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Original Article

Effects of high-intensity interval training on lipid metabolism, tumor necrosis factor-α, and C-reactive proteinin overweight children

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Abstract: Objective: To investigate the effects of high-intensity interval training on lipid metabolism and inflammatory factors in overweight children, and provide clinical guidance and recommendations for children's weight management. Methods: A retrospective study was conducted to analyze 60 overweight children, who were randomly divided into an experimental group (high-intensity interval training) and a control group (health education as intervention). Baseline data, physical indicators, and biochemical indicators were analyzed. Results: The body mass Index (BMI) of the experimental group decreased significantly more, with BMI of male and female participants showing change rates of 0.43% and 0.85%, respectively. After intervention, there were significant differences in triglycerides, total cholesterol, and lipoprotein levels between the two groups ($P<0.05$). After intervention, the serum tumor necrosis factor alpha levels of the experimental group showed significant differences ($P<0.01$), with an average value decreasing from 83.24 ng/L to 64.37 ng/L, and their C-reactive protein values also showed good intergroup and intragroup statistical differences ($P<0.05$). Conclusion: High-intensity interval training can effectively improve the physical fitness of overweight children, regulate their inflammatory factors, and help with weight loss.

Keywords: High-intensity interval training, overweight, total cholesterol, lipoprotein levels, serum tumor necrosis factor-α, C-reactive protein, visfatin, regulatory mechanism

Introduction

As a global health problem, the obesity rate among adults worldwide has significantly increased since 2000, according to statistics from the World Health Organization [1]. The body mass index (BMI) measures obesity levels, which can be divided into five categories based on their numerical value. For children, the criteria for determining weight are mainly based on BMI and the weight range of same-sex children of the same age. For children over two years old, a BMI above the 95th percentile of the weight range is considered obese. With improvements in living standards and dietary structure, the proportion of overweight children in China has increased [2-4]. Research shows that if overweight in children is not effectively and timely controlled, the probability of developing obesity is over 80%. Obesity not only affects the growth and development of children, but also leads to chronic diseases and harms their physical and mental health. Genetic factors, environmental conditions, dietary structure, and exercise habits all lead to increasingly severe obesity rates [5]. Children's self-control ability and willpower are relatively weak, and some parents lack health management awareness, leading to added difficulty for overweight children. Stinson analyzed the metabolic risks for overweight children's hearts. They found that the higher the BMI, the more likely for there to be high fasting blood sugar [6]. Rejeki et al. believed that exercise promoted changes in inflammatory cytokines, and treadmill exercise effectively prevents adolescent obesity and reduces the risk of chronic inflammatory diseases [7]. Adjusting the dietary structure, increasing the proportion of vegetables, fruits, and coarse grains, reducing the intake of

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high-energy foods, and strengthening exercise and regular daily routines are important for improving childhood obesity. Controlling calorie intake requires parents to have some nutrition knowledge. High-intensity interval training (HIIT) is a training mode that involves alternating short periods of low-intensity exercise or rest with several high-intensity exercises. HIIT requires reaching at least 85% of maximum oxygen uptake and 85% or at least 90% of maximum heart rate during exercise [8]. This training mode can improve cardiorespiratory endurance, enhance muscle strength, and improve body metabolism. Relevant research shows that excessive oxygen consumption stimulated by running training is beneficial for improving cardiovascular elasticity. Soylu et al. conducted an experimental analysis of HIIT and moderate-intensity physical fitness training. The results showed that interval training effectively improved the maximum oxygen uptake and physical fitness score of young people [9].

Cao et al. conducted a study on the cardiovascular metabolic risk factors of obese children and adolescents under HIIT and moderate intensity continuous training. The results showed HIIT was significanty more effective in improving cardiovascular health and systolic blood pressure, and reducing cardiovascular metabolic risk factors [10]. Meng et al. used HIIT to intervene and analyze the body composition and cardiovascular health of obese boys. The results showed that the training could reduce low-density lipoprotein cholesterol and insulin resistance index. However, there was no intergroup difference from its intervention effect on visceral fat [11]. Smith et al. also showed that HIIT could effectively improve the cardiorespiratory health of adolescents [12]. González-Gálvez et al. also found through controlled experiments that HIIT effectively improved the body composition, blood pressure, and pulse rate of obese adolescents during the cooling off period of physical education class [13]. There have been many studies on the impact of HIIT on the general population, showing significant improvement of the physical conditions of obese individuals. However, studies on regulation of blood lipid metabolism and inflammatory factors involved in HIIT are relatively limited, especially concerning the mechanism of its impact on overweight children. Unlike with adults and adolescents, the metabolic status and inflammatory response of overweight children may be different. For example, Gil-Cosano et al. found a correlation between vascular endothelial growth factor A and tumor necrosis factor alpha (TNF-α) in children aged 8-11 years old [14]. Higher inflammatory markers like TNF-α may increase chronic diseases such as cardiovascular disease and diabetes. Childhood obesity is associated with low-grade inflammation and cardiovascular metabolic risk. Lund et al. conducted a cross-sectional study, showing mild inflammation was associated with cardiovascular metabolic risk in children. Integrating multiple low-grade inflammation markers can identify high-risk subgroups of overweight/obese children [15].

Therefore, this study focuses on the effects of HIIT on lipid metabolism and the effects of TNF-α, CRP, and Visfatin in overweight children. A group of overweight children was selected for HIIT research and its effect on lipid metabolism and inflammatory factors. The content proposed in the study may explain the metabolic reactions of overweight children, enrich the biomarker research of Visfatin endogenous adipokines, and provide a reference for the intervention strategies for overweight children.

Materials and methods

General information

This study adopts a retrospective research method to collect physical health test data from all students in the third and fourth grades of a primary school, and calculates their BMI. According to the National Student Physical Health Standards, 60 students who met the overweight criteria were selected for analysis. Random numbers were generated using computer programs to ensure privacy. All participants' ID numbers were randomly assigned to the experimental group (n=30) or a control group (n=30). The experimental group received high-intensity interval exercise training, while the control group received exercise health education. The grouping number information was concealed. During the experiment, the data of the subjects were recorded and collected by a professional team, including self-reporting and exercise status of the subjects. All outliers were detected using statistical analysis software. The true outliers were included in the final analysis to ensure the robustness of the results. Multiple imputation was used to fill missing data to ensure data integrity. The content was approved by the hospital ethics committee.

Inclusion and exclusion criteria

Inclusion criteria: ① Subjects had stable weight, without significant changes in the past three months. ② Subjects had no regular exercise habits. ③ Subjects did not have contraindications related to cardiovascular, endocrine, or other relevant conditions for exercise. ④ Subjects were in good physical health, without acute respiratory or genetic diseases. ⑤ Subjects were willing to participate in the experiment and cooperate in completing questionnaires related to lifestyle and exercise. ⑥ Good compliance [16].

Exclusion criteria: ① Subjects were advised not to engage in strenuous exercise. ② Subjects who were unable to complete target movements during exercise testing and experienced severe dizziness, difficulty breathing, fatigue, or similar conditions. ③ Subjects who had experienced orthopedic injuries such as fractures or joint sprains within the past six months. ④ Subjects had regular exercise habits. ⑤ Subjects had mental disorders or impaired kidney function. ⑥ Subjects who withdrew from the experiment midway.

One month before the exercise intervention, dietary habit surveys were conducted on both groups, and their daily food intake was recorded. The total energy intake was calculated, and efforts were made to ensure that the subjects' dietary habits remained relatively consistent before and after the experiment, with no significant fluctuations, to avoid interference from other factors.

Experimental scheme

HIIT exercise program: The exercise took place in a sports institute and a physical fitness testing laboratory. Before the experiment, participants underwent maximal oxygen consumption testing to determine the load intensity corresponding to the peak value at 90% and 25% maximal oxygen consumption. The program lasted for 12 weeks, with different types of exercise training conducted during the first and last six weeks. During the first six weeks, the experimental group primarily engaged in treadmill training, including a 10-minute warm-up, 45 minutes of exercise, and a 10-minute cooldown period. During the exercise, participants in the interval training group performed 4 minutes of running at 90% Maximal Oxygen Uptake (VO_2max) intensity, followed by 2 minutes of complete rest. The target heart rate during exercise was set at 174 beats per minute. The running exercise was performed in 10 sets, three times a week, with no more than two days of rest between sessions. In the last six weeks of the experiment, the exercise modality switched to cycling training. This involved a 5-minute warm-up, alternating between 4 minutes of high-intensity and 2 minutes of low-intensity cycling, with a total relaxation time of 5 minutes. The exercise was performed in 6 sets, three times a week, with each session lasting 46 minutes. Participants wore a heart rate chest strap during the exercise to control the intensity. The specific exercise protocol was adjusted based on the subjects' self-perceived exertion and physical condition, with professional instructors providing guidance and safety assistance to ensure the successful completion of the experiment. Changes in participant data were recorded on the same day and timely feedback was provided to enhance compliance with intervention measures. Participants were not allowed to engage in any other form of exercise intervention during the research period, and their lifestyle and dietary habits remained unchanged.

Health education program: The content of the program was based on the results of health assessments, and targeted interventions were conducted for participants. This included nutrition lectures and other health promotion knowledge. Senior nutritionists were primarily responsible for conducting the lectures, which took place every six weeks. The content mainly focused on children's nutrition and health, children's dietary structure and composition, the causes of childhood obesity, and improvement measures.

Outcome measure

Morphologic indicators: Body shape indicators were measured according to the "Chinese Student Physical Fitness Monitoring Manual", including height, weight, waist-hip circumference, and body fat measurement. Measurements were conducted using a Height-Weight scale (DHM-16), a nylon tape measure, and a body composition analyzer (In Body 760). When measuring height and weight, participants removed their shoes and socks, to stand with both feet in the correct position, face forward without any inclination, and leave the scale once the reading stabilized.

Blood pressure measurement: A Yuyue desktop blood pressure monitor was used to measure diastolic and systolic blood pressure. Participants would expose their upper arms and sit in a relaxed position with their palms facing upwards. After releasing the air from the cuff, its lower edge was placed 2-3 cm above the elbow crease for measuring blood pressure.

Maximum oxygen uptake measurement: An AEI Moxus gas metabolism analyzer was used for incremental load tests. Before the experiment, the analyzer had be started and preheated to ensure good ventilation, with a temperature and relative humidity of around 22°C and 45%, respectively, and normal carbon dioxide detection concentration. After arriving at the testing site, participants put on a breathing mask, adjusted their heart rate chest strap for respiration, and then tested it after adjusting it to the optimal position. During the test, participants had to complete the exercise mode and intensity test at each VO_2 load and obtain exercise data at the maximum oxygen uptake state under protective supervision. The test was stopped when the maximum VO_2 value no longer changed with increasing exercise intensity or reached the heart rate data. If symptoms such as palpitations or dizziness occured during the experiment, the test was immediately terminated [17].

Biochemical indicator determination: Participants were required to have fasting blood samples taken from the same side forearm before and after exercise intervention. A 10 ml blood sample was collected from the elbow vein and placed at room temperature for 300 minutes, followed by centrifugation at 4000 rpm for 15 minutes. Serum was extracted using a pipette and stored at -40°C until the serum indicator was measured. A fully automated Biochemical Analyzer (BIOBASE-CRYSTAL) was used to measure inflammatory factors such as Triglycerides (TG), Total Cholesterol (TC), TNF-α, C-reactive protein (CRP), and Adipokines (Visfatin). All reagent kits were provided by Jiuzheng Biotechnology Company.

CRP concentration was determined using radioimmunoassay. The radioactive isotope-labeled antibody reacted with proteins in the blood to form immune complexes. Then, a precipitant was added to separate the unbound labeled antibody and impurities. The radioactive counts in the isotope were measured using a radioisotope counter and compared with the known CRP concentration standard curve.

Serum inflammatory factor levels were detected by Enzyme-Linked Immunosorbent Assay (ELISA) on the processed upper part of the venous blood sample. TNF-α is an important inflammatory regulatory factor in human physiology and pathology. It is a protein produced by immune system cells, that is often used to assess the inflammation degree or disease progression. TNF-α can promote inflammation in other cells and activate immune cells such as hematopoietic stem cells and macrophages. When TNF-α level is excessively high, it can intensify inflammatory reactions and lead to inflammatory diseases. ELISA mainly reflects changes in the TNF-α concentration based on the principle of specific antibody-protein binding. CRP is a protein present in human blood, that is commonly used as an inflammatory indicator. Elevated CRP may be associated with infections, inflammatory diseases, trauma, and surgery. Visfatins are hormones secreted by fat cells that play important roles in appetite regulation, energy metabolism, inflammation response, and pancreatic cell function. Abnormal levels of Visfatins are often associated with obesity, metabolic syndrome and other conditions [18, 19].

Statistical methods

The study utilized SPSS 23.0 for data analysis. Normally distributed metric data are presented as mean ± standard deviation. Between-group comparisons used independent sample t-tests, while paired t-tests were used for pre- and post-treatment analyses. Analysis of Variance (ANOVA) for repeated measures was employed to compare data at different time points. $P<0.05$ indicated a significant difference between the two groups, while $P<0.01$ being highly significant. Spearman's correlation coefficient was used to analyze non-normally distributed data. Multiple-factor logistic regression was used for correlation analysis.

Table 1. Baseline data

Variable		Experimental group (n=30)	Control group (n=30)	t/χ^2	*P*
Age (years)		8.25±1.03	8.21±0.89	0.153	0.623
Gender (male/female)		16/14	15/15	0.631	0.259
Height (cm)	Boys	120.16±3.37	121.34±3.29	0.780	0.304
	Girls	117.23±5.48	119.42±4.27	1.155	0.315
Body weight (kg)	Boys	44.25±3.12	45.67±2.74	0.626	0.266
	Girls	40.22±1.44	41.05±1.63	0.801	0.845
Body Mass Index (BMI)	Boys	20.44±1.68	20.05±1.04	-0.173	0.723
	Girls	19.02±2.13	18.78±2.41	-0.197	1.239
Family composition (only child/non only child)		17/13	16/14	1.134	2.074
Monthly household income (yuan)	<5000	10 (33.33%)	8 (26.67%)	0.523	1.163
	>5000	20 (66.67%)	22 (73.33%)	0.512	1.254
Household registration location (rural/urban)		13/17	14/16	1.376	3.217
Systolic blood pressure (mmHg)		108.23±5.67	110.12±3.24	0.132	0.289
Diastolic blood pressure (mmHg)		68.21±8.26	67.49±7.15	0.145	0.612

Table 2. Changes in body shape of the two groups of patients

Group	Time		Height (m)	Weight (kg)	BMI (kg/m^2)
Control group	Before intervention		1.18±2.23	42.23±2.06	19.23±1.54
	Six weeks after intervention		1.19±2.25*	43.25±1.39	20.11±1.03*
	12 weeks after intervention		1.19±2.36	47.22±1.43	20.54±1.69
	Difference (BMI)			0.85±1.94	
	Rate of change	0-6 weeks		-0.63%	
		6-12 weeks		1.22%	
		0-12 weeks		2.67%	
Experimental group	Before intervention		1.20±2.14	43.36±1.89	19.41±1.26*,#
	Six weeks after intervention		1.21±2.32*	40.26±1.47*,#	18.97±1.18*,#
	12 weeks after intervention		1.25±2.16*,#	38.11±1.68*,#	16.05±1.43*,#
	Difference (BMI)			-0.86±0.64#	
	Rate of change	0-6 weeks		-3.38%	
		6-12 weeks		-2.14%	
		0-12 weeks		-2.77%	

Note: "#" indicates $P<0.05$ between groups compared to before intervention, and "*" indicates $P<0.05$ within groups compared.

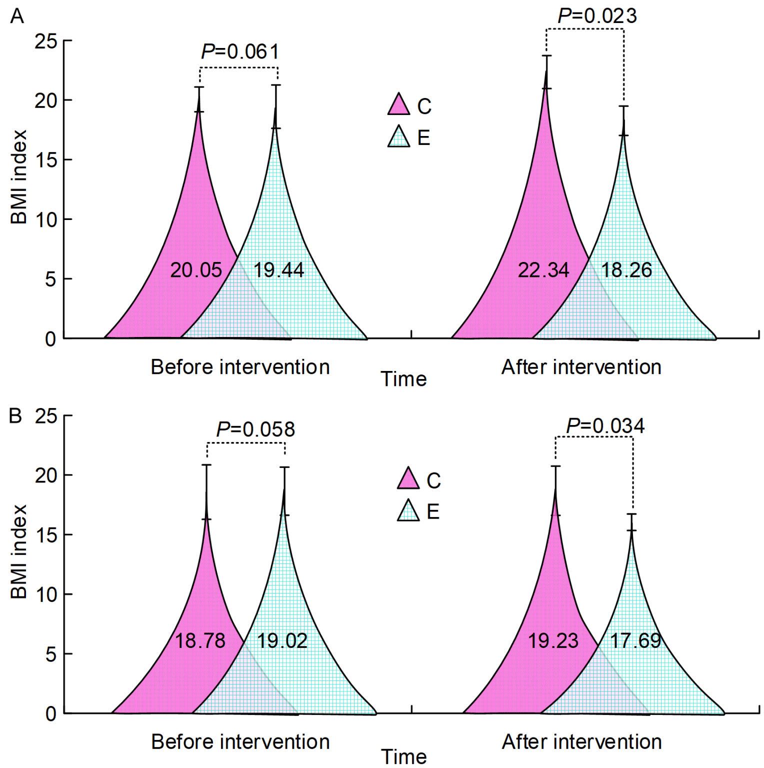
Results

Baseline data results for two groups of patients

Table 1 demonstrates the baseline characteristics such as height, age, weight, and blood pressure, indicating no significant differences ($P>0.05$). The average height of participants in both groups did not exceed 122 cm, which was shorter compared to the normal standard height. The BMI values also mostly fell within 18-20 kg/m^2. No significant differences were found in gender or monthly income between the two groups. Based on the baseline data results, further experiments were done.

Results of physical indicators and related morphologic changes in the two groups of patients

Table 2 showed that there were differences in height and BMI values of participants in the control group before and after the sixth week of intervention ($P<0.05$). The maximum increase in height was 1 cm, with an overall decrease of 0.63. However, participants did not show a significant decrease in values during the middle and later stages of the experiment, and there



Note: C represents the Control group; E represents the Experimental group.

Figure 1. Changes in body mass index (BMI) index of male and female students before and after the experiment (A. Changes in BMI of boys; B. Changes in BMI of girls).

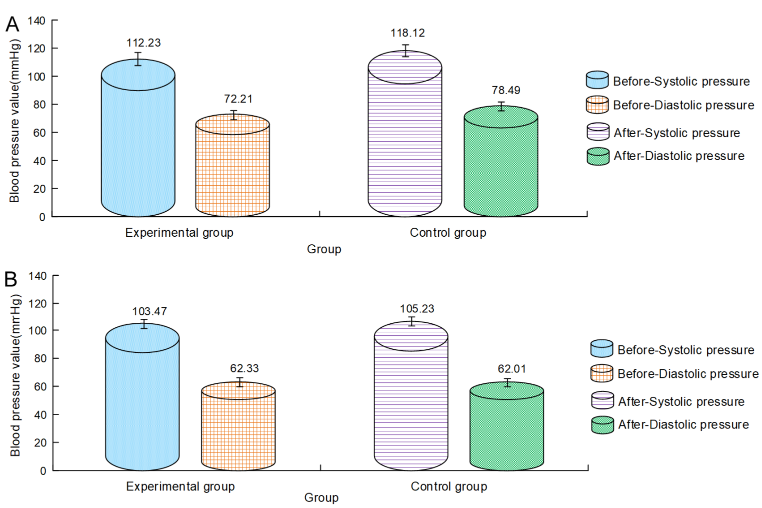


Figure 2. Results of blood pressure changes in male and female students before and after the experiment (A. Changes in blood pressure in boys; B. Changes in blood pressure in girls).

was a certain degree of rebound, with change rates reaching 1.22% and 2.67%, respectively. The experimental group participants showed various changes in body indicators as the intervention time increased. The maximum increase in height was 5 cm, and the maximum weight loss was 5 kg, resulting in an overall decrease in BMI average values. Although there were slight fluctuations in the decline rate of the experimental group participants during the intervention phase, this may have been to the presence of a weight loss platform. However, an overall downward trend was evident, with maximum and average decline rates of 3.38% and 2.76%, respectively. These results indicate that intermittent training effectively controled participants' weight changes.

Furthermore, the BMI values based on gender differences among participants were compared, and the results are shown in **Figure 1**. **Figure 1** indicated a 0.43% change rate in BMI data for male participants in the experimental group after intervention. For female participants, there was a 0.85% change rate in the comparison between groups.

The results of diastolic and systolic blood pressure in **Figure 2** showed no differences in the blood pressure data of the participants in both groups before and after the intervention (P>0.05). The data change rates were also generally less than 1%, with values within the normal range.

From the results for body fat percentage, both groups experienced varying degrees of decline. In the control group, the average body fat percentage for males and females after intervention reached 31.05% and 30.48%, respectively, with no significant differences compared to before the intervention (P>0.05), and the maximum difference in val-

Table 3. Changes in body fat percentage and waist hip ratio of both groups of subjects

Group	Time	Gender	Body fat percentage (%)	Waist to hip ratio (%)
Control group	Before intervention	Boys	32.23±2.06	0.87±0.01
		Girls	33.25±1.39	0.86±0.06
	After intervention	Boys	31.05±2.13	0.86±0.14
		Girls	30.48±2.19	0.85±0.13
Experimental group	Before intervention	Boys	33.82±1.83	0.86±0.03
		Girls	32.05±1.27*,#	0.87±0.02*,#
	After intervention	Boys	25.16±1.46	0.84±0.15
		Girls	29.13±1.05*,#	0.83±0.11*,#

Note: "#" indicates $P<0.05$ between groups compared to before intervention, and "*" indicates $P<0.05$ within groups compared after intervention.

Table 4. Changes in TG and TC of both groups of subjects after intervention

Group	Time	TG	TC
Control group	Before intervention	3.85±0.64	1.98±0.41
	Six weeks after intervention	4.34±0.71	1.22±0.76
	12 weeks after intervention	4.56±0.29	1.21±0.54
	Difference	0.49+0.22	0.25+0.46
	Rate of change	+13.26%	+23.16%
Experimental group	Before intervention	3.84±0.89	1.97±0.65
	Six weeks after intervention	3.82±0.64	0.82±0.27
	12 weeks after intervention	3.65±0.32	0.79±0.65
	Difference	-0.34+0.28	-0.27+0.13
	Rate of change	-6.22%	-22.47%

Note: "+" and "-" respectively represent an increase and a decrease. TG represents triglycerides, and TC represents total cholesterol.

ues was 1%. Additionally, there were no significant changes in waist-to-hip ratio values for the control group participants after intervention, and the overall change rate was not high. In contrast, for the experimental group, the average body fat percentage for male participants changed from 33.82% to 25.16%. For female participants, it changed from 32.05% to 29.13%. Overall, the differences existed between and within groups before and after intervention ($P<0.05$). Moreover, there were notable differences in waist-to-hip ratio data for the experimental group participants, with a maximum decline of 0.05% (**Table 3**).

Changes in lipid data after intervention in the two groups of subjects

Table 4 showed no statistical difference in TC between the first two groups before the experiment. However, after the intervention, the TG value of the control group increased, with the average value changing from 3.85 mmol/L to 4.56 mmol/L, representing an overall change rate exceeding 10%. The TG value of the experimental group decreased slightly, from 1.98 mmol/L to 1.21 mmol/L, reflecting a decrease rate of 5.23%. The data from these two groups showed significant differences after the intervention ($P<0.05$). As the intervention time increased, the increase in TC in the control group and the decrease in TC in the experimental group became more pronounced. Similarly, the TC values of these two groups also showed significant differences after intervention ($P<$ 0.05). The average TC values after intervention for both groups were 1.21 mmol/L and 0.81 mmol/L, respectively, corresponding to change rates of +20.37% and -21.49%. Intermittent exercise training demonstrated a prominent effect in reducing the TG and TC values in subjects, improving their lipid metabolism.

The lipoprotein data in **Figure 3** indicated that both health education and intermittent exercise training could improve the High-Density Lipoprotein (HDL) and Low-Density Lipoprotein (LDL) levels compared to before the interven-

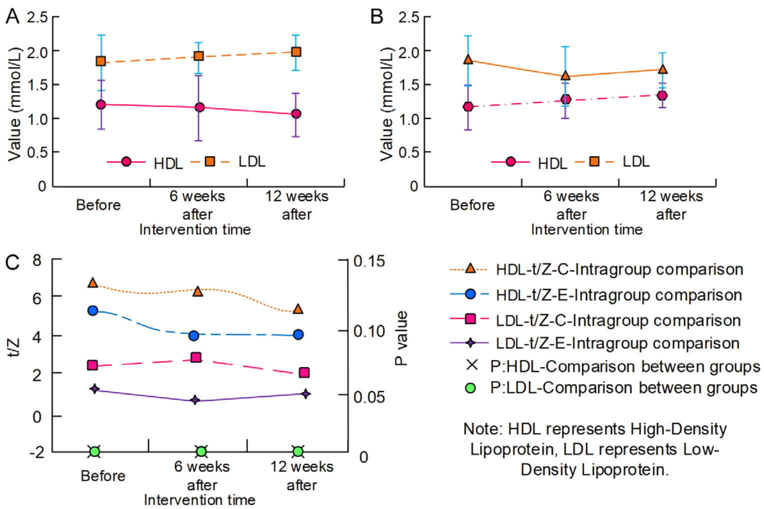
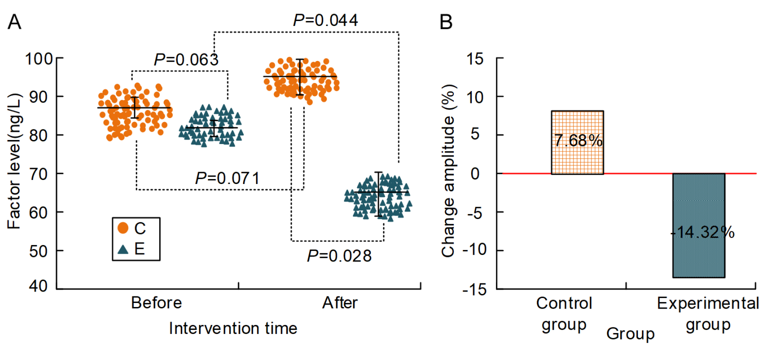


Figure 3. Lipoprotein data of subjects under different intervention methods (A. Control group; B. Experimental group; C. Changes in statistical data).



Note: C represents the Control group; E represents the Experimental group; TNF-α represents Tumor Necrosis Factor-α.

Figure 4. TNF-α changes of subjects before and after the experiment (A. TNF-α factor level; B. TNF-α changes in amplitude before and after intervention).

tion (P<0.05). Specifically, the HDL values of the control group subjects decreased by more than 10%, while the LDL values increased by 8.23%. In contrast, the experimental group subjects showed significantly greater changes in both HDL and LDL compared to the control group, with average post-intervention values reaching 1.31 mmol/L and 1.68 mmol/L, respectively. Furthermore, with the increase in intervention time, the improvement in lipoprotein values for both groups increased, with the overall change trend in the experimental group being superior.

Biochemical indicator measurement results

In **Figure 4**, the serum TNF-α level in the experimental group subjects decreased after the intervention compared to before (P=0.028), with the average value decreasing from 83.24 ng/L to 64.37 ng/L (14.32%). Moreover, after the intervention, there was a difference between the two groups (P=0.044). In contrast, the TNF-α level of the control group subjects showed an increase of more than 5% after the intervention, and their data did not differ from before the intervention (P=0.071).

In **Figure 5**, before the experimental intervention, there were no differences in the CRP concentration or Visfatin inflammation index data. After intervention, the average CRP value for the control group subjects changed from 2.21 mg/L to 2.53 mg/L (11.37%). Meanwhile, the experimental group showed a significant decrease in CRP values, with their post-intervention data mostly <2 mg/L, exhibiting statistical differences both between and within groups (P=0.032, P=0.036). The Visfatin data also indicated that intermittent training effectively reduced the subjects' inflammatory factors, with the post-intervention values (11.23±8.37) showing a significant difference compared to the control group (22.15±6.44) (P=0.037<0.05). These results show that intermittent exercise training effectively enhanced the subjects' resistance and improve their inflammatory markers.

Correlation result analysis

The blood lipid data and inflammatory factors of overweight children undergoing intermittent running training were subjected to Spearman correlation analysis to show their intrinsic relationship, as shown in **Figure 6**. From **Figure 6**, after six weeks of intervention, TC was positively correlated with TNF-α and CRP (r=0.318, r=0.257), (P<0.05). Similarly, there was a positive correlation between TG values and inflammatory factors (r=0.253, r=0.216), (P<0.05).

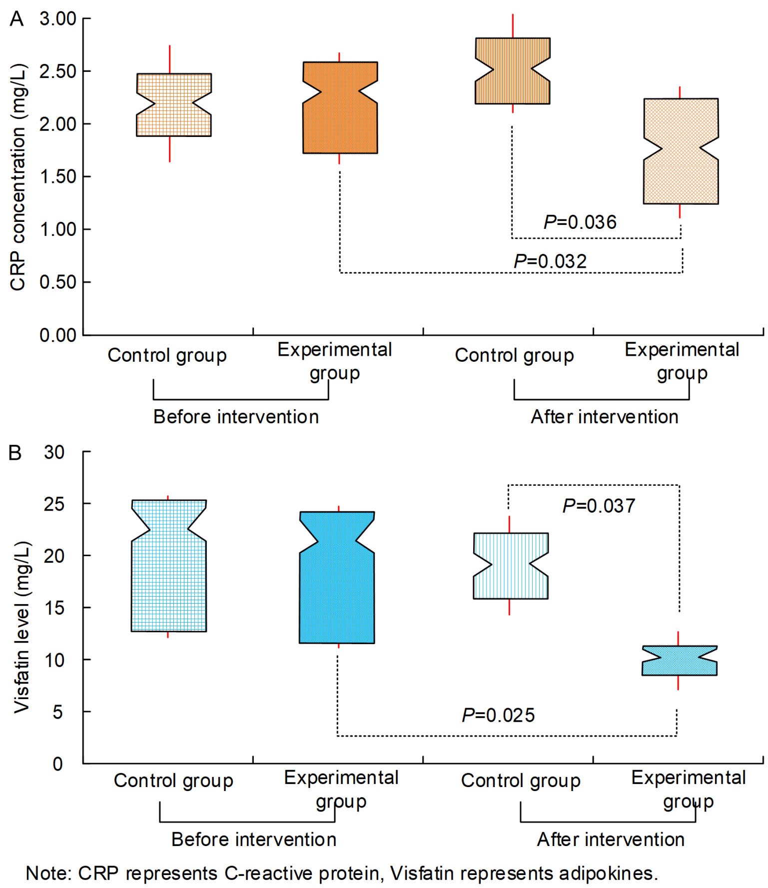


Figure 5. CRP concentration and visfatin inflammation data of two groups of subjects (A. CRP level; B. Visfatin level).

In **Table 5**, HDL-C protein was negatively correlated with TNR-α, CRP, and Visfatin inflammatory factors (r=-0.624, r=-0.231, r=-0.327), (all $P<0.05$). Meanwhile, LDL-C indicators exceeded statistical tests of inflammatory factors ($P<0.05$), demonstrating a significant positive correlation (r=0.235, r=0.148, r=0.481).

Taking research indicators as dependent variables and inflammatory factors as independent variables, a multiple regression analysis was conducted, with age and gender being corrected during the regression process. The regression results in **Table 6** showed that the BMI concentration was associated with inflammatory factors, (all $P<0.05$). Furthermore, lipid metabolism indicators also differed from the inflammatory factor TNF-α ($P<0.05$).

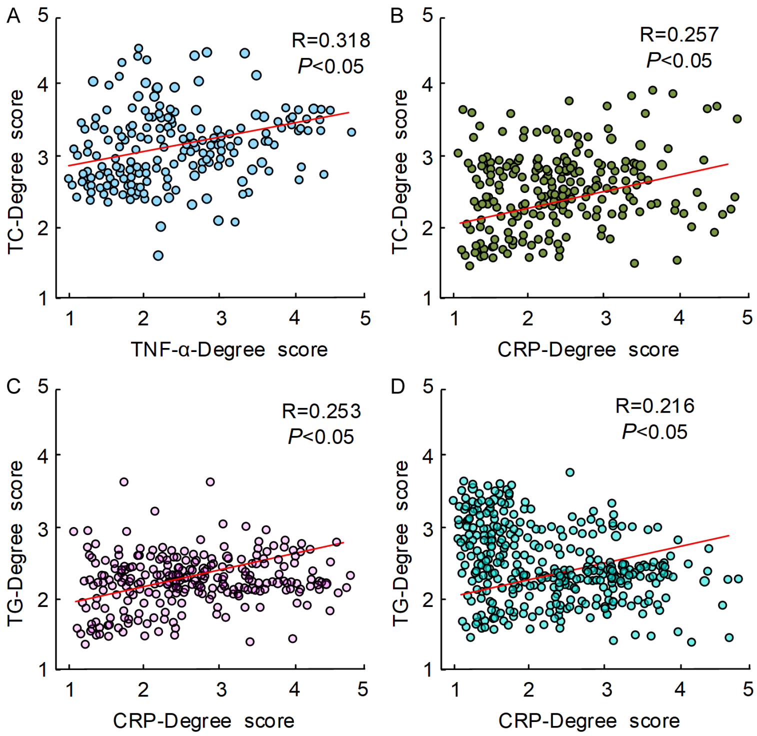
Subject satisfaction evaluation and follow-up effects

The satisfaction statistics of the two groups after the intervention are presented in **Figure 7**. **Figure 7** showed that there were no dissatisfied participants in the experimental group, with an overall satisfaction rate of 96.67%. In contrast, fewer participants in the control group acknowledged the experimental results, resulting in an overall satisfaction rate of only 60%. Additionally, a significant statistical difference existed in the improvement of overweight individuals between the two groups (12.34%>2.73%, $P=0.026<0.05$).

Subsequent follow-up analysis of the psychological state improvement in the two groups after the experimental intervention was conducted, with a perfect score of 10 representing a healthy psychological state, as shown in **Table 7**. Before the experimental intervention, participants in both groups exhibited varying degrees of negative emotions such as inferiority, depression, and self-denial. After the experiment, the negative emotions of the intermittent training group were improved, with a reduction in scores of 3 or more. The emotional state of the control group was slightly but not significantly improved ($P>0.05$).

Discussion

Obesity is an important health issue faced by people today. Related data shows that the global obesity rate has significantly increased, with more than 20% of adolescents now affected. There are many reasons for this, including genetic, environmental, and psychological factors, and its pathogenesis is complex and varies from person to person [20]. Nyangasa believes that genetic abnormalities lead to leptin deficiency in the body, which can lead to changes in personal diet and physical condition. In severe cases, it can also lead to obesity [21]. Other studies have shown that disturbances in energy metabolism can easily cause the body to be unable to return to normal weight. Overweight



Note: TG represents triglycerides, TC represents total cholesterol.

Figure 6. Correlation analysis of TC, TG, and TNF-α and CRP (A. TC and TNF-α indicators; B. TC and CRP indicators; C. TG and TNF-α indicators; D. TG and CRP indicators).

Table 5. Correlation between lipoprotein and inflammatory factors

Index	TNR-α		CRP		Visfatin	
	r	*P*	r	*P*	r	*P*
HDL-C	-0.624	<0.01	-0.231	<0.05	-0.327	<0.05
LDL-C	0.235	<0.05	0.148	>0.05	0.481	<0.05

Note: TNR-α represents Tumor Necrosis Factor-α, CRP represents C-reactive protein, and Visfatin represents adipokines.

Table 6. Multiple regression results

Index	TNR-α		CRP		Visfatin	
	F	*P*	F	*P*	F	*P*
BMI	1.065	0.318	5.745	0.028	2.561	0.412
TC	1.274	0.032	28.410	0.026	2.231	0.831
TG	1.451	0.028	32.162	0.033	15.791	0.672
HDL-C	4.109	0.001	11.293	0.016	0.862	0.013
LDL-C	2.166	0.039	1.956	0.847	42.174	0.023

often tends to develop into obesity, becoming the cause of cardiovascular disease, cancer, and related musculoskeletal disorders [22]. When a child's weight far exceeds the standard value, it affects growth and development, daily life, and even their psychological state. Overweight children are also more likely to become obese in adulthood. Exercise is a common weight control method, which differs from simple dietary restrictions, as it achieves fat burning and physical fitness. Many studies have shown that HIIT can achieve rapid fat burning in the shortest possible time. A study on lipid metabolism and inflammatory factors in overweight children provides feasible suggestions and measures for better management of children's health.

The research results indicated significant differences in the height and BMI of the control group subjects during the intervention at the sixth week and before the intervention ($P<0.05$). The numerical rates in the later stages of the experiment reached 1.22% and 2.67%, respectively, with some rebound. In contrast, the overall average BMI value of the experimental group decreased, with maximum and average decreasing rates of 0.38% and 2.76%, respectively. The BMI data change rates for boys and girls were 0.43% and 0.85%, respectively. This may have been because high-intensity training accelerated oxygen consumption, leading to an increase in adrenaline secretion to stimulate fat burning. This result was similar to the research conducted by Llorente-Cantarero [23]. Body fat percentage reflects the composition of body fat. A high body fat percentage can increase the risk of chronic diseases, while a low body fat percentage can lead to malnutrition and osteoporosis. In the experimental results, the average body fat percentage of both boys and girls in the experimental group

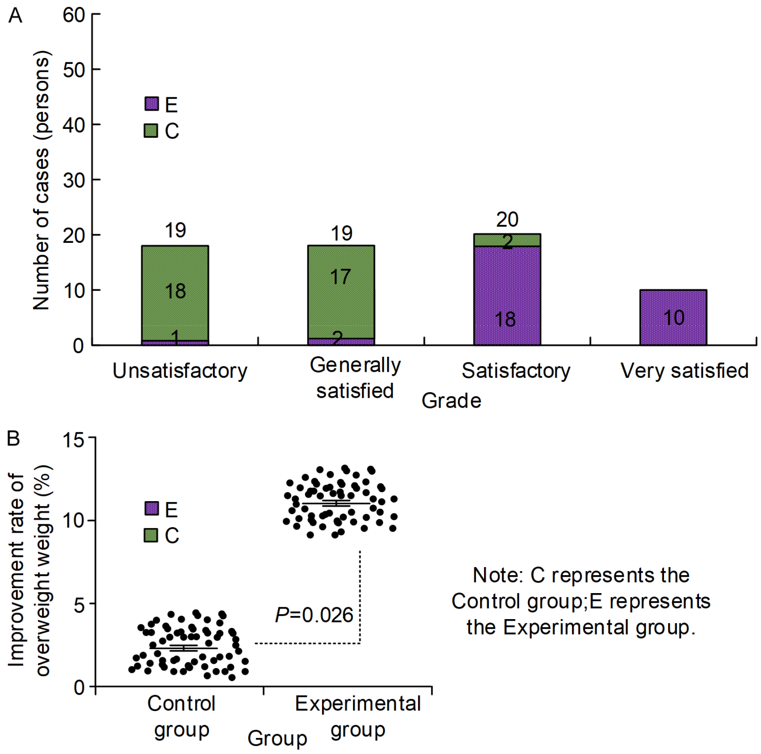


Figure 7. Evaluation results of subject satisfaction after intervention (A. Satisfaction evaluation results; B. Improvement rate of overweight weight in two groups of subjects (%)).

decreased. Differences existed between groups and within groups before and after the intervention (*P*<0.05), which was similar to the research conducted by Zhao et al. [24]. Studies have shown that exercise training can lower the TC and TG in the serum. Cholesterol is a lipid that is important in constructing cell membranes and for synthesis of hormones. Both high and low cholesterol levels are detrimental to the normal functioning of the body [24]. Results showed that the TG values of the control group subjects increased after the intervention, with the average value changing from 3.85 mmol/L to 4.56 mmol/L, an overall change rate exceeding 10%. The TG average value of the experimental group decreased slightly, from 1.98 mmol/L to 1.21 mmol/L, with a decrease rate of 5.23%. Differences existed between both groups after the experimental intervention (*P*<0.05). The average TC values after the intervention for both groups were 1.21 mmol/L and 0.81 mmol/L, respectively, corresponding to change rates of +20.37% and -21.49%. With an increase in intervention time, differences emerged (*P*<0.05) in the TG and TC values in both groups after the intervention. This result is similar to the research conducted by Zhao et al. [24]. Both health education and intermittent exercise training improved the HDL and LDL levels compared to before the intervention (*P*<0.05). The changes in higdensity and low-density lipids of the experimental group subjects were significantly greater, with average values reaching 1.31 mmol/L and 1.68 mmol/L, respectively. When the LDL is too high, it harms cardiovascular health [25]. When the inflammatory factor level is elevated, it causes insulin resistance. TNF-α inhibits insulin receptor activity through signaling pathways. Even in the absence of exogenous lipid intake, it can reduce LPL [26, 27]. The research results showed that the TNF-α levels in the experimental group subjects after intervention had significant statistical differences compared to before intervention (*P*<0.01), with the average value decreasing from 83.24 ng/L to 64.37 ng/L, and there were significant differences between the two groups after the intervention (*P*<0.05). Before the experiment, no significant differences existed in the CRP concentration or Visfatin inflammatory index data between the two groups (*P*>0.05). Thisresult is similar to the research content of Habibian et al. [28].

HIIT is an endurance aerobic exercise that can achieve weight loss and visceral fat accumulation by increasing insulin sensitivity and glucose transporter levels in tissues and organs. Moderate intensity regular exercise can enhance the body's anti-inflammatory state. In the long run, it can prevent the development of chronic diseases. Intense physical exercise can regulate immune responses, immediately redistribute immune cells to surrounding tissues, and improve immune surveillance and immune regulation status [29]. HIIT can reduce IL-6, IL-1α, and tumor necrosis factor stimulated by

Table 7. Improvement in psychological status of both groups of subjects

Indicator		Inferiority complex	Anxiety and depression	Self negation	Social fear
Experimental group	Before intervention	6.23±2.11	7.01±1.22	6.47±0.39	5.06±1.33
	After intervention	2.37±0.31	2.06±1.04	3.06±0.08	1.22±0.27
	Person χ^2	2.643	0.376	0.128	3.264
	P value	<0.05	<0.05	<0.05	<0.05
Control group	After 7 weeks of intervention	5.16±3.10	6.11±1.07	7.09±1.33	5.22±0.26
	After 14 weeks of intervention	4.29±1.06	5.07±2.22	5.89±1.32	5.16±0.27
	Person χ^2	0.369	0.184	0.365	0.823
	P value	>0.05	>0.05	>0.05	>0.05

Toll-like Receptor (TLR) ligands, and increase the number of circulating dendritic cells. The animal experiment conducted by Wang et al. showed that HIIT improved liver inflammation and lipid metabolism disorder in type 2 diabetes mice after 8 weeks [30]. Short term HIIT significantly increases energy expenditure. During the recovery period after exercise, the body releases a large amount of fatty acids from adipose tissue and restores energy balance through oxidative metabolism, which helps to increase lipid oxidation. During exercise, the body's fat breakdown accelerates, thereby increasing the utilization of free fatty acids and cholesterol, and improving lipid metabolism disorders [31]. Overweight often leads to obesity, which may affect the function of immune cells, such as the ability to regulate T cells, leading to a decrease in the immune system's ability to respond to pathogens. Obesity is usually accompanied by macrophage infiltration and inflammatory phenotype changes in adipose tissue. HIIT can improve fat metabolism to a certain extent and reduce the activation level of inflammatory cells. Khalafi et al. found that HIIT improved the circulating pro-inflammatory cytokine TNF-α, which could be used to control low-grade inflammation in patients with metabolic disorders [32]. HIIT may reduce oxidative stress levels by increasing the activity of antioxidant enzymes. Sun et al. found that HIIT increased pregnenolone, cortisol, and corticosterone in adipose tissue and serum, which had better anti-inflammatory activity regulation than moderate intensity continuous training [33]. Paahoo et al. found that HIIT had a more positive impact on atherosclerosis and inflammatory factors and lipid mass spectrum variables in overweight/obese children than aerobic exercise [34]. After the experimental intervention, the average CRP value for the control group subjects changed from 2.21 mg/L to 2.53 mg/L, with no significant difference in the experimental group (P>0.05). The CRP value of the experimental group subjects decreased significantly, with the post-intervention data mostly below 2 mg/L, showing differences compared to both within and between the groups (P<0.05). The Visfatin data also indicated that intermittent training effectively reduced the subjects' inflammatory factors, with significant differences (P<0.05), which was similar to the study conducted by Liberali et al. [35]. The correlation results showed that the TC after six weeks of intervention was positively correlated with TNF-α and CRP (r=0.318, r=0.257, and P<0.05). The TG values also showed a positive correlation with the inflammatory factors (r=0.253, r=0.216, and P< 0.05). The HDL-C protein was negatively correlated with TNR-α, CRP, and Visfatin inflammatory factors (r=-0.624, r=-0.231, r=-0.327, and P<0.05). After the experiment, the overall satisfaction rate of the experimental group was 96.67%. There was a significant difference in the improvement rate between the experimental group (12.34%) and the control group (2.73%) (P<0.05). Intermittent training greatly alleviated the negative emotions of the subjects (P<0.05). This is similar to the research conducted by Babaei and Hoseini [36].

In summary, high-intensity interval exercise training can effectively improve the body shape of overweight children, increase lipid metabolism levels, regulate inflammatory factors, enhance children's physical fitness, and reduce negative emotions such as inferiority and depression.

Disclosure of conflict of interest

None.

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