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Effects of Concurrent Strength and Aerobic Training on Blood Glucose Homeostasis and Lipid Profile in Females with Overweight and Obesity

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Abstract

Background: Physical activity is recognized as a basic component of the management of children with obesity.
Objectives: The current study aimed at exploring the effect of a 12-week concurrent strength and aerobic training on body composition, glycosylated hemoglobin, fasting blood sugar (FBS), homeostasis model assessment-estimated insulin resistance (HOMA-IR), plasma insulin, high-density lipoprotein (HDL), low-density lipoprotein (LDL), total cholesterol (TC), and triglyceride (TG) between the females with overweight and obesity.
Methods: The current semi-experimental study was conducted on 40 females (20 with obesity and 20 with overweight) aged 13 - 15 years selected and randomly assigned into four groups. Strength training was performed three days a week each session for 30 minutes at 50% to 80% of 1 repetition maximum (1RM), and aerobic training started from 50% and progressively reached 80% of maximum heart rate. Blood samples and anthropometric parameters were measured before and after practice. Data were analyzed by covariance. $P < 0.05$ was considered the significance level.
Results: Significant changes were observed in body mass index (BMI), weight, body fat percentage (%BF), and skinfold fat after the intervention ($P < 0.05$). But, no significant changes occurred in FBS, glycosylated hemoglobin, HOMA-IR, plasma insulin, HDL, LDL, TC, and TG ($P > 0.05$).
Conclusions: The current study suggested that concurrent strength and aerobic training can improve body composition of females with overweight and obesity, and normal blood lipid and glucose hemostasis. However, it did not affect glucose hemostasis and lipid profile.

Keywords: Insulin, Total Cholesterol, Glycosylated Hemoglobin, Body Composition

1. Background

There are associations between adolescent obesity and the increased overall risk of type 2 diabetes (1), cardiovascular disease (CVD), and mortality in adults (2). In the past two decades, the spread of obesity in children is witnessed (3). Obesity is considered as the main determinant of insulin resistance both in adults and children (4). Interestingly, body fat distribution is recognized as an important predictor of the adverse health consequences of obesity. In fact, lower visceral adipose tissue is related to higher cardiovascular and metabolic risk (5). The studies showed that the development of insulin resistance both in adults and children is affected more by abdominal visceral fat than the overall body fatness (6). Also, higher plasma free fatty acids (FFA) disrupt the glucose-fatty acid cycle in muscles, hindering elevated plasma FFA in insulin-mediated glucose transport (7). Moreover, it is shown that higher FFA plasma levels impair hepatic insulin action, increase hepatic glucose output, and alter lipoprotein metabolism (7). Weiss et al., (8) demonstrated that children and adults with obesity and insulin resistance vs. their peers with obesity and insulin sensitivity exhibited higher rates of visceral fat and intramyocellular lipids despite similar degrees of adiposity.

Concurrent training refers to the simultaneous performance of strength and aerobic training (9). Since skeletal muscles absorb more free fatty acid during muscle contraction (10), resistance training may play a role in dyslipidemia. In addition to its potential to increase muscle fiber size and strength, resistance training helps the improvement of lipid metabolism by reducing the synthesis of free fatty acids and inducing lipid oxidation (11). In comparison, aerobic exercise is a model usually recommended for individuals with obesity (12, 13). Some researchers claimed that combined trainings can produce even greater benefits to lipid profile and insulin sensitivity as compared with either aerobic or resistance trainings alone (14, 15).

Previous studies evaluating concurrent resistance and aerobic exercise sessions showed significant improvement in lipid profile (16, 17). In contrast, they did not find favorable changes in lipid profile (17, 18). Also, the effect of concurrent training on glucose homeostasis showed improvement (17) or no change (19). According to studies, concurrent exercise has better performance than resistance and aerobic trainings alone in promoting body composition (12, 20). On the other hand, two recent meta-analysis in adults with obesity and patients with type 2 diabetes revealed that concurrent exercise was the best method to enhance anthropometric indicators of adiposity (21) glycemic control, and blood lipids (22) as compared with aerobic or resistance alone. Although extensive studies are conducted on the benefits of aerobic and resistance alone, concurrent exercise in the children population is rarely examined (23). It cannot be confidently claimed that they would be similarly advantageous to treat children obesity. However, the evidence is ambiguous about the impact of concurrent exercise training on blood glucose homeostasis and lipid profile and the available data are contradictory. Therefore, the current study aimed at evaluating and comparing anthropometric parameters, blood glucose homeostasis, and blood lipid between the females with overweight and obesity after 12 weeks of concurrent training.

2. Methods

The current study was conducted on females with overweight and obesity in Lakan high school, Rasht, Guilan province, Iran. The current quasi-experimental study was conducted on 40 females within the age range of 13 - 15 years and body mass index (BMI) of 30.13 $\pm$ 3.73 kg/m^2 that voluntarily participated in the study and were randomly divided into four groups: obese (10 experimental and 10 control) and overweight (10 experimental and 10 control). The inclusion criteria were no exercise training in one year prior to the study and no illness. The tests were conducted in such a way that the subjects were in the first half of the menstrual cycle; i e, three to seven days after menstruation. Exercise training included the concurrent training of resistance and aerobic exercises for about 12 weeks. The study protocol was approved by human studies review committee of Islamic Azad University, Rasht, Iran as well as the ethics committee; the study was also registered in the Iranian registry of clinical trials (IRCT) (number: IRCT2015122222498N6). The participants provided written informed consent before participation in the study.

The weight and height were estimated by a standard calibrated scale and a stadiometer. BMI is weight in kilograms divided by height in meters squared. Caliper measured skinfold fat in three areas (arm, super iliac, and thigh). Then, the subcutaneous fat was calculated by the Jackson-Pollock body fat percent formula (24).

In the beginning and end of the study, the patients' blood glycemic tests of the brachial vein were collected after 12 hours fasting. Baseline blood glucose hemostasis tests including hemoglobin A1c (HbA1c), fasting blood sugar (FBS) (mg/dL), homeostasis model assessment (HOMA), and plasma insulin were measured. Blood lipid tests including high-density lipoprotein (HDL) and low-density lipoprotein (LDL) were performed by the direct method and Padco kits. Total cholesterol (TC) and triglycerides (TG) were estimated using the cholesterol oxidase-peroxidase (CHOD-PAP) method with Pars Azmoon enzyme kits (Iran). HbA1c was obtained by Biosystem autoanalyzer devices (Spain) and were performed using the turbid metric method. Insulin was obtained by Monobind kit and performed using the enzyme-linked immunosorbent assay (ELISA) technique. HOMA was measured by homeostasis model assessment-estimated insulin resistance (HOMA-IR).

HOMA-IR= FBS (mg/dL) $\times$ insulin (μU/mL) /22.5

The concurrent training was administered three times a week. Strength training was performed with 50% to 80% of 1 repetition maximum (1RM) for about 30 minutes, six to eight repetitions in each set and three minutes rest between sets that included four moves in the upper body: chest press machine, traction device, biceps, and butterflies and four moves in lower body: leg press, leg curl machine, leg extension machine, and standing calf machine. 1RM was calculated for eight moves in the experimental group and exercise intensity was calculated by the Brzycki formula to estimate muscle strength (25).

1 RM = 100 $\times$ load rep/ (102.78-2.78) $\times$ rep

Aerobic trainings were immediately applied as progression. First, the participants' rest heart rate (HR) was recorded and then their target HR was calculated by the Karvonen formula. The participants started the trainings on bicycle (15 minutes) and treadmill (15 minutes) with 50% - 60% of target HR for 30 minutes at the week 1, and they reached 70% - 80% of target heart rate by the weeks 7 and 8 (26). A treadmill and bicycle pulse test was used to check the target HR.

Target HR = (max HR - resting HR) $\times$ %intensity) + resting HR example

Table 1. The Range of Nutrient Intake of Females with Overweight and Obesity[a]

Variables	NDNS
Energy, kcal	1700
Fat, %	25
Protein, %	20
Carbohydrate, %	55

Abbreviation: NDNS, National Diet And Nutrition Survey (Ruston et al.).
[a]Data from females aged 11 to 18 years.

Dietary intake was individually prescribed by three-day recall technique before and during the research. The participants were asked to report the kinds and amounts of food and beverages they consumed both at home and away from home on a three-day recall basis; therefore, appropriate food items could be added to their dietary regimen and junk food items could be removed.

Mean daily intakes for total energy were 1700 kCal (27). The current study used a diet such as carbohydrates, protein, fat, fruits, and vegetables. Reduced fat spread (not polyunsaturated) was the most commonly consumed fat spread. The total consumption of vegetables and fruits was about 170 g/day (27). These items were given as a brochure in which the values of the indexes were mentioned (Table 1).

The normality of the data was indicated by the Kolmogorov-Smirnov test and according to the normality of the data, parametric statistics was used. Descriptive statistics such as mean $\pm$ standard deviation (SD) was used, and data were analyzed by covariance (ANCOVA) among the groups. The LSD post-hoc test was used to check the possible differences between time points. P value $\leq$ 0.05 was used as the significance level for all statistical analyses. Data processing was investigated with SPSS version 20.

3. Results

Results of analysis of ANCOVA for intergroup comparison of variables in groups with overweight and obesity are shown in Table 2. After 12 weeks of training, a significant difference was observed in %BF, skinfold fat, weight, and BMI among the four groups ($P < 0.001$), while FBS, HbA1c, insulin, and HOMA showed no significant reduction. Also, TC, LDL, HDL, and TG showed no significant changes.

LSD test showed a significant decrease in the weight, BMI, BF% and subcutaneous fat in both training groups with overweight and obesity ($P < 0.0001$) (Table 2).

4. Discussion

The current study compared the impacts of the concurrent resistance and endurance exercise training on body composition, blood glucose homeostasis and lipid profile after 12 weeks between the females with overweight and obesity. Despite the fact that concurrent training led to a significant reduction in BMI, weight, %BF, and skinfold fat, it did not significantly change FBS, glucose hemostasis, and blood lipid profile of females with overweight and obesity, which was consistent with the results of Medeiros et al., and Schranz et al. (12, 19). They showed that concurrent training was also effective on %BF and BMI. Lee et al., reported a significant reduction in abdominal subcutaneous and visceral fat (kg) within the aerobic and resistance exercise groups (11). The study was carried out on male adolescents, and the current study had similar aerobic training frequency and intensities that resulted in lower %BF in three months (12 weeks). Mello et al., looked at the long-term influences of aerobic + resistance training on the metabolic syndrome in 30 adolescents with obesity (aged 15 - 19 years) and found significant decreases in BMI, fat mass, and visceral fat (28). However, the study showed an improvement in fat index after 10 weeks of training that varied due to the maturity process between the two genders. Both genders exhibited higher body weight in the final stages of maturation. The fat mass and fat-free mass proportionally increased in females, while males demonstrated high fat-free mass and lower fat mass (29). Body fat may signal the risk of cardiovascular diseases (CVDs), blood pressure variations, cholesterol concentrations, and glucose tolerance (30, 31), whilst individuals with higher fat deposits in the upper body may be exposed to a higher risk of CVDs. However, the disease-related accumulations of fat in the trunk region can be firmly curbed by exercise.

In contrast, there were no significant differences in the weight and BMI in males with obesity aged 10 - 12 years after eight weeks of resistance training. The resistance training protocol included seven exercises consisting of three sets with 10 - 15 repetitions to fatigue three days per week (18). Furthermore, Alberga et al., assessed the effects of aerobic training, resistance training, or both in adolescents with obesity and the metabolic syndrome on male and female post-pubertal adolescents aged 14 - 18 years about 22 weeks and found no significant improvement in body composition in the concurrent group (13). In comparison, in terms of the training protocol the current study was different from Patel et al., which incorporated seven exercises consisting of three sets with 10 - 15 repetitions after eight weeks and Alberga et al., which incorporated aerobic exercise into their strength training program. These differences can be due short duration of the exercises with dif-

Table 2. Results of Measuring Parameters Related to Body composition and Hematology (N = 40)

Variable	Overweight		Obesity		ANCOVA[a]	
	Experimental[c]	Control[c]	Experimental[c]	Control[c]	F	Sig[b]
Body Composition						
Weight, kg					14.83	0.000*
Before	70.66 ± 4.42	72.99 ± 7.26	88.85 ± 6.65	88.54 ± 12.03		
After	68.51 ± 4.64[d]	73.81 ± 7.04[d]	85.46 ± 8.42[d]	89.24 ± 11.87[d]		
BMI, kg/m^2					14.89	0.000*
Before	26.45 ± 1.11	27.48 ± 1.55	32.73 ± 2.29	33.84 ± 2.44		
After	25.65 ± 1.42[d]	27.80 ± 1.45[d]	31.47 ± 2.83[d]	34.11 ± 2.34[d]		
Skinfold, mm					27.62	0.000*
Before	107.50 ± 14.15	122.60 ± 11.52	125. 50 ± 10.29	125.40 ± 12.13		
After	90.40 ± 11.43[d]	124.6 ± 10.73[d]	107.8 ± 9.08[d]	128.1 ± 11.29[d]		
Body fat, %					26.30	0.000*
Before	36.33 ± 3.54	39.76 ± 2.44	40.36 ± 2.06	40.32 ± 2.48		
After	32.04 ± 3.02[d]	40.19 ± 2.25[d]	36.49 ± 2.18[d]	40.87 ± 2.27[d]		
Biochemistry						
FBS, mg/dL					0.51	0.6
Before	93.10 ± 12.22	91.30 ± 6.03	91.50 ± 8.55	93.6 ± 12.48		
After	89.80 ± 6.57	89.10 ± 8.11	87.8 ± 5.7	92.6 ± 12.57		
HbA1c, %					2.47	0.07
Before	3.87 ± 0.46	4.17 ± 0.48	3.77 ± 0.24	4.17 ± 0.52		
After	3.84 ± 0.47	4.36 ± 0.50	3.74 ± 0.44	4.46 ± 0.61		
HOMA-IR					1.03	0.3
Before	2.34 ± 0.89	2.68 ± 1.55	3.10 ± 2.29	3.36 ± 4.29		
After	2.44 ± 2.48	5.97 ± 5.15	4.92 ± 4.48	5.33 ± 5.36		
Insulin, IU/mL					0.9	0.4
Before	5.63 ± 1.90	6.63 ± 3.87	7.88 ± 6.64	7.89 ± 10.18		
After	6.35 ± 7.32	15.13 ± 12.96	12.85 ± 11.80	12.81 ± 12.94		
TG, mg/dL					1.03	0.3
Before	94.9 ± 44.76	106.40 ± 24.44	107.10 ± 44.49	108.80 ± 54.00		
After	88.6 ± 41.91	122.5 ± 36.61	109.7 ± 46.33	107.2 ± 50.81		
HDL, mg/dL					2.06	0.1
Before	40.80 ± 8.09	40.50 ± 8.88	39.80 ± 8.03	41.00 ± 5.14		
After	41.30 ± 8.04	40.20 ± 8.57	40.00 ± 8.08	41.00 ± 5.27		
LDL, mg/dL					1.22	0.3
Before	91.4 ± 23.81-	84.9 ± 16.2	92.9 ± 10.61	98.6 ± 22.09		
After	89.9 ± 20.51	83.3 ± 17.61	97.6 ± 18.09	93.9 ± 21.86		
Total cholesterol, mg/dL					1.42	0.2
Before	139.7 ± 24.38	132.6 ± 14.23	142.8 ± 12.29	150.4 ± 25.72		
After	148.4 ± 22.52	141.6 ± 21.75	156.5 ± 22.52	149.7 ± 25.76		

Abbreviations: %BF, Percentage of Body Fat; BMI, Body Mass Index; FBS, Fasting Blood Sugar; HDL, High-Density Lipoprotein; LDL, Low-Density Lipoprotein; TG, Triglyceride.
[a]The values were analyzed by ANCOVA.
[b]Significant difference at $P < 0.05$.
[c]Values are expressed as mean ± SEM.
[d]The values were analyzed by post hoc (LSD test) for the experimental and control groups in both groups of obesity and overweight.

ferent exercise modalities.

The current study also showed no significant differences in fasting blood sugar, insulin, HbA1c, and HOMA. Recent studies showed that exercise results in higher GLUT4 (glucose transporter type 4) content, glycogen synthase activity, mitochondrial enzyme activity, and density in skeletal muscles (32). In addition, exercise improves insulin sensitivity via its improvement of body composition in long term (32). It was shown that HbA1c decreased in females after eight weeks of concurrent high intensity intermittent exercise (17). Ackel-D'Elia et al., evaluated the effects of aerobic plus resistance trainings after six months on males and females aged 15 - 19 years. They found that none of them had significant impacts on glucose, HOMA, and insulin (33). Also, Patel et al., exercised resistance training on males with obese aged 10 - 12 years for eight weeks and showed no decrease in insulin, HOMA, and glucose (18), which were in agreement with those of the current study. It is reported that higher skeletal muscle mass is associated with lower HbA1c supporting the hypothesis that resistance training helps better glycemic control by ramping up the skeletal muscle storage of glucose (33).

Inconsistent with the current study findings, Antunes et al., observed a reduction in fasting blood sugar after a 20-week concurrent training on adolescents with obesity and the age range of 12 - 15 years (mean: 13.4 $\pm$ 0.96) (26). This difference could be explained by the effect of almost a 20-week concurrent training on glycaemia. Piano et al., observed a change in glycaemia among adolescents with obesity (34). Fifty-eight post-pubertal adolescents with obesity were randomized to AT or AT + RT with diet. It seems that training methods with diet were the main differences of their study with the current study. Also, it was shown that fasting glycaemia, serum insulin, and HOMA-IR for insulin resistance decreased in females after eight weeks into a program of combined physical exercise (high intensity interval + resistance training) (17). In comparison, the current study differed in training protocol and age from Alvarez et al., which incorporated high intensity interval + resistance training.

Overall, in many researches, the subjects experienced a decrease in body mass and obesity along with a significant improvement in blood lipid profile after concurrent training. However, some studies reported no effects. Patel et al., after eight weeks of resistance training on males with obesity aged 10 - 12 years, observed no decreases in lipid profiles (18). Also, consistent with the current study findings for LDL-c and TC, similar results were found for concurrent training after 20 weeks in adolescents with obesity (20). In contrast, the current study results were in disagreement with those of Antunes et al., Monteiro et al., and Sung et al. In the study by Antunes et al., samples included 25 adolescents with obesity aged 12 - 15 years. It was reported that just the female group showed significant decreases in LDL and TC after 20 weeks. Training protocol in their study was similar to that of the current study (18, 20, 30). In a study on 82 children with obesity aged eight to eleven years, Sung et al., observed significant reductions in TC and LDL-C after a six week resistance training (35). The study by Sung et al., differed in training methods, training duration, and participants' age.

The reason for the lack of significant changes in glucose hemostasis and blood lipid indices in the current study was probably the normal level of the variables and the type, duration, and intensity of the exercise trainings. The limitations of the current study should be highlighted. Although the diet was used in the study, the amount of their follow-up to the diet is unclear. A more accurate diet and larger samples are recommended in future researches.

Overall, exercise training plays a key role to control the complications and symptoms of the obesity in females with overweight and obesity. As a result, concurrent training had a positive effect on body composition and it can be recommended to teachers and coaches to use concurrent training since these types of training can be an effective method to improve body composition in females with overweight and obesity.

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Footnotes

Authors' Contribution: Ramin Shabani, study design and coordinating the research; Zohreh Jalali, data collection; Marzieh Nazari, writing the manuscript and performing the statistical analyses. All authors revised the manuscript and approved the final copy.

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References

1. Maggi S, Busetto L, Noale M, Limongi F, Crepaldi G. Obesity: Definition and epidemiology. *Multidiscip Approach to Obesity*. 2015;**118**(4):31–9. doi: 10.1007/978-3-319-09045-0_3.
2. Goodman E, Daniels SR, Morrison JA, Huang B, Dolan LM. Contrasting prevalence of and demographic disparities in the World Health Organization and National Cholesterol Education Program Adult Treatment Panel III definitions of metabolic syndrome among adolescents. *J Pediatr*. 2004;**145**(4):445–51. doi: 10.1016/j.jpeds.2004.04.059. [PubMed: 15480365].
3. Ogden CL, Carroll MD, Lawman HG, Fryar CD, Kruszon-Moran D, Kit BK, et al. Trends in Obesity Prevalence Among Children and Adolescents in the United States, 1988-1994 Through 2013-2014. *JAMA*. 2016;**315**(21):2292–9. doi: 10.1001/jama.2016.6361. [PubMed: 27272581].
4. Chiarelli F, Marcovecchio ML. Insulin resistance and obesity in childhood. *Eur J Endocrinol*. 2008;**159 Suppl 1**:S67–74. doi: 10.1530/EJE-08-0245. [PubMed: 18805916].

5. Tchernof A, Despres JP. Pathophysiology of human visceral obesity: an update. *Physiol Rev*. 2013;**93**(1):359–404. doi: 10.1152/physrev.00033.2011. [PubMed: 23303913].
6. Goran MI, Ball GD, Cruz ML. Obesity and risk of type 2 diabetes and cardiovascular disease in children and adolescents. *J Clin Endocrinol Metab*. 2003;**88**(4):1417–27. doi: 10.1210/jc.2002-021442. [PubMed: 12679416].
7. Cornier MA, Dabelea D, Hernandez TL, Lindstrom RC, Steig AJ, Stob NR, et al. The metabolic syndrome. *Endocr Rev*. 2008;**29**(7):777–822. doi: 10.1210/er.2008-0024. [PubMed: 18971485]. [PubMed Central: PMC5393149].
8. Weiss R, Kaufman FR. Metabolic complications of childhood obesity: identifying and mitigating the risk. *Diabetes Care*. 2008;**31 Suppl 2**:S310–6. doi: 10.2337/dc08-s273. [PubMed: 18227502].
9. Amirkhizi F, Siassi F, Djalali M, Foroushani AR. Evaluation of oxidative stress and total antioxidant capacity in women with general and abdominal adiposity. *Obes Res Clin Pract*. 2010;**4**(3):e163–246. doi: 10.1016/j.orcp.2010.02.003. [PubMed: 24345664].
10. Kiens B. Skeletal muscle lipid metabolism in exercise and insulin resistance. *Physiol Rev*. 2006;**86**(1):205–43. doi: 10.1152/physrev.00023.2004. [PubMed: 16371598].
11. Lee S, Bacha F, Hannon T, Kuk JL, Boesch C, Arslanian S. Effects of aerobic versus resistance exercise without caloric restriction on abdominal fat, intrahepatic lipid, and insulin sensitivity in obese adolescent boys: a randomized, controlled trial. *Diabetes*. 2012;**61**(11):2787–95. doi: 10.2337/db12-0214. [PubMed: 22751691]. [PubMed Central: PMC3478522].
12. Schranz N, Tomkinson G, Olds T. What is the effect of resistance training on the strength, body composition and psychosocial status of overweight and obese children and adolescents? A Systematic review and meta-analysis. *Sports Med*. 2013;**43**(9):893–907. doi: 10.1007/s40279-013-0062-9. [PubMed: 23729196].
13. Alberga AS, Frappier A, Sigal RJ, Prud'homme D, Kenny GP. A review of randomized controlled trials of aerobic exercise training on fitness and cardiometabolic risk factors in obese adolescents. *Phys Sportsmed*. 2013;**41**(2):44–57. doi: 10.3810/psm.2013.05.2014. [PubMed: 23703517].
14. Davidson LE, Hudson R, Kilpatrick K, Kuk JL, McMillan K, Janiszewski PM, et al. Effects of exercise modality on insulin resistance and functional limitation in older adults: a randomized controlled trial. *Arch Intern Med*. 2009;**169**(2):122–31. doi: 10.1001/archinternmed.2008.558. [PubMed: 19171808].
15. Marques E, Carvalho J, Soares JM, Marques F, Mota J. Effects of resistance and multicomponent exercise on lipid profiles of older women. *Maturitas*. 2009;**63**(1):84–8. doi: 10.1016/j.maturitas.2009.03.003. [PubMed: 19356868].
16. Elmahgoub SM, Lambers S, Stegen S, Van Laethem C, Cambier D, Calders P. The influence of combined exercise training on indices of obesity, physical fitness and lipid profile in overweight and obese adolescents with mental retardation. *Eur J Pediatr*. 2009;**168**(11):1327–33. doi: 10.1007/s00431-009-0930-3. [PubMed: 19184101].
17. Alvarez C, Ramirez-Campillo R, Henriquez-Olguin C, Castro-Sepulveda M, Carrasco V, Martinez C. [Eight weeks of combined high intensity intermittent exercise normalized altered metabolic parameters in women]. *Rev Med Chil*. 2014;**142**(4):458–66. doi: 10.4067/S0034-98872014000400007. [PubMed: 25117036].
18. Patel SJ, Hanks LJ, Ashraf AP, Gutierrez OM, Bamman MM, Casazza K. Effects of 8 week resistance training on lipid profile and insulin levels in overweight/obese peri-pubertal boys-a pilot study. *J Diabetes Res Clin Metab*. 2015;**4**(1):2. doi: 10.7243/2050-0866-4-2.
19. Medeiros Nda S, de Abreu FG, Colato AS, de Lemos LS, Ramis TR, Dorneles GP, et al. Effects of concurrent training on oxidative stress and insulin resistance in obese individuals. *Oxid Med Cell Longev*. 2015;**2015**:697181. doi: 10.1155/2015/697181. [PubMed: 25722796]. [PubMed Central: PMC4334864].
20. Monteiro PA, Chen KY, Lira FS, Saraiva BT, Antunes BM, Campos EZ, et al. Concurrent and aerobic exercise training promote similar benefits in body composition and metabolic profiles in obese adolescents. *Lipids Health Dis*. 2015;**14**:153. doi: 10.1186/s12944-015-0152-9. [PubMed: 26611872]. [PubMed Central: PMC4660803].
21. Schwingshackl L, Dias S, Strasser B, Hoffmann G. Impact of different training modalities on anthropometric and metabolic characteristics in overweight/obese subjects: a systematic review and network meta-analysis. *PLoS One*. 2013;**8**(12). e82853. doi: 10.1371/journal.pone.0082853. [PubMed: 24358230]. [PubMed Central: PMC3866267].
22. Schwingshackl L, Missbach B, Dias S, Konig J, Hoffmann G. Impact of different training modalities on glycaemic control and blood lipids in patients with type 2 diabetes: a systematic review and network meta-analysis. *Diabetologia*. 2014;**57**(9):1789–97. doi: 10.1007/s00125-014-3303-z. [PubMed: 24996616].
23. Garcia-Hermoso A, Ramirez-Velez R, Ramirez-Campillo R, Peterson MD, Martinez-Vizcaino V. Concurrent aerobic plus resistance exercise versus aerobic exercise alone to improve health outcomes in paediatric obesity: a systematic review and meta-analysis. *Br J Sports Med*. 2018;**52**(3):161–6. doi: 10.1136/bjsports-2016-096605. [PubMed: 27986760].
24. Segheto W, Coelho FA, Cristina Guimaraes da Silva D, Hallal PC, Marins JC, Ribeiro AQ, et al. Validity of body adiposity index in predicting body fat in Brazilians adults. *Am J Hum Biol*. 2017;**29**(1). doi: 10.1002/ajhb.22901. [PubMed: 27502080].
25. Abdul-Hameed U, Rangra P, Shareef MY, Hussain ME. Reliability of 1-repetition maximum estimation for upper and lower body muscular strength measurement in untrained middle aged type 2 diabetic patients. *Asian J Sports Med*. 2012;**3**(4):267–73. doi: 10.5812/asjsm.34549. [PubMed: 23342225]. [PubMed Central: PMC3525823].
26. Antunes Bde M, Christofaro DG, Monteiro PA, Silveira LS, Fernandes RA, Mota J, et al. Effect of concurrent training on gender-specific biochemical variables and adiposity in obese adolescents. *Arch Endocrinol Metab*. 2015;**59**(4):303–9. doi: 10.1590/2359-3997000000095. [PubMed: 26331317].
27. Beverley B. *National Diet and Nutrition Survey. Results from Years 1-4 (combined) of the Rolling Programme (2008/2009- 2011/12)*. Northern Ireland; 2017.
28. de Mello MT, de Piano A, Carnier J, Sanches Pde L, Correa FA, Tock L, et al. Long-term effects of aerobic plus resistance training on the metabolic syndrome and adiponectinemia in obese adolescents. *J Clin Hypertens (Greenwich)*. 2011;**13**(5):343–50. doi: 10.1111/j.1751-7176.2010.00388.x. [PubMed: 21545395].
29. Daniels SR, Morrison JA, Sprecher DL, Khoury P, Kimball TR. Association of body fat distribution and cardiovascular risk factors in children and adolescents. *Circulation*. 1999;**99**(4):541–5. doi: 10.1161/01.CIR.99.4.541. [PubMed: 9927401].
30. van Greevenbroek MM, Schalkwijk CG, Stehouwer CD. Obesity-associated low-grade inflammation in type 2 diabetes mellitus: causes and consequences. *Neth J Med*. 2013;**71**(4):174–87. [PubMed: 23723111].
31. Ebbert JO, Jensen MD. Fat depots, free fatty acids, and dyslipidemia. *Nutrients*. 2013;**5**(2):498–508. doi: 10.3390/nu5020498. [PubMed: 23434905]. [PubMed Central: PMC3635208].
32. Eisenmann JC, DuBose KD, Donnelly JE. Fatness, fitness, and insulin sensitivity among 7- to 9-year-old children. *Obesity (Silver Spring)*. 2007;**15**(8):2135–44. doi: 10.1038/oby.2007.254. [PubMed: 17712133].
33. Ackel-D'Elia C, Carnier J, Bueno CJ, Campos RM, Sanches PL, Clemente AP, 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. [PubMed: 23868679].
34. de Piano A, de Mello MT, Sanches Pde L, da Silva PL, Campos RM, Carnier J, et al. Long-term effects of aerobic plus resistance training on the adipokines and neuropeptides in nonalcoholic fatty liver disease obese adolescents. *Eur J Gastroenterol Hepatol*. 2012;**24**(11):1313–24.

doi: 10.1097/MEG.0b013e32835793ac. [PubMed: 22932160].
35. Sung RY, Yu CW, Chang SK, Mo SW, Woo KS, Lam CW. Effects of dietary intervention and strength training on blood lipid level in obese children. *Arch Dis Child*. 2002;**86**(6):407–10. [PubMed: 12023168]. [PubMed Central: PMC1763008].