Diabetes, Metabolic Syndrome and Obesity

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REVIEW

Low-Carbohydrate Diet is More Helpful for Weight Loss Than Low-Fat Diet in Adolescents with Overweight and Obesity: A Systematic Review and Meta-Analysis

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Purpose: This manuscript performed a meta-analysis to compare the effects of a low-fat diet (LFD) and a low-carbohydrate diet (LCD) on body weight and lipid levels in adolescents with overweight and obesity.

Patients and Methods: PubMed and other databases were searched for the full-text literature comparing LFD and LCD up to November 2023 using a subject plus free word strategy, with search terms such as "low-fat diet", "low-carbohydrate diet", "obesity", "weight", "adolescents", "RCT", and so on. Two independent reviewers selected promising candidate trials, collected the data, and assessed the quality of the trials. RevMan 5.3 software was utilized to conduct a meta-analysis of the randomized controlled trials (RCTs) that were included.

Results: 5 RCTs with 192 participants were included in this meta-analysis. Weight (mean difference −2.81; 95% CI −5.38 to −0.25), Body Mass Index (BMI) (−1.13; 95% CI −2.14 to −0.11) and Triglyceride (TG) (−0.36; 95% CI −0.46 to −0.27) of the LCD were significantly lower than that of the LFD. At the same time, the high-density lipoprotein cholesterol (HDL) levels of the LCD were significantly higher than those of the LFD (0.08; 95% CI 0.04 to 0.12) ($P < 0.05$). However, there was no significant difference in the Homeostasis Model Assessment of Insulin Resistance (HOMA-IR), percent body fat, total cholesterol (TC), and low-density lipoprotein cholesterol (LDL) between the two groups ($P>0.05$).

Conclusion: According to this study, LCD is more helpful in improving weight loss, HDL and TG. Thus, LCD may serve as an effective intervention for weight management in adolescents with overweight and obesity, although further research is needed to determine its long-term effects.

Keywords: obesity, diet, weight loss, low-carbohydrate, low-fat

Introduction

Obesity is a chronic metabolic disease characterized by excessive accumulation or abnormal secretion of fat in the body, which is caused by various factors such as genetics and the environment.[1] For the diagnosis of overweight and obesity, the expert group of the "Guidelines for the Assessment, Treatment, and Prevention of Obesity in Chinese Children" recommends that Chinese children under 6 years of age should use BMI and the "Growth Curve of Body Mass Index for Chinese Children and Adolescents Aged 0–18 Years" published in China in 2009, while children and adolescents over 6 years of age should use the People's Republic of China health industry standard "Screening for Overweight and Obesity in School-Aged Children and Adolescents", published in 2018, for diagnosis. Obesity is considered a global epidemic with a significant effect on population health.[2]

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Over the past 20 years, the prevalence of overweight and obesity has increased every year. According to the World Obesity Atlas 2023, obesity rates in childhood and adolescence will increase the fastest of all age groups. From 2020 to 2035, the global incidence of obesity will increase from 10% to 20% in boys and 18% in girls.[3] The Report on Nutrition and Chronic Diseases of Chinese Residents (2020) also reported that the prevalence of overweight and obesity in the Chinese population under the age of 6 and 6~17 years of age reached 10.4% and 19.0% respectively.[4] Children and adolescents with overweight and obesity are still at risk of persistent obesity in adulthood.[5] Obesity has a significant effect on the physical and mental well-being of adolescents, as well as resulting in various chronic diseases, such as dyslipidemia, diabetes, cardiovascular disease and several types of cancers,[6–8] so it is of utmost importance to find effective ways to treat overweight and obesity.

Currently, common treatments for obesity include medications, physical activity, bariatric surgery and other options, but dietary treatment is still considered a safe and effective way to lose weight in children and adolescents. The American Heart Association Nutrition Committee in the Weight Loss Dietary Guidelines recommends LFD to reduce saturated fat intake as a common dietary strategy.[9] However, in recent years, some other dietary strategies have been proposed, such as low-carbohydrate diets. LCD is characterized by a strict restriction of dietary carbohydrate intake and an increase in fat and protein intake, which places the body in a state of available carbohydrate starvation, thereby promoting the metabolism of body fat and aiding in weight control.[10,11] Generally, it is a diet that restricts carbohydrates to less than 45% or 225 g/d of total calories consumed per day. LFD is a diet that limits fat intake to less than 30% of energy. Although LCD has been shown to have a beneficial effect on weight loss and metabolic improvement according to some studies,[12,13] few studies have been conducted on the effects of weight loss on adolescents. This study reviewed the literature on LCD and intervention in adolescents with overweight and obesity for a meta-analysis, aiming to examine the effect of LCD and LFD on weight loss and metabolism of adolescents with overweight and obesity and provide a theoretical basis for clinical guidance on effective weight loss and metabolic improvement.

Materials and Methods

The systematic review was reported according to the 2020 PRISMA guideline and all procedures of the PRISMA checklist were completed.

Search Strategy

The article was extracted from PubMed and other databases up to November 2023 using a subject plus free word strategy, with search terms such as "low-fat diet", "low-carbohydrate diet", "obesity", "weight", "adolescents", "RCT", and so on. If the inclusion criteria were not met, the selected literature was reviewed and classified.

Study Selection

The studies included in this meta-analysis conformed to all of the following inclusion criteria: (1) a low-carbohydrate or low-fat diet was used as the intervention condition, with a "low-carbohydrate diet" defined as a diet with up to 45% or 225 g/d carbohydrate, and a "low-fat diet" defined as less than or equal to 30% total fat and no cholesterol restriction;[14,15] (2) all study subjects were diagnosed as overweight or obesity; (3) subjects were under 18 years of age; (4) information on the presence of placebo or another control group should be described; (5) no other weight-loss drugs or surgical treatments were used; (6) studies should report baseline weight data and post-intervention data or different data; (7) the study period was longer than 1 month; (8) BMI was the primary outcome measure. In addition, weight, HOMA-IR, percent body fat, and lipid indices such as HDL, LDL, TC, and TG were included.

Data Extraction

Firstly, the titles and abstracts of the articles were selected by two independent authors (Yu Zhang and Tingting He) according to the inclusion and exclusion criteria. Subsequently, the full text of the selected articles was investigated by the two authors and another author (Yu Hu) according to the final criteria. Any disagreement between the two authors was resolved by discussion or consultation with the corresponding author (Chenlin Gao). The extracted data included: (1) relative information about the included studies: author's name, date of publication, and country; (2) basic characteristics of the research subjects: including age, BMI, body weight, percent body fat, dietary patterns, follow-up duration, and sample size; (3) specific details of the interventions; (4) data on relevant outcome indicators.

Risk of Bias Assessment

The risk of bias in the included studies was assessed using the RCT risk of bias assessment tool recommended by the Cochrane Handbook 5.1.0: (1) method of randomization; (2) whether the allocation was concealed; (3) whether subjects and research subjects were blinded; (4) whether the evaluators of the results were blinded; (5) whether the results of the study were reported selectively; (6) other sources of bias. The risk of bias in the included studies was independently assessed by two evaluators, and the results were cross-checked. Disagreements, if any, were discussed and resolved.

Data Analysis

Throughout the study, BMI was expressed in kg/m2, and lipids were expressed in mmol/L, if necessary, we converted mg/dL to mmol/L when necessary, and the standard deviation was calculated if a CI (confidence interval) or SE (standard error) from the mean was reported. In each included study, we calculated or extracted the mean change in BMI, body weight, HOMA-IR, percent body fat, and lipids relative to baseline for the two groups and compared the LCD with the LFD to derive the mean difference.

RevMan 5.3 statistical software was used for the meta-analysis, and as the outcome indicators were all continuous variables, the MD (mean difference) was used as the effect indicator, and point estimates and their 95% CIs were reported for each effect size. The heterogeneity of the included studies was tested with the χ^2 test (test level α=0.1) and combined with the I2 statistic. If the result of the heterogeneity test was I2 <50%, the fixed-effects model was used for meta-analysis; if the result of the heterogeneity test was I2 ≥50%, it indicated that there was a large heterogeneity of results between studies, and the source of heterogeneity needed to be further analyzed, and after excluding obvious clinical and methodological heterogeneity, the random-effects model was used for meta-analysis.

Results

Literature Search and Study Characteristics

A total of 938 articles were identified through a systematic literature search, excluding duplicates, and 43 articles were identified after reading the full text and re-screening to exclude incomplete data (n = 13), studies that did not meet the inclusion criteria (n = 21), inability to view the full text (n = 2), and too short an observation period (n = 2). A total of five studies were included.[16–20] Of these, a total of 192 subjects were included. The article selection procedure is shown in Figure 1, and the characteristics of the included randomized controlled trials are shown in Table 1.

Risk of Bias and Publication Bias

The percentages of trials with low bias, unclear bias, and high bias are summarized in Figure 2. Publication bias analysis was performed using RevMan 5.3, and the funnel plot had good symmetry, indicating low publication bias (shown in Figure 3).

Weight (Kg)

All four included studies (155 patients) were evaluated, and individuals assigned to LCD had significantly greater weight loss compared to those assigned to LFD (mean difference −2.81; 95% CI −5.38 to −0.25; P=0.03; I2: 62%) (shown in Figure 4a).

BMI (Kg/m2)

Five included studies compared LCD and LFD on BMI in adolescents. The pooled results of these studies displayed a statistically significant decrease in BMI with a low-carbohydrate diet (mean difference −1.13; 95% CI −2.14 to −0.11; P=0.03; I2: 0%) (shown in Figure 4b).

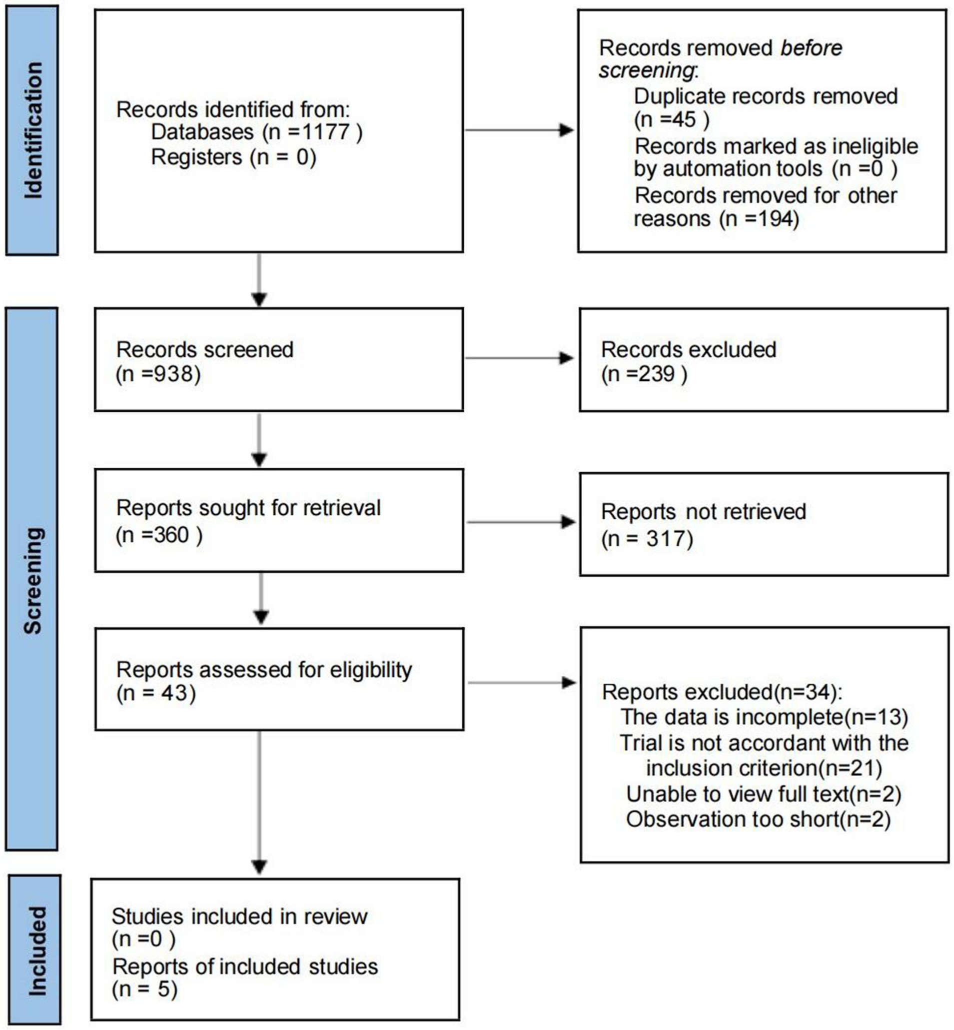

Figure 1 Preferred Reporting Items for Systematic Review and Meta-Analyses (PRISMA) flowchart of included articles.

Homa-Ir

Four studies (162 patients) were analysed for HOMA-IR, and this analysis did not show statistically significant results (mean difference 0.00; 95% CI −0.36 to 0.36; P=1.00; I2: 0%)(shown in Figure 4c).

Percent Body Fat (%)

Three studies were available for meta-analysis to assess changes in body fat at follow-up. This meta-analysis showed that there was no significant difference in changes in body fat between the two diets (mean difference 0.44; 95% CI −0.94 to 1.82; P=0.53; I2: 0%) (shown in Figure 4d).

Lipids(Mmol/L)

Meta-analysis of the results revealed no significant difference for LDL (0.25; 95% CI −0.02 to 0.52; P=0.07; I2: 57%) and TC (0.12; 95% CI −0.01 to 0.25; P=0.07; I2: 7%). The pooled MD in favour of low-carbohydrate was statistically significant in TG levels (−0.36; 95% CI −0.46 to 0.27; P<0.01; I2: 0%), and HDL was significantly elevated (0.08; 95% CI 0.04 to 0.12; P<0.0001; I2: 0%) (shown in Figure 5).

Table 1 Study Characteristics of Randomised Trials of Low-Carbohydrate vs Low-Fat Dietary Interventions

First Author, Year	Country	Age (Years) LCD/LFD	Participants LCD/LFD	BMI (kg/m^2) LCD/LFD	Weight (kg) LCD/LFD	Body fat(%) LCD/LFD	HOMA-IR LCD/LFD	Low-Carbohydrate Intervention	Low-Fat Intervention	Follow-Up Duration (Weeks)	Jadad Scale
de Ferranti, SD 2015[16]	USA	13.2±2.5	15 / 12	29.8±3.9	82.0±19.0 / 76.0±17.3	36.3±3.5 / 34.2±2.8	5.3±2.7 / 3.9±1.0	40% fat, 40% carbohydrates, 20% protein	20% fat, 60% carbohydrates, 20% protein	8	5
Demol, S 2009[17]	Israel	14.3±6.6 / 14.9±8.0	17 / 20	33.7±6.6 / 33.8±6.7	/	42.0±8.2 / 39.3±8.0	4.1±2.1 / 4.2±2.2	60 g carbohydrates (up to 20%), 60% fats and 20% proteins	50–60% carbohydrates, 30% fats and 20% proteins	12	6
Krebs, NF 2010[18]	USA	14.2±2.0 / 13.7±1.4	18 / 15	38.0±5.9 / 40.1±8.4	109.3±4.7 / 107.1±6.1	/	4.3±0.6 / 4.9±0.7	Very low carbohydrate intake (≤20 g/d) and high lean protein intake (2.0–2.5 g/kg/d), fat were not restricted	≤30% of calories from fat	13	5
Sondike, SB 2003[19]	USA	14.4±1.9 / 15.0±1.8	16 / 14	35.4±5.0 / 35.6±5.8	92.1±14.9 / 99.5±27.3	/	/	No more than 20 g/d of carbohydrate for the initial 2 weeks. Carbohydrate was increased to 40 g/d for weeks 3 through 12	<40 g/d of fat	12	3
Truby, H 2016[20]	Australia	13.2±1.9 / 13.2±2.1	33 / 32	32.47±4.9 / 32.62±5.9	86.23±18.18 / 86.63±22.6	38.61±4.55 / 39.67±6.38	1.8±0.9 / 1.7±1.0	35% carbohydrate, 30% protein, 35% fat	55% carbohydrate, 20% protein, 25% fat	12	4

Abbreviations: LCD, low-carbohydrate diet; LFD, low-fat diet; BMI, Body Mass Index; HOMA-IR, Homeostasis Model Assessment of Insulin Resistance.

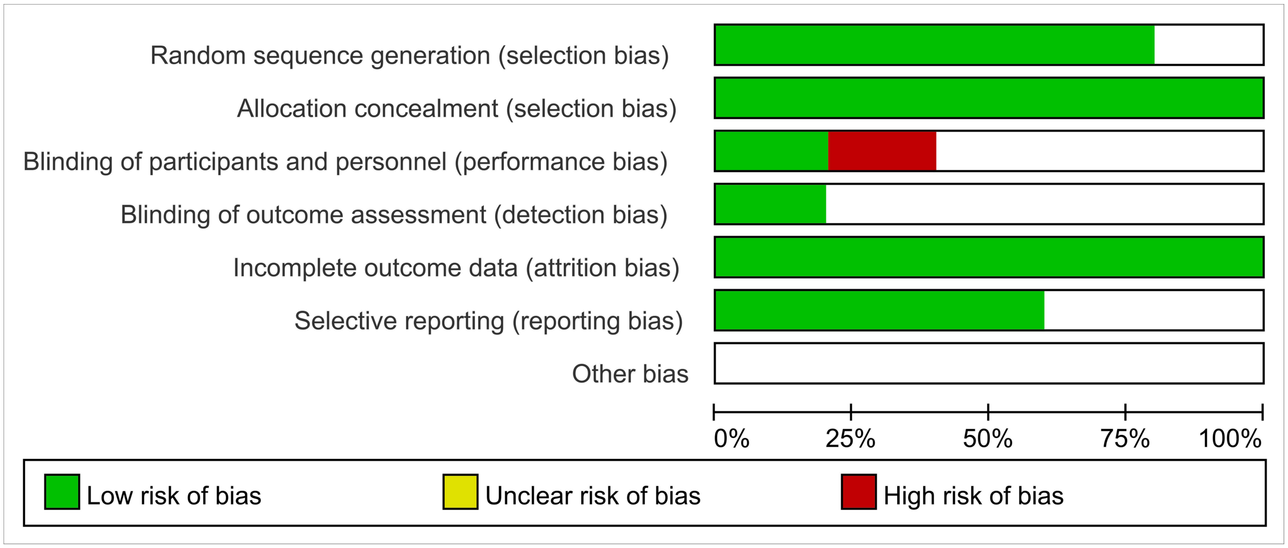

Figure 2 Quality assessment performed by authors on each risk of bias project represented as a percentage across all eligible studies.

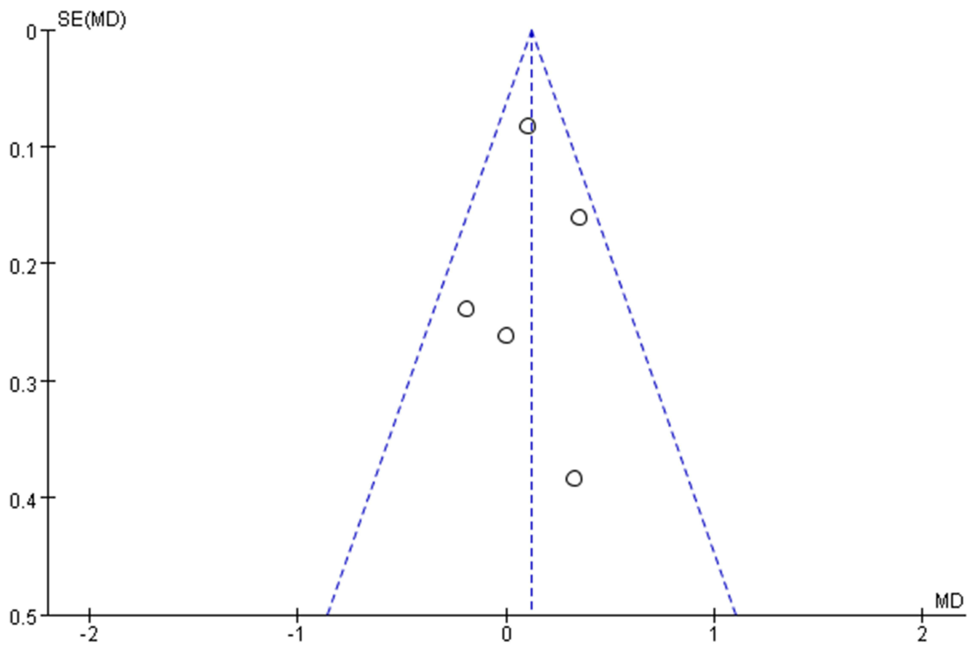

Figure 3 Funnel plot of publication bias.

Discussion

Many studies have compared the effects of the LCD and LFD on metabolic risk factors and weight loss in adults with overweight and obesity,[21–23] but fewer studies have been reported in adolescents with overweight and obesity. In this review, a meta-analysis of relevant randomized controlled trials was used to compare the effects of the LCD and LFD on metabolic risk factors and weight loss in juveniles with overweight and obesity. The meta-analysis showed that LCD subjects had greater reductions in body weight, BMI and TG, and greater increases in HDL, whereas HOMA-IR, percent body fat, TC and LDL did not change significantly between the two diets. Therefore, dietary choices can be made according to the relevant needs of the patients.

Both LCD and LFD are beneficial to weight loss, but LCD may be more effective than LFD. Previous studies have demonstrated that populations receiving LCD interventions show greater weight loss than those receiving LFD in both

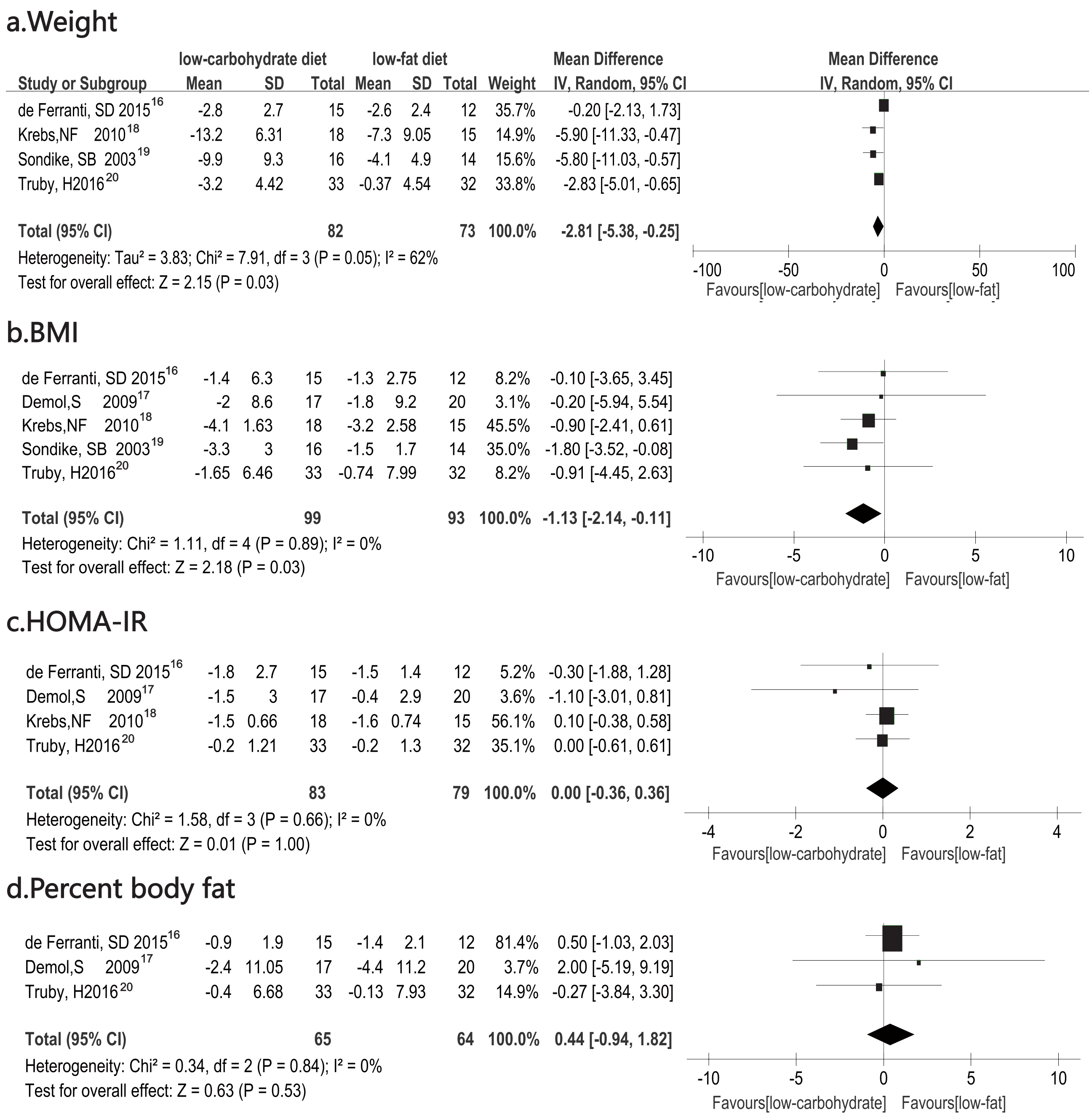

Figure 4 Forest plots showing the mean difference (MD) and 95% CI across all studies for (**a**) weight, (**b**) BMI, (**c**) HOMA-IR, (**d**) Percent body fat(%). Weight and BMI of the LCD were significantly lower than that of the LFD. There was no significant difference in HOMA-IR and percent body fat.

adult and adolescent patients with obesity.[24] The findings are consistent with the weight loss meta-analyses conducted by these authors (eg, Mansoor N, Hu T, and Chawla S),[23,25,26] in which LCD showed similar benefits for weight loss, although Chawla S also stratified results by length of follow-up to provide a more nuanced understanding of the effects of both diets. The study showed that 6–12 months of weight loss was better. One of the "mechanisms" associated with weight loss on the LCD may be that it leads to greater satiety, which is associated with lower calorie intake.[27] It is also important to consider other mechanisms such as energy consumption, hormone release, adipogenesis, and fatty acid metabolism.[28] In addition, several studies have demonstrated that both diets are equally effective in reducing weight and improving metabolic risk factors, especially blood lipid levels.[26]

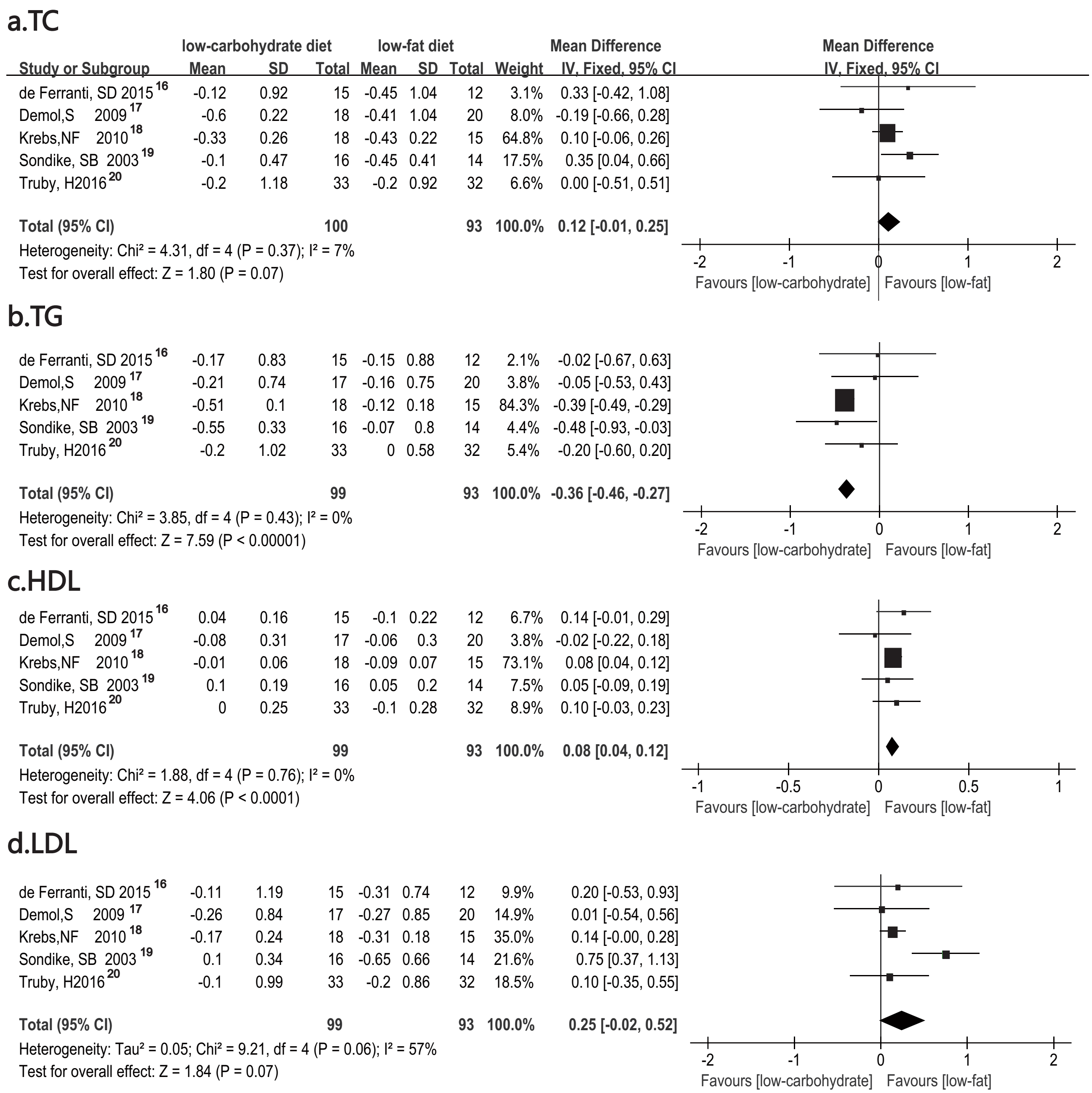

Figure 5 Forest plots showing the mean difference (MD) and 95% CI across all studies for (**a**) total cholesterol, (**b**) total cholesterol, (**c**) high-density lipoprotein cholesterol (HDL) cholesterol, (**d**) low-density lipoprotein cholesterol (LDL) cholesterol. LCD is more effective in improving HDL and TG. There was no significant difference in TC and LDL.

The results of the meta-analysis suggest that LCD is more favorable for improving TG and HDL but unfavorable for TC and LDL, which is consistent with previous reports.[23,29] Reduced carbohydrate intake may increase the systemic transport of lipid energy through VLDL spectral particles, leading to increased LDL cholesterol and HDL cholesterol and reduced TG through hyperlipoproteinemia, lipase-mediated remodeling of VLDL into LDL and HDL occurs.[30] In clinical practice, lipid levels of HDL, LDL, and TG are commonly used as prognostic markers of cardiovascular disease.[31] Epidemiological data support a negative correlation between serum HDL and cardiovascular disease risk, with a 1% increase in HDL levels associated with a 2–3% reduction in cardiovascular risk. However, it should be noted that elevated HDL cholesterol levels alone does not necessarily translate into therapeutic efficacy.[32,33] In the present study, LCD did not cause a significant reduction in LDL and TC compared to LFD, which may be related to the generally high saturated fat composition of LCD. Related studies have found that LDL levels are elevated in LCD subjects.[34–36] In this study, LCD did not cause a significant decrease in LDL or TC compared to LFD. This observation may be attributed to the fact that LCD generally contains higher amounts of saturated fats. Relevant studies have found an increase in LDL levels among subjects on LCD diets. However, the study did not observe such an increase in LDL levels among participants in the LCD diet. This discrepancy might be due to the weight loss during the dietary intervention or the higher content of unsaturated fatty acids present in the LCD. It is expected that moderate weight loss would lead to a reduction in serum concentrations of LDL.[37] Compared to LCD, LFD restricts the intake of saturated fatty acids, which may reduce liver-synthesized cholesterol production significantly lowering TC levels. In addition, LFD reduces the synthesis of very low-density lipoprotein cholesterol resulting in reduced LDL.

In terms of percentage body fat loss, LCD did not have a greater effect than LFD. This was also true in adults.[38] This may be related to the fact that both diets were low-calorie and achieved energy restriction. Insulin resistance is an important pathophysiological process in obesity. In the present study, LCD and LFD have some benefits in improving insulin resistance, but there was no significant difference between them. However, Meckling KA found that a low-carbohydrate diet as measured by HOMA-IR was more effective in improving fasting blood glucose and insulin levels, and insulin sensitivity in insulin-resistant individuals with obesity.[38–40] This may be related to the lack of large clinical studies in this study.

Our meta-analysis has several advantages: Firstly, we rigorously followed to the PRISMA guidelines for conducting a meta-analysis, which increased the reliability of our findings by assessing both the Jadad scale and publication bias. Secondly, all included studies were randomized controlled trials, which further strengthens the validity of our findings. Lastly, this study investigates the effect of the LCD and LFD on metabolic parameters related to adolescent obesity (such as weight, blood lipid levels, HOMA-IR index, and body fat percentage). Notably, adolescents at risk of overweight and obesity are more likely to benefit from a low-carbohydrate diet in terms of weight loss and improved metabolic risk factors, especially blood lipid levels.

There are still some limitations to the study. First, the definition of LCD is different. The definition of LCD was heterogeneous across the studies, and the degree of carbohydrate restriction is different. However, the definition of LFD is consistent and is characterized by a total fat content of 30% or less. Second, the duration of the trials varied from 2 to 4 months, and there were no trials that lasted longer than 1 year. LCD may lead to small short-term improvements in weight loss and lipid improvement, but more research is needed on the long-term effects. Third, most of the trials were relatively small, which limits the precision with which treatment effects can be estimated. Finally, the quality of the evidence for the outcomes in this review ranged from low to very low. Future research evidence is needed from well-designed randomized trials.

Conclusion

The weight loss efficacy of a low-carbohydrate diet may be helpful to that of a low-fat diet in adolescents with excess weight, with LCD showing greater improvements in TG and HDL. Therefore, LCD may serve as an effective intervention for adolescent patients with obesity and has significant potential for clinical application. Large-scale clinical studies should be conducted to investigate the long-term effects of LCD on metabolic risk factors in adolescents with overweight and obesity.

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Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

The authors declare no competing interests in this work.

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