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Low-carbohydrate diet improves glycemic control in patients with type 1 diabetes: a systematic review

La dieta baja en carbohidratos mejora el control glucémico en pacientes con diabetes tipo 1: una revisión sistemática

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Abstract

Objective: This systematic review and meta-analysis aimed to evaluate the effects of LCDs on glycemic control in adults with T1D.

Materials and Methods: A comprehensive search was conducted in PubMed, Scopus, and Web of Science up to September 2024. Eligible studies included randomised controlled trials, cohort studies, and non-randomised interventions in adults with type 1 diabetes following LCD. Two review authors independently completed study selection, data extraction, and risk of bias assessment. Ninety-three records were discovered, of which eight research studies met the inclusion criteria. The effect of LCD on glycemic control was assessed using the standardised mean difference and 95% confidence intervals (CIs), calculated from pre- and post-intervention values. Publication bias was assessed using funnel plots and the Egger test, and heterogeneity was assessed using Cochran's Q statistic and I^2 index.

Results: Our results revealed significant reductions in HbA1c (point estimate: 0.79 mmol/mol; 95% CI: 0.57 to 1.02; $p < 0.001$) and total daily insulin dose (point estimate: 0.96 U; 95% CI: 0,67 to 1.25; $p < 0.001$) in adults with T1D following LCD interventions. Nonetheless, we observed no significant changes in lipid profile, anthropometric parameters, and blood pressure.

Conclusions: DBCs may be effective in conjunction with drug therapy to maintain glycemic control in people with T1D. Evidence is limited by sample sizes, variability in diets, and risk of bias. Trials with appropriate methodological designs are required to validate these findings.

Keywords. Low-carbohydrate diet; Type 1 diabetes; Glycemic control; HbA1c; Carbohydrate-restricted diets.

Resumen

Objetivo: Esta revisión sistemática y metaanálisis tuvo como objetivo evaluar los efectos de los LCD en el control glucémico en adultos con diabetes tipo 1.

Materiales y Métodos: Se realizó una búsqueda exhaustiva en PubMed, Scopus y Web of Science hasta septiembre de 2024. Los estudios elegibles incluyeron ensayos controlados aleatorizados, estudios de cohorte e intervenciones no aleatorizadas en adultos con diabetes tipo 1 tras el LCD. Dos autores de la revisión completaron de forma independiente la selección de estudios, la extracción de datos y la evaluación de riesgo de sesgo. Se descubrieron noventa y tres registros, de los cuales ocho estudios de investigación cumplieron los criterios de inclusión. El efecto de la LCD en el control glucémico se evaluó utilizando la diferencia media estandarizada y los intervalos de confianza (IC) del 95%, calculados a partir de valores previos y posteriores a la intervención. El sesgo de publicación se evaluó usando diagramas de embudo y la prueba de Egger, y la heterogeneidad se evaluó usando la estadística Q de Cochran y el índice I^2.

Resultados: La HbA1c (0.79 mmol/mol; IC 95%: 0.57 a 1.02; $p < 0.001$) y la dosis diaria total de insulina (0.96 U; IC 95%: 0.67 a 1.25; $p < 0.001$) se redujeron de manera significativa tras las DCB. No observamos cambios en el perfil lipídico, parámetros antropométricos ni presión arterial.

Conclusiones: Las DBC pueden ser eficaces junto con la terapia farmacológica para mantener el control glucémico en personas con DT1. La evidencia es limitada por el tamaño de las muestras, la variabilidad en las dietas y el riesgo de sesgo. Se requieren ensayos con diseños metodológicos adecuados para validar estos hallazgos.

Palabras Claves: Dieta baja en carbohidratos; Diabetes tipo 1; Control glicémico; HbA1c; Carbohidratos de la dieta

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Introduction

Type 1 diabetes (T1D) is an autoimmune disease characterized by progressive loss of beta-cell mass and function, resulting in absolute insulin deficiency and hyperglycemia[1]. Once hyperglycemia occurs, people with T1D risk developing long-term damage to various organs, particularly the nerves, kidneys, eyes, and cardiovascular system[2]. Moreover, many patients with type 1 diabetes have difficulty meeting their glycemic goals (A1C level below 7%; <53 mmol/mol)[3,4]. In this sense, managing individuals with T1D requires exogenous insulin administration, physical activity, and appropriate diet intake[5].

Carbohydrate intake through the diet is essential for maintaining postprandial glucose levels 2. The glycemic response is influenced by total carbohydrate intake, carbohydrate and starch types, food preparation methods, and other macronutrients (lipids, protein, and fiber), as well as gastric emptying and intestinal nutrient absorption[6]. Dietary guidelines for individuals with diabetes aim to improve blood glucose control through consistent carbohydrate intake across various food groups[7]. Evidence suggests that a low-carbohydrate diet (LCD) may be a viable strategy for individuals with diabetes, particularly for weight loss and the prevention of hyperglycemia[8]. LCDs limit carbohydrate intake (<130 g per day), decrease insulin secretion, and promote the mobilization of fat from adipose tissue, leading to weight loss and metabolic improvements[9]. However, evidence regarding the benefits, safety, and efficacy of LCD is lacking[10,11].

Advancements in diabetes management technology, along with carbohydrate counting, can improve glycemic control and overall quality of life. Continuous subcutaneous insulin infusion and continuous glucose monitoring can reduce the risk of hypoglycemia[12]. These techniques could benefit patients, and dietitians could simplify carbohydrate counting without compromising glycemic control[13]. However, diabetes management and outcomes still depend on dietary choices. Accordingly, patients with DT1 need knowledge and decision-making skills for effective self-care[14]. This analysis of the current literature reveals a notable gap: although the importance of LCDs is recognized, the evidence about T1D is limited, especially concerning their impact on fundamental outcomes such as HbA1c and daily insulin requirements. This gap delays the development of precise, evidence-based dietary recommendations for those in this population. This emphasizes the need to integrate the current investigation of low-carbohydrate diets in these patients, thereby enabling future studies to be more standardized. Following the PICO framework[15], this systematic review and meta-analysis aimed to determine, in adults with type 1 diabetes (P), the effect of a low-carbohydrate diet intervention (I), compared to their pre-intervention state (C), on glycemic control as measured by changes in HbA1c and daily insulin dose (O).

Materials and Methods

The work was registered in the PROSPERO database (CRD42025641186) and designed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[16].

We conducted a comprehensive search strategy across PubMed, Scopus, and Web of Science, updated through September 2024. The search terms included "low carbohydrate diet," "low carb diet," "ketogenic diet," "carbohydrate-restricted diet," "diabetes mellitus," and "type 1," as well as various combinations using Boolean operators (AND, OR). We also manually searched the reference lists of the identified studies. The included studies were not limited to publication date or region.

After the electronic search of data sources, we conducted a systematic selection process based on the titles and abstracts of the identified articles. We chose studies based on four sets of predetermined criteria: 1. type of study (randomized controlled trials, cohort studies, non-randomized intervention studies); 2. diagnosis (T1D patients); 3. dietary pattern (low-carbohydrate diet interventions); and 4. outcome measures focusing on diabetes outcomes (HbA1c (% or mmol/mol), total daily insulin use, and BMI (kg/m²)). The study excluded reviews and single-case reports, focusing on primary research studies with original data. To highlight, the present work only included studies involving type 1 diabetes.

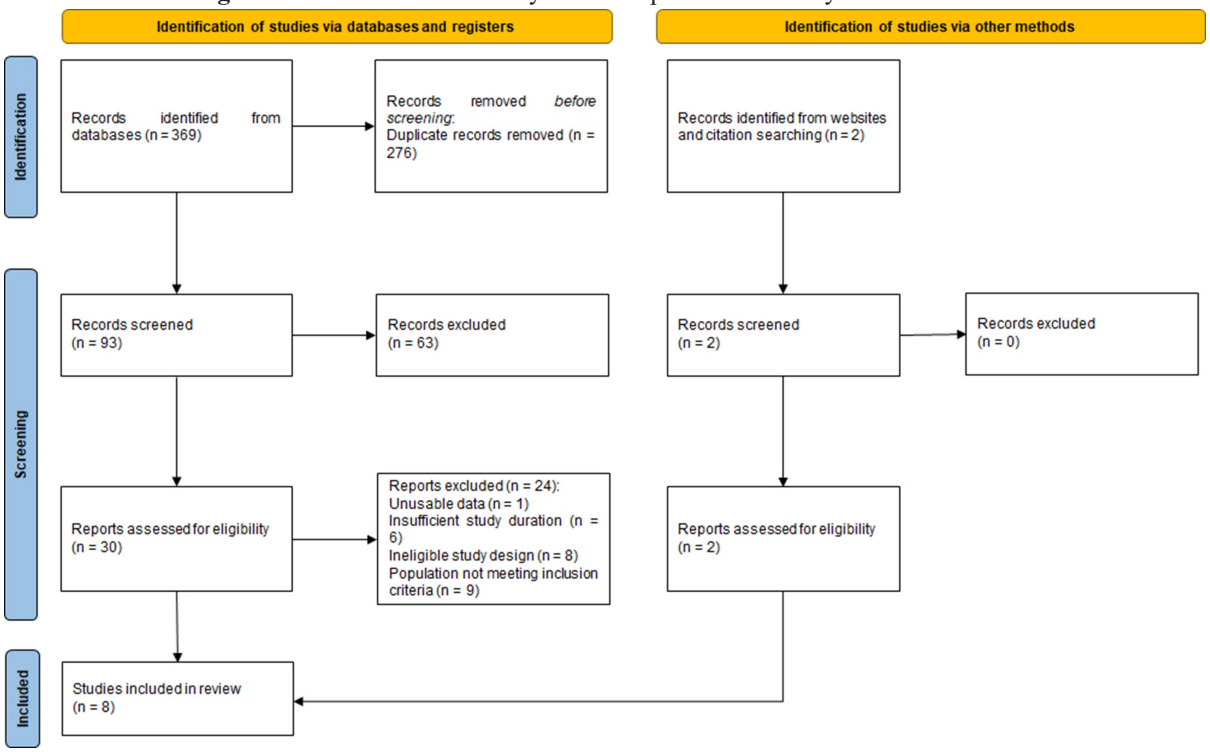
We extracted and tabulated the data in a standardized datasheet. The database included the following information: general data about the publication (first author name, year), study methodology (design), population characteristics (sample size, country of origin, diagnosis, years with diabetes, gender, and clinical characteristics), biochemical data (mean ± standard deviation), lifestyle factors (alcohol consumption and smoking), techniques used for the detection of the analyte of interest, and main results and conclusions.

To ensure precision and reduce bias, a dual, independent review procedure was conducted at three critical stages: study selection, data extraction, and risk-of-bias evaluation. Two researchers (J.D.C.-C. and I.E.J.-R.) independently performed the title/abstract screening, full-text assessment, data extraction from eligible articles, and evaluation of study quality. Any disagreements at any stage were first resolved through discussion between the two reviewers. If a consensus was not reached, a third researcher (T.B.G.-C.) was consulted to arbitrate and make the final decision.

We identified 93 studies in the preliminary database searches according to their titles and abstracts. Sixty-three papers were eliminated because they were based on animal models, a type of study design, review articles, or case reports. Subsequently, 30 articles were evaluated by the full-text publications using supplementary criteria for intervention length, other types of diabetes, and age to determine their eligibility for inclusion in the systematic review and meta-analysis. Eight articles meet all inclusion criteria[17,18,19,20,21,22,23,24].

The selected studies described the interventions, assessment methods, and their respective outcomes. The flowchart of the systematized search is shown in Figure 1. The search strategies used on databases (Table 1) and the list of excluded articles (Table 2) are provided in the supplementary material.

Figure 1. Flowchart of the study selection process for the systematic review



Source: Designed by the authors based on the PRISMA 2020 guidelines [16].

We used the ROBINS-I (Risk of Bias in Non-randomized Studies of Interventions) to assess risk of bias across all trials. This tool evaluates bias in seven domains: confounding, participant selection, intervention classification, deviations from intended interventions, missing data, outcome measurement, and selection of reported results. We categorized each item as low, moderate, or high risk of bias.

HbA1c values reported in percentage units were converted to mmol/mol for consistency across studies using the standardized formula: HbA1c (mmol/mol) = 10.929 × (HbA1c [%] - 2.15)[25].

To evaluate the effect of LCD on glycemic control in patients with T1D, a statistical analysis was conducted using standardized mean differences and 95% confidence intervals. This difference was calculated using pre- and post-intervention values from each study. Heterogeneity across studies was assessed using Cochran's Q statistic and the I^2 inconsistency index. A p-value of $Q < 0.10$ was considered indicative of significant heterogeneity. Meanwhile, the I^2 inconsistency index was classified as absent (0-25%), low (26-50%), moderate (50-75%), and high (75-100%). Publication bias was assessed graphically using a funnel plot of standard error versus standardized mean difference and quantitatively using Egger's test. A significant bias was considered present if the funnel plot showed asymmetry and/or if Egger's test yielded a p-value < 0.05. The meta-analysis used Comprehensive Meta-Analysis (CMA) software, version 3.0. The characteristics of the populations, LCD interventions, and study results were summarized using descriptive statistics derived from the data of the included studies.

Resultados

Table 1 shows the eight articles included in this review.

This systematic review includes studies published between 2012 and 2024 that investigated patients with T1D, with sample sizes ranging from 5 to 48 participants. All research encompassed both male and female subjects. The selected subjects were adults who were 18 years or older, did not have significant diabetic complications, used multiple daily insulin injections, and had stable blood pressure. The characteristics of the interventions are described in Table 1, and the results of each study are presented in Table 2.

All studies assessed exhibited a moderate risk of bias17,18,19,20,21,22,23,24. The moderate risk of bias is present in the domains of confounding and outcome measurement, except for the work by Igudesman et al. 17, which exhibited only moderate risk in outcome measurement. Regarding other domains, including participant selection, intervention classification, and missing data, all studies were assessed as having a low risk of bias (Table 3).

Table 1. Population characteristics of the studies included in the systematic review and meta-analysis

Author	Country	Sample size	Intervention
Nielsen, JV (2012)[17]	Sweden	48 adult individuals with T1D (years with diabetes 24 ± 12) of Caucasian origin.	The participants followed a carbohydrate-restricted diet (≤75 g/day) and received insulin dose adjustments over 12 weeks.
Krebs, JD (2016) [18]	New Zealand	5 adult individuals with T1D (years with diabetes 23 ± 9.9) of Caucasian origin.	Individuals in the carbohydrate-restricted diet group aimed to maintain a daily carbohydrate intake of 50-75 grams for 12 weeks.
Schmidt S (2019) [19]	Denmark	14 adult individuals with T1D (years with diabetes median 19 years, range 13-32 years) of Caucasian origin.	Participants in the LCD group followed individualized meal plans developed by a dietitian, with a daily carbohydrate intake of <100 g over 12 weeks.
Kleiner, A (2022) [21]	Italy	33 adult individuals with T1D (years with diabetes 14 ± 11.3) of Caucasian origin.	Participants in this case series transitioned from their typical high-carbohydrate diet (>200 g/day) to an Eucaloric EVLCD (50 g/day) over 12 weeks. The EVLCD was structured with an average composition of 70% fat, 25% protein, and 5% carbohydrate.
Paul J (2022) [20]	Australia	22 adult individuals with type 1 diabetes (mean age 43.2 ± 14.7 years; diabetes duration 17.1 ± 13.2 years).	Participants followed an individualized low-carbohydrate diet (<100 g/day) for 12 weeks.
Turton JL (2023) [23]	Australia	16 adult individuals with T1D (mean age 42.8 ± 13.9 years; duration of diabetes 21.2 ± 10.4) of Caucasian and Asian origin.	Participants underwent a 12-week LC diet intervention with a prescribed daily intake of 50 g of digestible carbohydrates, adjustable within 25-75 g/day based on blood glucose levels.
Igudesman D (2023) [22]	USA	16 adult individuals with T1D of African American, Asian, Native Hawaiian/Pacific Islander, Caucasian, and Hispanic origin.	The participants followed a hypocaloric, low-carbohydrate diet (45-75 g/day) for 12 weeks.
Hall RM (2024) [24]	New Zealand	16 adult individuals with T1D (duration of diabetes: 14.6 ± 11.8 years) of Caucasian, Māori, and Filipino origin.	Participants followed a carbohydrate-restricted diet (50-100 g/day) and received insulin dose adjustments for 12 weeks.

Source: Data compiled by the authors based on the included studies.

Table 2. Results of HbA1c, total daily insulin use, and BMI in included studies

Study	*Intervention*	*HbA1c (mmol/mol)*			*Total daily insulin (U)*			*BMI (kg/m²)*		
		Pre	*Post*	*Sig.*	*Pre*	*Post*	*Sig.*	*Pre*	*Post*	*Sig.*
Nielsen, JV (2012)	CRD	59.70 ± 10.90	45.40 ± 7.70	–	23.00 ± 9.00	13.00 ± 6.00	–	25.90 ± 3.50	25.00 ± 3.40	<0.00
Krebs, JD (2016)	CRD	63.00 ± 10.00	55.00 ± 4.00	<0.05	64.40 ± 25.30	44.20 ± 16.50	<0.05	27.50 ± 2.20	25.80 ± 1.00	–
Schmidt S (2019)	LCD	56.00 ± 5.00	57.00 ± 4.00	0.42	–	33.60 ± 8.10	–	–	–	–
Paul J (2022)	LCD	63.90 ± 18.60	54.10 ± 12.00	–	–	–	–	–	–	–
Kleiner, A (2022)	EVLCD	67.20 ± 18.60	50.80 ± 8.50	–	36.70 ± 14.90	28.90 ± 9.10	<0.00	23.90 ± 3.60	24.10 ± 3.10	0.42
Turton JL (2023)	LCD	60.80 ± 5.80	54.40 ± 7.50	<0.01	65.20 ± 23.20	49.00 ± 20.80	<0.00	31.90 ± 5.90	31.10 ± 5.60	<0.03
Igudesman D (2023)	LCD	56.30 ± 17.50	56.30 ± 17.50	–	–	–	–	–	–	–
Hall RM (2024)	CRD	57.20 ± 9.80	55.70 ± 10.60	–	38.70 ± 14.80	–	–	26.90 ± 4.70	26.50 ± 4.90	–

Note: CRD (Carbohydrate-restricted diet), EVLCD (Eucaloric very low-carbohydrate diet), LCD (Low-carbohydrate diet), Sig. (p-value);– (data not available). The data are presented as means ± standard deviation.
Source: Data compiled by the authors based on the included studies.

Table 3. Results of risk of bias assessment

Study	*Bias*							
	Confouding	*Selection of participants*	*Classification of intervetions*	*Deviations from intended interventions*	*Missing data*	*Measurment of outcomes*	*Reported result*	*Overall*
Hall RM (2024)	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate
Turton JL (2023)	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate
Igudesman D (2023)	Low	Low	Low	Low	Low	Moderate	Low	Moderate
Paul J (2022)	Low	Low	Low	Low	Low	Moderate	Low	Moderate
Kleiner, A (2022)	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate
Schmidt S (2019)	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate
Krebs, JD (2016)	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate
Nielsen, JV (2012)	Moderate	Low	Low	Low	Low	Moderate	Low	Moderate

Source: Analysis performed by the authors based on data from included studies.

The present study identified a significant reduction in HbA1c levels (point estimate: 0.79 mmol/mol; 95% CI: 0.57 to 1.02; $p < 0.001$) and in total daily insulin dose (point estimate: 0.96 U; 95% CI: 0.67 to 1.25; $p < 0.001$) after LCD intervention in patients with T1D (Table 4).

In the analysis of the lipid profile, no significant changes were found for total cholesterol (point estimate: -0.11 mmol/L; 95% CI: -0.37 to 0.15; $p = 0.45$), HDL (point estimate: -0.18 mmol/L; 95% CI: -0.43 to 0.08; $p = 0.19$), LDL (point estimate: 0.10 mmol/L; 95% CI: -0.29 to 0.49; $p = 0.61$), or triacylglycerols (point estimate: 0.22 mmol/L; 95% CI: -0.04 to 0.48; $p = 0.10$) due to the LCD intervention (Table 4).

The analysis of anthropometric and blood pressure variables revealed no significant changes in BMI (point estimate: 0.16 kg/m^2; 95% CI: -0.10 to 0.41; $p = 0.23$), body weight (point estimate: 0.13 kg; 95% CI: -0.10 to 0.37; $p = 0.27$), diastolic blood pressure (point estimate: 0.05 mmHg; 95% CI: -0.26 to 0.35; $p = 0.77$), or systolic blood pressure (point estimate: 0.11 mmHg; 95% CI: -0.19 to 0.41; $p = 0.47$) in patients with T1D following the LCD (Table 4).

Table 4. Meta-analysis of low-carbohydrate diet on glycemic control variables in subjects with type 1 diabetest

Variable	*Point estimate*	*Lower limit*	*Upper limit*	*P value (Z)*	*Df (Q)*	*P value (Q)*	*I²*	*P value (Egger)*
Diabetes control								
Total, daily insulin (U)	0.96	0.67	1.25	0.00	3.00	0.22	32.72	0.73
HbA1c (mmol/mol)	0.79	0.57	1.02	0.00	7.00	0.00	74.34	0.18
Lipids profile								
Cholesterol (mmol/L)	-0.11	-0.37	0.15	0.45	4.00	0.34	12.00	0.77
HDL (mmol/L)	-0.18	-0.43	0.08	0.19	4.00	0.52	0.00	0.90
LDL (mmol/L)	0.10	-0.29	0.49	0.51	2.00	0.48	67.10	0.56
Triacylglycerols (mmol/L)	0.22	-0.04	0.48	0.10	4.00	0.34	11.97	0.75
Anthropometric								
BMI (kg/m^2)	0.16	-0.10	0.41	0.23	4.00	0.62	0.00	0.38
Body weight (kg)	0.13	-0.10	0.37	1.11	0.27	0.72	6.00	0.00
DBP (mmHg)	0.05	-0.26	0.35	0.77	4.00	0.59	0.00	0.32
SBP (mmHg)	0.11	-0.19	0.41	0.47	4.00	0.96	0.00	0.35

Note: BMI (Body mass index), DBP (Diastolic blood pressure), SBP (Systolic blood pressure), HDL (High-density lipoprotein), LDL (Low-density lipoprotein).
Source:Analysis performed by the authors using data from included studies.

Discussion

This systematic review and meta-analysis evaluated the efficacy of an LCD in managing glycemic control in patients with T1D. Findings from the included population suggest that a low-carbohydrate diet may lead to a decrease in HbA1c levels (point estimate: 0.79 mmol/mol; 95% CI: 0.57 to 1.02; $p < 0.001$) and total daily insulin dose (point estimate: 0.96; 95% CI: 0.67 to 1.25; $p < 0.001$) after more than three months of follow-up. The results of our meta-analysis are consistent with those of other studies, which report significant reductions in HbA1c following LCD implementation[26]. This HbA1c reduction may be attributed to carbohydrate restriction effects on postprandial glucose, glycemic variability, and fasting glucose levels, as demonstrated by continuous glucose monitoring studies[27]. Additionally, HbA1c reflects mean blood glucose levels over the preceding 2–3 months and is widely used as an indicator of glycemic control, with high values suggesting significant glycemic fluctuations[3,28].

ADA Standards of Care Guidelines (2025) recommend that very-low-carbohydrate eating plans require consistent medical oversight for medication adjustments. Nonetheless, ADA remarks that very-low-carbohydrate eating plans should be used with caution in patients with T1D or T2D using SGLT2 inhibitors because of the potential risk of diabetic ketoacidosis. In addition, multivitamin supplementation may be necessary in patients with very-low-carbohydrate eating plans[29,30]. For children and adolescents with T1D, ISPAD recommends that carbohydrates should represent 40-50% of total energy. Likewise, carbohydrate restriction is discouraged because it could hamper growth in children and adolescents[31]. Although carbohydrate restriction is a long-studied approach for glycemic control, eating plans with low glycemic index and high fiber carbohydrates are recommended by ADA, International Diabetes Federation, and the German Diabetes Association[32,33,34].

Carbohydrate intake directly determines the amount of exogenous insulin needed. Intensive insulin therapy relies on accurate carbohydrate counting and the insulin-to-carbohydrate ratio to calculate the appropriate bolus insulin dose, which is necessary to achieve adequate glycemic control[2,35]. Furthermore, evidence suggests that carbohydrate counting helps improve metabolic control and reduce HbA1c[35]. In this regard, the effectiveness of basic carbohydrate counting (BCC) and advanced carbohydrate counting (ACC) in reducing HbA1c has already been reported; however, the possibility of jointly including individualized dietary counseling has also been raised to achieve a more far-reaching educational dietary approach in these patients[36]. Previous research has reported diminished daily insulin requirements in patients with diabetes who adhered to an LCD[37]. LCD has been shown to regulate blood glucose levels by diminishing glucotoxicity and promoting the recuperation of beta cells; this may decrease insulin requirements[38]. Other meta-analyses of this dietary pattern, incorporating studies of differing durations, had primarily documented benefits in daily glucose metrics (time in range) and insulin requirements, without demonstrating a significant overall effect on HbA1c[39,40]. This study provides substantial evidence that a 12-week low-carbohydrate diet intervention in patients with type 1 diabetes reduces HbA1c.

Systematic reviews and meta-analyses indicate that LCDs are associated with short-term weight loss, which has been linked to reductions in insulin levels, appetite suppression induced by ketogenesis, and increased energy expenditure[41]. However, our investigation did not find a significant decrease in body

weight (point estimate: 0.13 kg; 95% CI: -0.10 to 0.37; p = 0.27) or BMI (point estimate: 0.16 kg/m^2; 95% CI: -0.10 to 0.41; p = 0.23) associated with this dietary pattern. The increased fat intake on LCD may negatively affect the lipid profile[42]. However, we found no significant differences in total cholesterol (point estimate: -0.11 mmol/L; 95% CI: -0.37 to 0.15; p = 0.45), HDL (point estimate: -0.18 mmol/L; 95% CI: -0.43 to 0.08; p = 0.19), LDL (point estimate: 0.10 mmol/L; 95% CI: -0.29 to 0.49; p = 0.61), and triacylglycerols levels (point estimate: 0.22 mmol/L; 95% CI: -0.04 to 0.48; p = 0.10) after LCD. A previous meta-analysis found no significant differences in total cholesterol, HDL, and LDL levels at 3, 6, and 12 months of treatment in patients with diabetes who received very low-carbohydrate or control diets[43]. Additionally, there is evidence of an association between high levels of atherogenic lipoproteins and glycemic control in individuals with T1D [44]. Another study demonstrated that lipid levels were reduced in patients with improved glycemic control[45]. A multicenter study conducted in the Czech Republic that evaluated the relationship between LCDs and lipid profile and anthropometric parameters such as weight and body mass index (BMI) found no significant differences in these parameters but reported that patients receiving LCDs had a greater tendency toward long-term hypoglycemia. Therefore, it appears that LCD does not have a considerable impact on weight, BMI, and lipid profile[46].

Low-carbohydrate diets can have many benefits; they can also have some consequences, such as increased LDL and total cholesterol in the long term, particularly in lean individuals with healthy metabolisms. These individuals are referred to as the lean mass hyperresponsive phenotype[47,48]. In addition, they also exhibit low triglyceride levels, elevated HDL-cholesterol, and LDL-cholesterol, since under these conditions the liver produces a greater amount of VLDL lipoproteins, which would explain the increase in LDL-cholesterol in these individuals[47]. Other potential risks include the so-called keto flu, which includes cold-like symptoms (headache, fatigue, lethargy, mental confusion, gastrointestinal disturbances, syncope, and even heart rhythm abnormalities)[49]. This occurs because a decrease in glucose intake increases ketogenesis in the liver, with increased activity of enzymes such as hydroxymethylglutaryl-CoA lyase[50]. This increases the formation of ketone bodies and their concentration in the blood, which could also cause dehydration, metabolic acidosis with a high anion gap of the normochloremic type, among other alterations.

Although this review provides essential insights into the impact of these diets on glycemic control, it also presents certain limitations. The rigorous selection process identified only eight eligible clinical trials, highlighting the limited research available in this population. Additionally, small sample sizes and inconsistent study outcomes underscore the need for further research with larger, more diverse populations and standardized methodologies. Furthermore, the glycemic variables analyzed were limited to HbA1c levels. We were unable to meta-analyze daily glucose fluctuations, time-in-range, or hypoglycemic episodes as these metrics were not systematically reported across all included studies, and when available, data were often incomplete or from a subset of participants. In addition, our analysis could not control for potential confounding factors, such as age or diabetes duration, which may influence glycemic control. It is essential to consider that conditions such as dyslipidemia, renal failure, and hemolytic anemia can influence HbA1c levels[25], which was the primary outcome measure in this review. Despite these challenges, our study improves the understanding of LCDs in the management of T1D and highlights the importance of dietary interventions in diabetes care.

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Conclusion

This systematic review and meta-analysis demonstrate that LCDs can improve glycemic control in people with T1D by significantly reducing HbA1c levels and daily insulin requirements. It also appears that LCDs have no significant impact on lipid profile or anthropometric parameters, such as weight and IBM. Therefore, future research with larger cohorts and standardized diets is necessary to evaluate the efficacy, safety, and long-term effects of reducing dietary carbohydrates in individuals with type 1 diabetes. An essential aspect of this initiative will be to expand the evidence base by evaluating LCDs in key subgroups, such as young people and women, and to elucidate the influence of this dietary intervention on glycemic variability through continuous glucose monitoring.

Conflict of interest

The authors declare that there is no conflict of interest.

Ethical considerations

This study did not collect personal data from any participants and posed no privacy risks.

Use of artificial intelligence

The authors declare that they have not used any generative artificial intelligence applications, software, websites in the writing of the manuscript, in the design of tables and figures, or in the analysis and interpretation of the data.

Authors' contribution

Conceptualization: J.D.C.C., I.E.J.R., T.B.G.C.; Data curation: J.D.C.C., M.G.C.; Formal analysis: J.D.C.C., G.A.N.R., A.M.M.; Funding acquisition: I.E.J.R., A.M.M.; Investigation: J.D.C.C., M.G.C., G.A.N.R.; Methodology: J.D.C.C., M.G.C.; Project administration: I.E.J.R., A.M.M.; Resources: I.E.J.R., A.M.M.; Software: J.D.C.C., M.G.C.; Supervision: I.E.J.R., T.B.G.C., A.M.M.; Validation: J.D.C.C., M.G.C., G.A.N.R.; Visualization: J.D.C.C., M.G.C., T.B.G.C.; Writing – original draft: J.D.C.C., T.B.G.C.; Writing – review & editing: I.E.J.R., A.M.M.

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