The effect of rope jump training on serum levels of lipocalin-2, anthropometric parameters, and aerobic power in obese adolescent boys

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Abstract

Introduction: Lipocalin-2 derived from adipose tissue is associated with insulin resistance, systemic inflammation, and cardiovascular disease in obese people. The current study aimed to investigate the effect of rope jump exercise training on serum lipocalin-2 levels, anthropometric parameters, and maximal oxygen uptake (VO2max) in obese adolescent boys.
Materials and methods: Twenty obese adolescent boys participated voluntarily in the study and were equally assigned to control and rope jump groups. Rope jump exercise protocol was practiced in 8 weeks, 3 days per week. Blood samples were taken before and after the program. The VO2max of each participant was estimated using Cooper's 12-minute run test. Serum lipocalin-2 levels were measured using a commercial ELISA kit.
Results: Within-group comparisons revealed that rope jump exercise training resulted in a significant reduction in weight ($P = 0.005$), BMI ($P = 0.002$), abdominal circumference ($P = 0.001$), body fat percentage ($P = 0.001$), and serum levels of lipocalin-2 ($P = 0.002$). In contrast, lean body mass (LBM) ($P = 0.047$) and VO_2max ($P = 0.007$) increased significantly in the rope jump group. After the intervention, abdominal circumference ($P = 0.001$), body fat percentage ($P = 0.001$), weight ($P = 0.001$), and BMI ($P = 0.001$) were significantly lower in the rope jump group than in the control group. VO_2max in the rope jump group was significantly higher than in the control group at the end of the exercise training protocol ($P = 0.001$). However, no significant differences were found between the groups concerning lipocalin-2 level ($P = 0.105$), waist-to-hip ratio ($P = 0.461$), and LBM ($P = 0.053$) at the end of the protocol.
Conclusion: While rope jump exercise training enhanced anthropometric parameters and aerobic power in obese adolescents, it failed to significantly alter the serum lipocalin-2 level, as an inflammatory marker.

Keywords: Rope jump training, Lipocalin-2, Adolescents, Obesity

Introduction

Obesity is widely regarded as the most significant health challenge in the 21st century (1). Increased obesity in humans is associated with an increased risk of developing type 2 diabetes, cardiovascular disease, liver disease, airway disease, neurological disease, biliary disease, and cancer. Obesity-related diseases lead to lower life expectancy and, consequently, premature death (2, 3). The risk of obesity is immense and frightening worldwide, as it can affect all age groups, including children and

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adolescents (4, 5). According to the World Health Organization, the number of obese children and adolescents has increased from about 11 million in 1975 to 124 million in 2016. Iran has been shown to be one of the seven countries with the highest prevalence of childhood obesity (6). From 1995 to 2007, 8.82 percent of Iranian adolescents were reported as overweight and 4.5 percent as obese (7). The rates were 10.8% and 5.1% for overweight and obesity, respectively, during the 2007-2012 period, indicating that the prevalence of obesity among Iranian adolescents has increased in recent years (8, 9). Obesity has become widespread in many developed and developing countries. Studies have revealed a strong relationship between the risk of mortality from cardiovascular disease and obesity, which is not merely confined to adults but also affects obese children and adolescents (10). Research suggests that obese children over the age of 10 are at an increased risk for metabolic disorders, heart disease, and dyslipidemia (11). Obesity is associated with the secretion of inflammatory cytokines and with chronic inflammation in the adipose tissue, which results from fat accumulation in adipocytes (12). The adipose tissue secretes bioactive molecules called adipokines, which are conducive to maintaining stable whole-body conditions (13).

Over the past two decades, the interrelationships between adipokines, metabolic syndrome, and inflammatory diseases have been better understood. In this regard, lipocalin-2 has been suggested as one of the mediators responsible for systemic inflammation and obesity-related metabolic syndrome (14, 15). Lipocalin-2 (neutrophil gelatinase-related lipocalin), a 25-kDa protein belonging to the large family of lipocalins, is produced as an inflammatory marker in large quantities in adipocytes and is a marker associated with inflammation, ischemia, infection, and kidney damage (15). A positive relationship has been demonstrated between serum lipocalin-2 levels and the variables of obesity, hypertriglyceridemia, hyperglycemia, and C-reactive protein (CRP) levels. The lipocalin-2 mRNA and protein expression increase substantially in the adipose tissue and are positively correlated with the expression of proinflammatory cytokines (16). In obesity and the related disorders, increased expression of various proinflammatory cytokines such as interleukin-6, interleukin-1 beta, and tumor necrosis factor-alpha is strongly involved in the regulation of lipocalin-2 (15). A significant increase in lipocalin-2 levels has been reported in coronary heart disease and inflammatory diseases (17, 18, 19). Serum concentrations of lipocalin-2 are positively correlated with body mass index (BMI), body fat percentage, waist-to-hip ratio (WHR), and waist circumference and are higher in obese than in lean individuals (16, 17, 20). It has also been shown that serum levels of lipocalin-2 are higher in obese than normal-weight children and adolescents and that its concentration is closely related to obesity and its associated metabolic complications so that the measurement of this marker is vital for the evaluation of metabolic syndrome in children and adolescents (21).

Concerning the effect of exercise on lipocalin-2 levels, researchers have shown that after 8 weeks of endurance and resistance exercise, lipocalin-2 levels decrease significantly in healthy young men (22). Another study has found that 8 weeks of aerobic exercise decreases lipocalin-2 levels in healthy overweight men (23). Choi et al. (2009) reported no significant difference in lipocalin-2 levels after 3 months of aerobic and strength training (17). In one study, a decrease in serum levels of lipocalin-2 has been demonstrated in overweight and obese women with polycystic ovary syndrome after six months of a weight loss program (24).

Immediately after vigorous exercise, Lippi et al.'s study (2012) showed a 1.6-fold increase in serum lipocalin-2 and a 7.7-fold increase in urine lipocalin in marathon runners (25).
One of the exercises that can be used by adolescents is rope jumping. Studies have indicated the enjoyment, safety, and convenient learning of rope jump exercises by adolescents (26). Rope jumping is not only a game for children but is also a common exercise. Among the benefits of rope jumping is that it can be performed by individuals irrespective of time, place, and season. It can be practiced in a variety of ways, both individually and in groups. In terms of facilities, rope jumping merely requires one rope and is relatively inexpensive compared to other sports; it is also one of the most appropriate types of basic fitness training (27). Rope jump exercises have been shown to enhance physical fitness and improve BMI in children and adolescents (28). Given the increased urbanization and lack of space in homes and schools, rope jump exercises can be an excellent alternative to activities such as running in limited spaces; it is useful to promote physical fitness at home and in schools and training centers that are spatially confined, especially during childhood and adolescence (29). Cardiovascular disease and type 2 diabetes are rooted in childhood, and it is essential to provide early intervention in lifestyle, especially for obese children and adolescents (30). There is limited information concerning the effect of rope jump training on inflammatory markers, especially lipocalin-2. What is known is that a positive association holds between serum lipocalin-2 levels and anthropometric parameters such as BMI, body fat percentage, waist circumference, and WHR (16, 17). Therefore, the present study sought to answer the question of whether or not rope jump exercise can have a significant effect on anthropometric indices, aerobic power, and, subsequently, the lipocalin-2 inflammatory marker, which is reported to be of a higher level in obese than normal-weight adolescents.

Materials and methods

This quasi-experimental study incorporated voluntarily 20 obese inactive male subjects from Bojnord city (age: 13.40 ± 1.09 years; height: 154.70 ± 8.31cm; BMI: 27.12 ± 2.19 kg/m^2; body fat: 26.78 ± 3.19%). Obesity was determined according to the US Centers for Disease Control and Prevention (CDC) criteria. At baseline, the subjects completed the Baecke Physical Activity Questionnaire. Inclusion criteria consisted of obesity (having a BMI above 95% of the CDC criteria as per age and male gender), inactivity (not participating in a regular exercise program for the past 6 months), absence of cardiovascular and metabolic disease, and non-consumption of exercise and nutritional supplements. After the subjects' guardians were informed about the program, its benefits, and potential risks, they signed a consent form for the participation of their children in the study. Subjects pledged to have persistent participation in the program, to observe what was required of them, and to refrain from participating in other exercise programs. They were given the right to leave the program as long as they felt anxious about performing the protocol. All subjects were instructed on how to jump rope in the course of two weeks (three sessions per week). After their height and weight were measured and their BMI calculated, the subjects were matched for BMI and were divided into control (n = 10) and rope jump (n = 10) groups.
Height and weight were measured by digital and calibrated height and weight gauges in Javad Al-A'emeh Hospital in Bojnourd (Iran) at baseline and 48 hours after the last training session. Subjects' weight was measured in fasting conditions with their bladder empty

and the subjects having minimal clothing coverage (31). Moreover, when assessing body composition, the subjects were asked not to consume food or caffeine (32). BMI was calculated by weight ratio in kg / m2. Waist circumference was measured at the end of a natural expiration at the point between the last rib and iliac crest. Hip circumference was measured around the widest portion of the hips, and WHR was calculated as waist measurement divided by the hip measurement. Abdominal circumference was measured using a tape meter in the most prominent abdominal area. Jackson and Pollock's three-point method was employed to calculate body density. In this method, the subcutaneous fat thickness of the chest, thigh, and abdomen was measured using a Yagami caliper (made in Japan). Finally, the Siri equation was used to calculate body fat percentage (33). Lean Body Mass (LBM) is a component of body composition, which was calculated from the fraction of body fat weight from the total body weight. Moreover, Cooper's 12-minute test was applied to measure aerobic power (34).

The subjects in the rope jump group performed the exercise protocol for 8 weeks, 3 sessions per week. The exercise protocol of this study is modeled after the ones used in similar studies on the effect of rope jump training in obese adolescents (35), with slight changes considered in the current study after the pilot study (Table 1). The subjects were familiarized with and trained as to the manner of rope jumping in the first two weeks of the program. Instructions involved issues such as rolling the hands in circles, rotating the rope with the left and right hands on the side, rotating the rope with both hands in the front and over the head, turning the rope with the hands on the sides to form an '8', turning the rope with the right hand and left hand in sequence and jumping simultaneously, and turning the rope in the front and jumping. Moreover, tips were highlighted such as jumping for 3 to 5 cm above the ground so that the rope passes below the feet and non-landing on the heel, similar to the recommendations made in other studies (28). At the beginning and at the end of each training session, five minutes of warm-up and five minutes of cooling down were performed by stretching. Subjects in the control group performed daily activities and were prohibited from performing any exercise.

Table 1. Rope jumping exercise training protocol.

Week	The main body of the exercise	Intensity (number of jumps / min)
1	Training how to jump rope	Instructions on the technique
2	Training how to jump rope	Instructions on the technique
3	Twenty 1-minute sets with a 30-second rest between sets	40-50
4	Twenty 1-minute sets with a 30-second rest between sets	50-60
5	Fifteen 1.5-minute sets with a 30-second rest between sets	50-60
6	Ten 2.5-minute sets with a 30-second rest between sets	60-70
7	Eight 3-minute sets with a 30-second rest between sets	70-80
8	Six 4-minute sets with a 60-second rest between sets	80-90
9	Six 4-minute sets with a 60-second rest between sets	90-100
10	Five 5-minute sets with a 60-second rest between sets	100-110

Five cc blood samples were taken from subjects in fasting conditions (12 hours) at baseline and 48 hours after the last training session at Javad Al-A'emeh Hospital (Bojnord, Iran) from 8 to 9 a.m. after a 30-minute rest on the chair. Blood samples were centrifuged at 4 °C for 10 minutes at a speed of 3000 rpm (24T centrifuge, Aram Gostar Co., Iran). The centrifuged sera were poured into 0.5 ml microtubes (Kariz Mehr Co., Iran) and transferred under refrigerated conditions to Gonabad University of Medical Sciences for biochemical evaluation and stored at -80 °C. Biochemical evaluation of lipocalin-2 serum content was performed by a commercial 96-well lipocalin-2 human kits (ZellBio GmbH, Germany, Catalog No: ZB-11429C-H9648) with a sensitivity of 10 ng/L and a detection range of 200 to 6400 ng/L using the Sandwich ELISA based on the antibody-antigen reaction. Serum concentrations of lipocalin-2 were read at 450 nm by the BioTek microplate reader (EpocH2 Model, USA).

Statistical analysis

Statistical analysis was performed using SPSS software version 16 (SPSS Institute, Chicago, USA). The significance level was set at $P < 0.05$. Given the low number of subjects, the normal distribution of the data was assessed by the Shapiro-Wilk test. The dependent t-test was employed to examine within-group differences of the variables with a normal distribution. Wilcoxon statistical test was used to assess within-group differences in variables that did not have a normal distribution. Also, the analysis of covariance (ANCOVA) test was applied to better control for between-group differences. Results are presented as mean ± standard deviation.

Results

Concerning anthropometric variables, within-group assessments revealed no significant change in weight (P = 0.261), BMI (P = 0.257), WHR (P = 0.226), abdominal circumference (P = 0.917), body fat content (P = 0.430) and percentage (P = 0.375), and LBM (P = 0.867) in control group. However, within-group assessments showed that 8 weeks of rope jump training reduced weight (P = 0.005), BMI (P = 0.002), abdominal circumference (P = 0.001), fat percentage (P = 0.001), and body fat (P = 0.001) in obese adolescents, although it did not affect WHR values (P = 0.296). In contrast, the LBM of obese subjects increased significantly after rope jump training (P = 0.047). Between-group evaluations showed that there was a significant difference between abdominal circumference size (P = 0.001), body fat content (P = 0.001) and percentage (P=0.001), weight (P = 0.001), and BMI (P = 0.001) of the two groups at the end of the training. However, there was no significant difference in WHR (P = 0.461) and LBM (P = 0.053) between rope jump and control groups at the end of the training period (Table 2).

Regarding aerobic power, within-group assessments showed that VO_2max value was significantly higher in the rope jump group at post-test (26.68 ± 6.37 ml/kg/min) than baseline (21.12 ± 3.41 ml/kg/min) (P = 0.007). However, there was no significant difference between VO_2max values before (22.38 ± 3.60 ml/kg/min) and after the intervention (21.68 ± 3.26 ml/kg/min) in the control group (P = 0.113). Between-group assessments showed that the values in the rope jump group were higher than in the control group at the end of the training period (P = 0.001) (Figure 1).

In the case of lipocalin-2, within-group assessments showed that rope jumping decreased serum levels after the intervention (1113.54 ± 205 ng/l) as compared with baseline (1247.72 ± 211 ng/l) (P = 0.002). However, there was no significant difference in serum lipocalin-2 levels at baseline (1104.05 ± 182 ng/l) and after the protocol (1129.38 ± 99 ng/l) in the control group (P = 0.647). Moreover, between-group assessments indicated that there was no significant difference as for serum lipocalin-2 levels between the two groups at the end of the training period (P = 0.105) (Figure 2).

Discussion

Within-group results showed that rope training increased LBM and VO_2max levels, while it significantly reduced the weight, BMI, abdominal circumference, body fat content, body fat percentage, and serum lipocalin-2 levels of obese adolescents. Between-group evaluations showed no significant difference in lipocalin-2, WHR, and LBM levels between the rope jump and control groups at the end of the training period. However, abdominal size, body fat content, body fat percentage, weight, and BMI at the end of the training session were significantly lower in the rope jump group than in the control group, and VO_2max mean value of the rope jump group were significantly higher than that of the control group.

Table 2. Within-group and between-group assessment results for anthropometric variables.

Variable	group	Mean ± standard deviation		Interquartile range	
		Before	After	Before	After
Weight (Kg)	Control	67.56 ± 11.61	67.81 ± 11.29	23.08	22.32
	Rope jump	62.93 ± 8.60	60.83 ± 9.06*#	7.60	8.65
BMI (kg/m^2)	Control	27.58 ± 2.74	27.69 ± 2.64	4.84	4.42
	Rope jump	26.65 ± 1.48	25.76 ± 2.02*#	2.48	3.86
WHR	Control	0.89 ± 0.06	0.88 ± 0.06	0.12	0.14
	Rope jump	0.86 ± 0.030	0.85 ± 0.032	0.03	0.07
Abdominal circumference (cm)	Control	91.60 ± 7.78	91.65 ± 7.86	15.88	14.50
	Rope jump	87.35 ± 4.51	83.85 ± 4.69*#	7.88	8.12
Body fat (%)	Control	26.48 ± 3.23	26.75 ± 3.08	6.52	6.38
	Rope jump	27.08 ± 3.30	22.96 ± 4.02 *#	4.99	7.73
Body fat (Kg)	Control	18.07 ± 4.69	18.27 ± 4.36	9.05	9.41
	Rope jump	17.13 ± 3.60	14.18 ± 4.13*#	3.71	5.28
LBM (Kg)	Control	49.51 ± 7.69	49.53 ± 7.70	12.94	12.50
	Rope jump	45.79 ± 5.76	46.64 ± 5.47*	6.22	5.81

The * mark indicates a significant difference from baseline; the # mark denotes a significant difference with the control group at the end of the study. Abbreviations: BMI = Body Mass Index; LBM, Lean Body Mass; WHR: Waist-to-Hip Ratio.

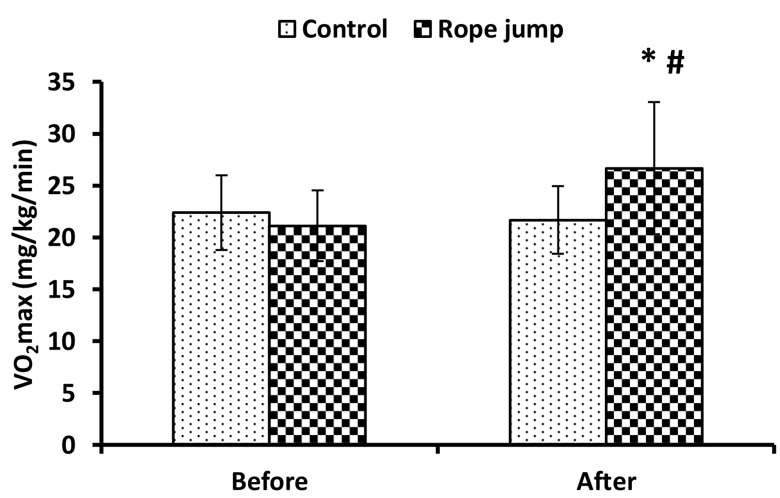

Figure 1. VO_2max values of inactive obese adolescents. Abbreviations: VO_2max, maximal oxygen uptake. The * mark denotes a significant difference from baseline; the # symbol stands for a significant difference with the control group.

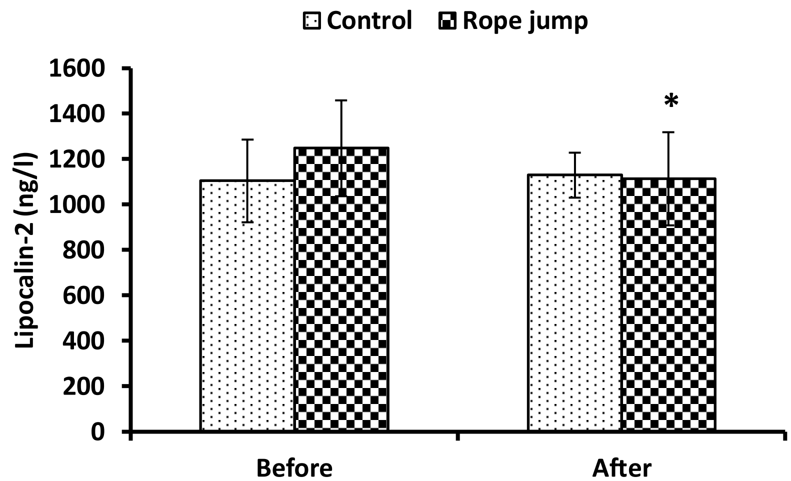

Figure 2. Serum lipocalin-2 levels in inactive obese adolescents. The * mark denotes a significant difference from baseline**.**

In a three-month study of an exercise protocol consisting of aerobic exercise at 60 to 75 percent of maximal heart rate (approximately 300 kcal/day) and muscle strength training (approximately 100 kcal/day) per session five times a week in inactive obese women, no significant change in lipocalin-2 levels was reported (17). In similar lines and consistent with our results, no significant change in lipocalin-2 levels was reported after 8 weeks of progressive resistance training in the range of 20% to 90% of maximal repetition four sessions a week in overweight and obese men (36). In the present study, although anthropometric parameters such as BMI, body fat content, and body fat percentage were significantly decreased, lipocalin-2 levels did not change significantly. Lipocalin-2 is expressed and produced in cells and tissues other than the adipose tissue, such as macrophages, endothelial cells, monocytes, and hepatocytes (37-39). Therefore, a lack of change in lipocalin-2 levels may be due to the different responses of these tissues to exercise activity, which requires further study. Moreover, it is likely that lipocalin-2 levels in this study were affected by WHR and LBM indices, as they did not change significantly over time.

The results of the present study are not in line with those of a study conducted with inactive healthy young men for 8 weeks in two groups of resistance training (65-80% of maximal repetition) and aerobic training (65-80% of maximal heart rate), where reduced serum lipocalin-2 levels were reported in both groups (22). Another study showed a decrease in serum levels of lipocalin-2 after 8 weeks of aerobic exercise with an intensity of 65 to 80% of maximal heart rate in obese men aged 27 years on average (23). Following a six-month weight loss program, including low-calorie diet and exercise, another study reported lower serum levels of lipocalin-2 in obese women with polycystic ovary syndrome (24), which is inconsistent with the results of our study. Consumption of saturated fatty acids is shown to alter lipocalin-2 levels (40). Hence, the different results found in different studies may be associated with the difference in dietary types adopted by participants in the studies, which needs further investigation.

Individual differences of subjects, age, nutritional status, and intensity and duration of exercise may be other reasons for the inconsistency of results with those of the present study. It should be noted that in the current study, serum levels of lipocalin-2 decreased after the rope jump training protocol, although the decrease was not statistically significant. As the levels of this molecule were significantly reduced in studies with greater weight loss and body fat percentage, longer exercise duration and a more substantial decrease in body weight and fat percentage in the present study could probably lead to a significant change in lipocalin-2. This, however, requires further research. In a study by Damirchi et al. (2011), a significant increase in serum levels of lipocalin-2 was found after the implementation of the Bruce protocol in obese and inactive normal-weight men (41). Increased serum and urine levels of lipocalin-2 after 60 km of running have been demonstrated in trained male athletes (25), the results of which are inconsistent with those of the present study. Elevated serum levels of lipocalin-2 in these studies may be due to inflammation after intense exercise, which is associated with a significant increase in CRP and WBC levels (41), as inflammatory markers. The lipocalin-2 expression has been found to increase in the face of oxidative stress and inflammatory factors (38, 42) and to decrease after 48 hours toward basal levels (43). Therefore, the elevated levels of this molecule in the two studies mentioned above may indicate increased inflammation caused by vigorous exercise. In sum, in the present study, despite the decreased levels of lipocalin-2 in the exercise group, no significant differences were found in the levels of this molecule between the two groups in obese adolescents.

Significant reductions in body fat percentage have been reported after 8 weeks of rope jump training in inactive overweight and obese girls, aged 20 to 25 years and boys with the mean age of 11 years (29), which is consistent with the results of our study. Another study shows a significant decrease in waist circumference, hip circumference, weight, BMI, body fat content, and body fat percentage after 6 weeks of rope jump training, five sessions per week, in obese adolescent boys (35). Catecholamines and growth hormone have been shown to increase during exercise, whereby the lipolysis content is increased. On the other hand, aerobic exercise increases the density of beta-adrenoceptors in the adipose tissue, which improves the sensitivity of the lipolysis process (44). While these aspects have not been examined in the present study, they may be among the potential mechanisms for improvement in anthropometric parameters. A 12-week rope jump training of 13- to 15-year-old students with thought disorders and a 10-week rope jump training of 13 to 15-year-old students with visual impairments led to no significant change in body mass index (27, 45), which are inconsistent with the results of our study. The inconsistent results can be attributed to the fact that the subjects in these studies had normal BMI, while the adolescents were obese in our study. In short, rope jump training seems to be one of the best exercises to improve anthropometric parameters in overweight and obese adolescents.

Aerobic training significantly increases mitochondrial oxidative enzymes and creates conditions where body tissues can have more oxygen available, thereby increasing the VO_2max and aerobic power (44). Alongside this, studies have shown a significant increase in VO_2max after 8 weeks of rope jump training in inactive girls (46), which is consistent with the results of our study. A significant increase in aerobic power and cardiorespiratory endurance has been reported after 8 weeks of rope jump training in boys with an average age of 11 years and after 12 weeks of rope jump training in students with thought disorders (29, 44). Reports indicate increased aerobic power and capacity after 10 weeks of rope jump training in 10- to 12-year-old boys as well as students with visual impairment ranging in age from 15 to 17 years (27, 28), which corresponds with the results of the current study. In summary, the results of the present study showed that rope jump training increased aerobic fitness in obese male adolescents.

Conclusion

Overall, in the present study, eight weeks of rope jump training led to significant reductions in weight, BMI, abdominal size, body fat content, and body fat percentage in obese adolescents. However, serum levels of lipocalin-2, WHR, and LBM did not change significantly. It was also shown that aerobic power significantly increased after this training protocol. In fact, although anthropometric indices improved and aerobic fitness increased after 8 weeks of rope jump training in obese adolescents, serum levels of lipocalin-2, as an inflammatory marker, did not change significantly.

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Ethical approval

The study was approved by the Institutional Ethical Committee for Human Use (IR.IAU.BOJNOURD.REC.1399.003).

Conflicts of interest

The authors declare that they have no conflict of interest.

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References

1. Wang YC, McPherson K, Marsh T, Gortmaker SL, Brown M. Health and economic burden of the projected obesity trends in the USA and the UK. Lancet. 2011; 378(9793): 815-25. doi: 10.1016/S0140-6736(11)60814-3.
2. Amin MN, Hussain MS, Sarwar MS, Moghal MM, Das A, Hossain MZ, et al. How the association between obesity and inflammation may lead to insulin resistance and cancer. Diabetes Metab Syndr. 2019; 29: 1213-24. doi: 10.1016/j.dsx.2019.01.041.
3. Gregor MF, Hotamisligil GS. Inflammatory mechanisms in obesity. Annu Rev Immunol. 2011; 29: 415-45. doi: 10.1146/annurev-immunol-031210-101322.
4. Dehghan M, Akhtar-Danesh N, Merchant AT. Childhood obesity, prevalence and prevention. Nutr J. 2005; 4(1): 24. doi: 10.1186/1475-2891-4-24.
5. Ben-Sefer E, Ben-Natan M, Ehrenfeld M. Childhood obesity: current literature, policy and implications for practice. Int Nurs Rev. 2009; 56(2): 166-73. doi: 10.1111/j.1466-7657.2008.00708.x.
6. Kelishadi R, Hashemi Pour M, Sarraf-Zadegan NI, Sadry GH, Ansari R, Alikhassy H, et al. Obesity and associated modifiable environmental factors in Iranian adolescents: Isfahan Healthy Heart Program− heart health promotion from childhood. Pediatr Int. 2003; 45(4): 435-42. doi: 10.1046/j.1442-200x.2003.01738.x.
7. Kelishadi R, Ardalan G, Gheiratmand R, Gouya MM, Razaghi EM, Delavari A, et al. Association of physical activity and dietary behaviours in relation to the body mass index in a national sample of Iranian children and adolescents: CASPIAN Study. Bull World Health Organ. 2007; 85(1): 19-26. doi: 10.2471/blt.06.030783.

8. Kelishadi R, Haghdoost AA, Sadeghirad B, Khajehkazemi R. Trend in the prevalence of obesity and overweight among Iranian children and adolescents: a systematic review and meta-analysis. Nutrition. 2014; 30(4): 393-400. doi: 10.1016/j.nut.2013.08.011.
9. Kargarfard M, Lam ET, Shariat A, Asle Mohammadi M, Afrasiabi S, Shaw I, et al. Effects of endurance and high intensity training on ICAM-1 and VCAM-1 levels and arterial pressure in obese and normal weight adolescents. Phys Sportsmed. 2016; 44(3): 208-16. doi: 10.1080/00913847.2016.1200442.
10. Skilton MR, Celermajer DS. Endothelial dysfunction and arterial abnormalities in childhood obesity. Int J Obes (Lond). 2006; 30(7): 1041-9. doi: 10.1038/sj.ijo.0803397.
11. Camarillo-Romero E, Dominguez-Garcia MV, Amaya-Chavez A, Camarillo-Romero MD, Talavera-Piña J, Huitron-Bravo G, et al. Effects of a physical activity program on markers of endothelial dysfunction, oxidative stress, and metabolic status in adolescents with metabolic syndrome. ISRN endocrinol. 2012; 2012: 970629. doi: 10.5402/2012/970629.
12. Roth CL, Kratz M, Ralston MM, Reinehr T. Changes in adipose-derived inflammatory cytokines and chemokines after successful lifestyle intervention in obese children. Metabolism. 2011; 60(4): 445-52. doi: 10.1016/j.metabol.2010.03.023.
13. Ohashi K, Shibata R, Murohara T, Ouchi N. Role of anti-inflammatory adipokines in obesity-related diseases. Trends Endocrinol Metab. 2014; 25(7): 348-55. doi: 10.1016/j.tem.2014.03.009.
14. Kamble PG, Pereira MJ, Sidibeh CO, Amini S, Sundbom M, Börjesson JL, et al. Lipocalin 2 produces insulin resistance and can be upregulated by glucocorticoids in human adipose tissue. Mol cell endocrinol. 2016; 427: 124-32. doi: 10.1016/j.mce.2016.03.011.
15. Moschen AR, Adolph TE, Gerner RR, Wieser V, Tilg H. Lipocalin-2: a master mediator of intestinal and metabolic inflammation. Trends Endocrinol Metab. 2017;28(5):388-97. doi: 10.1016/j.tem.2017.01.003.
16. Catalán V, Gómez-Ambrosi J, Rodriguez A, Ramírez B, Silva C, Rotellar F, et al. Increased adipose tissue expression of lipocalin-2 in obesity is related to inflammation and matrix metalloproteinase-2 and metalloproteinase-9 activities in humans. J Mol Med (Berl). 2009;87(8):803. doi: 10.1007/s00109-009-0486-8.
17. Choi KM, Kim TN, Yoo HJ, Lee KW, Cho GJ, Hwang TG, et al. Effect of exercise training on A-FABP, lipocalin-2 and RBP4 levels in obese women. Clin endocrinol (Oxf). 2009; 70(4): 569-74. doi: 10.1111/j.1365-2265.2008.03374.x.
18. 18.Makhezer N, Khemis MB, Liu D, Khichane Y, Marzaioli V, Tlili A, Mojallali M, et al. NOX1-derived ROS drive the expression of Lipocalin-2 in colonic epithelial cells in inflammatory conditions. Mucosal immunol. 2019;12(1):117-131. doi: 10.1038/s41385-018-0086-4.
19. 19.Buonafine M, Martínez-Martínez E, Amador C, Gravez B, Ibarrola J, Fernández-Celis A, et al. Neutrophil gelatinase-associated lipocalin from immune cells is mandatory for aldosterone-induced cardiac remodeling and inflammation. J Mol Cell cardiol. 2018;115:32-8. doi: 10.1016/j.yjmcc.2017.12.011.
20. Singh RG, Pendharkar SA, Plank LD, Petrov MS. Role of human lipocalin proteins in abdominal obesity after acute pancreatitis. Peptides. 2017; 91: 1-7. doi: 10.1016/j.peptides.2017.03.001.

21. Zaki ME, El-Bassyouni H, Youness E, Mohamed N. Lipocalin-2 is an inflammatory biomarker associated with metabolic abnormalities in Egyptian obese children. J App Pharm Sci. 2015; 5(05): 007-12. doi: 10.7324/JAPS.2015.50502.
22. Moghadasi M, Domieh AM. Effects of resistance versus endurance training on plasma lipocalin-2 in young men. Asian J Sports Med. 2014; 5(2): 108-14.
23. Mohammadi A, Khajehlandi A. Hs-CRP and adipokin (lcn2): response to exercise training in obese men. Biomed Pharmacol J. 2014; 7(1): 17-22. doi:https://dx.doi.org/10.13005/bpj/447.
24. Koiou E, Tziomalos K, Katsikis I, Kandaraki EA, Kalaitzakis E, Delkos D, Vosnakis C, et al. Weight loss significantly reduces serum lipocalin-2 levels in overweight and obese women with polycystic ovary syndrome. Gynecol endocrinol. 2012; 28(1): 20-4. doi: 10.3109/09513590.2011.588745.
25. Lippi G, Sanchis-Gomar F, Salvagno GL, Aloe R, Schena F, Guidi GC. Variation of serum and urinary neutrophil gelatinase associated lipocalin (NGAL) after strenuous physical exercise. Clin Chem Lab Med. 2012; 50(9): 1585-9. doi: 10.1515/cclm-2011-0954.
26. Liu JH, Alderman BL, Song TF, Chen FT, Hung TM, Chang YK. A randomized controlled trial of coordination exercise on cognitive function in obese adolescents. Psychol Sport Exerc. 2018; 34: 29-38. doi: 10.1016/j.psychsport.2019.101604.
27. Chen CC, Lin SY. The impact of rope jumping exercise on physical fitness of visually impaired students. Res Dev disabil. 2011;32(1):25-9. doi: 10.1016/j.ridd.2010.08.010.
28. 28. Eler N, Acar H. The effects of the rope jump training program in physical education lessons on strength, speed and VO_2max in children. Univers J Educ Res. 2018; 6(2): 340-5. doi: 10.13189/ujer.2018.060217.
29. Arazi H, Jalali-Fard A, Abdinejad H. A comparison of two aerobic training methods (running vs rope jumping) on health-related physical fitness in 10 to 12 years old boys. Phys Act Rev. 2016; 4: 9-17.
30. DeBoer MD. Obesity, systemic inflammation, and increased risk for cardiovascular disease and diabetes among adolescents: a need for screening tools to target interventions. Nutrition. 2013; 29(2): 379-86. doi: 10.1016/j.nut.2012.07.003.
31. Monteiro AG, Aoki MS, Evangelista AL, Alveno DA, Monteiro GA, da Cruz Piçarro I, et al. Nonlinear periodization maximizes strength gains in split resistance training routines. J Strength Cond Res. 2009; 23(4): 1321-6. doi: 10.1519/JSC.0b013e3181a00f96.
32. Ackel-D'Elia C, Carnier J, Bueno Jr CR, Campos RM, Sanches PL, Clemente AP, Tufik S, et al. Effects of different physical exercises on leptin concentration in obese adolescents. Int J Sports Med. 2014; 35(2): 164-71. doi: 10.1055/s-0033-1345128.
33. De Lima C, Boullosa DA, Frollini AB, Donatto FF, Leite RD, Gonelli PR, et al. Linear and daily undulating resistance training periodizations have differential beneficial effects in young sedentary women. Int J Sports Med. 2012;33(09):723-7. doi: 10.1055/s-0032-1306324.
34. Calders P, Deforche B, Verschelde S, Bouckaert J, Chevalier F, Bassle E, et al. Predictors of 6-minute walk test and 12-minute walk/run test in obese children and adolescents. Eur J Pediatr. 2008; 167(5): 563-8. doi: 10.1007/s00431-007-0553-5.

35. Kim ES, Im JA, Kim KC, Park JH, Suh SH, Kang ES, et al. Improved insulin sensitivity and adiponectin level after exercise training in obese Korean youth. Obesity (Silver Spring). 2007; 15(12): 3023-30. doi: 10.1038/oby.2007.360.
36. Ghorbanian B, esmaeilzadeh D. Effect of progressive resistance training on serum lipocalin-2 and lipid profiles in in-active men. IJEM. 2017; 18(5): 378-85.
37. Yan QW, Yang Q, Mody N, Graham TE, Hsu CH, Xu Z, et al. The adipokine lipocalin 2 is regulated by obesity and promotes insulin resistance. Diabetes. 2007; 56(10): 2533-40. doi: 10.2337/db07-0007.
38. Owen HC, Roberts SJ, Ahmed SF, Farquharson C. Dexamethasone-induced expression of the glucocorticoid response gene lipocalin 2 in chondrocytes. Am J Physiol Endocrinol Metab. 2008; 294(6): E1023-34. doi: 10.1152/ajpendo.00586.2007.
39. Esteve E, Ricart W, Fernández-Real JM. Adipocytokines and insulin resistance: the possible role of lipocalin-2, retinol binding protein-4, and adiponectin. Diabetes care. 2009; 32 Suppl 2(Suppl 2): S362-7. doi: 10.2337/dc09-S340.
40. Moreno-Navarrete JM, Manco M, Ibanez J, Garcia-Fuentes E, Ortega F, Gorostiaga E, et al. Metabolic endotoxemia and saturated fat contribute to circulating NGAL concentrations in subjects with insulin resistance. Int J Obes (Lond). 2010; 34(2): 240-9. doi: 10.1038/ijo.2009.242.
41. Damirchi A, Rahmani-Nia F, Mehrabani J. Lipocalin-2: response to a progressive treadmill protocol in obese and normal-weight men. Asian J Sports Med. 2011; 2(1): 44-50. doi: 10.5812/asjsm.34821.
42. Hemdahl AL, Gabrielsen A, Zhu C, Eriksson P, Hedin U, Kastrup J, et al. Expression of neutrophil gelatinase–associated lipocalin in atherosclerosis and myocardial infarction. Arterioscler Thromb Vasc Biol. 2006; 26(1): 136-42. doi: 10.1161/01.ATV.0000193567.88685.f4.
43. Spiropoulos A, Goussetis E, Margeli A, Premetis E, Skenderi K, Graphakos S, et al. Effect of inflammation induced by prolonged exercise on circulating erythroid progenitors and markers of erythropoiesis. Clin Chem and Lab Med. 2010;48(2):199-203. doi: 10.1515/CCLM.2010.034.
44. Purnell JQ, Kahn SE, Albers JJ, Nevin DN, Brunzell JD, Schwartz RS. Effect of weight loss with reduction of intra-abdominal fat on lipid metabolism in older men. J Clin Enocrinol Metab. 2000;85(3):977-82. doi: 10.1210/jcem.85.3.6402.
45. Chen CC, Lin YC. Jumping rope intervention on health-related physical fitness in students with intellectual impairment. J Hum Resour Adual. 2012; 8(1): 56.
46. Ghorbanian B, Shokrollahi F. The effects of rope training on paraoxonase-1 enzyme, insulin resistance and lipid profiles in inactive girls. Tehran Univ Med J. 2017; 75(4): 307-15.