Original Article

The effect and safety of high-intensity interval training in the treatment of adolescent obesity: a meta-analysis

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Background: It's necessary to conduct meta-analysis to quantitatively evaluate the effect and safety of high-intensity interval training (HIIT) on obese adolescents, to provide a basis for the management of obesity in adolescents.

Methods: Randomized controlled trials (RCTs) on the role of HIIT in the obese adolescents were searched from PubMed databases and so on up to Jan 15, 2021. Two researchers independently performed literature screening, literature quality evaluation and data extraction according to the inclusion and exclusion criteria. Revman 5.3 Software and Stata 12.2 Software were used for data analysis.

Results: A total of 11 RCTs with 488 obese adolescents were included. Meta-analysis indicated that HIIT can effectively reduce the body weight (MD =−1.73 kg, 95% CI: −3.25 to −0.21, P=0.02), BMI (MD =−1.42 kg/m^2, 95% CI: −1.97 to −0.87, P<0.001), body fat percentage (MD =−1.70%, 95% CI: −2.94 to −0.45, P=0.007) and waist circumference (MD =−1.80 cm, 95% CI: −3.5 to −0.10, P=0.04). The "high-intensity short-interval" HIIT program can significantly reduce waist circumference (MD =−2.31 cm, 95% CI: −4.20 to −0.42, P=0.022), the "high-intensity long-interval" HIIT program is more beneficial to reduce the BMI (MD =−1.44 kg/m^2, 95% CI: −2.03 to −0.84, P=0.001) and body fat percentage (MD =−0.56, 95% CI: −1.08 to −0.05, P=0.009).

Conclusions: HIIT can effectively improve the body composition of obese adolescents and produce an effective fat-reducing effect, which should be promoted for the clinical treatment of adolescent obesity.

Keywords: High-intensity interval training (HIIT); obesity; adolescent; treatment; care

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Introduction

Obesity is a chronic metabolic disease caused by many factors, which has been listed by the World Health Organization as the fifth most important disease affecting human health (1). With the development of the world economy and changes in dietary structure, high-calorie foods are becoming more and more popular among young people, leading to a significant increase in the obesity rate of young people worldwide (2,3). Obesity is an important cause of chronic non-communicable diseases; adolescent obesity is not only accompanied by a decline in cardiorespiratory endurance, but also closely related to the occurrence of cardiovascular and metabolic diseases in adulthood (4-6). Therefore, adolescent obesity is a serious public health challenge facing the world in the 21st century.

The fat-reducing effect of exercise can be reflected by indicators such as weight, body mass index (BMI), waist circumference, and body fat percentage (7). The fat-reducing effect of exercise in weight control is recognized by more and more people. High-intensity interval training (HIIT), as a more time-saving and efficient form of exercise, has been widely used in the field of public fitness and chronic disease prevention (8,9). Although HIIT has been used in the weight control of obesity, the HIIT scheme used in the current research is not uniform, and the effects and safety of HIIT schemes in the body weight reduction of adolescents remains unclear (10). Therefore, we aimed to perform a meta-analysis to quantitatively evaluate the effects and safety of HIIT in the treatment of adolescent obesity, to provide a theoretical basis for the treatment of adolescent obesity. We present the following article in accordance with the PRISMA reporting checklist (available at https://dx.doi.org/10.21037/apm-21-757) (11).

Methods

Literature retrieval strategy

We searched PubMed, Web of Science, Embase, the Cochrane Library, EBSCO, CNKI, Wanfang database for randomized controlled trials (RCTs) on the effects and safety of HIIT in the treatment of adolescent obesity. The search time was from the establishment of the database to Jan 15, 2021. The literature search strategies were as following: ("High-intensity training"[Title/Abstract] OR "Highintensity interval training"[Title/Abstract] OR "highintensity interval training"[MeSH Terms] OR "high intensity intermittent training"[Title/Abstract] OR "Repeated sprint training"[Title/Abstract] OR "interval training"[Title/Abstract] OR "intermittent training"[Title/Abstract] OR "high intensity sprint"[Title/Abstract] OR "aerobic interval training"[Title/Abstract] OR "Highintensity interval training"[Title/Abstract] OR "highintensity interval exercise"[Title/Abstract] OR "highintensity interval exercise"[Title/Abstract] OR "highintensity intermittent exercise"[Title/Abstract] OR "highintensity intermittent exercise"[Title/Abstract] OR "high intensity intermittent training"[Title/Abstract] OR "high intensity intermittent training"[Title/Abstract] OR

"HIIE"[Title/Abstract] OR "HIIT"[Title/Abstract]) AND("adolescent"[MeSH Terms] OR "minors"[MeSH Terms] OR "adolescent"[Title/Abstract] OR "minors"[Title/Abstract] OR "Youth"[Title/Abstract] OR "juvenile"[Title/Abstract] OR "teen"[Title/Abstract] OR "teenager"[Title/Abstract] OR "Childhood"[Title/Abstract] OR "adolescence"[Title/Abstract] OR "schoolchild"[Title/Abstract] OR "Schoolchildren"[Title/Abstract] OR "young"[Title/Abstract]). The original results obtained from the search were imported into the Endnote software for literature screening. In addition, we searched and screened relevant references for potential studies.

Inclusion and exclusion criteria

The inclusion and exclusion criteria for this meta-analysis were: (I) language: Chinese and English full-text reports; (II) RCT study design, research types such as observational studies, cross-sectional studies, and prospective cohort studies were excluded; (III) populations: obese adolescents (6–18 years old) were included. The criteria for determining obesity should be based on the recognized standards of the World Health Organization or the country where the subjects are located; animal-based, normal-weight adolescents and age-incompatible subjects were excluded; (IV) intervention: HIIT intervention measures were used, the exercise intensity ≥80% of the maximum heart rate (HR_{max})/peak oxygen consumption (VO_{peak}) or ≥100% of the maximum aerobic speed (MAS), exercise duration <5 min, resting rest or low-intensity aerobic exercise in the intermittent period, exercise frequency and duration should also be reported; (V) related outcome indicators should be reported, including body weight, BMI, waist circumference, body fat percentage.

Literature selection and quality evaluation

Two researchers independently carried out literature screening and data extraction, and when the results were inconsistent, they would be discussed and resolved for consents. We adopted Cochrane's risk of bias assessment tool for the quality evaluation of included RCTs, and conducted the bias risk assessment on the random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other biases. Each item was rated as "high risk, low risk, and unclear" based on related criteria.

Data collection

Two authors used a standardized data collection form to extract key information from included RCTs. Any discrepancies in the extraction process were resolved by consensus. We also attempted to contact authors to obtain additional data or to clarify data of missing details.

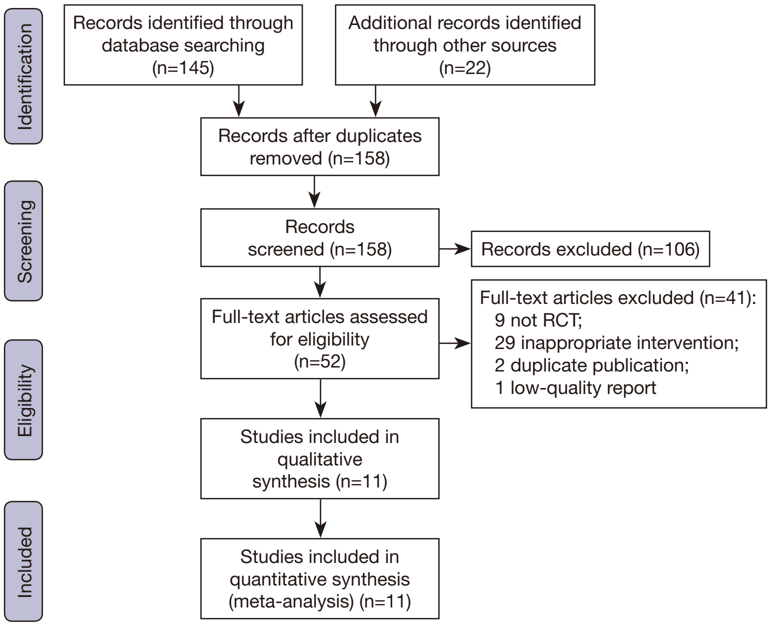

Figure 1 The PRISMA flow chart of study selection.

Two reviewers independently extracted the following information: first author, year of publication, study location, patient population, details of treatment, main outcomes, and study results.

Statistical analysis

We used Revman 5.3 and Stata 12.2 software to conduct meta-analysis in this study. The combined effect size of continuous variables was expressed as mean difference (MD). Q test and I^2 test were used for heterogeneity test, and Egger test was used for publication bias analysis. If P>0.01, I^2<50%, it was considered that there was no heterogeneity, then the fixed effect model was adopted; if P<0.10, I^2>50%, it was considered that there was heterogeneity, then the random effect model was adopted, and we further used sensitivity analysis and meta regression analysis to detect the heterogeneity. Besides, subgroup analysis was used to compare the effects of different HIIT exercise programs.

Results

Literature selection

Through database search, a total of 158 related documents were obtained; according to the inclusion and exclusion criteria, through the selection process of reading titles and abstracts, and reading the full text (see *Figure 1* for details), 11 RCTs (12-22) were finally included.

Characteristics of included literatures

In the included 11 RCTs (12-22), a total of 488 obese adolescents aged 7–16 years were included. The basic characteristics of the included RCTs were detailed in *Table 1*.

The risk of bias assessment

As presented in *Figures 2,3*, three RCTs (12,19,20) did not report the methods for sequence generation, then they were rated as "unclear risk of bias. No RCT reported the allocation concealment. Since it was difficult to blinding participants and personnel, it was all rated as "high risk of bias". Only one RCT (17) reported the blinding of outcome assessment. No significant biases were found in the items of incomplete outcome data, selective reporting, and other biases.

Meta-analyses

Ten RCTs (12-20,22) reported changes in body weight, 8 RCTs (12,13,15-18,21,22) reported changes in BMI,

Table 1 The characteristics of included RCTs

Study	Country	Sample size	Age, years	Types of sport	HIIT intervention	Frequency	Duration	Control
Cvetkovic 2018	Serbia	28	11–13	Run	Exercise: 10–20s (100% MAS); Intermittent: 10–20 s (rest at rest); 15–30 times	3 times/week	12 weeks	Blank control
Dias 2017	Norway	67	7–16	Run	Exercise: 4 min (85–95% HR_{max}); Intermittent: 3 min (50–70% HR_{max}); 4 times	3 times/week	12 weeks	Dietary intervention
Racil 2013	Tunisia	23	15.9	Run	Exercise: 30 s (100–110% MAS); Intermittent: 30 s (50% MAS); 12–16 times	3 times/week	12 weeks	Dietary intervention
Racil 2016	Tunisia	31	14.2	Run	Exercise: 15 s (100% MAS); Intermittent: 15 s (50% MAS); 24–48 times	3 times/week	12 weeks	Dietary intervention
Pizzi 2017	Brazil	54	10–15	Run	Exercise: 30 s (100% MAS); Intermittent: 30–60 s (50% MAS); 8–16 times	3 times/week	12 weeks	Blank control
Lau 2014	Korea	27	10.4 ±0.9	Run	Exercise: 15 s (120% MAS); Interval: 15 s; 12 times	3 times/week	6 weeks	Blank control
Chuensiri 2018	Thailand	32	8–12	Bicycle	Exercise: 2 min (90% W_{peak}); Intermittent: 1 min; 8 times	3 times/week	12 weeks	Blank control
Tjonna 2009	Norway	54	14±0.3	Run	Exercise: 4 min (90%HR_{max}); Intermittent: 3 min (70% HR_{max}); 4 times	2 times/week	12 weeks	Blank control
Racil 2016	Tunisia	42	16	Run	Exercise: 30 s (100% VO_{2peak}); Intermittent: 30 s (50% VO_{2peak}); 12–16 times	3 times/week	12 weeks	Blank control
Wang 2018	China	90	9–16	Run	Exercise: 4 min (85% HR_{max}); Intermittent: 3 min (40–60% HR_{max}); 4 groups	3 times/week	12 weeks	Walking
Cao 2012	China	40	13–15	Run	Exercise: 4 min (90–95% HR_{max}); Intermittent: 3 min (70% HR_{max}); 4 times	2 times/week	8 weeks	Blank control

RCT, randomized controlled trial; MAS, maximum aerobic speed.

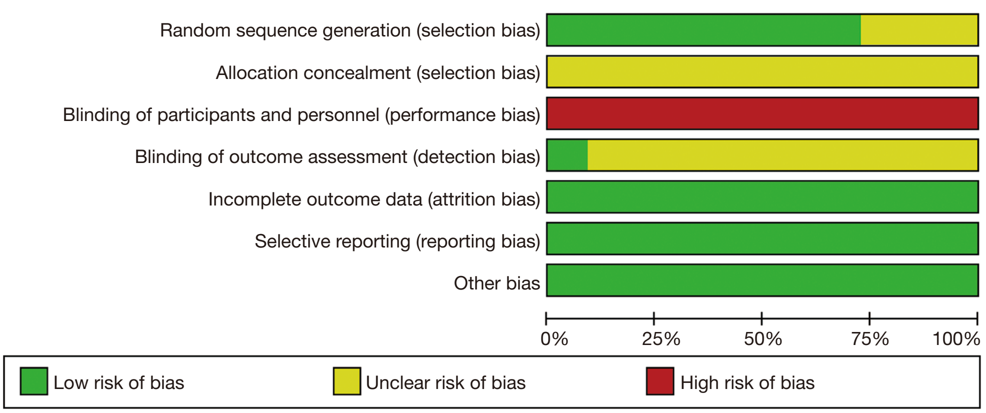

Figure 2 Risk of bias graph.

6 RCTs (14,16,18-20,22) reported changes in waist circumference, and 8 RCTs (12-14,16,17,19,20,22) reported changes in body fat percentage. As presented in *Figure 4*, There was no heterogeneity among HIIT studies on the effects of body weight, BMI, and waist circumference and fixed effects model was applied. The results showed that HIIT significantly reduced body weight (MD =−1.73 kg, 95% CI: −3.25 to −0.21, P=0.02) (*Figure 4A*), BMI (MD

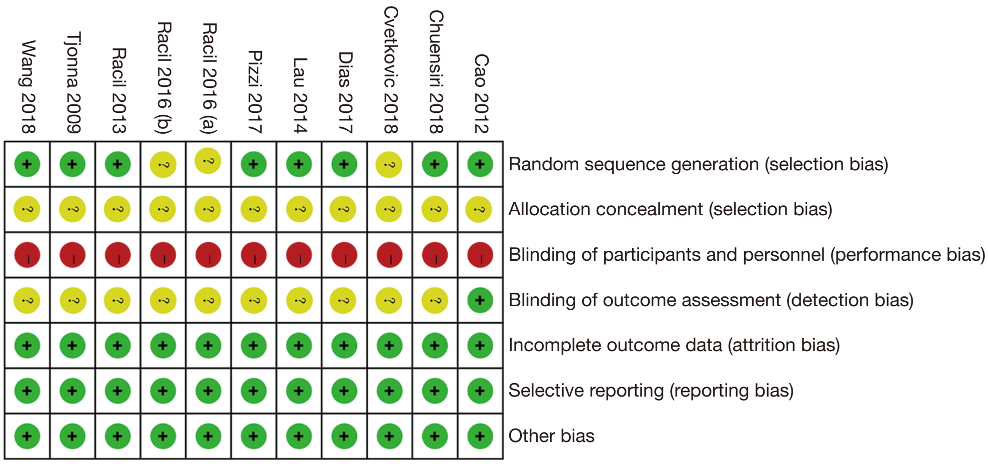

Figure 3 Risk of bias summary.

=−1.42 kg/m^2, 95% CI: −1.98 to −0.87, P<0.001) (*Figure 4B*) and waist circumference (MD =−1.8 cm, 95% CI: −3.50 to −0.10, P=0.04) (*Figure 4C*). There was heterogeneity among the studies on the effect of HIIT on body fat percentage. The random effects model showed that HIIT had a significant effect on reducing body fat percentage (MD =−1.70 %, 95% CI: −2.94 to −0.45, P=0.007) (*Figure 4D*). In order to ensure the reliability of the research results, we adopted the method of excluding RCT one by one, and the fixed effect model and the random effect model were interchanged for sensitivity analysis, and we found that the effect size did not change significantly, indicating that the research results were reliable.

There was heterogeneity among the studies on the effect of HIIT on body fat percentage, which might be related to the factors of gender, age, BMI, and duration of HIIT. To this end, we used the above factors as covariates to perform meta regression analysis to explore possible sources of heterogeneity. As presented in *Table 2*, the results showed that none of the above factors was the main source of heterogeneity between studies (all P>0.05)

Subgroup analysis

According to the length of the HIIT interval, we divided the HIIT program into "short HIIT: exercise time 10–30 s, intermittent time 10–30 s, and "long HIIT: exercise time 2–4 min, intermittent time 1–3 min for subgroup analysis. As shown in *Table 3*, short HIIT had more advantage on reducing waist circumference (MD =−2.31 cm, 95% CI: −4.20 to −0.42, P=0.022), but long HIIT had more advantages on reducing BMI (MD =−1.44 kg/m^2, 95% CI: −2.03 to −0.84, P=0.001) and body fat percentage (MD =−0.56, 95% CI: −1.08 to −0.05, P=0.009).

Publications

As presented in *Figure 5*, the dots in the funnel plots of different synthesized outcomes were evenly distributed. Besides, the Egger linear regression method was used to quantitatively evaluate publication bias for the included indicators. As shown in *Table 4*, no significant bias was found in each index of the included study (all P>0.05).

Discussion

Obesity of adolescents seriously endanger their health and are closely related to chronic diseases in adulthood (23). There is a dose-effect relationship between physical activity and health outcomes (24). The exercise dose produced by the combination of exercise intensity-time-frequency is the key to triggering the biological effect of the body (9,25). On the road of exploring exercise to control weight, HIIT, as a time-saving and efficient form of exercise, is characterized by high-intensity load, and has demonstrated its advantages in reducing fat (10). It's been found that interventions to promote moderate-to-vigorous-intensity physical activity should start before adolescence (26). This meta-analysis study found that compared with the control group, the HIIT group can significantly reduce the weight, BMI, waist circumference and body fat percentage of obese adolescents. Previous related research results also show that

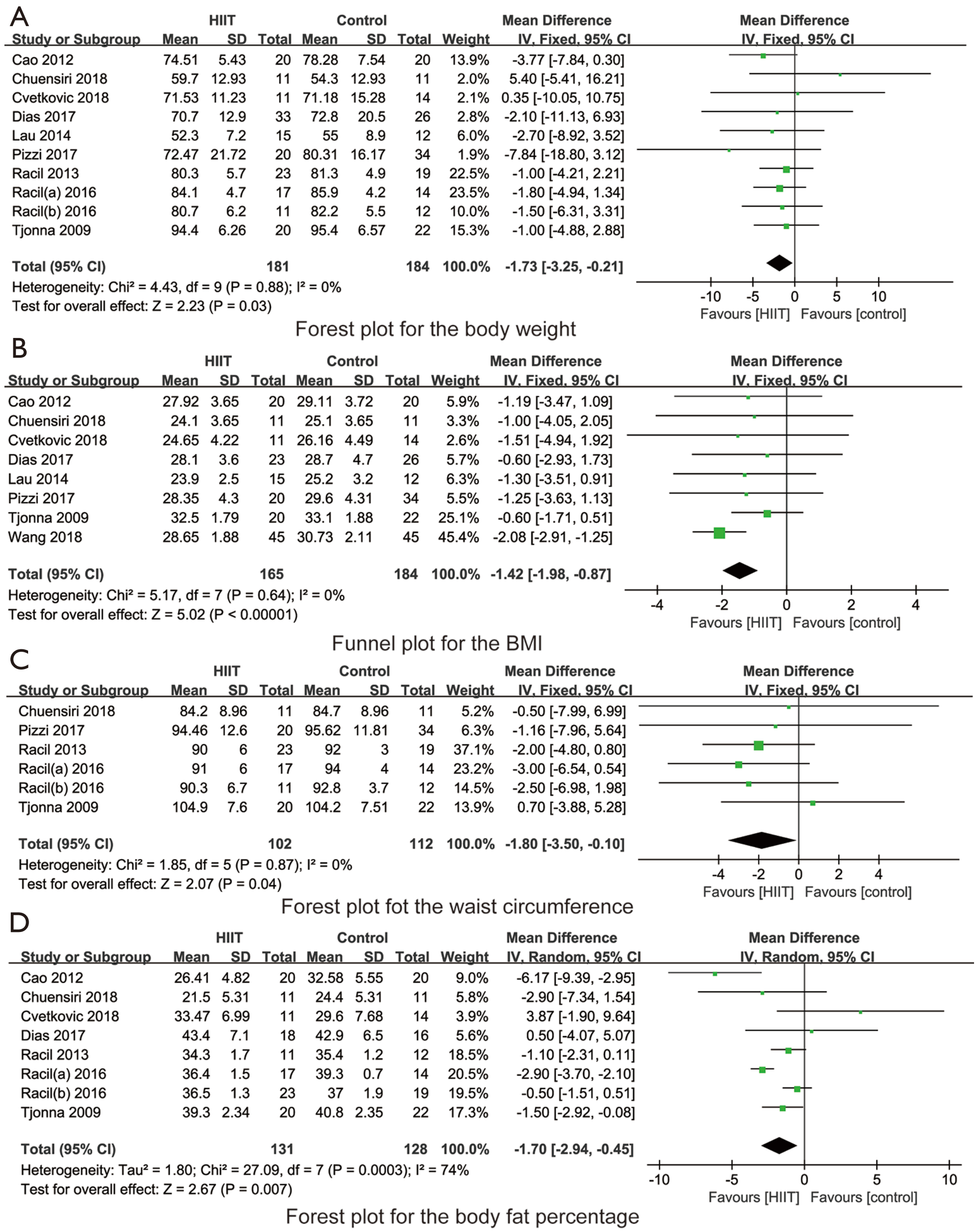

Figure 4 The forest plots for synthesized outcomes. (A) Forest plot for the body weight; (B) forest plot for the BMI; (C) forest plot fot the waist circumference; (D) forest plot for the body fat percentage.

HIIT has a good effect in reducing body fat and improving body composition in obese adults, which is similiar to our findings.

The short HIIT program is better for reducing waist circumference, while the long HIIT program is more conducive to improving BMI and body fat percentage. From the perspective of dose-effect, the exercise dose in weight control is the key to the body's fat-reducing effect. Under the combined conditions of different exercise duration and intermittent time, the exercise intensity that the body can withstand is bound to be different (27,28). This results in different combinations of exercise time and intermittent time to stimulate the body differently, resulting in different fat-reducing effects produced by the body. Waist circumference

Table 2 Multivariate regression analysis of the effect of HIIT on the body fat percentage

Variables	β	Standard error	*t*	P>|t|	95% CI
Gender	–0.714	1.108	0.762	0.501	–5.123 to 8.077
Age	0.453	1.227	0.518	0.669	–1.264 to 1.925
BMI	0.749	1.593	0.126	0.433	–1.105 to 2.009
Duration of HIIT	0.115	1.218	0.260	0.197	–3.324 to 4.957

HIIT, high-intensity interval training; BMI, body mass index.

Table 3 subgroup analysis on the effects of HIIT in childhood obesity

Variables	Intervention	Sample size	MD (95% CI)	P	I^2 (%)
Body weight (kg)	Short HIIT	202	–1.67 (–3.54, 0.20)	0.083	0
	Long HIIT	123	–1.85 (–4.46, 0.75)	0.162	0
BMI (kg/m^2)	Short HIIT	106	–1.32 (–2.78, 0.14)	0.087	0
	Long HIIT	243	–1.44 (–2.03, –0.84)	0.001	22
Waist circumference (cm)	Short HIIT	150	–2.31 (–4.20, –0.42)	0.022	0
	Long HIIT	64	0.37 (–3.53, 4.28)	0.851	0
Body fat percentage (%)	Short HIIT	121	0.69 (–1.74, 0.36)	0.203	86
	Long HIIT	138	–0.56 (–1.08, –0.05)	0.009	75

HIIT, high-intensity interval training; BMI, body mass index.

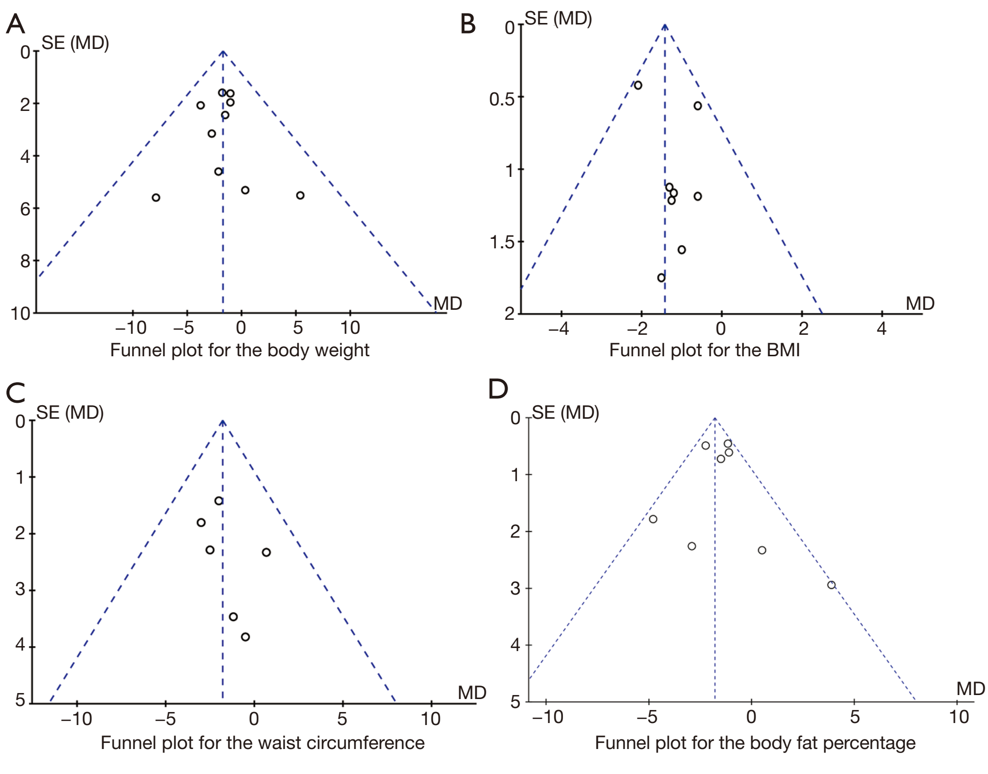

Figure 5 The funnel plots for synthesized outcomes.

Table 4 The analysis on the publication bias of the included studies

Variables	Number of included studies	β	Standard error	*t*	P>|t|	95% CI
Body weight (kg)	10	−0.003	0.485	−0.02	0.904	−1.305 to 1.442
BMI (kg/m^2)	8	−0.679	0.232	−2.17	0.062	−1.277 to 0.026
Waist circumference (cm)	6	0.351	0.449	0.23	0.184	−2.108 to 1.195
Body fat percentage (%)	8	−0.294	0.217	0.19	0.116	−0.285 to 1.189

BMI, body mass index.

is a simple evaluation index for evaluating visceral fat, and waist circumference reduction is of great significance for reducing the risk of cardiovascular disease (29). The high-intensity short-interval HIIT program can withstand exercise intensity above 100% MAS (30). This program has a significant effect on reducing the waist circumference of overweight and obese adolescents, which may be due to the higher sensitivity of human body fat to exercise intensity. Besides, HIIT significantly increases cardiorespiratory fitness by almost double that of MICT in patients with lifestyle-induced chronic diseases (31). Studies (32,33) have reported that HIIT can reduce the visceral fat content and waist-to-hip ratio in obese women, while moderate-intensity continuous training with the same energy consumption has no such effect.

BMI and body fat percentage are commonly used indicators to reflect body composition. For the high-intensity long-interval HIIT program, although the body cannot withstand the same exercise intensity as the "high-intensity short-interval" HIIT program, it still needs to maintain a high-intensity exercise of 85% to 95% HR_{max}, and this program shows a significant improvement of body composition in reducing body fat percentage. The physiological mechanism may be associated with excess post-exercise oxygen consumption (EPOC), HIIT can lead to EPOC, and the degree of EPOC is positively correlated with exercise intensity, and the energy metabolism substrate of EPOC after exercise mainly comes from fat (34).

Studies (35,36) have found that although the oxygen consumption during HIIT exercise is low, the total oxygen consumption is similar to moderate-intensity aerobic exercise due to the presence of EPOC, and the fat oxidation rate during the recovery period is significantly higher than that of moderate-intensity aerobic exercise. Previous studies (37,38) have found that high-intensity exercise and moderate-intensity exercise within 24 hours after exercise have similar fat consumption. Furthermore, HIIT can increase the secretion of catecholamines, growth hormone, etc., and increase the activity of fat metabolism enzymes, thereby increasing fat oxidation and decomposition (39). Studies (40,41) have found that 4 weeks of HIIT training can increase the fat oxidation rate of obese people and reduce the production of lactic acid. At the same time, HIIT can significantly increase the body's fat oxidation rate.

The internal mechanism of body fat oxidation may be related to the increase in the activity of mitochondrial enzymes involved in lipid oxidation and transport and the increase in the protein content of PGC-1a and PLIN2/PLIN5 (42). Studies (43,44) have shown that high-intensity exercise is more effective in increasing the concentration of β-endorphin and promoting lipid metabolism. In addition, studies (45,46) have found that HIIT can increase the body's sense of fullness and reduce appetite after exercise. From the perspective of energy balance, the loss of appetite after the human body engages in HIIT exercise is bound to make it easier for the body to achieve negative energy balance (47). The total amount of negative energy balance formed under long-term exercise conditions is greater, and the resulting fat reduction effect is also more obvious (48).

This meta-analysis still has certain limitations that should be considered. First of all, we did not pre-registered in this study in the PROSPERO, and the intervention programs included in the study (exercise intensity, intermittent time, duration) are not uniform, which may affect the accuracy of the research results, but the sensitivity analysis used in this study did not find a significant impact on the combined results. Secondly, because the intervention duration and intervention frequency included in the study are relatively consistent, it is not possible to further explore the advantages of different intervention frequencies and intervention cycles for the fat reduction effect of obese adolescents. Thirdly, we included obese adolescents with age of 6 to 18 years old in this study, WHO determines that adolescent is from 10 to 19 years old, it may be explained that the age of adolescents may vary between different countries. In the future, a large sample of RCTs are needed to further explore the fat reduction effects of HIIT exercise programs with different exercise frequencies and intervention cycles. In addition, it is worth noting that in the future, in the application of HIIT to obese adolescents, the safety of HIIT application in this population should be fully considered, and their health status should be fully evaluated (49).

Conclusions

In conclusion, HIIT can effectively improve the body composition of overweight and obese adolescents, and produce an effective fat-reducing effect. High-intensity short-interval HIIT program (exercise 10–30 s, interval 10–30 s, exercise intensity 100–120% MAS) is beneficial to reduce the visceral fat. And high-intensity long interval HIIT program (exercise 2–4 min, interval 1–3 min, exercise intensity 85–95% HR_{max}) can significantly improve body composition and reduce body fat content. Still, more studies with larger sample size and longer follow-up periods are needed to further evaluate the role of HIIT in the obesity.

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Footnote

Reporting Checklist: The authors have completed the PRISMA reporting checklist. Available at https://dx.doi.org/10.21037/apm-21-757

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Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://dx.doi.org/10.21037/apm-21-757). The authors have no conflicts of interest to declare.

Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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