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Effect of a carbohydrate-restricted diet on weight loss in overweight and obese pediatric population: a meta-analysis of randomized controlled trials

Pejman Rohani[1], Zahra Rasoulizadeh[2], Sogand Tavakoli[4], Hosein Alimadadi[1], Koroush Vahidshahi[3], Somaye Fatahi[4], Mohammad Hassan Sohouli[1*] and Nathalia Sernizon Guimarães[5]

Abstract

Background There are conflicting findings regarding the effect of low-carbohydrate diets on obesity-related factors. This study aimed to investigate the effect of a carbohydrate-restricted (CR) diet on changes in anthropometric indicators of adiposity and fat distribution in pediatrics populations.

Methods A systematic search was conducted in PubMed/MEDLINE, Web of Science, Scopus, and Embase electronic databases using predefined keywords to identify all randomized controlled trials examining the effects of CR on obesity-related factors. The pooled weighted mean difference (WMD) and 95% confidence intervals (CI) were calculated using a random-effects model.

Results Findings from 11 studies demonstrated significant reductions in weight (WMD: -2.31 kg; 95% CI: -4.44, -0.18), BMI (WMD:-1.08 kg/m^2; 95% CI: -1.91, -0.26), and fat mass (WMD: -1.43%; 95% CI: -2.43 to -0.43) as well as a significant increase in adiponectin levels (WMD: 0.74 ng/ml; 95% CI: 0.02, 1.47) in the CR diet group compared to the control group. However, no significant effect was observed on BMI z-score (WMD:-0.10; 95% CI: -0.21, 0.01), waist circumference (WMD:-3.03 cm; 95% CI: -6.57, 0.51) or leptin levels (WMD: -0.82 ng/ml; 95% CI: -2.26, 0.61). Stratified analysis rrevealed a greater effect of CR on weight and BMI reduction in interventions ≤ 12 weeks and in very low-carbohydrate diets.

Conclusions In conclusion, it appears that CR diet, along with other lifestyle factors, can lead to significant improvements in weight loss on pediatrics with obesity/overweight.

Keywords Low-carbohydrate diets, Lifestyle, Obesity, Weight loss, Meta-analysis

*Correspondence:
Mohammad Hassan Sohouli
mohammadhassansohouli@gmail.com
[1]Pediatric Gastroenterology and Hepatology Research Center, Pediatrics Centre of Excellence, Children's Medical Center, Tehran University of Medical Sciences, Tehran, Iran
[2]School of Medicine, Shahid Sadoughi University of Medical Sciences, Yazd, Iran
[3]Department of Pediatrics, School of Medicine, Shahid Modarres Hospital, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[4]Department of Clinical Nutrition and Dietetics, Faculty of Nutrition and Food Technology, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[5]Department of Nutrition, School of Nursing, Universidade Federal de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil

Introduction

Over the past few decades, the prevalence of obesity (defined as a body mass index [BMI, kg/m^2] above the 95th percentile) in children and adolescents has more than doubled [1–3]. Long-term follow-up studies on pediatric patients with obesity show that those who were more overweight as children are more likely to become obese as adults [3, 4]. Obesity-related health risks include dyslipidemia, type 2 diabetes, and hypertension [5, 6], all of which increase the likelihood of cardiovascular disease later in life. Several strategies have been used to manage weight in children with obesity including reducing overall caloric intake, limiting fat intake, and incorporating exercise interventions to alter weight [6–8]. However, due to the limited effectiveness of these treatments, researchers are exploring novel approaches for addressing pediatric obesity.

Obesity is associated with an increase in adipose tissue, particularly visceral fat, which is a known risk factor for insulin resistance [9]. Evidence suggests that adipocytes secrete adipokines such as TNF-α, IL-6, leptin, and adiponectin, which are critical for maintaining systemic metabolic homeostasis, influencing insulin sensitivity, and contributing to the development of obesity-related complications [10–12]. Metabolic syndrome, obesity, and type 2 diabetes are often linked to low levels of adiponectin, which plays a role in mediating insulin action and improving peripheral insulin sensitivity [13]. In children with obesity, visceral fat and insulin sensitivity are negatively correlated [14]. Leptin also plays a key role in regulating energy balance [15]. Studies have identified a relationship between increased fat mass, elevated leptin levels, and insulin resistance in children with obesity [15–18].

Maintaining an energy intake lower than energy expenditure is a therapeutic strategy for treating obesity. Consequently, experts recommend low-fat and calorie-restricted diets as initial approaches [19]. More recently, dietary interventions focusing on modifying carbohydrate intake have gained prominence in weight management. Low-carbohydrate diets, as well as very low-carbohydrate diets that provide sufficient protein and calories for proper growth, have shown benefis for glycemic control and ketosis [20–22]. Additionally, these diets may influence metabolic pathways involved in fuel metabolism and potentially regulate impaired insulin homeostasis [23]. Carbohydrate restriction is increasingly popular as a weight loss strategy and for achieving better glycemic control in people with diabetes, including type 1 and type 2 diabetes [24]. However, evidence to support low-carbohydrate diets in youth (children and adolescents 2–18 years of age) with obesity or diabetes is limited [24]. There are no guidelines for restricting dietary carbohydrate consumption to reduce risk for diabetes or improve diabetes outcomes in youth. Thus, there is a need to provide practical recommendations for pediatricians regarding the use of low-carbohydrate diets in patients who elect to follow these diets, including those with type 1 diabetes and for patients with obesity, prediabetes, and type 2 diabetes [24]. Another, the quality of a mother's diet is important to ensure child growth and development and keep women healthy [25]. Carbohydrate restriction during lactation may be harmful to the lactating woman and contribute to the state of lactational ketoacidosis, but infant outcomes are mainly a change in feeding patterns [25]. Thus, education on food and nutrition is necessary for this population.

The objective of this systematic review and meta-analysis of randomized-controlled trials is to comprehensively assess the current research on the effects of a low-carbohydrate diets on children and adolescents with overweight or obesity. By synthesizing evidence from various studies, we aim to enhance understanding of the potential role of low-carbohydrate diets as a dietary intervention for obesity management.

Methods

Search strategy

This systematic review and meta-analysis was conducted without any time or language restrictions, following the writing of Preferred Reporting Criteria for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [26]. A comprehensive search strategy was completed by March 2024, encompassing major databases including PubMed/MEDLINE, Web of Science, Scopus, and Embase. This search strategy incorporated the medical subject headings (MeSH) and Emtree (Embase subject title) and included the following search terms:: (Diet, Low Carbohydrate OR Low Carbohydrate Diets OR Carbohydrate-Restricted Diet OR Atkins Diet) AND ("Body Weight" OR "Body Weight Changes" OR "Body Mass Index" OR "Weight Loss" OR "Obesity" OR "Waist Circumference" OR "Adipose Tissue" OR "BMI Z-score Index"OR "Waist Circumference" OR "Quetelet Index" OR "BMI" OR "Weight Reduction" OR "Abdominal Obesity" OR "Central Obesity" OR "Visceral Obesity" OR "Leptin" OR "Adiponectin" OR "fat mass" OR "adiposity" OR "Body Fat") AND ("Child" OR "Adolescent" OR "Pediatrics" OR youth OR teen) AND ("Clinical Trials as Topic" OR "Cross-Over" OR "Double-Blind" OR "Single-Blind " OR "Random Allocation" OR "Clinical Trial"). To ensure comprehensive coverage, we also manually reviewed reference lists from relevant studies, meta-analyses, and review articles.

Eligibility criteria

To determine eligibility, two authors independently reviewed the studies, removing duplicates and evaluating

each base of Population, Intervention, Comparison, Outcomes and Study design (PICOS) criteria.The following criteria were used: (1) The study population included children and adolescents (≤18 years old) who are overweight or obese; (2) The intervention involved a carbohydrate-restricted diets (≤40% of total caloric intake); (3) The control group consisted of individuls following a normal or controlled diet (non-carbohydrate–restricted diet as defined below); (4) randomized controlled clinical trial.

The definition of diets examined in our study as control and intervention groups is based on existing nutritional guidelines as follows [27]: (1) non-carbohydrate–restricted diets: 45-60% of total calories; (2) mild low carbohydrate diets: 26-45% of total calories; and (3) very low carbohydrate diets: less than 26% of total calories (or <130 g/day of carbohydrates).

Additionally, studies were eligible if the intervention lasted at least 2 weeks and provided baseline and post-intervention data on weight, body mass index (BMI), waist circumference (WC), fat mass, leptin, and adiponectin. In cases with multiple follow-up periods, only data from the final follow-up were analyzed. Studies involving animals, those with repeated data, those without control groups, and systematic reviews or meta-analyses were excluded from the analysis.

EndNote software was utilized for efficient management of eligible articles and removal of duplicates.

Data extraction

To systematically review and analyze the data, two authors independently extracted the relevant details from the eligible studies, including the first author´s name, year of publication, sample size for both the intervention and control groups, mean age, body mass index of the participants, the study population, details of the interventions for both groups, and the mean and standard deviation (S.D.) of the investigated outcomes at baseline and at the last follow-up (or the changes between baseline and post-intervention).

Quality assessment

The methodological quality of the trials was evaluated using the most recent version of the Cochrane risk-of-bias tool for randomized trials (RoB 2) [28]. Several potential sources of bias were examined and ranked by the study's authors including incomplete outcome data, selective reporting, participant and staff blinding, allocation concealment, blinding of volunteers and researchers, and random sequence generation. Each study was assessed by two authors, who independently determined the level of bias, classifying it as low, high, or unclear. A third author was consulted to resolve any disagreements, ensuring consensus. The quality of this systematic review and meta-analysis was further evaluated using the GRADE (Grading of Recommendations Assessment, Development, and Evaluation) system. The GRADE checklist, a 10-point grading system, assesses various factors affecting study quality across seven distinct domains: [1] risk of bias, [2] precision, [3] heterogeneity, [4] directness, [5] publication bias, [6] funding bias, and [7] study design [32].

Data synthesis and statistical analysis

Data analysis was performed using software STATA version 12.0. Means and standard deviations (S.D.s) were calculated using a predefined method [29, 30]. In the absence of standard deviations, the following technique was used to determine the amount of the change: To find the formula for the change in standard deviation, we first take the square root of the difference between the sum of the squares of the baseline and final standard deviations, then subtract twice the product of the baseline and final standard deviation correlation coefficients, and finally, we add the absolute values of the standard deviations to get the final SD. This formula was also used to derive the standard deviation from the standard error of the mean (SEM): multiplying SEM by the square root of the sample size (n) for each group provided the S.D. Meta-analysis of the study results was conducted using a random-effects model, applying the inverse variance method. This approach allowed for the integration of multiple time points into a single study cohort. Heterogeneity was assessed using Q statistics and I-squared (I2) values, with heterogeneity classified as low, moderate, or high based on I2 values ranging from 0 to 25%, 26–50%, 51–75%, and 76–100% [35]. Subgroup analysis was used to investigate potential sources of heterogeneity, such as the level of carbohydrate restriction and intervention duration. Sensitivity analysis was conducted to determine the influence of each study on the overall mean difference. Publication bias was assessed using Egger's test, a widely recognized statistical method [36].

Results

The flow diagram of the study, including identification, screening, eligibility and the final sample, is presented in Fig. 1. After an exhaustive search of the main databases as described in the methodology, 1,898 publications were entered into the Endnote software. Of these, 834 studies were removed due to duplication, leaving 1,064 studies for evaluation and screening. After the initial evaluation, which included assessing titles, abstracts, and eligibility based on inclusion and exclusion criteria, 1,031 studies were excluded, and 33 studies were identified for futher full-text evaluation. Of these 33 studies, 11 studies were excluded for various reasons detailed in Fig. 1, and 12

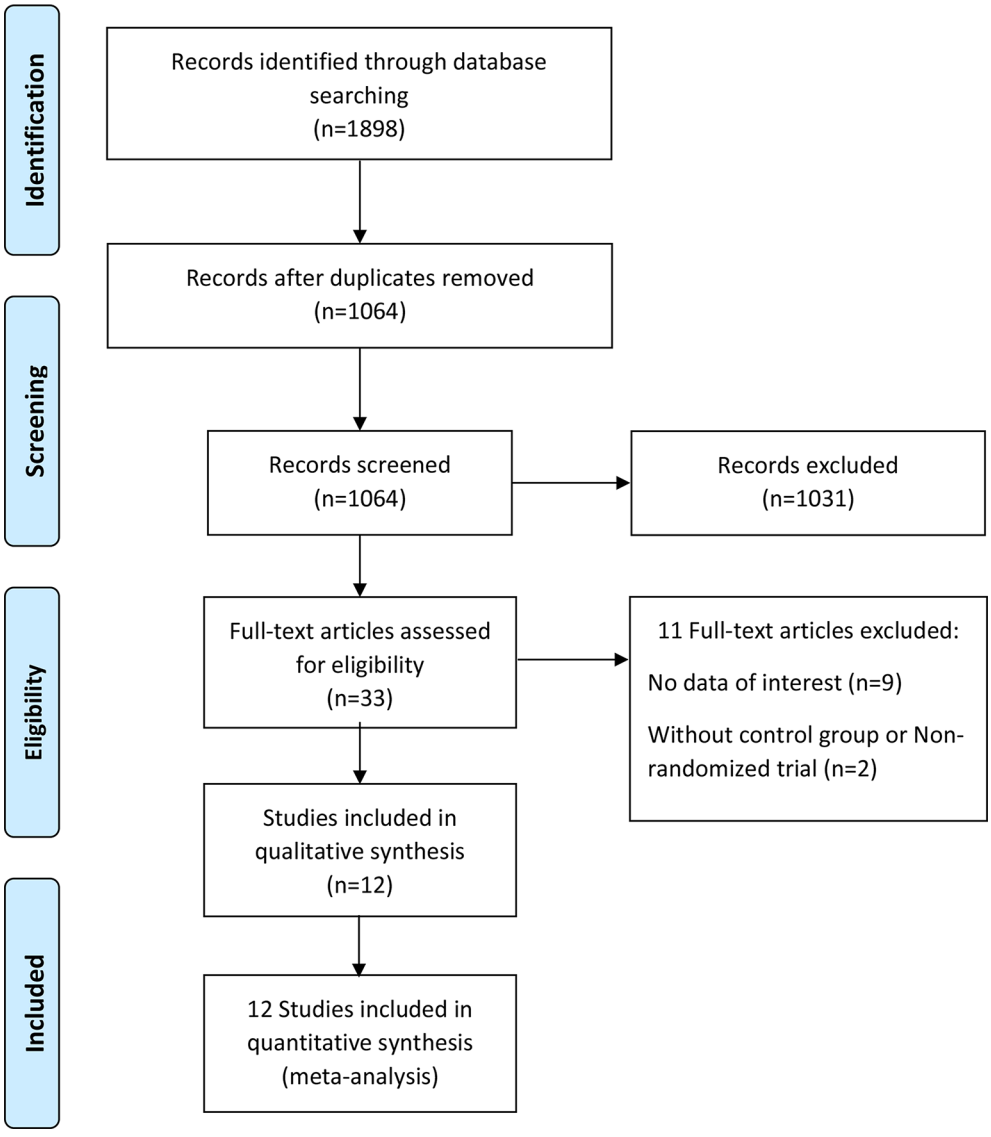

Fig. 1 Literature search and review flowchart for selection of studies

studies [21, 31–41] were ultimately included in the meta-analysis for systematic review and data analysis.

Study characteristics

The characteristics of the aggregated studies are summarized in Table 1. As shown, six studies were conducted in the Americas, four in Europe, and two in Australia, all using the parallel design. These studies were publicated between 2003 and 2020, with follow-up interventions varied from 8 to 52 weeks.The participants baseline characteristics showed that the average age ranged from 9.8 to 14.7 years, with the proportion of male participants varying between 0 and 74.4%. The mean baseline BMI across the studies ranged from 28.1 to 39.05. In eight studies, the intervention was involved a very low carbohydrates diet, while in four studies the intervention utilized a mild carbohydrate restriction. All the studies focused on overweight and obese participants, with some also diagnosed with non-alcoholic fatty liver disease (NAFLD) or metabolic syndrome.

Table 2 displays the results of the assessment conducted to evaluate the quality of the eligible studies. Moreover, the quality of the present meta-analysis was evaluated using the NutriGRADE score method, resulting in a grade of 9, indicating a very good level of quality.

Meta-analysis

The quantitative meta-analysis revealed that carbohydrate-restricted diets significantly reduced weight (WMD: -2.31 kg; P=0.034; 95% CI: -4.44, -0.18; P=0.580; I^2 = 0.0%), BMI (WMD: -1.08 kg/m^2; P=0.010; 95% CI: -1.91, -0.26; P=0.120; I^2 = 35.8%), and fat mass (WMD:

Table 1 Characteristics of eligible studies

First author et al.	Years	Country	Population	Mean Age year	Sex (Male %)	SampleSize Study		Follow up of intervention (Weeks)	Type of RCTs	Intervention group	Control group	Baseline of BMI (kg/m^2)
						Intervention	Control					
Partsalaki	*2012*	*Greece*	*Obese*	*13.6*	*46/5*	*29*	*29*	*24*	*Parallel*	*Very low carbohydrate diet: < 20 g/day carbohydrates, with a gradual increase towards 30–40 g/day*	*The hypocaloric diet were instructed to reduce their caloric intake by 500 calories daily while deriving 28 – 33% and 50 – 55% of these calories from fat and carbohydrate, respectively.*	*30.8*
Bailes	*2003*	*USA*	*Obese*	*11.5*	*64/8*	*27*	*10*	*8*	*Parallel*	*Carbohydrate restricted diet (<30 g/day), with unlimited calories, protein, and fat*	*Calorie restricted diet (Low Cal Diet).*	*36.68*
Casazza	*2012*	*USA*	*Obese girls*	*12.4*	*0*	*12*	*14*	*16*	*Parallel*	*Moderately restricted carbohydrate (CHO) (42% energy from CHO) + 1000-calorie reduction)*	*Standard carbohydrate (CHO) (55% energy from CHO) + 1000-calorie reduction)*	*NA*
Truby	*2016*	*Australia*	*Obese*	*13.6*	*31*	*37*	*14*	*12*	*Parallel*	*"Structured modified carbohydrate" (SMC, 35% carbohydrate; 30% protein; 35% fat)*	*Controls were not provided with any dietary advice;*	*32.47*
Goss	*2020*	*UK*	*Obese with NAFLD*	*14.35*	*50*	*16*	*16*	*8*	*Parallel*	*CHO-restricted diet (CRD) (<25:25:>50% energy from CHO: protein: fat)*	*Fat-restricted diet (FRD) (55:25:20)*	*35.9*
Jensen	*2015*	*Australia*	*Obese*	*13.6*	*74/4*	*32*	*11*	*12*	*Parallel*	*Reduced carbohydrate (35% carbohydrate;30% protein; 35% fat) dietary programme + 20% daily energy restriction*	*Control diet (untreated) + 20% daily energy restriction*	*32.6*
Krebs	*2010*	*USA*	*Severely obese*	*13.95*	*66/6*	*18*	*15*	*13*	*Parallel*	*Low carbohydrate (20 g/d) diet*	*Low fat (30% of calories) regimen*	*39.05*
Sondike	*2003*	*USA*	*Overweight and Obese*	*14.7*	*NA*	*16*	*14*	*12*	*Parallel*	*Low-carbohydrate (LC): consume <20 g of carbohydrate per day for 2 weeks, then <40 g/day for 10 weeks, and to eat LC foods according to hunger.*	*Low-fat (LF) diet: The control group (LF) (n = 14) was instructed to consume <30% of energy from fat.*	*35.5*
Demol	*2008*	*Israel*	*Obese*	*14.45*	*28.9*	*18*	*20*	*52*	*Parallel*	*Low-carbohydrate, low-fat, protein-rich diet containing 1200–1500 kcal a day: 60 g carbohydrates (up to 20%), 30% fats and 50% proteins.*	*High-carbohydrate, low-fat diet containing 1200–1500 kcal a day: 50–60% carbohydrates, 30% fats and 20% proteins*	*35.2*

Table 1 (continued)

First author et al.	Years	Country	Population	Mean Age year	Sex (Male %)	SampleSize Study		Follow up of intervention (Weeks)	Type of RCTs	Intervention group	Control group	Baseline of BMI (kg/m^2)
						Intervention	Control					
Ibarra-Reynoso	*2015*	*México*	*Obese*	*9.8*	*48.3*	*53*	*45*	*8*	*Parallel*	*Low-carbohydrate (L-CHO) diet (50% carbohydrate, 30% fat and 20% protein)*	*Low fat (60% carbohydrate, 25% fat and 15% protein.)*	*28.1*
Yackobovitch-Gavan	*2008*	*Israel*	*Obese*	*14.3*	*46.2*	*18*	*36*	*12*	*Parallel*	*Low-carbohydrate low-fat (LCLF): Low-carbohydrate (60 g, 20%), high-protein (150 g, 50%), low-fat (40 g, 30%)*	*High carbohydrate low fat: High-carbohydrate (150–180 g, 50–60%), low-protein (60 g, 20%), low-fat (40 g, 30%)*	*36*
Kirk	*2012*	*USA*	*Obese*	*9.8*	*42.2*	*35*	*31*	*24*	*Parallel*	*Low carbohydrate: The subjects were instructed to follow a 2-week induction phase with #20 g CHO/day and unrestricted intake of high-protein foods (e.g., meat, poultry, fish, eggs) and added fats. After induction, CHO intake was increased by 5–10 g/week up to a maximum of 60 g/day*	*Portion-controlled (PC) diet: Subjects in the PC diet group were instructed to consume age-appropriate. Calories were distributed as 55-60% CHO, 10-15% protein, and 30% fat*	*29.4*

BMI: body mass index

Table 2 Risk of bias assessment according to the Cochrane collaboration's risk of bias assessment tool

Study, Year (reference)	Random sequence generation	Allocation concealment	Blinding of participants and personnel	Blinding of outcome assessment	Incomplete outcome data	Selective reporting	Overall assessment of risk of bias
1. ***Partsalaki***	Low	Low	Low	Low	Unclear	Low	Low
2. ***Bailes***	Low	Unclear	Low	Low	Unclear	Low	Unclear
3. ***Casazza***	Low	Low	Low	High	Unclear	Low	Unclear
4. ***Truby***	Low	Low	Unclear	Unclear	Unclear	Low	Unclear
5. ***Goss***	Low	Low	High	Low	Unclear	Low	Unclear
6. ***Jensen***	Low	Low	Unclear	Low	Unclear	Low	Low
7. ***Krebs***	Low	High	Low	Low	Unclear	Low	Low
8. ***Sondike***	Low	Low	High	Low	Unclear	Low	Unclear
9. ***Demol***	Low	Low	Unclear	Low	Unclear	Low	Low
10. ***Ibarra-Reynoso***	Low	Unclear	Low	Low	Unclear	Low	Unclear
11. ***Yackobovitch-Gavan***	Low	Low	Low	Low	Unclear	Low	Low
12. ***Kirk***	Low	Unclear	Unclear	Low	Unclear	Low	Low

-1.43%; P=0.005; 95% CI: -2.43, -0.43; P=0.111; I^2 = 42.0%). Additionally, the carbohydrate-restricted diet led to a significant increase in adiponectin levels (WMD: 0.74 ng/ml; P=0.044; 95% CI: 0.02, 1.47; P<0.001; I^2 = 94.7%). However, no significant effects were found on BMI Z-score (WMD: -0.10; P=0.079; 95% CI: -0.21, 0.01; P=0.115; I^2 = 41.4%), waist circumference (WMD: -3.03 cm; P=0.093; 95% CI: -6.57, 0.51; P=0.977; I^2 = 0.0%), or leptin levels (WMD: -0.82 ng/ml; P=0.261; 95% CI: -2.26, 0.61; P=0.464; I^2 = 0.0%) following the intervention (Figs. 2, 3 and 4).

A stratified analysis based on carbohydrate restriction levels and intervention duration indicated that carbohydrate-restricted diets had a more significant effect on reducing weight and BMI during interventions lasting 12 weeks or less, particularly with very low carbohydrate diets. Furthermore, BMI Z-scores decreased significantly during interventions of 12 weeks or less, compared to those lasting longer than 12 weeks. In addition, body fat percentage decreased more significantly with very low carbohydrate diets than with mild carbohydrate restriction (Supplementary Table 1).

Sensitivity analysis

The leave-one-out method was employed to evaluate the influence of individual studies on the overall effect size. The results remained robust after sequentially excluding studies (Supplemental Fig. 1).

Publication bias

Visual inspection of the funnel plot revealed no evidence of publication bias in the effects of carbohydrate restriction on the outcome measures. Egger's regression test further confirmed the absence of significant publication bias for weight (P=0.322), BMI (P=0.421), BMI Z-score (P=0.099), fat mass (P=0.293), waist circumference (P=0.174), leptin (P=0.327), and adiponectin (P=0.624) (Supplemental Fig. 2). The trim-and-fill analysis did not identify any missing studies.

Discussion

To our knowledge, this is the first systematic review and meta-analysis to access the impact of carbohydrate-restricted diets on weight loss in children and adolescents with overweight or obesity. Overall, this meta-analysis of nine clinical trials found that carbohydrate-restricted diets significantly reduced weight, BMI, fat mass among children and adolescents with overweight and obesity.

Body weight decreased consequently with a decrease in intake of carbohydrates lasting less than or equal to 12 weeks. Despite this, Carbohydrate restriction did not appreciably lower body weight after more than a year of follow-up. Likewise, meta-analysis in adults similarly conclude that carbohydrate restriction are effective at 6- and 12 month follow-ups [42]. Gau et al. and colleagues [43], conducted a systematic review in which they compared the impact of several diets with varying macronutrient contents on children and adolescents with overweight and obesity. The findings demonstrated that if a low-calorie diet is followed, performance metrics like BMI z-score will show favorable changes independent of the diet's macronutrient composition. According to Gau et al., the short-term benefits of low-carbohydrate diets over higher carbohydrate diets are no longer obvious in long-term follow-up studies. In the intervention by Demol et al. [44] and Krebs et al. [45], BMI Z-scores reduced by an average of 0.25 after a low-carbohydrate diet among adolescents with obese and severely obese. Similarly, our study found a 0.10 drop in BMI Z-scores following a carbohydrate-restricted diet.

Traditionally, weight loss diets have primarily concentrated upon calorie restriction, predominantly especially via carbohydrate and fat restriction [46]. Low-carbohydrate diets have diminished effectiveness in decreasing weight in overtime due to low adherence [47]. Moreover,

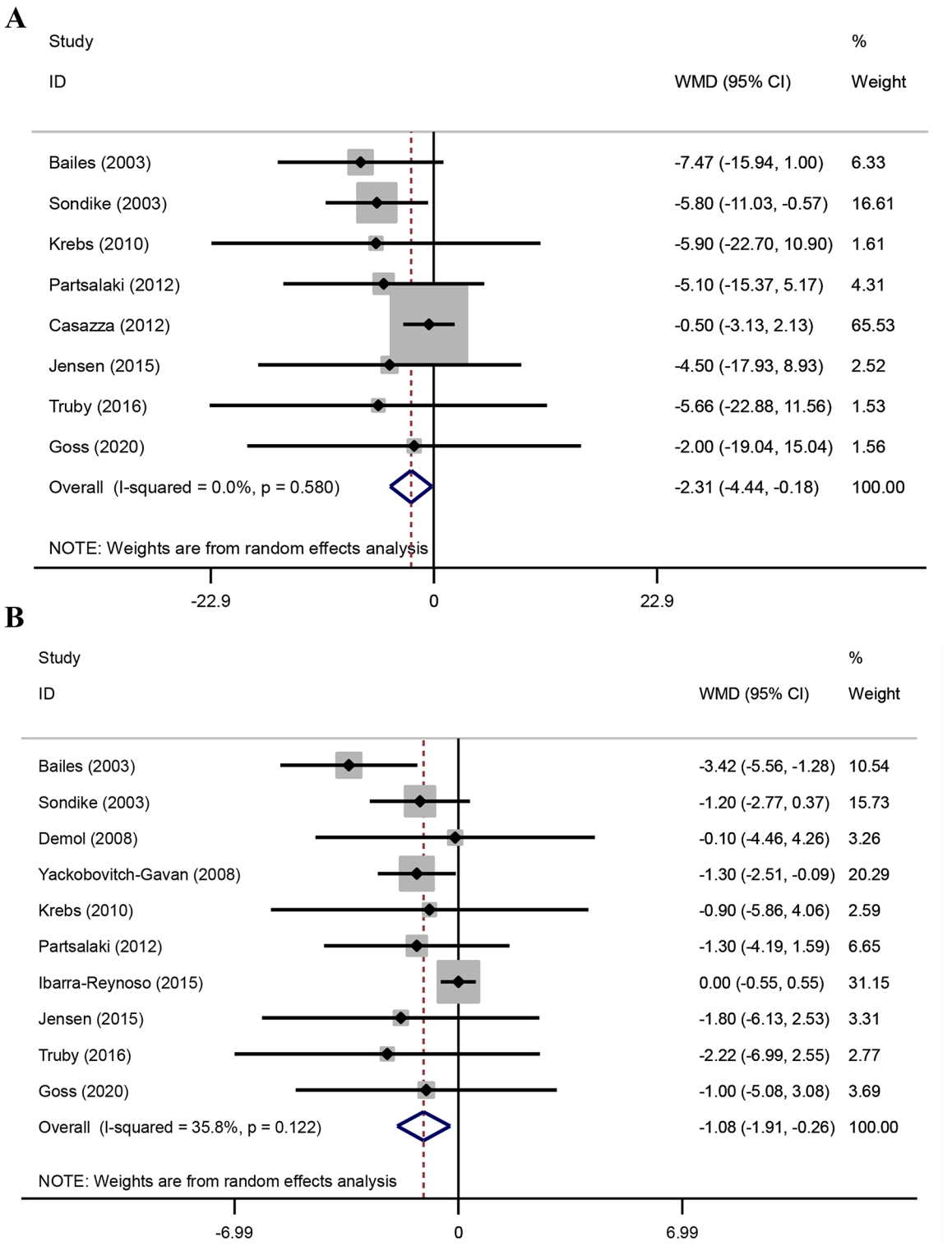

Fig. 2 (**A**) Forest plots from the meta-analysis of clinical trials investigating the effects of dietary carbohydrate restriction on weight. (**B**) Forest plots from the meta-analysis of clinical trials investigating the effects of dietary carbohydrate restriction on BMI

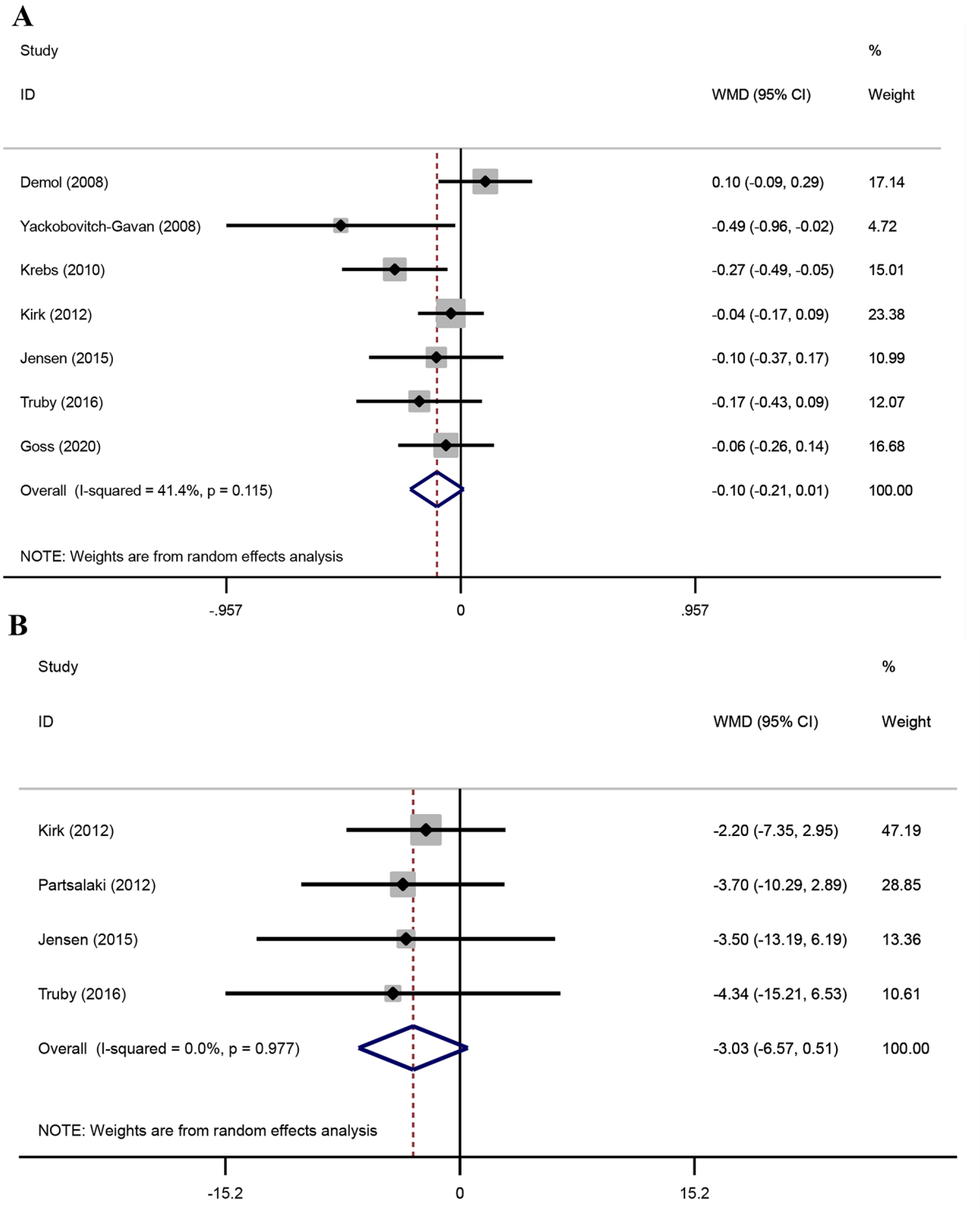

Fig. 3 (**A**) Forest plots from the meta-analysis of clinical trials investigating the effects of dietary carbohydrate restriction on BMI Z Score. (**B**) Forest plots from the meta-analysis of clinical trials investigating the effects of dietary carbohydrate restriction on on WC

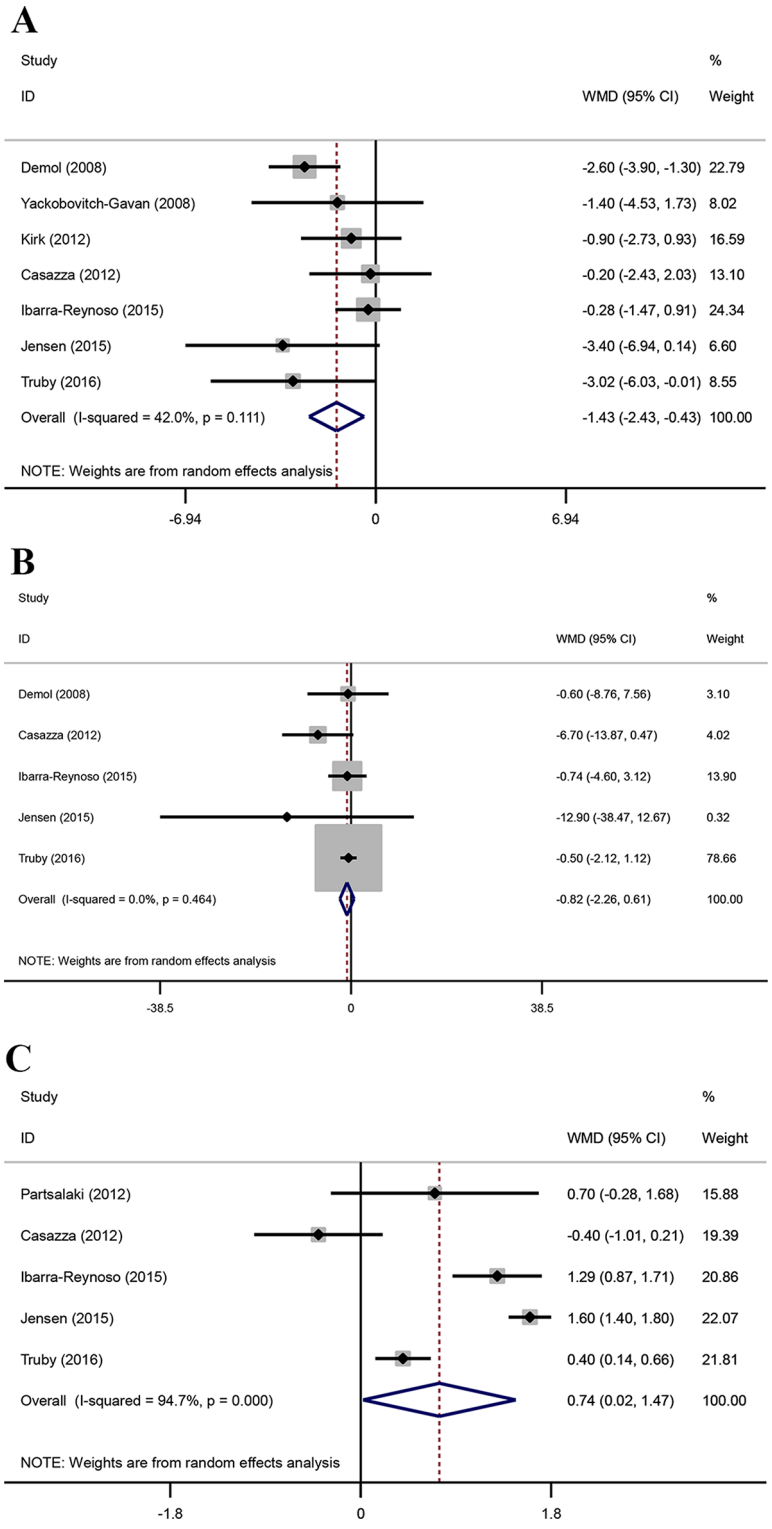

Fig. 4 (**A**) Forest plots from the meta-analysis of clinical trials investigating the effects of dietary carbohydrate restriction on on fat mass (%). (**AB**) Forest plots from the meta-analysis of clinical trials investigating the effects of dietary carbohydrate restriction on on leptin (ng/ml). (**C**) Forest plots from the meta-analysis of clinical trials investigating the effects of dietary carbohydrate restriction on on adiponectin (ng/ml)

carbohydrate-restricted diets remove the desire for sweet tastes, lessen the desire for eating, and limit the choices of foods, making them harder to maintain over time [48]. Focusing only on the short term may result in treatment failure and weight gain, which can cause demotivation and low self-esteem. In addition, long-term weight management plans can encounter weight plateaus and weight regain due to physiological responses to weight loss Because of the lowered energy expenditure and body metabolism, behavioral interventions for treatment of obesity, such as calorie restriction, result in rapid weight reduction accompanied by slowing down and even weight regain [49]. Nevertheless, the low-carbohydrate diet is still one of the most popular methods for losing weight.

Numerous possible causes have been proposed to explain how carbohydrate restriction can help you achieve a healthy body weight at a young age while also preventing obesity later in life. The carbohydrate-insulin hypothesis explains the majority of this, implying that high-carbohydrate food intake causes hyperinsulinemia. Hyperinsulinemia leads to increased fat storage and body weight [50]. Acute carbohydrate deprivation also leads to ketone body production, which can suppress appetite and reduce food intake [51]. Carbohydrate-restricted diets may also cause weight loss by increasing energy expenditure, decreasing ghrelin and leptin levels, and increasing calories burned [50]. These findings may be highlighted by the decrease in appetite linked to extremely low-carbohydrate (ketogenic) diets and their impact on neurotransmitters that control hunger in addition to effects caused by ketones themselves [52, 53].

According to a recent study, children and adolescents with severe obesity who followed a protein-sparing modified fast, or a low carbohydrate, high-protein diet, lost 3.7 kg, 5.5 kg, and 4.7 kg after 1, 3, and 6 months, respectively [54]. A randomized clinical trial in children with obese compared carbohydrate-modified diets against a standard-portion restricted diet. Both groups lost identical amounts of weight when they restricted their caloric intake. However, adhering to a low-carbohydrate diet was proven difficult, especially in the long term [31].

Our meta-analyses found lowering carbohydrate consumption lead to greatest reduction in body weight. This implies that of all carbohydrate-restricted diets, very-low-carbohydrate (ketogenic) diets are the most successful in lowering BMI-Z scores in children and adolescents with overweight/obese ($p=0.046$, respectively). Low-carbohydrate diets have some problems, including the possibility of adverse effects Additionally to its possible advantages, a carbohydrate-restricted diet may also pose some challenges for pediatric patients, such as limited dietary choices and difficulties adhering to the diet.

The short-term symptoms of the diet may include nausea, constipation, exhaustion, dehydration, and electrolyte abnormalities [31, 55]. A sudden increase in carbohydrate consumption may also lead to a reduction in ketosis 'benefits [56, 57]. It is unclear how diet affects growth and development, cardiovascular and bone health over the long term [58]. Few data are available about the potential impact on growth in the pediatric age group. Short-term ketogenic diets are increasingly popular among young adults as a weight-loss strategy [53, 56]. In fact, the diet's long-term effects are less evident and call for more research. All patients on a ketogenic diet require ongoing monitoring; even when used for short periods of time, Despite the fact that ketogenic diets are often used for short periods of time, they should always be monitored and treated under medical supervision to ensure the best possible outcome [59].

While carbohydrate-diets can have difficulties, when followed appropriately and closely supervised by medical professionals, these diet remains effective in treating pediatric patients with epilepsy and other conditions [57]. Even while the diet can be a useful strategy in some situations to improve health outcomes, Additional research is needed to clarify the potential long-term impacts on young patients.

Strengths and limitations

This study has several strengths. It is the first systematic review and meta-analysis to evaluate the effects of carbohydrate-restricted diets on weight loss in children and adolescents with overweight or obesity. Our meta-analysis design, based on eligible clinical trials, supports strong causal inference. Additionally, our findings can help inform decisions about the appropriateness of carbohydrate-restricted diets for pediatric weight loss.

However, some limitations should be considered. We did not examine the effects of carbohydrate restriction on other anthropometric measures. Evaluating additional outcomes, such as body composition, could provide deeper insights. Furthermore, we could not assess the impact of dietary interventions on the severity of obesity due to a lack of data. Another limitation is the origin of macronutrients in the diet. While we assessed carbohydrate intake, the type of carbohydrate consumed was not considered in the included studies. Additionally, the quality of the meal, as well as dietary sources of fats, proteins, and micronutrients, may influence body weight, but these factors were largely overlooked.

Ultimately, longer-term studies are needed to assess how meal composition affects body weight and other health outcomes.

Conclusions

The findings of this study suggest that weight loss is proportionate to carbohydrate reduction at the 6- and 12-month follow-ups. This indicates that among carbohydrate-restricted diets, very-low-carbohydrate (ketogenic) diets may be the most effective strategy for reducing BMI Z-scores in children and adolescents with overweight or obesity. Further research is needed to clarify how different macronutrient intakes and dietary patterns influence the effectiveness of low-carbohydrate diets in this population.

Supplementary Information

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Supplementary Material 1

Supplementary Material 2

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Data availability
The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Declarations

Ethical approval
This study was approved by the research council and Ethics Committee of Tehran University of Medical Sciences, Tehran, Iran.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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