns. An analysis showed that results from height velocity chart patterns matched those from clinical Tanner staging at 87% of visits.
Conclusions	The simple and objective approach to determining puberty status emphasizes growth as a reliable measure for assessing the onset and progression of puberty.
Title	**Choice of basal insulin therapy is associated with weight and height development in type 1 diabetes: A multicenter analysis from the German/Austrian DPV registry in 10 338 children and adolescents.**
Authors	Vollbach, H., Auzanneau, M., Reinehr, T., Wiegand, S., Schwab, K., Oeverink, R., Froehlich-Reiterer, E., Woelfle, J., De Beaufort, C., Kapellen, T., Gohlke, B., and Holl, R. W. (2021)
Country	Germany and Austria
Study Type	Prospective-longitudinal study
Purpose	This analysis explores the growth of height and body mass index in pediatric patients with type 1 diabetes based on the choice of basal insulin therapy.
Tool	The study used longitudinal data from the Diabetes Perspective Follow-up (DPV) registry, which includes information from 10,338 children and adolescents with type 1 diabetes across Germany and Austria. Four main insulin regimens were compared: Neutral Protamine Hagedorn (NPH), Insulin Detemir (IDet), Insulin Glargine (IGla) and Continuous Subcutaneous Insulin Infusion (CSII). Anthropometric measurements such as weight, height and body mass index were collected during clinic visits, and body mass index and height were calculated using German population-based reference data. Multiple models were used to estimate changes in these scores, adjusting for factors such as gender, age and HbA1c levels to ensure reliable analysis.
Results	The study found that body mass index increased across all insulin regimens, with the most significant increase observed in girls. Among girls, the IDet regimen was associated with better body mass index outcomes compared with the CSII regimen. A general decrease in height was observed with the NPH, IDet, and IGla regimens, whereas the CSII regimen showed a nearly constant height trajectory, especially in girls. Younger children (5.0–7.9 years) experienced a decrease in body mass index, in contrast to significant increases observed in the older groups. The CSII regimen had the most favorable impact on growth patterns.
Conclusions	The findings highlight the impact of basal insulin regimens on weight and height in pediatric patients with type 1 diabetes. CSII regimen emerged as the most effective treatment for growth, while NPH showed advantages in controlling body mass index for specific age groups. All treatments resulted in an increase in body mass index, particularly in girls, signaling a critical need for weight management strategies in this population. These results highlight the importance of adjusting basal insulin therapy to optimize growth and weight outcomes in children and adolescents with type 1 diabetes.
Title	**Linear Growth and Final Height in People with Type 1 Diabetes: A Study from Karachi, Pakistan**
Authors	Shaikh, W., Riaz, M., Askari, S., and Basit, A. (2022)
Country	Pakistan
Study Type	Observational study
Purpose	The aim of the study was to determine physical development and final height in children and adolescents with type 1 diabetes mellitus.
Tool	The study used growth charts to monitor the physical development and growth velocity of children and adolescents with type 1 diabetes mellitus. Anthropometric measurements such as height, weight

	and body mass index were recorded, and height was compared to a target height determined based on the heights of the parents.
Results	The gender gap was notable, with only 50% of boys and 85.7% of girls reaching their genetic height. Height and duration of diabetes were found to have a significant negative correlation for both genders.
Conclusions	The study concluded that a large proportion of children and adolescents with diabetes, particularly boys, failed to reach their target height. The findings highlight the importance of close monitoring of glucose levels and growth parameters in young people with diabetes to mitigate growth disorders.
Title	**Role of glucose variability on linear growth in children with type 1 diabetes**
Authors	Blasetti, A., Castorani, V., Polidori, N., Mascioli, I., Chiarelli, F., and Giannini, C. (2023)
Country	Italy
Study Type	Retrospective study
Purpose	The study aimed to identify and characterize the effects of glycemic variability on the physical development of preadolescent children with type 1 diabetes mellitus.
Tool	The researchers used indices of glycemic variability along with height and weight, measured at baseline and every 4 months for over 2 years. These measurements were used to assess changes in growth and their association with glycemic control.
Results	The study included 144 preadolescent children with diabetes, who were followed for two years. According to growth, taller children had significantly lower glycemic variability indices. A negative correlation was found between glycemic variability and growth: higher glycemic variability was associated with lower height improvements. Although mean HbA1c levels did not differ significantly between groups, they decreased slightly.
Conclusions	The study concluded that glycemic variability significantly affects growth in children with diabetes. Low glycemic variability was associated with better developmental outcomes, highlighting the need for therapeutic strategies and technologies to minimize glucose fluctuations in the management of type 1 diabetes in children.

4. Discussion

Type 1 diabetes mellitus is a chronic disease with significant impacts on physical development in children and adolescents. The interplay between glycemic control, insulin therapy, the growth hormone/insulin-like growth factor-1 (GH/IGF-1) axis, and developmental outcomes creates a complex relationship that has been analyzed in many studies [3] [7] [9]. Therefore, studying the relationship between diabetes and physical development is particularly important. The purpose of this specific limited review was to investigate the association between type 1 diabetes mellitus and physical development in children and adolescents. Therefore, three research questions emerged.

The first question concerns how diabetes relates to physical growth. Type 1 diabetes significantly affects physical growth, particularly in children and adolescents, due to its effects on growth patterns, puberty, and body composition. The growth hormone/insulin-like growth factor (GH/IGF-1) axis, which is essential for healthy growth, is often disrupted by diabetes. Poor glycemic control can reduce circulating levels of IGF-1, an important hormone that mediates the effects of growth hormone on physical growth and bone development, resulting in delayed growth. Children may also experience slower growth rates, especially if the disease is poorly controlled, and may result in reduced final height [7].

Diabetes can affect the onset and progression of puberty. Puberty triggers a major burst of physical growth, and reduced insulin secretion or insulin resistance can delay or affect this growth. However, with improved glycemic control and insulin therapy, this can be normalized [3]. Type 1 diabetes significantly affects physical development in children and adolescents, particularly growth and body composition. The study by Shaikh et al. conducted in Pakistan, highlighted the importance of good glycemic control to ensure normal linear growth and final height. It revealed that children with poorly controlled diabetes exhibited growth retardation, while those with better metabolic control reached almost normal final height, highlighting the critical role of early glucose management [6]. Similarly, Blasetti et al. demonstrated that reduced glycemic variability was positively associated with better growth, indicating that stable glucose levels are essential for optimal growth during prepubertal development [3].

In the study by Vollbach et al. the type of insulin therapy was associated with both height and weight, with continuous subcutaneous insulin infusion (CSII) showing better height gain than other basal insulin regimens, although all treatments contributed to increased body mass index, especially in girls [9]. The study by Blasetti et al. also used the rate of height gain as a key indicator of growth during puberty, highlighting the role of insulin therapy in normalizing pubertal growth [3]. Another study that focused on children with diabetes in China was that by Song et al. This study found that while IGF-1 levels were lower in patients with diabetes, height outcomes were not significantly affected, suggesting that residual insulin secretion and glycemic control were protective factors for growth despite reduced IGF-1 signaling [7]. Collectively, these studies demonstrate that metabolic control, insulin therapy, and glycemic stability play a critical role in preventing diabetes-related growth disorders by ensuring normal physical growth trajectories during childhood and adolescence.

The second question concerns how physical growth in children and adolescents is affected by type 1 diabetes mellitus. The study by Shaikh et al. showed that poor glycemic control, reflected by elevated HbA1c, was directly associated with reduced height outcomes and reduced final height. It was observed that children and adolescents with long-term hyperglycemia exhibit reduced height growth rate and general growth retardation due to disruption of insulin-dependent pathways that mediate growth. This study also highlighted that, children with good metabolic control achieved near-normal final height, reinforcing the importance of early diagnosis and effective glycemic management for maintaining normal growth [6]. Along similar lines, Blasetti et al. examined the role of glycemic variability in height development. Unlike HbA1c alone, which provides an average measure of glucose levels, glycemic variability accounts for glucose fluctuations that may have independent effects on growth. Their findings highlighted that lower glycemic variability was associated with improved growth trajectories and height velocity in preadolescent children, suggesting that not only overall glycemic control, but also maintenance of stable glucose levels are essential parameters for mitigating growth impairment [3].

The role of insulin therapy in promoting or reducing physical growth is another key component examined in these studies. The study by Vollbach et al. evaluated how different basal insulin regimens, including NPH insulin, insulin glargine, insulin detemir, and continuous subcutaneous insulin infusion (CSII), affect growth and body mass index. The results revealed that while all insulin therapies contributed to increased body mass index, CSII stood out as having the most favorable relationship with height growth. This is likely to reflect its ability to more effectively mimic physiological insulin release, reducing hyperglycemia while ensuring adequate insulin levels to enhance growth. However, the increase in body mass index, observed across all types of treatment, highlights the anabolic effects of insulin and the potential for excessive weight gain when insulin therapy is not well-balanced, creating the need for tailored therapeutic approaches to maintain normal physical growth [9]. Similarly, the study by Bizzarri et al. investigated growth trajectories in children using intensive insulin regimens and observed that treatments such as CSII largely normalized growth, helping children achieve near-normal final height. Despite these improvements, subtle growth impairments remained in individuals with persistent poor glycemic control, highlighting the importance of insulin optimization and glucose monitoring [2].

Disruption of the GH/IGF-1 axis in diabetes also emerges as a critical factor affecting growth. IGF-1 is essential for promoting normal growth and bone development, as it mediates the effects of growth hormone (GH). However, endogenous insulin deficiency reduces hepatic IGF-1 production, thereby impairing this pathway. The study by Song et al. revealed significantly lower IGF-1 levels in patients with diabetes compared to healthy control groups. Interestingly, while IGF-1 levels were reduced, children's height outcomes were not severely compromised when glycemic control was adequate, and insulin therapy was effective. This suggests that improved nutritional status, estrogen effects in girls, and higher doses of exogenous insulin may compensate for some of the deficits caused by reduced IGF-1 synthesis. In addition, the study found that IGF-1 levels were positively correlated with C-peptide and insulin levels, highlighting the influence of residual β-cell function and insulin action on growth hormone regulation [7]. This finding is consistent with previous observations that insulin is the key to stimulating hepatic IGF-1 production, which cannot be fully replaced by exogenous insulin when administered subcutaneously.

The study by Zhu et al. highlights the impact of type 1 diabetes on growth during adolescence, particularly the potential for delayed or disrupted growth spurts, which are critical. It demonstrated that poor glycemic control, characterized by elevated glucose levels and metabolic instability, often leads to delayed puberty. Using height growth rate as a reliable indicator of puberty status, the study demonstrated how poor metabolic control during adolescence can negatively impact long-term growth outcomes. These findings highlight the importance of closely monitoring growth trajectories in children with diabetes, allowing for early recognition and intervention to mitigate developmental challenges associated with the condition [10].

The third question concerns how much final height differs from target height. The difference between final height and target height in children and adolescents with type 1 diabetes mellitus is a central concern due to the impact of inadequate glycemic control, insulin therapy, and hormonal imbalances (such as disorders in the GH/IGF-1 axis). The study by Song et al. directly addresses the relationship between final height and target height by analyzing the height standard deviation score (HSDS) in relation to the target height standard deviation score (THSDS). The findings revealed that children had HSDS that were 0.43–0.48 SDS higher than their THSDS, particularly in the group with good glycemic control. Despite significantly lower IGF-1 levels, children maintained normal or slightly elevated height results. This observation suggests that adequate insulin therapy and improved nutritional status can compensate for some of the growth impairments caused by the hormonal dysfunction associated with diabetes. Consequently, even with impairments in the GH/IGF-1 axis, good glycemic control appears sufficient to minimize or eliminate the difference between final height and target height [7].

Other studies indirectly highlight how discrepancies between final height and target height can arise due to inadequate metabolic control. The study by Shaikh et al. found that children with poor glycemic control had more significant deficits in growth and final height. In these cases, elevated HbA1c and chronic hyperglycemia affect GH action and IGF-1 production, parameters that are necessary for achieving normal height. However, for children with good glycemic control, the gap between final height and target height was significantly smaller, with many of them ultimately achieving heights close to their genetic potential [6].

The study of Bizzarri et al. about the growth trajectories in children with diabetes further supports this conclusion, finding that with modern intensive insulin therapy, such as multiple daily injections (MDI) or continuous subcutaneous insulin infusion (CSII), children were able to achieve near-normal final height. However, the study also noted subtle height deficits in children with persistently poor glycemic control, highlighting that metabolic dysregulation remains a barrier to achieving target height in cases of poor management. While the overall differences are small, these impairments confirm the importance of stable glucose levels throughout the preadolescent and adolescent growth period [2].

The study by Vollbracht et al. highlights the role of insulin therapy in influencing growth outcomes relative to target height. The analysis showed that children treated with CSII had more favorable height growth compared to those receiving long-acting basal insulin therapies, such as insulin glargine or NPH insulin. This is likely due to the ability of CSII to mimic normal insulin secretion, thereby better supporting hepatic IGF-1 production and reducing episodes of hyperglycemia [9].

While the study by Zhu et al. on height velocity and pubertal timing does not directly measure the final outcomes of height relative to target height, it does provide relevant insight into how diabetes may delay pubertal growth spurts, particularly in children with poor glucose management. Since adolescence is a critical period for achieving final height, delays or disruptions in pubertal growth may widen the gap between final height and target height, particularly in cases of poor management. By using height growth rate as a marker for pubertal development, this study reinforces the need to closely monitor both growth trajectories and pubertal progression in children with type 1 diabetes [10].

5. Conclusion

The findings highlight the significant impact of type 1 diabetes mellitus on the growth of children and adolescents, underscoring the importance of intensive insulin therapy and effective glycemic control. Modern therapeutic approaches, such as CSII, have allowed many children with type 1 diabetes mellitus to eventually achieve heights consistent with their genetic potential. However, abnormalities in the growth hormone/insulin-like growth factor-1 (GH/IGF-1) axis persist, with circulating IGF-1 levels often not affected by glycemic control alone. In some cases, higher doses of insulin or hormonal agents, such as estrogen in girls, contribute to increased IGF-1 levels and improved height outcomes. Despite these advances, many individuals, particularly boys, with poor metabolic control face a continued risk of not reaching target height. This highlights the need for targeted growth monitoring and targeted interventions to support healthy growth.

Beyond growth outcomes, insulin therapy and glycemic variability also significantly influence body composition and growth trajectories. While CSII therapy has shown benefits for height growth, all insulin regimens are associated with increases in body mass index, especially in girls, requiring a dual focus on weight management and glycemic control. Furthermore, reducing glycemic variability, as well as achieving low HbA1c, are particularly important for improving growth outcomes. This highlights the importance of proper management and regular monitoring to maintain stable blood glucose levels. A holistic approach, including frequent glucose monitoring, individualized insulin therapy, and

ongoing assessment of growth parameters, is essential to minimize the long-term effects of type 1 diabetes on the physical development of young patients.

Limitations

Some limitations were encountered during the preparation of this review. The main limitation was the language of the articles, as only articles in English were selected, thus excluding relevant research conducted in other languages. Another limitation was the number of databases searched for articles, as well as the fact that the search was conducted by a single researcher. Searching for relevant articles in multiple databases would likely have been more efficient if it had been conducted by more than one researcher.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflict of interest.

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