Effects of Aerobic Versus Resistance Training on Serum Leptin and Insulin Resistance in Healthy Sedentary Men

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Abstract

Background: New pieces of evidence show that the leptin released from adipose tissue is associated with obesity; however, leptin response to different types of exercise programs in humans is unknown.

Objectives: The aim of this study was to compare the effects of aerobic versus resistance training on serum leptin and insulin resistance in sedentary men.

Methods: Thirty male volunteers with a mean age of 23.2 ± 1.23 years, body mass index (BMI) 23.9 ± 0.95 kg.m^{-2}, fat percent 18.28 ± 1.15, and waist-to-hip ratio 0.89 ± 0.02 were randomly assigned into three groups, including aerobic, resistance exercise, and control groups (n = 10). The resistance exercise program was performed for 60 minutes at 70% of one repetition maximum for 3 sets. Every set consisted of 10 repetitions per move (RPM) followed by a 30-second-rest interval between every station accompanied by a 2-minute-rest between every set. The aerobic exercise program consisted of running on a treadmill for 30 minutes at 60 to 70 percent of reserved heart rate (maximum heart rate-heart rate rest). Fasting blood samples were collected before and after 6 weeks after the termination of the exercise protocol in order to determine the plasma leptin level and insulin resistance.

Results: The results of one-way ANOVA showed that body fat percentage and waist-to-hip ratio were significantly decreased in both experimental groups and maximum aerobic power and one repetition maximum of bench press plus leg press were significantly increased (P < 0.05). In addition, insulin resistance levels were significantly decreased in both exercises groups compared with the control group. However, the leptin level was significantly decreased in the aerobic exercise group compared with the other two groups (P < 0.05).

Conclusions: According to these findings, both aerobic and resistance training without changes in body weight and body mass index appear to be a non-prescriptive therapeutic approach to lower the insulin levels and insulin resistance in sedentary men. However, aerobic versus resistance training may play a role in regulating systemic leptin.

Keywords: Exercise, Insulin Resistance, Leptin

1. Background

Leptin is a hormone with several functions, including long-term adjustment of body weight, energy balance, and body temperature. This hormone is mainly produced by adipocytes, which causes the feeling of fullness through the hypothalamus neurotransmitter regulation and energy expenditure. There are pieces of evidence showing a strong association between the serum leptin and fat level within the body; however, there may be other factors, including catecholamine, insulin, free fatty acids, food intake rate and gender involved in regulating the leptin levels. In addition, previous studies show leptin plays a regulatory role in absorption and energy use (1). Research findings show that exercise increases energy expenditure that may alter body composition and may change plasma leptin concentration (2).

Research results showed that short-term aerobic exercise training caused no significant change in serum leptin level (3). While other studies showed that extreme physical activity may lead to a decrease in leptin concentration due to a decrease in weight and fat mass (4). However, there are insufficient research findings to show that short-term exercise (less than 12 weeks) have any significant effect on leptin unless when the exercise is linked to fat mass reduction (2, 5).

With respect to the exercise type, aerobic training is commonly used for different reasons; however, resistance

training is more beneficial for gaining physical fitness, increased performance, injury prevention, increased muscle size, as well as different physiological and biochemical responses (6). Several studies have shown that resistance training programs resulted in positive changes in body composition in obese individuals (7, 8). The results of several studies have indicated that 6-week-resistance training has no significant effect on leptin levels in healthy men (9) or in type 2 diabetes men (10) whereas Abedi and Abbasi-Bakhtiari reported a decrease in leptin concentration and insulin resistance after combined training in overweight men (11).

2. Objectives

Considering the lack of concrete evidence against the effectiveness of aerobic versus resistance training on serum leptin level, this research was designed to compare the effect of 6-week-aerobic training with resistance training in sedentary healthy men.

3. Methods

This quasi-experimental research was comprised of three groups: aerobic, resistance exercise, and control groups (Table 1). The inclusion criteria were body mass index (BMI) within the range of 18.5 to 24.9 kg.m^{-2}, systolic blood pressure lower than 140 mmHg, diastolic pressure below 90 mmHg, low-density lipoprotein cholesterol (LDL- C) less than 130 mg.dL^{-1}, HDL-C (40 - 60 mg.dL^{-1}), total cholesterol (TC) less than 200 mg.dL^{-1}, blood glucose less than 100 mg.dL^{-1}, and the waist-to-hip ratio (less than 0.95). The individuals with a history of regular physical activity, weight change of more than 2 kg, any disease history, cigarette smoking for the past six months, and BMI above 25, acute disease aggravated by sport, use of any medication were excluded from the study. The participants were informed about the purpose, benefits, and risks of the research and fulfilled a written informed consent before the start of the project. The characteristics of the subjects are presented in Table 1.

The participants referred to the laboratory at 8 - 10 AM on the day of the exercise program for body composition assessment. The body weight was measured bare-footed with minimum cloth by a digital glass scale (GES-07) with a precision of ± 0.1 kg and the height was measured by a wall tread (model 44440 made by Kaveh Co., Iran with a precision of ± 0.1 cm) in an erect standing position beside the wall. The waist circumference was measured at the

narrowest part of the waist at the end of a normal exhalation. Hip circumference was measured at its most prominent part. An elastic strip of non-reactive tape was used to measure the size with no pressure applied to the body. BMI was calculated by dividing body weight (kg) by squared height (m^2). Body fat percentage was calculated by using three-site skinfold measures on chest, abdomen, and thigh on the right side of the body repeated for three consecutive times with 20 seconds rest interval between every measurement. The average score was calculated and used as the score to analyze the data. Jackson-Pollack formula (12) and the Siri equation (13) were measured in the following ways:

Body fat percentage = 4.99: (BD) - 4.55 × 100 (for people under the age of 19)

Body fat percentage = 4.95: (BD) - 4.55 × 100 (for people over the age of 19)

BD = 1.10938 - 0.0008267 × (total fat in three areas/mm) = 0.0000016 × (total fat in three areas/mm)^2 - 0.0002574 × (age to year)

Following the completion of the procedures, the participants referred to the gym for learning how to use the sport equipment and perform the exercise program. They learned how to use weight lifting techniques and treadmill (7410 Runner Made Italy). Every participant started his program after 10 minutes of special warm-up exercise to determine one repetition maximum (1RM). Maximum Bruce test was employed to estimate maximum oxygen consumption (VO2$_{max}$) (14). Three days after the 1RM test assignment and estimation of VO2$_{max}$, the participants started the exercise protocol.

The participants' dietary data was recorded by a 24-hour recall questionnaire in three days (two days at the beginning of the week and one day at the end of the week) and recorded in a special diet sheet (15, 16). The participants were asked to record all foods and beverages consumed during the last 24 hours. To analyze the data, the food consumed in grams was recorded. By using Dorosty Food Processor software (NIII FP2), diet information was analyzed to determine macronutrients during the entire time of the activities. The participants received instruction about a standard diet (15, 16). The energy requirement of basic metabolism was calculated based on age, sex, weight according to Harris Benedict's formula. The total energy needed per day was calculated after adjusting the activity factor (17).

The exercise protocol included a general warm-up (10 minutes), special warm-up (3 to 5 minutes), aerobic, resistance, stretching and cold-down exercise (5 minutes). The resistance exercise was performed at 70% of one repetition maximum, 10 repetitions per move for 3 consecutive sets

Table 1. The Physical Characteristics of the Subjects in Pre- and Post-Test[a]

Variable/Time Group	Aerobic Group	Resistance Group	Control Group	F	P Value
Age, y				0.704	-
Pre-test	23.30 ± 1.34	23.1 ± 1.37	22.9 ± 1.66		
Height, cm				1.593	-
Pre-test	168.6 ± 4.27	167.8 ± 4.49	173.8 ± 10.32		
Weight, kg				0.8	0.6
Pre-test	68.37 ± 3.57	67.12 ± 5.61	69.89 ± 5.93		
Post-test	68.26 ± 3.58	67.11 ± 5.77	69.78 ± 4.93		
BMI, kg.m^{-2}				1.85	0.28
Pre-test	24.04 ± 0.86	23.79 ± 1.15	24.05 ± 0.81		
Post-test	23.99 ± 0.87	23.79 ± 1.2	24.25 ± 0.92		
VO2$_{max}$, mL.kg^{-1}.min^{-1}				2.65	0.02[b]
Pre-test	37.27 ± 2.80	38.12 ± 2.28	35.74 ± 2.49		
Post-test	40.27 ± 2.06[b]	38.66 ± 1.88[b]	36.24 ± 1.89		
Fat, %				2.45	0.02[b]
Pre-test	18.88 ± 1.17	18.76 ± 1.63	18.71 ± 1.24		
Post-test	17.6 ± 1.35[b]	17.9 ± 0.98[b]	18.91 ± 0.01		
WHR, cm				1.85	0.03[b]
Pre-test	0.89 ± 0.009	0.89 ± 0.015	0.89 ± 0.01		
Post-test	0.87 ± 0.013[b]	0.87 ± 0.012[b]	0.92 ± 0.01		
1RM chest press, kg				2.65	0.012[b]
Pre-test	66 ± 9.13	6.2 ± 10.11	64.3 ± 10.01		
Post-test	68.1 ± 8.7[b]	75.6 ± 9.32[b]	63.15 ± 9.41		
1RM leg press, kg				2.35	0.028[b]
Pre-test	120.5 ± 12.45	124.05 ± 14.75	118 ± 16.3		
Post-test	128 ± 12.13[b]	135.1 ± 13.48[b]	119 ± 13.2		

[a]Values are expressed as mean ± SD.
[b]The value of P ≤ 0.05 was considered statistically significant.

with a 30-second-rest interval between every station and a 2-minute-rest interval between every set. Resistance exercise program was performed in 10 stations as follows (1) leg flexion, (2) leg extension, (3) foot press, (4) squats, (5) armpit pull, (6) chest press, (7) cross-dumbbell movement (8) curl with bar, (9) triceps and, (10) sit-up. The aerobic exercise was performed on a treadmill. The participants ran for 30 minutes at 60 to 70% of maximum oxygen consumption (18).

The blood sample was collected by a lab technician after 8 to 10 hours of fasting before and after the start and termination of the exercise protocol by drawing 10 cc of venous blood in a sitting position. The serum was immediately separated in a lab through a centrifugal procedure at 3000 rpm and kept frozen at -70°C until the analysis day.

Fasting blood glucose was measured by glucose oxidase enzyme (kits of Pars Azmoon Co., Tehran, Iran) and by Hitachi 902 (Germany). Serum leptin level was assessed by using a leptin kit (DRG-Diagnostica, GmbH, Germany) with a sensitivity of 1 ng.mL^{-1} and a coefficient of intrinsic and extraversion changes of 4.5 and 6.6%, using competitive sandwich ELISA. Serum insulin level was measured using an insulin kit (DRG-Diagnostica, GmbH, Germany) with a sensitivity of 1.76 μUI.mL^{-1} and an intra-control and extraversion coefficient of 2.19 and 4.43%, respectively by competitive sandwich ELISA. The homeostasis model assessment (HOMA) index was calculated based on the product of fasting blood glucose concentration (mmol.L^{-1}) in the fasting insulin concentration (μg.mL^{-1}) divided by the constant factor of 22.5. All blood samples were evaluated for every

variable at a specific time to minimize variation (6). Concentrations of hormones after the activity were adjusted for plasma volume changes. In the present study, Shapiro-Wilk method confirmed the normality of the dependent variables. Furthermore, parametric statistical methods, including one-way ANOVA and Tukey's post hoc test were used to compare the differences. All the analyses were performed by using SPSS 21 software at a significance level of 0.05.

4. Results

In Table 1, the physical characteristics of the experimental and control groups before and after the exercise program are presented. The results of One-way ANOVA indicated that there was a significant difference in fat percentage change, waist-to-hip ratio, maximum aerobic power, maximum repeat bench press, and leg press in three groups ($P \leq 0.05$). Tukey's post hoc test showed that the experimental groups (aerobic and resistance) improved significantly compared with the control groups in these variables after the exercise program.

In addition, the result of ANOVA showed that there was a significant difference between the levels of insulin resistance and leptin in the 3 groups ($P < 0.05$); Tukey's post hoc test showed that the levels of insulin resistance were significantly decreased in both aerobic and resistance exercise groups compared with the control group. Also, the leptin level was significantly decreased in the aerobic exercise group in comparison to the resistance and control groups. These results are presented in Table 2.

5. Discussion

According to the results of this study, six weeks of exercise regardless of its type (aerobic, resistance) reduced total insulin resistance in sedentary individuals. These results were in agreement with the findings of some other studies that reported improvement in insulin resistance in healthy and obese subjects after participation in the endurance training program (19, 20). In addition, the result of this study showed that insulin resistance was decreased without any significant change in body weight and BMI; a finding similar to the findings of other studies reported earlier (21, 22).

It has been well documented that endurance exercise (acute and prolonged) improves insulin resistance due to temporary muscle contraction and increased glucose uptake and skeletal muscle mass (23). Several studies suggest that similar resistance exercise together with endurance training can lead to improvement in insulin resistance (21-23). Some studies also suggest that resistance exercise may be a useful intervention to increase insulin sensitivity in free-fat tissue masses in normal subjects (21, 24) and young people with insulin resistance (25). Therefore, the mechanism responsible for improving insulin function includes both and glucose transfer protein (Glut-4) and positive regulation of insulin receptor components such as insulin receptor protein, protein kinase B, and glycogen synthesis (22). The present study showed that exercise regardless of its type improves the insulin activity in the sedentary men accompanied by no change in weight and BMI. However, the decrease in body fat percent, waist/hip ratio (W/H), upper strength (BPmax), and lower limb (LPmax) in the participants of this study show that it is possible to decrease insulin resistance without these changes; nevertheless, considering these changes as a potential mechanism for decrease in insulin resistance needs further research. Therefore, the improvement in insulin resistance as a result of exercise may have occurred via other mechanisms such as adipokine mediators (26).

This study also showed that 6-week-aerobic exercise reduces leptin response in healthy sedentary men. Friedman et al. observed that 8 to 12 weeks of aerobic exercise performed in 5 days a week, 1.5 hours per day at 70% maximum rate of oxygen consumption ($VO2_{max}$) intensity resulted in the 85% lower expression of leptin mRNA in subcutaneous fat in rats. The exercise group also showed a lower body fat percentage that may indicate a relationship between the expression of leptin and body fat (27). In addition, Fedewa et al. examined the effect of moderate aerobic exercise (50% $VO2_{max}$) and showed a decrease in leptin level concentrations in middle-aged obese inactive females. The ratio of leptin concentration to body mass and BMI was decreased after the exercise program. These authors suggested that the decrease in leptin concentration was probably due to weight loss (28). On the other hand, Karacabey examined the effect of 12 weeks of aerobic exercise performed by 40 obese boys and concluded the BMI, LDL-C, cortisol, leptin, and insulin levels were significantly lower in the training group after 12 weeks compared with baseline values, whereas HDL-C levels were significantly higher. In contrast, in the control group, LDL-C, cortisol and leptin levels after 12 weeks were significantly higher than baseline values while HDL-C levels were significantly lower. These results show the importance of regular training in the regulation of body weight and protection against cardiovascular risk factors in obese children (29); however, it is unclear how the leptin responds to exercises considering the contradictory results reported earlier. Probably the contradictory findings in regard to leptin response to exercise

Table 2. The Serum Levels of Insulin, Glucose, Insulin Resistance, and Leptin in Pre- and Post-Test[a]

Variable/Time Group	Aerobic Group	Resistance Group	Control Group	F	P Value
Insulin, mcIU.mL^{-1}				2.869	0.057
Pre-test	6.74 ± 0.82	6.25 ± 0.32	6.54 ± 0.56		
Post-test	6.86 ± 0.42[b]	$5.8 \pm .022$[b]	6.54 ± 0.6		
Glucose, mmol.L^{-1}				2.09	0.069
Pre-test	4.7 ± 0.19	4.57 ± 0.38	4.93 ± 0.39		
Post-test	4.7 ± 0.17	4.55 ± 0.32	4.93 ± 0.39		
Insulin resistance				3.28	0.04[b]
Pre-test	1.41 ± 0.21	1.28 ± 0.13	1.43 ± 0.24		
Post-test	1.22 ± 0.9[b]	1.17 ± 0.93[b]	1.63 ± 0.34		
Leptin, ng. mL^{-1}				2.69	0.04[b]
Pre-test	6.34 ± 1.23	6.05 ± 0.85	6.35 ± 1.20		
Post-test	5.03 ± 0.53[b]	5.8 ± 0.67	6.55 ± 1.42		

[a]Values are expressed as mean $\pm$ SD.
[b]The value of $P \leq 0.05$ was considered statistically significant.

are due to the population (male, female, trained and not practiced), types of exercises used (type, intensity, duration and volume) or energy costs for the participants ([2]). Leptin plays an important role in regulating food intake and energy costs. In other words, leptin reduces appetite through the central nervous system by neuropeptide Y (an appetite enhancer). Moreover, it leads to an increase in caloric intake by stimulating the sympathetic system, thus the response of the central nervous system to plasma leptin leads to a decrease in the volume of adipose tissue and inhibits the production of leptin ([30]). Some researchers have reported that lowering leptin due to exercise tends to increase catecholamine and lower serum insulin levels. Physical activity includes a significant part of the energy cost of humans. This indicates that energy consumption positively or negatively affects the expression level of the leptin gene expression. Thus energy expenditure changes may affect the amount of leptin via the exercise ([31]).

The findings of the present research were inconsistent with the findings of other researchers with respect to the effect of resistance exercise on leptin in which it was demonstrated leptin change was associated with a decrease in weight ([32]). Resistance training may lead to a lower energy consumption state as the time of exercise continues; this kind of exercise compared with aerobic and concurrent exercise results in maintaining body mass fatfree through a lower metabolic rate. Contradictory findings have been reported about the effect of strength training on leptin when limited number of short-term exercise studies have been contrasted with longer period studies ([33]). For instance, Eftekhari et al. studied physical activity, lipid profiles, and leptin who observed the fiveweek moderate- intensity aerobic training had significant changes in BW and HDL in young females but had no significant impact on BMI, FP, FM, FFM, LDL, TG, TC, and leptin concentration ([34]). In a randomized controlled study, Abedi and Abbasi-Bakhtiari examined the effect of exercise program on leptin response and reported that leptin changes were strongly associated with the metabolic rate of rest, anthropometric, BMI, and W/H ratios changes. While the percentage of decrease in leptin level was positively correlated with a decrease in BMI, it was inversely associated with the changes in the metabolic rate of rest. Thus a significant change in leptin depended on aerobic exercise, the individual, resistance exercise program, condition of the participants, and energy balance. As has been stated earlier, resistance training results in a significant decrease in leptin secretion when the frequency of exercise sessions approaches the true point ([11]).

5.1. Conclusions

According to the findings, both aerobic and resistance training without changes in body weight and body mass index appear to be a non-prescriptive therapeutic approach to lower insulin levels and insulin resistance in sedentary men. However, aerobic versus resistance training may play a role in regulating systemic leptin.

Supplementary Material

Supplementary material(s) is available here [To read supplementary materials, please refer to the journal web-

site and open PDF/HTML].

References

1. Paz-Filho GJ. The effects of leptin replacement on neural plasticity. *Neural Plast*. 2016;**2016**:8528934. doi: 10.1155/2016/8528934. [PubMed: 26881138]. [PubMed Central: PMC4735938].

2. Bouassida A, Chamari K, Zaouali M, Feki Y, Zbidi A, Tabka Z. Review on leptin and adiponectin responses and adaptations to acute and chronic exercise. *Br J Sports Med*. 2010;**44**(9):620–30. doi: 10.1136/bjsm.2008.046151. [PubMed: 18927166].

3. Nuri R, Moghaddasi M, Darvishi H, Izadpanah A. Effect of aerobic exercise on leptin and ghrelin in patients with colorectal cancer. *J Cancer Res Ther*. 2016;**12**(1):169–74. doi: 10.4103/0973-1482.155982. [PubMed: 27072232].

4. Yu N, Ruan Y, Gao X, Sun J. Systematic review and meta-analysis of randomized, controlled trials on the effect of exercise on serum leptin and adiponectin in overweight and obese individuals. *Horm Metab Res*. 2017;**49**(3):164–73. doi: 10.1055/s-0042-121605. [PubMed: 28249299].

5. Hulver MW, Houmard JA. Plasma leptin and exercise: Recent findings. *Sports Med*. 2003;**33**(7):473–82. doi: 10.2165/00007256-200333070-00001. [PubMed: 12762824].

6. Malina RM. Weight training in youth-growth, maturation, and safety: An evidence-based review. *Clin J Sport Med*. 2006;**16**(6):478–87. doi: 10.1097/01.jsm.0000248843.31874.be. [PubMed: 17119361].

7. Yu CC, Sung RY, So RC, Lui KC, Lau W, Lam PK, et al. Effects of strength training on body composition and bone mineral content in children who are obese. *J Strength Cond Res*. 2005;**19**(3):667–72. doi: 10.1519/14994.1. [PubMed: 16095423].

8. Shaibi GQ, Cruz ML, Ball GD, Weigensberg MJ, Salem GJ, Crespo NC, et al. Effects of resistance training on insulin sensitivity in overweight Latino adolescent males. *Med Sci Sports Exerc*. 2006;**38**(7):1208–15. doi: 10.1249/01.mss.0000227304.88406.0f. [PubMed: 16826016].

9. Ara I, Perez-Gomez J, Vicente-Rodriguez G, Chavarren J, Dorado C, Calbet JA. Serum free testosterone, leptin and soluble leptin receptor changes in a 6-week strength-training programme. *Br J Nutr*. 2006;**96**(6):1053–9. doi: 10.1017/BJN20061956. [PubMed: 17181880].

10. Kanaley JA, Fenicchia LM, Miller CS, Ploutz-Synder LL, Weinstock RS, Carhart R, et al. Resting leptin responses to acute and chronic resistance training in type 2 diabetic men and women. *Int J Obes Relat Metab Disord*. 2001;**25**(10):1474–80. doi: 10.1038/sj.ijo.0801797. [PubMed: 11673769].

11. Abedi B, Abbasi-Bakhtiari R. [The effect of a 12-week combined training program on serum leptin, C- reactive protein and the insulin resistance index in overweight men]. *Feyz J Kashan Univ Med Sci*. 2015;**19**(4):293–301. Persian.

12. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. *Br J Nutr*. 1978;**40**(3):497–504. doi: 10.1079/BJN19780152. [PubMed: 718832].

13. Siri W. *In advances in biological and medical physics*. **4**. London and New York: Academic press Inc; 1956. p. 239–80.

14. Balady GJ. ACSM's guidelines for exercise testing and prescription. *Am Coll of Sports Med*. 2000.

15. Mahan L, Escott-Stump S. Macronutrients: Carbohydrates, proteins, and lipids. In: Etlinger S, editor. *Krauses food nutrition and diet therapy*. 11th ed. Saunders; 2004. p. 50–62.

16. Mahan L, Escott-Stump S. Medical nutrition therapy in cardiovascular disease. In: Debra AK, editor. *Krauses food nutrition and diet therapy*. 11th ed. Saunders; 2004. p. 860–44.

17. Harris JA, Benedict FG. A biometric study of human basal metabolism. *Proc Natl Acad Sci USA*. 1918;**4**(12):370–3. [PubMed: 16576330]. [PubMed Central: PMC1091498].

18. Buschbacher RM, Prahlow ND, Dave SJ. *Sports medicine and rehabilitation: A sport-specific approach*. Lippincott Williams & Wilkins; 2008.

19. Marcell TJ, McAuley KA, Traustadottir T, Reaven PD. Exercise training is not associated with improved levels of C-reactive protein or adiponectin. *Metabolism*. 2005;**54**(4):533–41. doi: 10.1016/j.metabol.2004.11.008. [PubMed: 15798963].

20. Kriketos AD, Gan SK, Poynten AM, Furler SM, Chisholm DJ, Campbell LV. Exercise increases adiponectin levels and insulin sensitivity in humans. *Diabetes Care*. 2004;**27**(2):629–30. doi: 10.2337/diacare.27.2.629. [PubMed: 14747265].

21. Poehlman ET, Dvorak RV, DeNino WF, Brochu M, Ades PA. Effects of resistance training and endurance training on insulin sensitivity in nonobese, young women: A controlled randomized trial. *J Clin Endocrinol Metab*. 2000;**85**(7):2463–8. doi: 10.1210/jcem.85.7.6692. [PubMed: 10902794].

22. Duncan GE, Perri MG, Theriaque DW, Hutson AD, Eckel RH, Stacpoole PW. Exercise training, without weight loss, increases insulin sensitivity and postheparin plasma lipase activity in previously sedentary adults. *Diabetes Care*. 2003;**26**(3):557–62. doi: 10.2337/diacare.26.3.557. [PubMed: 12610001].

23. Henriksen EJ. Invited review: Effects of acute exercise and exercise training on insulin resistance. *J Appl Physiol (1985)*. 2002;**93**(2):788–96. doi: 10.1152/japplphysiol.01219.2001. [PubMed: 12133893].

24. Miller JP, Pratley RE, Goldberg AP, Gordon P, Rubin M, Treuth MS, et al. Strength training increases insulin action in healthy 50- to 65-yr-old men. *J Appl Physiol (1985)*. 1994;**77**(3):1122–7. doi: 10.1152/jappl.1994.77.3.1122. [PubMed: 7836113].

25. Ishii T, Yamakita T, Yamagami K, Yamamoto T, Miyamoto M, Kawasaki K, et al. Effect of exercise training on serum leptin levels in type 2 diabetic patients. *Metabolism*. 2001;**50**(10):1136–40. doi: 10.1053/meta.2001.26745. [PubMed: 11586483].

26. Holten MK, Zacho M, Gaster M, Juel C, Wojtaszewski JF, Dela F. Strength training increases insulin-mediated glucose uptake, GLUT4 content, and insulin signaling in skeletal muscle in patients with type 2 diabetes. *Diabetes*. 2004;**53**(2):294–305. doi: 10.2337/diabetes.53.2.294. [PubMed: 14747278].

27. Friedman JE, Ferrara CM, Aulak KS, Hatzoglou M, McCune SA, Park S, et al. Exercise training down-regulates ob gene expression in the genetically obese SHHF/Mcc-fa(cp) rat. *Horm Metab Res*. 1997;**29**(5):214–9. doi: 10.1055/s-2007-979024. [PubMed: 9228205].

28. Fedewa MV, Hathaway ED, Ward-Ritacco CL, Williams TD, Dobbs WC. The effect of chronic exercise training on leptin: A systematic review and meta-analysis of randomized controlled trials. *Sports Med*. 2018;**48**(6):1437–50. doi: 10.1007/s40279-018-0897-1. [PubMed: 29582381].

29. Karacabey K. The effect of exercise on leptin, insulin, cortisol and lipid profiles in obese children. *J Int Med Res*. 2009;**37**(5):1472–8. doi: 10.1177/147323000903700523. [PubMed: 19930853].

30. Pandit R, Beerens S, Adan RAH. Role of leptin in energy expenditure: The hypothalamic perspective. *Am J Physiol Regul Integr Comp Physiol*. 2017;**312**(6):R938–47. doi: 10.1152/ajpregu.00045.2016. [PubMed: 28356295].

31. Luan B, Goodarzi MO, Phillips NG, Guo X, Chen YD, Yao J, et al. Leptin-mediated increases in catecholamine signaling reduce adipose tissue inflammation via activation of macrophage HDAC4. *Cell Metab*. 2014;**19**(6):1058–65. doi: 10.1016/j.cmet.2014.03.024. [PubMed: 24768298]. [PubMed Central: PMC4207085].

32. Kang SJ, Kim JH, Gang Z, Yook YS, Yoon JR, Ha GC, et al. Effects of 12-week circuit exercise program on obesity index, appetite regulating hormones, and insulin resistance in middle-aged obese females. *J Phys Ther Sci*. 2018;**30**(1):169–73. doi: 10.1589/jpts.30.169. [PubMed: 29410591]. [PubMed Central: PMC5788800].

33. Zafeiridis A, Smilios I, Considine RV, Tokmakidis SP. Serum leptin responses after acute resistance exercise protocols. *J Appl Physiol (1985)*. 2003;**94**(2):591–7. doi: 10.1152/japplphysiol.00330.2002. [PubMed: 12391130].

34. Eftekhari E, Zafari A, Gholami M. Physical activity, lipid profiles and leptin. *J Sports Med Phys Fitness*. 2016;**56**(4):465–9. [PubMed: 25766051].