Review

Impact of Dietary and Exercise Interventions on Weight Change and Metabolic Outcomes in Obese Children and Adolescents
A Systematic Review and Meta-analysis of Randomized Trials

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IMPORTANCE Diet and exercise represent the mainstays of obesity treatment. No systematic review has been conducted comparing the effect of dietary and exercise intervention in reducing metabolic risks in overweight children.

OBJECTIVE To compare the effects of diet-only intervention with those of diet plus exercise or exercise only on weight loss and metabolic risk reduction in overweight children.

EVIDENCE REVIEW English-language articles from 1975 to 2010 available from 7 databases were reviewed. One person searched the databases. Two independent reviewers assessed abstracts and articles against the following eligibility criteria: randomized controlled trials conducted in overweight and obese children aged 18 years or younger, comparing dietary intervention with a diet plus exercise program or an exercise-only program. Study quality was critically appraised by 2 reviewers using established criteria. The main outcome measures were body mass index, body fat percentage, lean body mass, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, triglycerides, fasting glucose, and fasting insulin.

FINDINGS Fifteen studies were identified and included. Based on the small number of short-term trials currently available, both diet-only and diet plus exercise interventions resulted in weight loss and metabolic profile improvement. However, the addition of exercise to dietary intervention led to greater improvements in levels of high-density lipoprotein cholesterol (3.86 mg/dL [to convert to millimoles per liter, multiply by 0.0259]; 95% CI, 2.70 to 4.63), fasting glucose (−2.16 mg/dL [to convert to millimoles per liter, multiply by 0.0555]; 95% CI, −3.78 to −0.72), and fasting insulin (−2.75 μIU/mL [to convert to picomoles per liter, multiply by 6.945]; 95% CI, −4.50 to −1.00) over 6 months. The diet-only intervention caused greater reductions in levels of triglycerides (at the end of active intervention) and low-density lipoprotein cholesterol (at subsequent follow-up).

CONCLUSIONS AND RELEVANCE This review provides insights into the impact of dietary and exercise interventions on metabolic risk reduction in the pediatric population. However, further studies are required to confirm the evidence with rigorous design, appropriate sample size, longer duration of follow-up, and better strategies to improve compliance and achieve long-term sustainability.

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Obesity in children and adolescents is a major public health problem, with high or increasing prevalence reported in many countries.[1,2] Diet and exercise represent the mainstays of obesity treatment.[3,4] Several systematic reviews of the treatment of childhood obesity have found positive effects of interventions that include a dietary or exercise component.[5-8] However, these reviews did not assess the effect of diet or exercise separately—dietary interventions were evaluated as adjuncts to exercise interventions, or vice versa. It is therefore unclear whether diet plus exercise or exercise only is more effective than a diet-only intervention for improving weight status in overweight and obese children and adolescents. It is also unclear how best to combine dietary and exercise interventions.

Childhood obesity is linked to a range of immediate and long-term health complications, including an increased risk of cardiovascular disease.[3,9-12] To our knowledge, no systematic review has been conducted on the effects of dietary and exercise intervention in reducing metabolic risks in overweight and obese children. This review aimed to systematically assess the effects of diet-only interventions compared with diet plus exercise interventions on both weight loss and metabolic risk reduction. We also directly compared diet-only programs with exercise-only programs to examine the isolated effects of dietary modification and increased physical activity on weight loss and metabolic risks.

Methods

This review's protocol is based on a peer-reviewed protocol registered with the Joanna Briggs Institute[6] and covers English-language literature published between 1975 and 2010. The search strategy, exclusion criteria, details of study selection, quality assessment, and data extraction have been previously published.[8] In brief, a medical librarian conducted the literature search. Two independent reviewers assessed abstracts and articles against eligibility criteria and critically appraised the methodological quality using established criteria (eAppendix in Supplement).

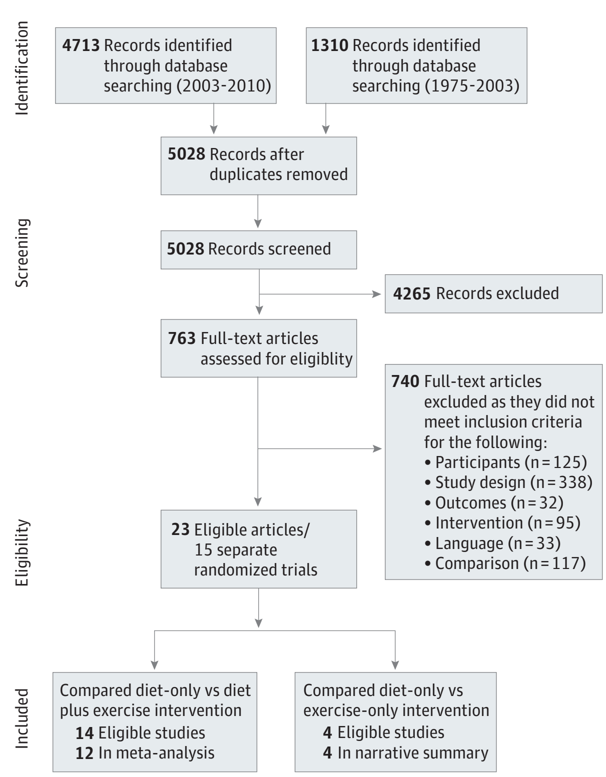
Eligibility Criteria

Eligible studies were randomized trials of treatment for overweight and obesity in children and adolescents aged 18 years or younger comparing the effectiveness of dietary intervention programs with that of diet plus exercise or an exercise-only intervention. To be included in this review, the studies had to report at least 1 anthropometric outcome. Programs that involved the entire family or were directed exclusively at parents of overweight or obese children and adolescents were also included.

Data Synthesis

Review Manager software version 5.1 (Cochrane Collaboration) was used for meta-analyses. Body mass index (BMI; calculated as weight in kilograms divided by height in meters squared) was the primary anthropometric outcome, and secondary outcomes were body fat percentage (%BF) and lean body mass (LBM). Metabolic outcomes were levels of low-density lipoprotein cholesterol (LDL-C), high-density lipoprotein cholesterol (HDL-C), triglycerides, fasting glucose, and fasting insulin.

Figure 1. Flowchart for Identification of Trials for Inclusion in the Systematic Review and Meta-analyses



A weighted mean difference was calculated if the same measurement scale was used. When mean differences and associated standard deviations for anthropometric and metabolic outcomes were not published, they were estimated from the prevalues and postvalues based on methods from the *Cochrane Handbook for Systematic Reviews of Interventions*.[13] A fixed-effect model was used for the meta-analyses as we hypothesized that the diet and exercise interventions were estimating 1 underlying effect. We performed meta-analyses among subgroups by exercise type (aerobic, resistance training, and a combination of both) when there were 2 or more studies in the subgroup. Heterogeneity was assessed by I^2 statistics. Where outcomes could not be meta-analyzed, they are summarized narratively. Egger's regression test and funnel plots were generated using Comprehensive Meta-analysis software version 2.2.064 (Biostat) to examine for publication bias if there were more than 10 studies for a given comparison. A significant statistical test ($P < .05$) or funnel plot asymmetry suggests potential publication bias.

Results

Literature Search

The literature search identified 6023 references (**Figure 1**), and 763 full articles were retrieved. Twenty-three articles (15 different studies) met all inclusion criteria.[14-36] Fourteen studies compared diet-only intervention with diet plus exercise intervention[*] and 4 compared diet-only intervention with exercise-only intervention.[20,23,25,26]

References 18, 19, 21-27, 29, 31, 33, 35, 36

Table 1. Study Characteristics of Included Trials, Structured by Year of Publication

Source (Country/Setting)	Participants: Study Arm (Sample Size, No.)[a]	Participants: Age, y (Sex)	Participants: Selection Criteria[b]	Intervention Duration/Follow-Up From Baseline	Retention[c]
Epstein et al,[28-30] 1984 (US/unclear)[d]	D (18), D + E (18)	8-12 (F + M)	Obese (≥20% overweight and triceps skin fold >85th percentile)	6 mo/1, 5, and 10 y	Overall: 94% at 1 y
Becque et al,[27] 1988 (US/hospital environment)	D (11), D + E (11)	12-13 (F + M)	Overweight and obese (BW and triceps skin fold >75th percentile)	20 wk/20 wk	NR
Hills and Parker,[31] 1988 (Australia/obesity clinic)[d]	D (10), D + E (10)	Prepubertal (F + M)	Obese (>95th percentile weight for age and BMI >25)	16 wk/16 wk	D: 70%, D + E: 60%
Rocchini et al,[32-34] 1988 (US/hospital environment)	D (22), D + E (23)	10-17 (F + M)	Overweight and obese (weight for height >75th percentile and triceps and subscapular skin folds >80th percentile)	20 wk/20 wk	D: 85%, D + E: 92%
Schwingshandl et al,[35] 1999 (Austria/community)	D (16), D + E (14)	6-18 (F + M)	NR	12 wk/6 and 12 mo	D: 71%, D + E: 63%
Sung et al,[36] 2002 (Hong Kong/hospital environment)	D (41), D + E (41)	8-11 (F + M)	Obese (>120% of median weight for height)	6 wk/6 wk	Overall: 100%
Woo et al,[14,16,18] 2004 (Hong Kong /hospital environment)	D (41), D + E (22)	9-12 (F + M)	Overweight and obese (IOTF cutoff)	6 wk/1 y	NR
Ribeiro et al,[19] 2005 (Brazil/hospital environment)	D (18), D + E (21)	8-12 (F + M)	Overweight and obese (IOTF cutoff)	16 wk/16 wk	NR
Kelishadi et al,[20] 2008 (Iran/hospital environment)	D (50), E (50)	7-9 (F + M)	Obese (CDC growth chart BMI >95th percentile)	6 mo/1 y	D: 90%, E: 84%
Leach and Yates,[21] 2008 (US/primary care and community, chiropractic clinic, sport center)	D (8), D + E (14)	4th graders (F)	Obese (CDC growth chart BMI >97th percentile)	8 wk/17-18 wk	D: 79%, D + E: 88%
Davis et al,[22] 2009 (US/unclear)	D (10), D + ST (9), D + CAST (15)	14-18 (F)	Overweight and obese (CDC growth chart BMI >84th percentile)	16 wk/16 wk	Overall: 82%
Elloumi et al,[23] 2009 (Tunisia/school)	D (7), E (7), D + E (7)	Mean 13.1 (M)	Obese (French growth reference BMI >97th percentile)	2 mo/2 mo	NR
Prado et al,[24] 2009 (Brazil/hospital environment)	D (17), D + E (21)	8-12 (F + M)	Obese (CDC growth chart BMI >95th percentile)	16 wk/16 wk	NR
Shalitin et al,[25] 2009 (Israel/hospital environment)	D (55), E (52), D + E (55)	6-11 (F + M)	Obese (BMI >95th percentile)	12 wk/1 y	D: 49%, E: 42%, D + E: 51%
Okely et al,[15,17,26] 2010 (Australia/community)	D (42), E (63), D + E (60)	5-9 (F + M)	Overweight and obese (IOTF cutoff)	6 mo/1 and 2 y	At 1 y, D: 71%, E: 52%, D + E: 72%

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); BW, body weight; CAST, aerobic and strength training; CDC, Centers for Disease Control and Prevention; D, dietary intervention; E, physical activity intervention; IOTF, International Obesity Taskforce; NR, not reported; ST, strength training; US, United States.

[a] Sample size indicates the number of participants at baseline.

[b] Classification of overweight and obesity was standardized using the following definitions: overweight, BMI 85th to 95th percentile for age and sex; obese, BMI 95th percentile or higher for age and sex or weight 120% or higher of average weight for height.

[c] Retention rates reported following intervention if no follow-up, or at latest point of follow-up.

[d] Not included in the meta-analyses.

Description of Included Studies

Table 1 summarizes study characteristics. Five were conducted in the United States,[21,22,27,29,33] 2 in Australia,[26,31] 2 in Brazil,[19,24] and 2 in Hong Kong.[18,36] Eight recruited obese children exclusively[20,21,23-25,29,31,36]; the rest targeted both overweight and obese children. Most (n = 9) were conducted in a hospital environment,[18-20,24,25,27,31,33,36] 3 in the community,[21,26,35] and 1 in a school.[23] Most (n = 10) were in children (defined as aged ≤12 years),[18-21,24-26,29,31,36] 2 were in adolescents,[22,23] and the rest enrolled both children and adolescents.[27,33,35] Sample size ranged from 20 to 165, with a median of 38 participants per study. Intervention duration varied from 6 weeks to 6 months. About half (n = 7) followed up participants after the completion of active intervention[18,20,21,25,26,29,35]; however, only 1 study followed up participants longer than 1 year from baseline.[29]

Methodological Quality

The study quality of included studies was generally suboptimal. Details of randomization,† allocation concealment,‡ and study blinding§

†References 18, 19, 22-24, 27, 29, 31, 33, 35

Table 2. Description of Interventions and Results of Main Weight-Related Outcomes, Structured by Year of Publication

Source	Intervention: D	Intervention: E	Weight-Related Outcome Reported	Significance Weight Loss Difference Between Groups[a]
Epstein et al,[28-30] 1984[b]	Traffic Light Diet (1200-1500 kcal/d, limit to 4 red foods/wk); daily minimum of 2 servings high-protein food plus 2 servings dairy, 2 servings starches, 4 servings fruit and vegetables; 15 treatment sessions, parent and child in separate groups (sessions 1-8 weekly; sessions 9-11 biweekly; sessions 12-15 monthly); parents encouraged to lose weight too	Lifestyle change exercise program; increase energy expenditure 200-400 kcal/d	Change in % overweight	No significant differences at 6 mo and 1, 5, and 10 y (D = D + E)
Becque et al,[27] 1988	American Dietetic Association exchange program with kcal prescription to give weight loss of 1-2 lb/wk; weekly nutrition education materials plus adjustment of eating pattern and kcal intake	Exercise training 3 times/wk: 10 min stretching and muscle strengthening exercise plus 40 min aerobic exercise (total: 150 min/wk)	%BF (hydrostatic weighing)	No (D = D + E)
Hills and Parker,[31] 1988[b]	2 Individual consultation sessions aimed to identify individual dietary behavior goals and highlight food selection	Weekly 50-min supervised session (cardiorespiratory task such as gymnastics, dance, and motor skill activities) plus 20 min aerobic exercise at home, 3-4 times/wk (total: 110 min/wk)	Sum of skin folds (triceps, subscapular, biceps, and suprailiac)	Yes (D + E > D)
Rocchini et al,[32-34] 1988	Modified kcal exchange program (1200-1800 kcal/d) to produce weight loss of approximately 1 lb/wk; weekly 1-h behavior change class	Supervised exercise 3 times/wk: 1 h each, 10 min stretching and muscle strengthening exercise plus 40 min aerobic exercise (total: 180 min/wk)	%BF (hydrostatic weighting)	Yes (D + E > D)
Schwingshandl et al,[35] 1999	Energy restriction (1000-1400 kcal/d, 50% energy from CHO, 20% from protein, 30% from fat); initial session of group teaching, subsequent visits at 4, 8, and 12 wk and 6 and 12 mo on individual basis	Supervised training twice/wk in a public gym (60-70 min each), mainly resistance training (total: 120-140 min/wk)	Change in BMI *z* score and LBM (BIA)	At 12 wk: BMI *z* score: no, LBM: yes (D + E > D); 12-mo results NR
Sung et al,[36] 2002	Hypocaloric diet (900-1200 kcal/d, 50%-60% energy from CHO, 25%-30% from protein, 20%-25% from fat); child and parent met with dietitian biweekly	75-min training session (20 min strength training, 10 min aerobic exercise, 10 min agility training) (total: 75 min/wk)	Change in BMI, %BF, and LBM (DXA)	No (D = D + E)
Woo et al,[14,16,18] 2004	Hypocaloric diet (900-1200 kcal/d, 50%-60% energy from CHO, 25%-30% from protein, 20%-25% from fat); parent and child visited dietitian twice weekly for first 6 wk, then twice/mo	75-min exercise session twice/wk (30 min resistance training, 10 min aerobic training, 10 min agility training) for first 6 wk, then once/wk (total: 150 min/wk for 6 wk, then 75 min/wk)	BMI, %BF (DXA), waist to hip ratio	At 6 wk: no (D = D + E); at 1 y: %BF: yes (D + E > D), BMI: no
Ribeiro et al,[19] 2005	Hypocaloric diet (400 kcal, 50%-70% energy from CHO, 10%-15% from protein, 15%-30% from fat); visited clinical nutritionist on alternate wk	60-min exercise sessions (30 min aerobic exercise plus 30 min recreational exercise) 3 times/wk (total: 180 min/wk)	BMI and BMI *z* score	BMI: no (D = D + E), BMI *z* score: yes (D + E > D)
Kelishadi et al,[20] 2008	Optimized mixed diet (55% energy from CHO, 15% from protein, 30% from fat); 6 monthly family-centered nutrition education sessions	40-min aerobic exercise session 5 d/wk (total: 200 min/wk)	BMI, BMI *z* score, WC, WHR, skin fold thickness	At 6 mo: BMI and skin fold thickness: no (D = E), BMI *z* score: yes (D > E), WC: yes (E > D); at 1 y: BMI *z* score: no, BMI and skin fold thickness: yes (E > D), WC: yes (D > E)
Leach and Yates,[21] 2008	Nutrition handout for families plus 15-min DVD lesson (based on USDA My Pyramid)	Recreational soccer for 8 wk	BMI	No (D = D + E)
Davis et al,[22] 2009	≤10% of energy from added sugar plus ≥14 g/1000 kcal/d of dietary fiber; weekly 90-min dietary session plus 4 motivational interview sessions	ST group: 60 min strength training twice/wk (total: 120 min/wk); CAST group: 30 min cardio and 30 min strength training twice/wk (total: 120 min/wk)	BMI, BMI *z* score, BMI percentile, LBM, and total fat mass (DXA)	No (D = D + E)
Elloumi et al,[23] 2009	Energy restriction −500-kcal deficient based on reported intake (55% energy from CHO, 15% from protein, 30% from fat)	Supervised exercise program of indoor exercise (running, jumping, ball games) 4 d/wk, 90 min/d (total: 360 min/wk)	BMI, BMI *z* score, fat mass (skin fold), WC	BMI, BMI *z* score, fat mass: yes (D > E; D + E > D), WC: yes (D + E > D; D = E)
Prado et al,[24] 2009	Hypocaloric diet (1800 kcal/d, 65% total energy from CHO, 15% from protein, 20% from fat); monthly nutritional and eating behavior group meeting	Supervised exercise training with 60-min sessions (30 min aerobic exercise plus 30 min recreational exercise) 3 times/wk (total: 180 min)	BMI, BMI *z* score, %BF (BIA)	BMI and BMI *z* score: yes (D + E > D), %BF: yes (D > D + E)
Shalitin et al,[25] 2009	Hypocaloric diet (1200 kcal/d, 55%-65% energy from CHO, 10%-15% from protein, 25%-30% from fat); 12 weekly group-based meetings of children and parents (60 min each)	90-min exercise session (45 min aerobic exercise plus 45 min resistance training) 3 times/wk (total: 270 min/wk)	BMI, BMI *z* score, %BF (BIA), WC	No significant difference between diet-only and diet plus exercise groups (D = D + E); at 12 wk and 1 y: BMI *z* score, WC, and %BF: yes (D > E); BMI: yes at 12 wk (D > E) but no at 1 y (D = E)
Okely et al,[15,17,26] 2010	Used food-based guidelines, targeted to reduce total energy, fat, and saturated fat intake; 10 weekly face-to-face nutrition sessions (2 h each) plus telephone follow-up, once per mo for 3 mo (parent only)	Physical activity skill-development program, ten 2-h face-to-face weekly sessions (child only) (total: 120 min/wk)	BMI, BMI *z* score, WC, WC *z* score	At 6 and 12 mo: BMI, BMI *z* score (D = D + E; D > E)

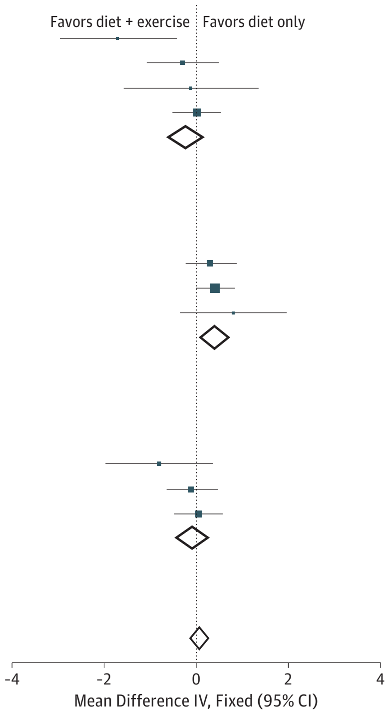
Abbreviations: BIA, bioelectrical impedance analyzer; BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); CAST, aerobic and strength training; CHO, carbohydrate; D, dietary intervention; DXA, dual-energy x-ray absorptiometry; E, physical activity intervention; LBM, lean body mass; NR, not reported; WC, waist circumference; WHR, waist to height ratio; ST, strength training; USDA, US Department of Agriculture; %BF, body fat percentage.

[a] D + E > D indicates that the diet plus exercise intervention group had a greater reduction than the diet-only intervention group ($P < .05$).

[b] Not included in the meta-analyses.

Figure 2. Meta-analysis of Studies Comparing Diet Plus Exercise and Diet-Only Interventions Using Change in Body Mass Index at the End of Active Intervention

Study or Subgroup	Diet + Exercise Mean	Diet + Exercise SD	Diet + Exercise Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight, %	Mean Difference IV, Fixed (95% CI)
Aerobic training								
Elloumi et al,[23] 2009, 2 mo	−4.4	1.16	7	−2.7	1.22	7	2.6	−1.70 (−2.95 to −0.45)
Prado et al,[24] 2009, 4 mo	−3.5	1.27	21	−3.2	1.14	17	6.8	−0.30 (−1.07 to 0.47)
Leach and Yates,[21] 2008, 5 mo	0.27	1.57	11	0.4	1.47	7	2.0	−0.13 (−1.56 to 1.30)
Ribeiro et al,[19] 2005, 4 mo	−3	0.79	21	−3	0.78	18	16.4	0.00 (−0.49 to 0.49)
Subtotal (95% CI)			**60**			**49**	**27.8**	**−0.24 (−0.62 to 0.14)**
Heterogeneity: $\chi^2_3 = 6.22$ ($P = .10$); $I^2 = 52\%$								
Test for overall effect: $Z = 1.24$ ($P = .21$)								
Resistance training								
Sung et al,[36] 2002, 6 wk	−0.2	1.5	41	−0.5	0.9	41	14.0	0.30 (−0.24 to 0.84)
Woo et al,[18] 2004, 6 wk	−0.2	0.8	41	−0.6	1.1	41	23.1	0.40 (−0.02 to 0.82)
Davis et al,[22] 2009, 4 mo, ST	1.1	0.6	9	0.3	1.2	5	3.2	0.80 (−0.32 to 1.92)
Subtotal (95% CI)			**91**			**87**	**40.3**	**0.40 (0.08 to 0.71)**
Heterogeneity: $\chi^2_2 = 0.62$ ($P = .73$); $I^2 = 0\%$								
Test for overall effect: $Z = 2.47$ ($P = .01$)								
Resistance plus aerobic training								
Davis et al,[22] 2009, 4 mo, CAST	−0.5	0.9	15	0.3	1.2	5	3.1	−0.80 (−1.95 to 0.35)
Okely et al,[26] 2010, 6 mo	−0.9	1.55	60	−0.8	1.28	42	13.2	−0.10 (−0.65 to 0.45)
Shalitin et al,[25] 2009, 3 mo	−2.02	1.41	55	−2.06	1.3	55	15.6	0.04 (−0.47 to 0.55)
Subtotal (95% CI)			**130**			**102**	**31.9**	**−0.10 (−0.45 to 0.26)**
Heterogeneity: $\chi^2_2 = 1.73$ ($P = .42$); $I^2 = 0\%$								
Test for overall effect: $Z = 0.54$ ($P = .59$)								
Total (95% CI)			**281**			**238**	**100.0**	**0.06 (−0.14 to 0.26)**
Heterogeneity: $\chi^2_9 = 16.12$ ($P = .06$); $I^2 = 44\%$								
Test for overall effect: $Z = 0.60$ ($P = .55$)								
Test for subgroup differences: $\chi^2_2 = 7.55$ ($P = .02$); $I^2 = 73.5\%$								



CAST indicates aerobic and strength training; IV, inverse variance; and ST, strength training. Body mass index is calculated as weight in kilograms divided by height in meters squared.

were inadequately reported for most studies. Nearly half (n = 7) did not report dropout rate explicitly at all follow-up points.[18,19,23,24,27,29,31] Retention rates for the remaining studies ranged from 42% to 100% at the latest point of follow-up (Table 1) and were similar for diet-only, exercise-only, and diet plus exercise intervention arms. A third (n = 5) used intention-to-treat analysis.[18,25,26,33,36]

Dietary Interventions

Most studies (n = 9) used a calorie restriction approach, with energy levels ranging from 900 to 1800 kcal/d and with varied macronutrient combinations[18,19,23-25,27,33,35,36] (**Table 2**). Others either used the Traffic Light Diet,[29] aimed at limiting added sugar consumption and increasing dietary fiber intake,[22] or provided general dietary advice. A dietitian was reported to be involved in the delivery of dietary interventions in 9 studies.[18-20,23,25-27,33,36] The intensity of nutrition education interventions varied from a one-off 15-minute DVD session[21] to 10 weekly 2-hour nutrition sessions plus monthly telephone follow-up for 3 months[26] (Table 2). Seven studies measured compliance to dietary recommendations,[18,19,23,25,27,29,36] with only 4 reporting these results[18,23,29,36] (eTable 1 in Supplement).

‡References 18, 19, 21-25, 27, 29, 31, 33, 35
§References 18, 19, 21-25, 27, 29, 31, 33, 35, 36

Exercise Interventions

Thirteen studies conducted supervised training sessions, although the intensity and variety varied.[18-20,22-27,31,33,35,36] Eight predominantly involved aerobic exercise[19-21,23,24,27,31,33] and 4 predominantly involved resistance training.[18,22,35,36] Two investigated the effects of aerobic plus resistance training.[22,25] One study targeting younger children (aged 5-9 years) provided a physical activity skills development program.[26] All studies except one[29] provided at least 70 minutes of exercise per week and 1 school-based program provided a total of 6 hours of indoor exercise per week[23] (Table 2). Most did not mention who delivered exercise interventions. Only 4 measured and reported compliance to exercise training[18,24,29,36] (eTable 1 in Supplement).

Comparing Diet-Only vs Diet Plus Exercise Intervention

Effects on Anthropometric Outcomes

Twelve of 14 studies reported a reduction in BMI and/or %BF over 6 months. Meta-analysis of the postintervention effects of 9 studies including 519 participants showed no significant differences in BMI between the diet-only and the diet plus aerobic subgroups ($P = .21$) or a combination of aerobic and resistance training subgroups ($P = .59$) (**Figure 2**). The diet-only group showed a greater BMI reduction than the diet plus resistance training group (pooled difference, −0.40; 95% CI, −0.71 to −0.08; $I^2 = 0\%$) over 4 months.

In 3 studies reporting BMI outcomes at 1-year follow-up, BMI change was not significantly different between intervention groups (P = .67) (eFigure 1A in Supplement).

We examined effects of the intervention on body composition using 5 studies for which data on %BF or LBM were reported. Subgroup analysis showed that participants involved in 20 to 60 minutes of resistance training per week for 6 weeks achieved greater %BF loss than the diet-only group (pooled difference, −0.50%; 95% CI, −0.94 to −0.06; I^2 = 0%) (eFigure 1B in Supplement). An opposite trend was observed in the diet plus aerobic training group, but the heterogeneity was high (I^2 = 75%) and this finding needs to be interpreted with caution. Two studies followed up participants at 1 year from baseline: %BF loss was significantly greater in the diet plus exercise intervention group compared with the diet-only group (pooled difference, −2.73%; 95% CI, −4.38 to −1.09; I^2 = 55%) (eFigure 1C in Supplement).

This result was consistent with the meta-analysis based on changes in LBM, which showed that diet plus resistance training led to greater muscle gain than the diet-only intervention (pooled difference, 0.44 kg; 95% CI, 0.04 to 0.84; I^2 = 46%) over 4 months (eFigure 1D in Supplement).

There was no evidence of publication bias or small study effect with Egger's test (P = .22) or visual inspection of the funnel plot for anthropometric outcomes (eFigure 2 in Supplement). Two studies were not included in meta-analyses because weight loss was reported as change in percentage overweight or sum of skin folds[29,31] (Table 1 and Table 2).

Effects on Lipid Profile

Six studies reported blood lipid results[18,19,25-27,36] (eTable 2 in Supplement). All reported a reduction in BMI and/or %BF in both intervention groups after active intervention. The diet-only arm had a BMI loss of 0.5 to 3.0 and a %BF loss of 0.2% to 4.5%, while the diet plus exercise group had a BMI loss of 0.2 to 3.0 and a %BF loss of 0.7% to 3.5% over 6 months. In parallel, total cholesterol, LDL-C, and triglycerides levels were improved or maintained in both intervention groups. At the end of active intervention, the pooled difference in the triglycerides level was 13.27 mg/dL (to convert to millimoles per liter, multiply by 0.0113) in favor of the diet-only intervention (95% CI, −23.89 to −1.77; I^2 = 0%; 376 participants) compared with diet plus exercise (**Figure 3**A). However, the diet plus exercise intervention showed a greater improvement in the HDL-C level (pooled difference, 3.86 mg/dL [to convert to millimoles per liter, multiply by 0.0259]; 95% CI, 2.70 to 4.63; I^2 = 67%; 437 participants) (Figure 3B). These differences became nonsignificant at 1-year follow-up from baseline (eFigure 3, A and B in Supplement). Changes in the LDL-C level were the same for both intervention groups after active intervention (Figure 3C), and the pooled difference in the LDL-C level was 5.41 mg/dL (to convert to millimoles per liter, multiply by 0.0259) (95% CI, −9.27 to −1.16; I^2 = 0%; 275 participants) in favor of the diet-only intervention at subsequent follow-up (eFigure 3C in Supplement).

Effects on Fasting Glucose and Insulin Levels

Five studies reported fasting glucose and insulin results.[19,22,25,26,32] One was excluded from the fasting insulin meta-analyses as the baseline readings were significantly higher in the diet-only group compared with the diet plus exercise group.[19] Meta-analyses showed a greater improvement in the fasting glucose level (pooled difference, −2.16 mg/dL [to convert to millimoles per liter, multiply by 0.0555]; 95% CI, −3.78 to −0.72; I^2 = 30%; 318 participants) and the fasting insulin level (pooled difference, −2.75 μIU/mL [to convert to picomoles per liter, multiply by 6.945]; 95% CI, −4.50 to −1.00; I^2 = 0%; 279 participants) in the diet plus exercise group compared with the diet-only intervention after active intervention (**Figure 4**). However, the differences became nonsignificant at subsequent follow-up (eFigure 4 in Supplement).

Comparing Diet-Only vs Exercise-Only Intervention

Effects on Anthropometric Outcomes

At the end of active intervention, all studies (n = 4) showed a reduction in BMI, BMI z score, waist circumference, or waist circumference z score in both treatment arms.[20,23,25,26] Over 6 months, diet-only interventions had mean BMI reductions ranging from 0.8 to 2.7 and mean waist circumference reductions ranging from 1.1 to 3.8 cm. In the exercise-only group, mean BMI reductions ranged from 0.3 to 1.0 and mean waist circumference reductions ranged from 0.7 to 3.9 cm. Three studies followed up participants 6 to 9 months after active intervention.[20,25,26] Only 1 study, conducted in younger children, showed that the BMI change was sustained at subsequent follow-up in the diet-only group in which nutrition education was provided to parents only.[26] Meta-analysis was not conducted as the heterogeneity was high.

Effects on Metabolic Outcomes

Three studies reported results on blood lipids, fasting glucose, and fasting insulin[20,25,26] (eTable 2 in Supplement). Shalitin et al[25] compared the effect of a hypocaloric diet of 1200 kcal/d (55%-65% carbohydrate, 10%-15% protein, and 25%-30% fat) vs 90 minutes of moderate exercise (aerobic plus resistance training) 3 days/week in obese children aged between 6 and 11 years (Table 2). At 12 weeks, BMI, %BF, and blood lipids improved in both groups, and the diet-only group showed greater reductions in BMI (−1.1; 95% CI, −1.5 to −0.6) and LDL-C level (−7.72 mg/dL; 95% CI, −15.44 to −0.77) compared with the exercise-only group. Both groups regained weight after 9 months. The decreases in LDL-C and triglycerides levels in the diet-only group were preserved, while other metabolic outcomes regressed so that there were no group differences at 1-year follow-up (eTable 2 in Supplement).

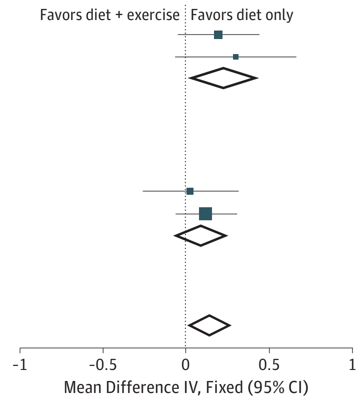
Kelishadi et al[20] compared a balanced diet (55% carbohydrate, 15% protein, and 30% fat) vs 40 minutes of aerobic exercise training 5 days/week. Participants of both groups had significant weight loss as well as reductions in total cholesterol and triglycerides levels after 6 months; however, they regained weight from the end of intervention to follow-up at 12 months from baseline, and blood lipids returned to baseline levels (eTable 2 in Supplement). Both studies reported no significant change in fasting glucose or insulin levels after active intervention or at subsequent follow-up.[20,25]

Okely et al[26] compared a parent-centered dietary program with a child-centered physical activity program and found no group difference in the changes in metabolic profiles after a 6-month trial or at 1-year follow-up from baseline. Meta-analysis was not conducted as the heterogeneity was high.

Figure 3. Meta-analysis of Studies Comparing Diet Plus Exercise and Diet-Only Interventions, With Changes in Triglycerides (A), HDL-C (B), and LDL-C (C) at the End of Active Intervention as Outcomes

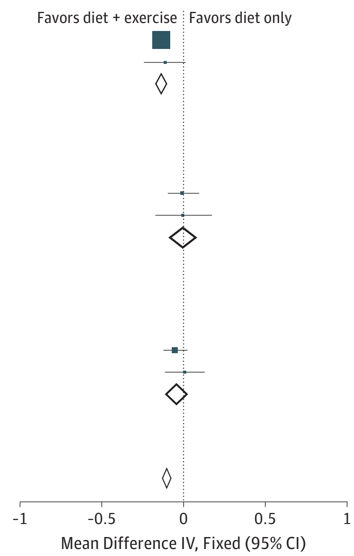
A

	Diet + Exercise			Diet Only				
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight, %	Mean Difference IV, Fixed (95% CI)
Resistance training								
Sung et al,[36] 2002, 6 wk	0.3	0.6	41	0.1	0.5	41	25.7	0.20 (−0.04 to 0.44)
Woo et al,[18] 2004, 6 wk	0.3	0.86	41	0	0.78	41	11.6	0.30 (−0.06 to 0.66)
Subtotal (95% CI)			**82**			**82**	**37.3**	**0.23 (0.03 to 0.43)**
Heterogeneity: $\chi_1 = 0.21$ ($P = .65$); $I^2 = 0\%$								
Test for overall effect: $Z = 2.28$ ($P = .02$)								
Aerobic plus resistance training								
Okely et al,[26] 2010, 6 mo	0	0.74	60	−0.03	0.71	42	18.1	0.03 (−0.25 to 0.31)
Shalitin et al,[25] 2009, 3 mo	−0.16	0.47	55	−0.28	0.5	55	44.6	0.12 (−0.06 to 0.30)
Subtotal (95% CI)			**115**			**97**	**62.7**	**0.09 (−0.06 to 0.25)**
Heterogeneity: $\chi_1 = 0.27$ ($P = .60$); $I^2 = 0\%$								
Test for overall effect: $Z = 1.20$ ($P = .23$)								
Total (95% CI)			**197**			**179**	**100.0**	**0.15 (0.02 to 0.27)**
Heterogeneity: $\chi^2_3 = 1.63$ ($P = .65$); $I^2 = 0\%$								
Test for overall effect: $Z = 2.35$ ($P = .02$)								
Test for subgroup differences: $\chi_1 = 1.15$ ($P = .28$); $I^2 = 13.1\%$								



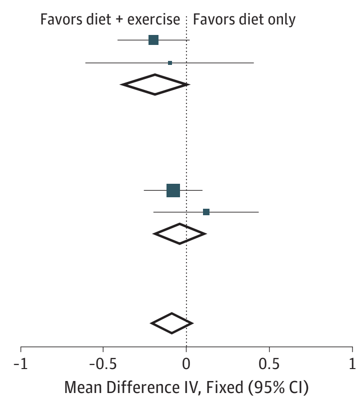
B

	Diet + Exercise			Diet Only				
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight, %	Mean Difference IV, Fixed (95% CI)
Aerobic training								
Ribeiro et al,[19] 2005, 4 mo	0	0.04	18	0.13	0.06	21	65.9	−0.13 (−0.16 to −0.10)
Becque et al,[27] 1988, 5 mo	0.1	0.16	11	0.21	0.13	11	4.4	−0.11 (−0.23 to 0.01)
Subtotal (95% CI)			**29**			**32**	**70.4**	**−0.13 (−0.16 to −0.10)**
Heterogeneity: $\chi^2_1 = 0.10$ ($P = .76$); $I^2 = 0\%$								
Test for overall effect: $Z = 8.24$ ($P < .001$)								
Resistance training								
Sung et al,[36] 2002, 6 wk	−0.1	0.2	41	−0.1	0.2	41	8.8	0.00 (−0.09 to 0.09)
Woo et al,[18] 2004, 6 wk	−0.1	0.36	41	−0.1	0.42	41	2.3	0.00 (−0.17 to 0.17)
Subtotal (95% CI)			**82**			**82**	**11.1**	**0.00 (−0.08 to 0.08)**
Heterogeneity: $\chi^2_1 = 0.00$ ($P > .99$); $I^2 = 0\%$								
Test for overall effect: $Z = 0.00$ ($P > .99$)								
Aerobic plus resistance training								
Shalitin et al,[25] 2009, 3 mo	−0.07	0.18	55	−0.02	0.19	55	13.8	−0.05 (−0.12 to 0.02)
Okely et al,[26] 2010, 6 mo	0.04	0.29	42	0.03	0.31	60	4.8	0.01 (−0.11 to 0.13)
Subtotal (95% CI)			**97**			**115**	**18.5**	**−0.03 (−0.09 to 0.03)**
Heterogeneity: $\chi^2_1 = 0.74$ ($P = .39$); $I^2 = 0\%$								
Test for overall effect: $Z = 1.14$ ($P = .26$)								
Total (95% CI)			**208**			**229**	**100.0**	**−0.10 (−0.12 to −0.07)**
Heterogeneity: $\chi^2_5 = 15.26$ ($P = .009$); $I^2 = 67\%$								
Test for overall effect: $Z = 7.40$ ($P < .001$)								
Test for subgroup differences: $\chi^2_2 = 14.42$ ($P = .001$); $I^2 = 86.1\%$								



C

	Diet + Exercise			Diet Only				
Study or Subgroup	Mean	SD	Total	Mean	SD	Total	Weight, %	Mean Difference IV, Fixed (95% CI)
Resistance training								
Sung et al,[36] 2002, 6 wk	−0.4	0.5	41	−0.2	0.5	41	30.5	−0.20 (−0.42 to 0.02)
Woo et al,[18] 2004, 6 wk	−0.3	1.2	41	−0.2	1.14	41	5.6	−0.10 (−0.61 to 0.41)
Subtotal (95% CI)			**82**			**82**	**36.1**	**−0.18 (−0.38 to 0.01)**
Heterogeneity: $\chi_1 = 0.13$ ($P = .72$); $I^2 = 0\%$								
Test for overall effect: $Z = 1.82$ ($P = .07$)								
Aerobic plus resistance training								
Shalitin et al,[25] 2009, 3 mo	−0.19	0.42	55	−0.11	0.49	55	49.1	−0.08 (−0.25 to 0.09)
Okely et al,[26] 2010, 6 mo	0.03	0.81	60	−0.09	0.77	42	14.8	0.12 (−0.19 to 0.43)
Subtotal (95% CI)			**115**			**97**	**63.9**	**−0.03 (−0.18 to 0.12)**
Heterogeneity: $\chi^2_1 = 1.23$ ($P = .27$); $I^2 = 18\%$								
Test for overall effect: $Z = 0.44$ ($P = .66$)								
Total (95% CI)			**197**			**179**	**100.0**	**−0.09 (−0.21 to 0.03)**
Heterogeneity: $\chi_3 = 2.77$ ($P = .43$); $I^2 = 0\%$								
Test for overall effect: $Z = 1.44$ ($P = .15$)								
Test for subgroup differences: $\chi^2_1 = 1.41$ ($P = .23$); $I^2 = 29.3\%$								

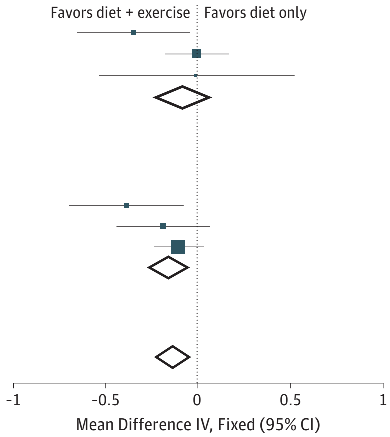


IV indicates inverse variance. To convert triglycerides from millimoles per liter to milligrams per deciliter, divide by 0.0113. To convert high-density lipoprotein cholesterol (HDL-C) and low-density lipoprotein cholesterol (LDL-C) from millimoles per liter to milligrams per deciliter, divide by 0.0259.

Figure 4. Meta-analysis of Studies Comparing Diet Plus Exercise and Diet-Only Interventions, With Changes in Fasting Glucose (A) and Fasting Insulin (B) at the End of Active Intervention as Outcomes

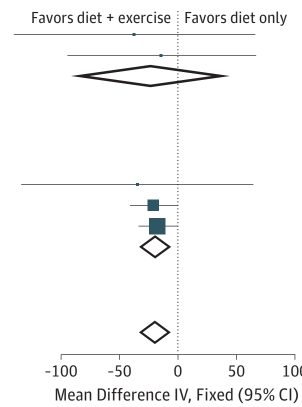
A

Study or Subgroup	Diet + Exercise Mean	Diet + Exercise SD	Diet + Exercise Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight, %	Mean Difference IV, Fixed (95% CI)
Aerobic or resistance training								
Davis et al,[22] 2009, 4 mo, ST	−0.2	0.24	9	0.14	0.29	5	8.4	−0.34 (−0.64 to −0.04)
Ribeiro et al,[19] 2005, 4 mo	−0.28	0.21	21	−0.28	0.32	18	25.1	0.00 (−0.17 to 0.17)
Rocchini et al,[32] 1987, 4 mo	−0.11	0.83	18	−0.11	0.71	15	2.7	0.00 (−0.53 to 0.53)
Subtotal (95% CI)			**48**			**38**	**36.2**	**−0.08 (−0.22 to 0.06)**
Heterogeneity: $\chi^2_2 = 3.82$ ($P = .15$); $I^2 = 48\%$								
Test for overall effect: $Z = 1.08$ ($P = .28$)								
Aerobic plus resistance training								
Davis et al,[22] 2009, 4 mo, CAST	−0.24	0.34	15	0.14	0.29	5	8.0	−0.38 (−0.69 to −0.07)
Okely et al,[26] 2010, 6 mo	−0.11	0.66	60	0.07	0.61	42	12.1	−0.18 (−0.43 to 0.07)
Shalitin et al,[25] 2009, 3 mo	−0.08	0.33	55	0.02	0.37	55	43.7	−0.10 (−0.23 to 0.03)
Subtotal (95% CI)			**130**			**102**	**63.8**	**−0.15 (−0.26 to −0.04)**
Heterogeneity: $\chi^2_2 = 2.77$ ($P = .25$); $I^2 = 28\%$								
Test for overall effect: $Z = 2.71$ ($P = .007$)								
Total (95% CI)			**178**			**140**	**100.0**	**−0.12 (−0.21 to −0.04)**
Heterogeneity: $\chi^2_5 = 7.19$ ($P = .21$); $I^2 = 30\%$								
Test for overall effect: $Z = 2.81$ ($P = .005$)								
Test for subgroup differences: $\chi^2_1 = 0.60$ ($P = .44$); $I^2 = 0\%$								



B

Study or Subgroup	Diet + Exercise Mean	Diet + Exercise SD	Diet + Exercise Total	Diet Only Mean	Diet Only SD	Diet Only Total	Weight, %	Mean Difference IV, Fixed (95% CI)
Aerobic or resistance training								
Davis et al,[22] 2009, 4 mo, ST	−5.56	64.59	9	31.25	106.95	5	1.4	−36.81 (−139.61 to 65.99)
Rocchini et al,[32] 1987, 4 mo	−48.6	134.8	18	−34.7	100.2	15	2.3	−13.90 (−94.21 to 66.41)
Subtotal (95% CI)			**27**			**20**	**3.7**	**−22.58 (−85.87 to 40.70)**
Heterogeneity: $\chi^2_1 = 0.12$ ($P = .73$); $I^2 = 0\%$								
Test for overall effect: $Z = 0.70$ ($P = .48$)								
Aerobic plus resistance training								
Davis et al,[22] 2009, 4 mo, CAST	−3.47	53.48	15	31.25	106.95	5	1.5	−34.72 (−132.29 to 62.85)
Okely et al,[26] 2010, 6 mo	−20.14	53.75	60	0.69	49.03	42	36.4	−20.83 (−40.95 to −0.71)
Shalitin et al,[25] 2009, 3 mo	−12.94	47.02	55	4.44	37.43	55	58.4	−17.38 (−33.26 to −1.50)
Subtotal (95% CI)			**130**			**102**	**96.3**	**−18.96 (−31.33 to −6.60)**
Heterogeneity: $\chi^2_2 = 0.17$ ($P = .92$); $I^2 = 0\%$								
Test for overall effect: $Z = 3.01$ ($P = .003$)								
Total (95% CI)			**157**			**122**	**100.0**	**−19.09 (−31.23 to −6.96)**
Heterogeneity: $\chi_4 = 0.30$ ($P = .99$); $I^2 = 0\%$								
Test for overall effect: $Z = 3.08$ ($P = .002$)								
Test for subgroup differences: $\chi^2_1 = 0.01$ ($P = .91$); $I^2 = 0\%$								



CAST indicates aerobic and strength training; IV, inverse variance; and ST, strength training. To convert glucose from millimoles per liter to milligrams per deciliter, divide by 0.0555. To convert fasting insulin from picomoles per liter to micro-international units per milliliter, divide by 6.945.

Discussion

To our knowledge, this is the first systematic review examining the effects of diet-only and diet plus exercise interventions on change in weight and metabolic risks in overweight and obese children and adolescents. Based on the small number of short-term randomized trials available, we found that diet plus resistance training led to a greater gain in LBM and reduction in %BF compared with diet alone. Some evidence of achieving greater improvement in HDL-C, fasting glucose, and fasting insulin levels by adding exercise training to dietary interventions was found, although diet-only intervention had a greater reduction in triglycerides levels immediately following intervention and a greater reduction in LDL-C levels 1 year from baseline.

Findings on BMI change are consistent with a review[37] of the effects of resistance training on metabolic outcomes in children that found resistance training did not favorably affect BMI relative to no-treatment or diet-only controls. Our meta-analyses suggest that the observed increase in BMI in the diet plus exercise group, especially when resistance training was added, may be due to gain in LBM, which is beneficial for long-term weight loss. This reiterates that BMI is a less sensitive indicator of body composition and weight change in children and adolescents. Future dietary and exercise interventions should consider including other outcome measures of adiposity, such as %BF and LBM.

Subgroup analyses demonstrated that diet plus aerobic training resulted in significantly greater improvement in HDL-C levels compared with diet plus resistance training. This was consistent with others[38] who showed that aerobic exercise resulted in a greater change in HDL-C levels in school-aged youths (including healthy and overweight participants) compared with resistance training. However, our meta-analyses showed that diet plus aerobic and resistance training in combination was superior to diet plus either modality alone in decreasing fasting glucose and insulin concentrations. This suggests that future lifestyle interventions should incorporate both aerobic and resistance training to achieve a better metabolic outcome.

The diet-only arm showed a greater reduction in levels of triglycerides (at the end of active intervention) and LDL-C (at 1-year follow-up) compared with diet plus exercise. Most studies did not provide information on adherence to dietary or exercise prescriptions or the actual dietary intake and physical activity levels, making it impossible to assess the impact of dietary compliance overall. Because levels of triglycerides and LDL-C are highly correlated with dietary intake,[39] one possible explanation is that the diet plus exercise group received exercise training and regarded dietary intervention as a subsidiary part of the treatment, thus having lower adherence to the dietary prescriptions and reducing the intervention effect compared with the diet-only group. We recommend that future studies monitor and report intervention adherence as well as explore strategies to improve dietary and physical activity compliance.

The review showed that partial weight regain, and the subsequent regression in metabolic profiles to baseline levels, is common in the diet-only, exercise-only, and diet plus exercise intervention arms at subsequent follow-up times. Future diet and exercise studies should explore strategies to enhance effective weight maintenance following an initial intervention.

Concerns have been expressed that dietary restrictions used in obesity treatment may adversely decrease resting metabolic rate and muscle mass.[40] This review found that an energy-restricted diet (900-1400 kcal/d) along with a moderate protein content (20%-30%) did not result in a loss of LBM in 6- to 18-years-olds over 4 months. Loss of LBM was reported in the diet plus exercise arm of a small study (n = 38) in which participants were prescribed an 1800-kcal diet with 65% total energy from carbohydrate and 15% from protein and were offered supervised exercise training 3 times per week (60 minutes/session).[24] Participants lost 1.3 kg in LBM (95% CI, −2.01 to −0.59) over 4 months. However, adequately powered research is needed to confirm this and to explore the effect of varying the macronutrient distribution within dietary interventions in pediatric populations.

There were insufficient studies to allow direct comparison of the effects of diet-only vs exercise-only interventions. Diet-only interventions appeared to result in a greater BMI reduction in the short term compared with exercise-only arms. Without information on change in LBM, it is not possible to comment on whether this is because the exercise-only group was gaining LBM, the diet-only group was losing LBM, or both. It remains unclear whether diet-only or exercise-only interventions are more effective for reducing weight and metabolic risk in the pediatric population. Also, more trials are required to explore the effects of diet plus aerobic training and diet plus resistance training in this population.

Several limitations should be acknowledged. First, this review was confined to published literature, and publication bias cannot be excluded. Second, a high degree of clinical and statistical heterogeneity among the included studies means that the results should be interpreted with caution. Potential sources of heterogeneity include variations in the participant populations, the intensity and duration of interventions, and differences in the diet and exercise regimens. The review was also limited by suboptimal methodological quality of included studies and lack of information on intervention adherence. To facilitate future systematic reviews, authors should report intervention adherence and actual dietary intake and physical activity levels. Further limitations were the short duration of follow-up and the small sample size of many studies. Finally, without individual participant data, we were not able to determine to what extent the change in metabolic risk was associated with weight loss or whether participants with abnormal metabolic profiles obtained greater benefit from the intervention compared with those with normal profiles. Despite these limitations, this review included meta-analyses that improve the statistical power, provide more precise estimates, and resolve issues relating to the conflicting results among the small studies.

Conclusions

This review provides support for the importance of dietary interventions as an essential component for managing childhood obesity and provides insights into the impact of different exercise modalities on weight loss and metabolic risk reduction. Dietary interventions in conjunction with exercise interventions are effective in reducing metabolic risks, particularly HDL-C and fasting insulin levels, in overweight and obese children in the short term. Future studies should aim to strengthen the evidence with rigorous design, appropriate sample size, and longer follow-up periods and should explore better strategies to improve compliance and achieve long-term sustainability.

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Drafting of the manuscript: Ho, Garnett, Burrows, and Stewart.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: Ho and Burrows.
Administrative, technical, and material support: Ho, Burrows, Neve, and Collins.
Study supervision: Garnett, Baur, and Collins.

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