Systematic review of macronutrients modified dietary intervention in the management of overweight/obese children and adolescents

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Running title: macronutrients composition & obese children and adolescents

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Abstract

The prevalence of obesity in both adults and children is rapidly increasing worldwide. Obesity is one of main causes developing chronic diseases and various problems like economic consequence. It can be affected by genetic, environmental, psychological, and socioeconomic factors. Dietary modification is a well-known important factor in weight control. Precisely, dietary macronutrients composition, food selection, and dietary patterns along with energy restriction can affect weight reduction. The intervention programs related to diet and lifestyle modification for obesity are continuously being conducted in children and adolescents. Several studies demonstrated that dietary macronutrients modification affects body composition and metabolic-related markers. On the other hand, hypocaloric diets regardless of macronutrients composition have been reported to be effective and stable for weight loss in obese children. However, there are few intervention studies for the association between dietary macronutrients composition and obesity in Korean children and adolescents. Therefore, this systematic review was conducted to suggest a basic evidence to identify optimal macronutrients composition that can be applied in obesity management in Korean children and adolescents.

Keywords: obesity; macronutrients; children; adolescents
Key Message

- Several studies demonstrated that dietary macronutrients modification affects body composition and metabolic markers in children and adolescents.

- Hypocaloric diets regardless of macronutrients composition were also reported as effective and stable for weight loss in obese children.

- In the future, more intervention studies including Korean children and adolescents need to be conducted enough to do meta-analysis, which can suggest a basic information applied to Korean children and adolescents.
Introduction

The prevalence of obesity is rapidly increasing in both adults and children, that causes various problems like economic consequence and other chronic diseases\(^1,2\)). Obesity is associated with a risk of noncommunicable diseases such as type 2 diabetes, hypertension, cardiovascular diseases, heart failure, stroke, and several types of cancers\(^3,4\)). All of these problems would cause the low-quality of lifestyle with increased health-cost\(^2,5\)). According to the report by the World Health Organization (WHO), 39 million children aged under 5 years, and 340 million children and adolescents aged 5-19 years were overweight or obese in 2016\(^6\)), which become an global health issue. Compared to maintaining a healthy weight in childhood and adolescence, being obese in these periods may increase up to 5 times the possibility of being obese in adulthood\(^7\)). In addition, having become obese since childhood and adolescence increases metabolic and cardiovascular risk in adulthood\(^8\)).

The causes of obesity are complex, and may be influenced by genetic, environmental, psychological, and socioeconomic factors\(^9\)). Dietary modification is an important factor in weight loss: for example, dietary macronutrients composition, food selection, and dietary patterns along with energy restriction can affect weight loss\(^10\)). Therefore, studies on intervention programs related to diet and lifestyle modification for the treatment and improvement of obesity are continuously being conducted in children and adolescents\(^11-14\)). Several studies reported that the macronutrients composition affect body composition and metabolic-related markers\(^15-19\)). On the other hand, hypocaloric diets have been reported to be effective and stable for weight loss in obese children, regardless of macronutrients composition\(^20,21\)). Based on these results, more researches are needed to determine whether macronutrients composition in diet rather than simple energy restriction may be more effective on the weight loss. Optimal macronutrient composition may play an important role in growth
and development during childhood and adolescence besides obesity regulation\textsuperscript{22,23}. It is also related to satiety, hunger, insulin sensitivity, and lipid metabolism\textsuperscript{18,24-26} which are significantly related to the occurrence of diabetes and cardiovascular disease.

In Korea, the prevalence of overweight and obesity among children and adolescents aged 2-18 years was 18.6\% in 2017\textsuperscript{27}. In addition, obesity prevalence increased in 2020 compared to 2019 due to social, environmental factors, and lifestyle changes caused by COVID-19, especially among male adolescents aged 12-15 years\textsuperscript{28}. Several studies reported that obese children in Korea were associated with metabolic comorbidity including metabolic syndrome, dyslipidemia, and elevated blood pressure\textsuperscript{29}. Also, severe obese adolescents had abnormal metabolic risk factors such as unfavorable lipid parameters, HbA1c, and systolic blood pressure\textsuperscript{30}. Despite the risk of being obesity during childhood, few studies related systematic reviews have been reported on the association between dietary macronutrients composition and the management of obesity in Korean children and adolescents. Therefore, this systematic review was performed to identify optimal macronutrients composition that can be applied in Korea obese children and adolescents.

\textbf{Methods}

\textbf{1. Literature search strategy}

All research articles included our systematic review were searched from international databases such as PubMed and Web of Science. Our search strategy was using PICO framework (P, participant; I, Intervention; C, Comparison; O, Outcomes). Participant (population and patient) included children and adolescents with obesity, but not adults. Intervention included macronutrients modified diet and eating habit. Comparison was composed of all possible...
groups broadly. Finally, outcome included results on the body composition including obesity-related trait, lipid, and glycemic parameters. Based on our search strategy, we used the following keywords: (Obesity[MeSH Terms]) AND (((Adolescent) OR (Children)) NOT (Adults)) AND (Macronutrient) OR (Eating habit) AND (Body composition); (Obesity[MeSH Terms]) AND (((Adolescent) OR (Children)) NOT (Adults)) AND (Ketogenic diet) OR (Atkins diet) OR (Zone diet) AND (Body composition) published from January 1, 2000 to January 7, 2023.

2. Eligibility criteria

Researches included in this systematic review should satisfy the following criteria: 1) children or adolescents with obesity or overweight, but not adults; 2) comparison among macronutrients modification intervention groups; 3) randomized controlled trial (RCT); 4) intervention period with more than 3 months. Exclusion criteria are as follows: 1) books, proceedings, comments, editorial, or review articles etc. which are not research articles; 2) unavailable articles; 3) no clinical trial; 4) other disease excluding obesity. The literature selection procedure following inclusion and exclusion criteria, was confirmed and discussed by two authors.

3. Data extraction

For the present systematic review, we extracted several study traits. The extraction data are as followed: 1) first author and publication year; 2) investigation region; 3) Subjects information (number, sex, age, and BMI percentile); 4) Intervention and follow-up duration; 5)
dietary intervention type (diet intervention groups, macronutrient distribution or consumption, and other information about diet); 5) Main findings such as body composition and biochemical parameter changes. The information to be confirmed during the data extraction process was discussed by the two researchers.

4. Risk of bias

This study assessed the quality of the studies using a revised Cochrane risk-of-bias tool for randomized trials (RoB 2)\(^{31}\). This RoB tools confirmed several bias domains and signaling question: bias arising from the randomization process; bias due to deviations from intended interventions; bias due to missing outcome data; bias in measurement of the outcome; bias in selection of the reported result. Each question was answered by response options such as yes, Y; probably yes, PY; no, N; probably no, PN; no information, NI; not applicable, NA. According to each question and answer, each study was assessed and judged for risk of bias, and the possible judgement followed: lower risk of bias; some concerns; high risk of bias. Furthermore, visualization for risk of bias was using Risk-of-bias VISualization (robvis) tool\(^{32}\). All of assessment procedure and result of risk of bias were identified and discussed by two researchers.

Results

1. Study selection

According to the search strategy, 2,192 articles were identified in the two database (704 articles in PubMed and 1,488 articles in Web of Science). After duplicate articles were removed,
the 2,078 records were screened based on title and abstract, and then 2,053 were excluded.

25 articles that passed the screening and 6 additional articles cited in the literature were included for screening the full-text articles. Among the 31 articles, 22 articles were excluded for the following reasons: 1) no macronutrients modification-based intervention (n = 14); 2) no randomized controlled trial (RCT) (n = 5); 3) short communication (n = 2); 4) other disease (n = 1). Finally, 9 studies were eligible and included in this systematic review. Figure 1 shows the flow diagram of studies for the systematic review based on the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)\textsuperscript{33}.

2. Risk of bias assessment

The traffic-light plot and summary plot for risk of bias assessment are shown in Figure 2 and 3, respectively. Data analysis of the studies included in the systematic review were performed using the intention-to-treat (ITT) or per-protocol (PP) method which is used in the analysis of RCT research. Overall, studies showed 'some concerns' of risk of bias, if the study has 'some concerns' at least in one domain among the 5 domains. Briefly explaining why they were categorized to 'some concerns' as follows: first, all studies were designed as randomized controlled trials, but several studies did not mention the method exactly in the text. Thus, these studies were categorized to 'some concerns' in domain a asking about 'bias arising from the randomization process'. Second, the studies conducted dietary intervention with modification of macronutrients composition, and then, assigned participants to follow the prescribed diet. Thus, it might be difficult to design the study double-blinded. Thus, these studies were categorized to 'some concerns' in domain 2 asking about 'bias due to deviations from intended intervention'. Third, dietary interventions were conducted for children and adolescents, thus it
was difficult to do a complete analysis due to inevitable dropouts. Thus, these studies were categorized to 'some concerns' in domain 3 asking about 'bias due to missing outcome data'.

3. Characteristics of the studies

The characteristics of the 9 articles \(^{34-42} \) included in this systematic review were shown in Table 1. The articles were published between 2003 and 2016 years, and studies were conducted in USA, France, Israel, Greece, and Australia. Study subjects were children and adolescents with overweight or obesity that was mainly defined by BMI percentiles (>90\(^{\text{th}}\), >95\(^{\text{th}}\) or >97\(^{\text{th}}\) percentile). In addition, a study defined obesity with primary obesity or \(\geq 175\%\) of ideal weight (50\(^{\text{th}}\) percentile) \(^{37} \). One another study used the BMI z-score (1.60–2.65) \(^{40} \). The number of participants was in between 26 and 121, and both boys and girls were included in the studies except one study which included girls \(^{38} \). Dietary interventions were conducted for at least 3 months (from 12 weeks to a 9 months). Some studies had follow-up period after or including the intervention period, which was separately described. Dietary intervention was performed with modification of macronutrients composition in the diet and the details were summarized in Table 1.

4. Main findings following macronutrients-modification intervention

All of 9 studies showed the improvement in body composition and/or lipid and glycemic parameters after the dietary intervention (Table 1). In the 7 studies \(^{35,36,38-42} \), BMI z-scores, body fat mass, lipid profile, and glycemic parameter were significantly improved after dietary intervention, but no differences in the changed values were observed among the diet groups.
However, the other 2 studies comparing the low-carbohydrate (LC) and low-fat (LF) diets showed different results from the above 7 diet groups\textsuperscript{34,37}. Sondike SB et al.\textsuperscript{34}, reported that weight loss was greater in the LC diet group than in the LF diet group after intervention, but changes of lipid profiles were not significantly different between the two groups. Precisely, non-HDL-cholesterol levels were decreased in both diet groups after the intervention, but the improvement was greater in the LC diet group compared with the LF diet group. Also, triglyceride (TG) levels were significantly decreased only in the LC diet group, but no significance difference were observed between the two groups. On the other hand, LDL-cholesterol levels were significantly improved only in the LF group from baseline. Another study by Krebs NF et al.\textsuperscript{37} comparing the high-protein low-carbohydrate (HPLC) and the LF diet groups showed the decreased BMI z-scores in both groups. This reduction was maintained during the follow-up period. Despite similar energy intake, the improvement was more greater in the HPLC diet group compared with LF diet group.

In addition, several studies have reported nonserious side effects during the dietary intervention period\textsuperscript{34,36,37}. The major side effects were mainly headache, fatigue, and gastrointestinal discomfort (diarrhea, constipation, and nausea).
Discussion

This systematic review aimed to identify the optimal macronutrients composition in diet for managing obesity in children and adolescents, thereby suggesting a basic evidence that can be applied in obesity management in Korean children and adolescents. Finally, a total of 9 studies performed in various populations confirmed that macronutrients-modified interventions are effective in managing overweight or obesity in children and adolescents. However, most studies showed that improvement of body composition and metabolic parameters among the diet groups were not significantly different according to the specific macronutrients composition.

On the other hand, two studies showed that body composition improvement after the intervention were significantly different between dietary intervention groups. Sondike SB et al.\textsuperscript{34)} reported that compared with the LF diet, the LC diet is more effective on short-term weight loss in overweight adolescents without caloric restriction without harmful effect on lipid profiles. Krebs NF et al.\textsuperscript{37)} reported that a HPLC diet group had significantly greater reduction in BMI z-scores than a LF diet group. In other words, the LC diet was more effective in weight loss than the LF diet. Until now, a lot of researches has been conducted for weight loss through the LC intake. In similar with the research included in our systematic review, the LC diet and Mediterranean diets were more effective on weight loss than the LF diet in obese adults\textsuperscript{43)}. A meta-analysis study showed that a LC diet consumption resulted in higher weight loss for up to 1 year compared to a LF diet consumption\textsuperscript{44)}. In addition, the LC diet consumers showed improvement in HDL-cholesterol and triglyceride profiles compared the LF diet consumers\textsuperscript{44)}. However, the LC diet group showed more increased LDL-cholesterol and total cholesterol than the LF diet group.
On the other hand, Demol S et al. reported that LC diets with LF or HF were effective on weight loss in obese adolescents, but did not have any advantage compared with the HCLF diet\(^3\). According to the report by Truby H et al.\(^4\), the structured-LF diet and structured-modified carbohydrate diet groups compared to the control group, showed significant weight loss and improvement in body composition among obese adolescents, but there was no significant difference between the intervention groups. Given these contradictory results, more researches on the effect of different levels of carbohydrate intake on body composition and metabolic parameters are needed.

As similar with the results shown in the most studies in this review, a systematic review also showed that the effect of LC diet on weight loss or cardiovascular risk factors in overweight and obese participants was not different from the effect of balanced carbohydrate diet\(^3\). In addition, Casazza K et al. reported that both reduced-carbohydrate diet and the standard-carbohydrate diet with hypocaloric diet conducted in overweight/obese girls improved body weight and adiposity, but they were not significantly different in terms of weight loss\(^3\). Kirk S et al.\(^4\) also demonstrated that the adherence was significantly lower in the LC diet group compared to other diet groups such as reduced glycemic load and portion-controlled group, which suggested that a long-term LC diet is difficult for obese children to maintain. In addition, although it is not serious, side effects such as headache and gastrointestinal discomfort have been observed through several studies\(^3,34,36,37\). Based on these results, more researches need to be conducted to elucidate whether long-term LC diet is effective in weight control among obese children and adolescents.

In fact, recommendation for the range in dietary macronutrients composition are different according to the national dietary guideline, and among the diets which are well-known in the world. For example, one of famous diet, the Atkins diet which is indicated as a very LC diet
limits carbohydrate intake to 20, 40, and 100g per day, and recommends to avoid sugar, simple carbohydrate, and starch food\textsuperscript{46,47}. Another popular diet, the zone diet is a LC diet that consisted of 40% carbohydrate, 30% protein, and 30% fat \textsuperscript{46,48}. On the other hand, the 2020 Dietary Reference Intakes for Koreans (KDRIs) recommends consumption of 55-65% carbohydrate, 7-20% protein, and 15-30% fats from total calorie intake\textsuperscript{49}. In addition, data of the Korean Health and Nutrition Examination Survey shows that abdominal obesity in Korean adolescents were associated with high fat intake, but accounting for 24% of energy intake\textsuperscript{50} which is in fact, in normal range recommended by KDRIs\textsuperscript{49}. Interestingly, the higher ratio of fat composition in energy intake was associated with abdominal obesity particularly in Korean boys, but LC intake was also related to abdominal obesity\textsuperscript{50}. However, this study was designed cross-sectionally, which may indicate the need of RCT to identify the causality.

As mentioned above, our systematic review investigated several macronutrients modified diets for obesity improvement among children and adolescents. However, carbohydrate composition-\textit{modified} diets were not more effective on weight loss than other diet\textsuperscript{38,39}. Standard-carbohydrate and reduced-carbohydrate diet with hypocaloric diet improved body composition, but their effect were not significantly different\textsuperscript{38}. Also, the ketogenic and hypocaloric diet reduced body weight, BMI, fat mass, and waist circumference in obese children and adolescents, but the ketogenic diet was not more advantageous than the hypocaloric diet\textsuperscript{39}. In other words, modification of macronutrients composition may improve body composition, but the effect may be associated with restriction of caloric intake, not directly due to macronutrients modification. Further researches are needed to determine whether modification of dietary macronutrients composition is more beneficial in obese Korean children and adolescents than a hypocaloric diet. Moreover, optimal dietary macronutrients composition together with adjusting calorie consumption for weight loss among obese children
and adolescents should also be beneficial for their growth and development\textsuperscript{23}).

The prevalence of obesity in Korean adolescents aged in 13-18 years increased significantly together with increasing of obesity-related dietary habits such as unhealthy food intake and skipping breakfast\textsuperscript{51}. In particular, skipping breakfast has been reported to be associated with obesity and cardiometabolic risk factors\textsuperscript{52,53}. On the other hand, Korean children with higher adherence to dietary guidelines had a better quality in the diet, and a reduced risk of obesity\textsuperscript{54}). That is, following the suggested dietary guidelines can contribute to reducing the risk of obesity.

Similarly, an intervention of dietary-behavioral-physical activity promotion did not significantly affect BMI level, but improved the nutrition and physical knowledge/preference, and reduced percent of overweight children\textsuperscript{55}). The multi-component model of nutrition and lifestyle intervention also affected nutrition knowledge, and improved body composition, and biochemical parameter in adolescents\textsuperscript{56}). Dietary interventions combined with interventions for changes in physical activity and eating behavior are more effective than dietary intervention only\textsuperscript{57}). Also, it has been reported that customized nutrition intervention in obese children and adolescents has a positive effect on body composition\textsuperscript{58}). A report by Rolland-Cachera MF et al.\textsuperscript{35}) included in our systematic review demonstrated that increased body weight in spite of moderate energy intake after the intervention period might be associated with unhealthy behavior. Based on these results, controlling eating habit and physical activity together with modulation of optimal macronutrients composition in diet can help obese adolescents maintain normal growth and development as well as healthy body composition, which can be achieved through appropriate dietary education and dietary behavior education. Also, as presented in the Korea guidelines for childhood and adolescent obesity, a family-based, multidisciplinary, and comprehensive approach will be required to achieve behavioral interventions for obesity treatment\textsuperscript{59}). In addition, the research using KNHANES showed an association between a high
fat intake rate even within the normal range of the KDRI and abdominal obesity in Korean adolescents although it was not an RCT\textsuperscript{50}. In fact, it is opposite to the results\textsuperscript{34,37} that showed that LC was more effective in reducing body fat referred in this systematic review. This emphasizes the need to confirm the appropriate level of fat intake and macronutrient ratio for Korean children and adolescents, even if the KDRI is within the normal range.

This review had several limitations. First, the number of studies included in the analysis was relatively small. In the future, more studies need to be performed for a meta-analysis. Second, the intervention studies in this review were not designed with double-blindness due to diet traits and age of participants. Thus, the studies showed 'some concerns' of risk of bias assessment. Modification of RoB tool need to be considered for this kind of cases. Third, there is no study performed in Korean children and adolescents. Despite several limitations, this systematic review is meaningful to confirm that dietary macronutrients modification with adequate energy intake can affect weight loss in obese children and adolescents, which can suggest a basic information applied to Korean children and adolescents. In the future, more intervention studies including Korean children and adolescents need to be conducted enough to do meta-analysis.

**Competing interests:** The authors declare no conflicts of interest.

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References


Figure legends

Fig. 1. PRISMA flow diagram of studies for the systematic review.

Fig. 2. Risk of bias assessment plot of the studies included in the systematic review.

Fig. 3. Risk of bias summary of the studies included in the systematic review.
### Table 1. Study characteristics and main findings.

<table>
<thead>
<tr>
<th>Study (author)</th>
<th>Country</th>
<th>Subjects</th>
<th>Intervention Duration (*)</th>
<th>Intervention details</th>
<th>Main findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Songkla SB et al. (2003)(4)</td>
<td>USA</td>
<td>Overweight adolescents (n=39; aged 12-18y; BMI=95th percentile)</td>
<td>12 weeks (none)</td>
<td>Low-CHO (LC; ≤20g/d CHO for 2 weeks and ≤40g/d CHO for 10 weeks, ad libitum PRO, FAT)</td>
<td>The LC diet group showed more significant weight loss than the LF diet group. Non-HDL-cholesterol decreased in both diet groups, but more greatly reduced in the LC diet group. TG levels were significantly improved in the LC diet group, but no significant differences were observed between the two groups. Both TC and LDL-cholesterol levels significantly decreased only in LF diet groups, but changed levels of LDL-cholesterol were significantly different between the two groups.</td>
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<tr>
<td>Rolland-Cachera MF et al. (2004)(5)</td>
<td>France</td>
<td>Massively obese children (n=121, 32 boys, 89 girls; aged 11-16y; BMI=97th percentile)</td>
<td>9 months (1&amp;2 years)</td>
<td>PRO-T (54% CHO, 15% PRO, 31% FAT)</td>
<td>Both PRO-T and PRO+ diets groups showed weight loss during the intervention period. However, body weight increased in both groups during the follow-up period. In addition, the changed values of body weight were not significantly different between two diet groups.</td>
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<tr>
<td>Demol S et al. (2009)(6)</td>
<td>Israel</td>
<td>Obese adolescents (n=55, 21 boys, 34 girls; aged 12-18y; BMI=95th percentile)</td>
<td>12 weeks (12 months)</td>
<td>Low-CHO, Low-FAT (LCLF; 1200-1500kcal/d: 60g CHO (up to 20%), 50% PRO, 30% FAT)</td>
<td>All types of diet groups (LCLF, LCHF, and HCLF) had improvement in anthropometric parameters such as BMI, BMI-SDS, and mean body fat (%) after the intervention, but the changed values were not significantly different among the groups. Insulin and HOMA levels decreased in LC groups. Lipid parameters were significantly improved, but changed values were not different among the groups. The LC diet had no apparent advantage over the HCLF diet group.</td>
</tr>
<tr>
<td>Krebs NF et al. (2010)(7)</td>
<td>USA</td>
<td>Severely overweight adolescents (n=46, 21 boys, 25 girls; aged 12-18y; primary obesity or ≥175% of ideal body weight; 50th percentile)</td>
<td>12 weeks (24&amp;36 weeks)</td>
<td>High-PRO, Low-CHO (HPLC; ≤50 g/d CHO, high lean PRO intake: 2.0-2.5g protein/kg ideal body weight per day)</td>
<td>Both HPLC and LF diet groups showed decreased BMI z-scores. However, the HPLC diet group showed a greater improvement than LF diet group. In addition, reduced BMI z-scores were maintained during the follow-up period. Insulin resistance related- and cardiovascular risk related-parameters were improved in both diet groups. The HPLC diet is more effective on insulin resistance related parameters than the LF diet.</td>
</tr>
<tr>
<td>Casaza K et al. (2012)(8)</td>
<td>USA</td>
<td>Overweight/obese African American (n=26, girls; aged 9-14y; BMI≥92th percentile)</td>
<td>16 weeks (none)</td>
<td>Reduced-CHO (SPEC; 42% CHO, 18% PRO, 40% FAT)</td>
<td>Both STAN and SPEC diet groups had decreased body weight and adiposity, but no significant differences were observed between the two groups. The SPEC diet group showed a more decreased TG levels than the STAN diet group. In the solid meal test, glucose insulin homeostasis were improved in the SPEC diet group up to 3h post-ingestion.</td>
</tr>
<tr>
<td>Partalaki I et al. (2012)(9)</td>
<td>Greece</td>
<td>Obese children/adolescents (n=58, 27 boys, 31 girls; aged 8-18y; BMI=95th percentile)</td>
<td>6 months (none)</td>
<td>Ketogenic diet (aimed for &lt;20g/d CHO, if indicate ketosis, gradual increase towards 30-40g/d)</td>
<td>Ketogenic and hypocalyoric diet groups showed reduction of body weight, BMI, fat mass, and waist circumference. Glycemic parameters such as fasting insulin, WBISI, and HOMA-IR were improved in both groups. The ketogenic diet group had increased adiponectin levels, but no changes in lipid profile, fat-free mass, and blood pressure. No significant differences were observed between the two groups, but the values were relatively more improved in the ketogenic diet group.</td>
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<tr>
<td>Kirk S et al. (2012)(10)</td>
<td>USA</td>
<td>Obese children (n=102, 43 boys, 59 girls; aged 7-12y; BMI z-score of 1.60-2.65; with fasting blood glucose≤100 mg/dl)</td>
<td>3 months (6&amp;12 months)</td>
<td>Low-CHO (LC; induction phase with ≤20g/d CHO, after induction; increased by 5-10g/week CHO and up to maximum of 60g/d)</td>
<td>All diet groups had decreased BMI z-scores and body fat (%) after the intervention. This effect was maintained for 12 months. But no significant differences were observed among the groups. LC diet group had improved TG and HDL-cholesterol levels. PC and RGL are relatively more effective in lowering fasting insulin and glucose levels. However, diet adherence was significantly lower in the LC diet group than others.</td>
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<tr>
<td>Mirza NM et al. (2013)(11)</td>
<td>USA</td>
<td>Obese Hispanic children (n=113, 58 boys, 55 girls; aged 7-15y; BMI=95th percentile)</td>
<td>12 weeks (1&amp;2 years)</td>
<td>Low-glycemic load diet (LGD; 45-50% Low-GI CHO; 20-25% PRO, 30-35% FAT)</td>
<td>Both LFD and LF diet groups had reduced BMI z-scores, waist circumference, and systolic blood pressure after the intervention. However, no significant differences were observed between the two groups.</td>
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<tr>
<td>Truby H et al. (2016)(12)</td>
<td>Australia</td>
<td>Obese adolescents (n=87, 24 boys, 63 girls; aged 10-17y; BMI=90th percentile)</td>
<td>12 weeks (none)</td>
<td>Control</td>
<td>Both SLF and SMC diet groups showed weight loss and improved body composition, lipid profile, and HOMA-IR compared with the control diet group. But no significant differences were observed between SLF and SMC diet groups.</td>
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</table>

**Note:**

* follow-up duration after or including the intervention, BMI, body mass index; BMI-SDS, body mass index-standard deviation scores; CHO, carbohydrate; d, day; GI, glycemic index; HDL, high-density lipoprotein; HMW, high molecular weight; HOMA, homeostasis model assessment; IR, insulin resistance; LDL, low-density lipoprotein; PRO, protein; TC, total cholesterol; TG, triglyceride; WBISI, whole-body insulin sensitivity index; y, year.
Fig. 1. PRISMA flow diagram of studies for the systematic review.
Fig. 2. Summary for the risk of bias assessment plot of the studies included in the systematic review.
**Fig. 3.** Risk of bias summary of the studies included in the systematic review