

# The Effects of Circuit Resistance Training on Inflammatory Status, Insulin Resistance and Body Composition in Overweight Adolescent Boys

Hamid Alizadeh<sup>\*1</sup>, Alireza Safarzade<sup>2</sup>, Elahe Talebi-Garakani<sup>3</sup>

1. PhD. of Exercise Physiology, Faculty of Sport Sciences, University of Mazandaran, Babolsar, Mazandaran, Iran.  
 2. Associate Professor of Exercise Physiology, Faculty of Sport Sciences, University of Mazandaran, Babolsar, Mazandaran, Iran.  
 3. Associate Professor of Exercise Physiology, Faculty of Sport Sciences, University of Mazandaran, Babolsar, Mazandaran, Iran.

#### \*Correspondence:

Hamid Alizadeh, PhD. of Exercise Physiology, Faculty of Sport Sciences, University of Mazandaran, Babolsar, Mazandaran, Iran.  
**Tel:** (98) 918 068 6634  
**Email:** exercise.physiology92@gmail.com

**Received:** 17 May 2019

**Accepted:** 07 August 2019

**Published in November 2019**

#### Abstract

**Objective:** The overweight-related health problems among adolescents are obvious. Resistance training is recognized as a safe and efficacious exercise modality to have health-promoting effects in overweight adolescents. This study aimed to assess the efficacy of circuit resistance training (CRT) in improving inflammatory status, insulin resistance and body composition in overweight male adolescents.

**Materials and Methods:** Twenty overweight adolescent boys (aged: 18.5 ( $\pm$ 1), weight: 81.1 ( $\pm$ 4.5), body mass index: 27.7 ( $\pm$ 0.7)) completed this study. The participants were randomly and equally divided into two groups of control (CG; n=10) and circuit resistance training (CRT; n=10). The CG did their daily routine activities and the CRT group performed its training protocol 3 days a week for 6 weeks. Body composition components and serum variables were measured a day before and after the study. Insulin resistance index was measured by HOMA-IR.

**Results:** The subjects in the CG showed significantly increased changes compared with pre-training values. Moreover, significant changes were found for the changes of BW ( $P$ -value= 0.005), BMI ( $P$ -value= 0.001) and BF% ( $P$ -value= 0.003) between groups.

**Conclusion:** This study suggested that although six weeks of CRT failed to induce meaningful anti-inflammatory cytokine responses, and to improve body composition and HOMA-IR in overweight adolescent boys, but had protective effects on inflammatory status, HOMA-IR and body composition and prevented them from being deteriorated.

**Keywords:** Circuit resistance training, Obesity, Anti-inflammatory cytokine response, Insulin resistance, body composition

#### Introduction

The adverse consequences of systemic inflammatory condition in which the overweight/obesity among adolescents are obvious (1). Obesity triggers a cytokine production is disrupted and resulted

in the increased and decreased pro-and anti-inflammatory cytokine production respectively (2,3,4). Low-grade inflammation connects obesity to some severe diseases such as metabolic syndrome and type 2 diabetes mellitus (T2DM) (5,6). Cytokines are secreted by a variety of immune and non-immune cells (7-11) and considered as the index of inflammation (12,13). Interleukin-4 (IL-4) and interleukin-13 (IL-13) are involved in modulating energy metabolism (14). IL-4 delays lipid accumulation, leading to reduced body fat and weight gain (15-19). An inverse relationship between IL-4 and weight gain is proposed (15). Moreover, IL-4 is considered as the trigger of signal for insulin action, thereby regulating the insulin signaling pathways (19). IL-13 performs a variety of functions, including restoring glucose homeostasis and limiting inflammation (20). The favorable effects of exercise on inflammation are demonstrated, showing an inverse relationship between exercise and inflammatory condition (21-23). Exercise induced improvements to body composition improve the inflammatory status and health risk factors (24). The influence of exercise training over inflammatory indicators is associated with the alterations of body composition induced by anti-inflammatory effects of exercise training (25,26). Resistance exercise training (RET) is recommended as an effective option to treat obesity for adolescents (27-31). However, the anti-inflammatory effect of RET on cytokine responses has not been given attention enough and is unclear. Unlike the pro-inflammatory cytokines, exercise-induced alterations in the anti-inflammatory cytokines are less identified. Few available studies have used RT as a muscle-damaging exercise protocol to induce inflammation (12,32,33). In addition to this, most of the data regarding the IL-4 and IL-13 is derived from protein/mRNA of these cytokines in response to exercise training (34) and there is a lack of evidence on the circulating alterations of these cytokines in response to exercise training. Therefore, this

study was designed to assess the effects of a six-week weight loss circuit resistance training protocol on inflammatory status, insulin resistance and body composition in overweight adolescent boys.

## Materials and Methods

Twenty out of 100 overweight adolescent boys (aged: 18.5 ( $\pm$ 1) years, weight: 81.1 ( $\pm$ 4.5) kg, body mass index: 27.7 ( $\pm$ 0.7) kg/m<sup>2</sup>) announced their preparation to take part in this study. All of the students were informed of the study through announcements distributed to all high school in the area (Abdanan County, Ilam Province, Iran). Prior to the commencement of the trial, the written consents of both participants and their parents were obtained through a meeting in which all details of the study were shared in depth with them. The anthropometric and serum variables of all of the subjects were determined at the baseline and at the end of the study. The subjects were randomly and equally assigned into the circuit resistance training (CRT; n= 10) and control (CG; n= 10) groups. The CRT group performed a weight-loss protocol 3 days/week for 6 weeks.

## Anthropometric and serum measurements

The stature, body weight (BW) and body mass index (BMI) of all the subjects were measured by an electronic scale (model Seca 763, made in Germany, with the precision of 50g) in the health center of the physical education group of the education department. The body fat percentage (BF%) was determined by the slim guide skinfold caliper and Jackson and Pollack's three points formula (triceps brachii, abdomen and thigh) (35). To measure the serum levels of glucose, insulin, IL-4 and IL-13, the amount of nearly 10 cc blood were taken from each individual in a fasting state. After being separated, the serum of each person was stored at -20 °C for future analysis. Analysis of IL-4 (Cat No. 950.020.096, Diaclone, French), IL-13 (Cat No. 850.080.096, Diaclone, French) concentrations

was performed using ELISA kits from Diaclone company with the minimum detectable concentration of 0.7 pg/ml, 1.5 pg/ml respectively. The intra- and interassay variations were less than 5% and 10% for both IL-4 and IL-13. Analysis of insulin concentrations was performed using ELISA kits from Accubind (Monobind Inc., Lake Forest, CA, USA) with sensitivity of 0.75 $\mu$ U/mL, intra-assay variability was 4.3 to 8.3%. Serum concentrations of glucose were measured by photometric method (Pars Azmun Company Kits, Iran). Insulin resistance index (IRI) was calculated using the homeostasis model assessment (HOMA).  $IRI = (\text{fasting insulin } [\mu\text{ U/mL}] \times \text{fasting glucose } [\text{mmol/L}]) / 22.5$  (36). The two time-points considered for determining the anthropometric and serum variables of all of the subjects were 24 hours before the beginning and 24-28 hours after the ending of study in a fasting state at the same time at 8 o'clock in the morning. Tables 1 and 2 depict the anthropometric characteristics, HOMA-IR and IL-4, IL-13 respectively.

### Circuit Resistance Training Protocol

The CRT group performed a nine-exercise protocol (9 different work-outs) 3 days a week for 6 weeks in which the principal muscle groups were involved. The protocol consisted of chest press, leg press, shoulder press, seated rows, leg extension, triceps extension, leg curl, biceps curl and sit-up. Each exercise included 8-12 repetitions at the workload of 60% of the subjects' one repetition maximum (1RM). Each session consisted of three circuits and in each circuit 9 movements which were previously mentioned were done one after another. The duration of each movement was 30 seconds (8-12 repetitions), the duration of resting between two consecutive movements was 30 seconds and the duration of resting between the two circuits was considered to be 120 seconds. Each session lasted 50-55 minutes. The principle of overload was designed after each three weeks of training. In

this study the Brzycki formula was used to calculate the 1RM (37).

### Statistical analysis

The distribution of variables was assessed by Kolmogorov-Smirnov test. The Paired T-test was used for determining the possible changes in each group after 6 weeks. Moreover, to compare groups, we calculated the difference (after- before) for each group and tested it by independent T-test. The SPSS version 16.0 was used to analyze the data and the significance level was considered at 5 %.

### Ethical considerations

This study was approved by the Ethics Committee of the University of Mazandaran with the code of 2269045.

### Results

BW ( $P$ -value= 0.54), BMI ( $P$ -value= 0.17) and BF% ( $P$ -value= 0.096) of the subjects in the CRT group showed insignificantly decreased changes compared with pre-training values whereas those of the subjects in the CG showed significantly increased changes compared with pre-training values. Moreover, significant changes were found for the changes of BW ( $P$ -value= 0.005), BMI ( $P$ -value= 0.001) and BF% ( $P$ -value= 0.003) between groups (table 1).

The serum levels of glucose ( $P$ -value= 0.33), insulin ( $P$ -value= 0.64) and HOMA-IR ( $P$ -value= 0.63) showed insignificantly decreased changes compared with pre-training values whereas that of glucose ( $P$ -value= 0.002) of the subjects in the CG showed a significantly increased change compared with pre-training value. Moreover, no significant changes were found for the changes of glucose ( $P$ -value= 0.61), insulin ( $P$ -value= 0.24) and HOMA-IR ( $P$ -value= 0.23) between groups (table 1).

The serum levels of IL-4 ( $P$ -value= 0.68) and IL-13 ( $P$ -value= 0.21) showed insignificantly increased changes compared with pre-training values following 6 weeks of training whereas for the control group, IL-4 ( $P$ -value= 0.44) and IL-13 ( $P$ -value= 0.46) showed insignificantly

decreased changes compared with pre-training values. Moreover, no significant changes were found for the changes of IL-4 ( $P$ -value= 0.38) and IL-13 ( $P$ -value= 0.15) between groups (table 2).

## Discussion

This study suggested that although six weeks

of CRT failed to induce meaningful anti-inflammatory cytokine responses, and to improve body composition and HOMA-IR in overweight adolescent boys, but had protective effects on inflammatory status, HOMA-IR and body composition and prevented them from being deteriorated when compared with those of control group (tables 1& 2). Exercise

**Table 1. The changes of body composition parameters and metabolic profile in studied groups**

Variables/Groups	Pre-training Mean ( $\pm$ SD)	Post-training Mean ( $\pm$ SD)	$\Delta^b$	$P$ -values <sup>c</sup>
<b>BW, kg</b>				
CG	80.93 ( $\pm$ 5.04)	81.30 ( $\pm$ 5.07 <sup>d</sup> )	0.35 ( $\pm$ 0.31)	0.006
CRT	81.27 ( $\pm$ 4.06)	81.22 ( $\pm$ 4.14)	-0.05 ( $\pm$ 0.25 <sup>e</sup> )	0.544
$P$ -values <sup>f</sup>	0.870	0.977	0.005	-
<b>BMI, kg/m<sup>2</sup></b>				
CG	27.53 ( $\pm$ 0.60)	28.67 ( $\pm$ 0.68 <sup>d</sup> )	1.14 ( $\pm$ 0.12)	0.007
CRT	27.89 ( $\pm$ 0.73)	27.80 ( $\pm$ 0.72)	-0.09 ( $\pm$ 0.10 <sup>e</sup> )	0.17
$P$ -values <sup>f</sup>	0.248	0.703	0.001	-
<b>BFP, %</b>				
CG	22.41 ( $\pm$ 3.14)	23.42 ( $\pm$ 3.14 <sup>d</sup> )	1.006 ( $\pm$ 0.005)	0.005
CRT	2.57 ( $\pm$ 2.54)	2.56 ( $\pm$ 2.53)	-0.005 ( $\pm$ 0.008 <sup>e</sup> )	0.096
$P$ -values <sup>f</sup>	0.908	0.915	0.003	-
<b>Glucose, mg/dL</b>				
CG	84.50 ( $\pm$ 7.41)	86.80 ( $\pm$ 7.61 <sup>d</sup> )	2.30 ( $\pm$ 1.63)	0.002
CRT	87.10 ( $\pm$ 6.08)	86.60 ( $\pm$ 6.38)	-1.50 ( $\pm$ 4.62)	0.332
$P$ -values <sup>f</sup>	0.403	0.574	0.612	-
<b>Insulin, <math>\mu</math>L U/mL</b>				
CG	9.75 ( $\pm$ 6.80)	10.22 ( $\pm$ 7.01)	0.46 ( $\pm$ 0.72)	0.075
CRT	7.75 ( $\pm$ 4.63)	7.12 ( $\pm$ 4.46)	-0.62 ( $\pm$ 0.90)	0.648
$P$ -values <sup>f</sup>	0.403	0.364	0.243	-
<b>HOMA-IR</b>				
CG	2.06 ( $\pm$ 1.48)	2.20 ( $\pm$ 1.54 <sup>a</sup> )	0.14 ( $\pm$ 0.17)	0.032
CRT	1.64 ( $\pm$ 0.93)	1.57 ( $\pm$ 0.91)	-0.07 ( $\pm$ 0.21)	0.632
$P$ -values <sup>f</sup>	0.460	0.368	0.232	-

Abbreviations: CG, control group; CRT, circuit resistance training; BW, body weight; BMI, body mass index; BFP, body fat percentage; HOMA-IR, homeostasis model assessment of insulin resistance.

<sup>a</sup>Values are expressed as mean $\pm$ SD

<sup>b</sup> $\Delta$ , Post-test vs. Pre-test values

<sup>c</sup>Paired T-test.

<sup>d</sup> $P$ -value < 0.05 compared pre- and post-test values (paired T-test).

<sup>e</sup> $P$ -value < 0.05 compared the differences between groups (independent T-test).

<sup>f</sup> $P$ -value < 0.05 Independent T-test.

**Table 2. The changes of serum levels of interleukins in both groups**

Variables Groups	Pre-training <sup>a</sup>	Post-training <sup>a</sup>	$\Delta^b$	$P$ -values <sup>c</sup>
<b>IL-4, pg/ml</b>				
CG	1.88 ( $\pm$ 0.82)	1.72 ( $\pm$ 1.03)	-0.15 ( $\pm$ 0.63)	0.447
CRT	2.21 ( $\pm$ 0.60)	2.27 ( $\pm$ 0.58)	0.06 ( $\pm$ 0.45)	0.680
$P$ -values <sup>d</sup>	0.312	0.163	0.384	-
<b>IL-13, pg/ml</b>				
CG	1.70 ( $\pm$ 1.68)	1.57 ( $\pm$ 1.34)	- 0.14 ( $\pm$ 0.58)	0.463
CRT	1.28 ( $\pm$ 1.02)	1.56 ( $\pm$ 1.30)	0.28 ( $\pm$ 0.66)	0.215
$P$ -values <sup>d</sup>	0.505	0.996	0.149	-

Abbreviations: CG, control group; CRT, circuit resistance training; IL, interleukin.

<sup>a</sup>Values are expressed as mean $\pm$ SD.

<sup>b</sup> $\Delta$ , Post-test vs. Pre-test values.

<sup>c</sup>Paired T-test.

<sup>d</sup>Independent T-test

training directs the production of cytokines towards an anti-inflammatory state in diverse organs such as skeletal muscle and adipose tissue (38). RET showed to be connected with decreased systemic inflammation related to diseases such as insulin resistance and obesity (39). Some studies have indicated the anti-inflammatory effects of RET in different populations including overweight adults (40), elderly individuals (41), patients (42) and healthy young men (43). Few studies have assessed the changes in circulating levels of IL-4 and IL-13 in response to RET at resting. Salehzadeh et al. demonstrated that a 10-week incremental RET did not change the plasma concentrations of IL-4 in overweight men (44). Prokopchuk et al. reported that six weeks of neither high intensity nor low intensity RET does not increase the circulatory levels of IL-4 and IL-13 in healthy active individuals, whereas their RNA expression for both IL-4 and IL-13 showed significantly increased levels (45). One of the mechanisms related to the anti-inflammatory effects of exercise training is fat reduction (46). Excess fat mass, especially visceral fat is considered as a major risk factor for systemic inflammation (47). It's been suggested that exercise training exerts a positive reducing effect on the inflammatory condition through directing the secretion of cytokines towards an anti-inflammatory state leading to reduce the amount of adipose tissue (38,48). Consequently, it's probable that alterations in the inflammatory state of cytokines lead to confirmed health advantages of exercise training. There are studies with conflicting results assessing if the anti-inflammatory effect of exercise training is linked to body fat, some of which suggest a relationship (49), whereas the other studies indicate no relationship (50). IL-4 is suggested to be inversely proportional to weight gain and adiposity (15). In the current study, compared to subjects in the control group, subjects in the training group had insignificantly decreased BW, BMI, BF% values and insignificantly increased serum levels of IL-4 which indicates the protective effect of CRT. It might be

concluded that six weeks of CRT has not been able to increase IL-4 enough so as to significantly decrease BW, BMI and BF%. Another variable investigated in this study was HOMA-IR. The proposed CRT protocol had no significant effect on HOMA-IR within overweight adolescent boys. RET has been reported to enhance insulin sensitivity by lowering systemic inflammation and increasing glucose uptake by muscle cells (51). These results may, to some extent, be due to an improved body composition and increased muscle mass (52). The discrepancies regarding the effectiveness of RET on inflammatory response, body composition and metabolic profile could be interpreted in various ways including, the variety of RET interventions, training variables such as intensity, duration, volume and metabolic condition of participants. It remains unclear if a higher intensity or longer duration of the proposed CRT protocol would result in significant anti-inflammatory cytokine responses, improvements to body composition and metabolic profile within overweight adolescent boys.

There are some limitations to be considered in the current research. There is limited data regarding the effect of CRT on anti-inflammatory cytokine responses, in particular IL-4 and IL-13 that emphasizes the necessity for more researches into these cytokines. In the present study, the dietary intakes of the participants were not monitored, and they were simply asked to have their routine dietary regimens. Another issue is that the post-training sampling time taken at 24-28 hours after the last session of CRT is the major issue that may interfere with the chronic effect of CRT on inducing an anti-inflammatory cytokine response. Due to the residual effects of the last session of exercise can last up to 72 hours, the future studies need to clarify this issue by determining the time course secretion of these anti-inflammatory cytokines in response to CRT. Finally, the sample size of this study was rather small, and further studies

with larger numbers of subjects should be undertaken in the future.

## Conclusions

This study suggested that although six weeks of CRT failed to induce a meaningful anti-inflammatory cytokine responses, and to improve body composition and HOMA-IR in overweight adolescent boys, but had protective effects on inflammatory status, HOMA-IR and body composition and prevented them from being deteriorated.

## Acknowledgments

This work is originally described in the Ph.D. thesis of one of the authors; Hamid Alizadeh. The authors are thankful for the funding provided by Mazandaran University. We would like to appreciate the Pars laboratory's staff for their support and the adolescent students for their voluntary participation in this study.

## Funding

This study was supported by the University of Mazandaran.

## Conflict of Interest

The authors state no conflict of interest.

## References

- Goran MI, Ball GD, Cruz ML. Obesity and risk of type 2 diabetes and cardiovascular disease in children and adolescents. *The Journal of Clinical Endocrinology & Metabolism*. 2003;88(4):1417-27.
- Petersen AM, Pedersen BK. The anti-inflammatory effect of exercise. *Journal of applied physiology*. 2005;98(4):1154-62.
- Lumeng CN, Bodzin JL, Saltiel AR. Obesity induces a phenotypic switch in adipose tissue macrophage polarization. *The Journal of clinical investigation*. 2007;117(1):175-84.
- Schipper HS, Prakken B, Kalkhoven E, Boes M. Adipose tissue-resident immune cells: key players in immunometabolism. *Trends in Endocrinology & Metabolism*. 2012;23(8):407-15.
- Renaldi O, Pramono B, Sinorita H, Purnomo LB, Asdie RH, Asdie AH. Hypoadiponectinemia: a risk factor for metabolic syndrome. *Acta Medica Indonesiana*. 2009; 41(1):20-4.
- Hotta K, Funahashi T, Arita Y, Takahashi M, Matsuda M, Okamoto Y, et al. Plasma concentrations of a novel, adipose-specific protein, adiponectin, in type 2 diabetic patients. *Arteriosclerosis, thrombosis, and vascular biology*. 2000;20(6):1595-9.
- Nelms K, Keegan AD, Zamorano J, Ryan JJ, Paul WE. The IL-4 receptor: signaling mechanisms and biologic functions. *Annual review of immunology*. 1999; 17(1):701-38.
- Paul WE. Interleukin-4: a prototypic immunoregulatory lymphokine. *Blood*. 1991;77(9):1859-70.
- Jacquemin V, Butler-Browne GS, Furling D, Mouly V. IL-13 mediates the recruitment of reserve cells for fusion during IGF-1-induced hypertrophy of human myotubes. *Journal of Cell Science*. 2007;120(4):670-81.
- Lowenthal JW, Castle BE, Christiansen J, Schreurs J, Rennick D, Arai N, et al. Expression of high affinity receptors for murine interleukin 4 (BSF-1) on hemopoietic and nonhemopoietic cells. *The Journal of Immunology*. 1988;140(2):456-64.
- Van Den Berg Jg, Aten J, Chand MA, Claessen N, Dijkink L, Wijdenes J, et al. Interleukin-4 and interleukin-13 act on glomerular visceral epithelial cells. *Journal of the American Society of Nephrology*. 2000;11(3):413-22.
- Moldoveanu AI, Shephard RJ, Shek PN. The cytokine response to physical activity and training. *Sports medicine*. 2001;31(2):115-44.
- Nieman DC, Henson DA, Smith LL, Utter AC, Vinci DM, Davis JM, et al. Cytokine changes after a marathon race. *Journal of applied physiology*. 2001;91(1):109-14.
- Queiroz JC, Alonso-Vale MI, Curi R, Lima FB. Control of adipogenesis by fatty acids. *Arquivos Brasileiros de Endocrinologia & Metabologia*. 2009;53(5):582-94.
- Tsao CH, Shiao MY, Chuang PH, Chang YH, Hwang J. Interleukin-4 regulates lipid metabolism by inhibiting adipogenesis and promoting lipolysis. *Journal of lipid research*. 2014;55(3):385-97.
- El-Wakkad A, Hassan NE, Sibaii H, El-Zayat SR. Proinflammatory, anti-inflammatory cytokines and adiponectin in students with central obesity. *Cytokine*. 2013;61(2):682-7.
- Damluji AA, Ramireddy A, Al-Damluji MS, Marzouka GR, Otalvaro L, Viles-Gonzalez JF, et al. Association between anti-human heat shock

- protein-60 and interleukin-2 with coronary artery calcium score. *Heart*. 2015;101(6):436-41.
18. Ricardo-Gonzalez RR, Eagle AR, Odegaard JI, Jouihan H, Morel CR, Heredia JE, et al. IL-4/STAT6 immune axis regulates peripheral nutrient metabolism and insulin sensitivity. *Proceedings of the National Academy of Sciences*. 2010;107(52):22617-22.
  19. Chang YH, Ho KT, Lu SH, Huang CN, Shiao MY. Regulation of glucose/ lipid metabolism and insulin sensitivity by interleukin-4. *International journal of obesity*. 2012;36(7):993.
  20. Stanya KJ, Jacobi D, Liu S, Bhargava P, Dai L, Gangl MR, et al. Direct control of hepatic glucose production by interleukin-13 in mice. *The Journal of clinical investigation*. 2012; 123(1).
  21. Fischer CP, Berntsen A, Perstrup LB, Eskildsen P, Pedersen BK. Plasma levels of interleukin 6 and C-reactive protein are associated with physical inactivity independent of obesity. *Scandinavian journal of medicine & science in sports*. 2007;17(5):580-7.
  22. Lavie CJ, Church TS, Milani RV, Earnest CP. Impact of physical activity, cardiorespiratory fitness, and exercise training on markers of inflammation. *Journal of cardiopulmonary rehabilitation and prevention*. 2011;31(3):137-45.
  23. Pinto A, Di Raimondo D, Tuttolomondo A, Buttà C, Milio G, Licata G. Effects of physical exercise on inflammatory markers of atherosclerosis. *Current pharmaceutical design*. 2012;18(28):4326-49.
  24. Lee CD, Blair SN, Jackson AS. Cardiorespiratory fitness, body composition, and all-cause and cardiovascular disease mortality in men. *The American journal of clinical nutrition*. 1999;69(3):373-80.
  25. Kondo T, Kobayashi I, Murakami M. Effect of exercise on circulating adipokine levels in obese young women. *Endocrine journal*. 2006;53(2):189-95.
  26. 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. *British journal of sports medicine*. 2010;44(9):620-30.
  27. Lau PW, Kong Z, Choi CR, Clare CW, Chan DF, Sung RY, et al. Effects of short-term resistance training on serum leptin levels in obese adolescents. *Journal of Exercise Science & Fitness*. 2010;8(1):54-60.
  28. McGuigan MR, Tatasciore M, Newton RU, Pettigrew S. Eight weeks of resistance training can significantly alter body composition in children who are overweight or obese. *The Journal of Strength & Conditioning Research*. 2009;23(1):80-5.
  29. Naylor LH, Watts K, Sharpe JA, Jones TW, Davis EA, Thompson A, et al. Resistance training and diastolic myocardial tissue velocities in obese children. *Medicine and science in sports and exercise*. 2008;40(12):2027-32.
  30. 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. *Medicine and science in sports and exercise*. 2006;38(7):1208.
  31. Treuth MS, Hunter GR, Figueroa-Colon RE, Goran MI. Effects of strength training on intra-abdominal adipose tissue in obese prepubertal girls. *Medicine and Science in Sports and Exercise*. 1998;30(12):1738-43.
  32. Tomiya A, Aizawa T, Nagatomi R, Sensui H, Kokubun S. Myofibers express IL-6 after eccentric exercise. *The American journal of sports medicine*. 2004;32(2):503-8.
  33. Willoughby DS, McFarlin B, Bois C. Interleukin-6 expression after repeated bouts of eccentric exercise. *International journal of sports medicine*. 2003;24(01):15-21.
  34. Figueroa A, Cuadrado A, Fan J, Atasoy U, Muscat GE, Munoz-Canoves P, et al. Role of HuR in skeletal myogenesis through coordinate regulation of muscle differentiation genes. *Molecular and cellular biology*. 2003;23(14):4991-5004.
  35. Lohman TG. Advances in body composition assessment. *Medicine & Science in Sports & Exercise*. 1993 Jun 1;25(6):762.
  36. Wallace TM, Levy JC, Matthews DR. Use and abuse of HOMA modeling. *Diabetes Care*. 2004;27:1487-95.
  37. Nascimento MA, Cyrino ES, Nakamura FY, Romanzini M, Pianca HJ, Queiróga MR. Validation of the Brzycki equation for the estimation of 1-RM in the bench press. *Revista Brasileira de Medicina do Esporte*. 2007;13(1):47-50.
  38. Görgens SW, Eckardt K, Jensen J, Drevon CA, Eckel J. Exercise and regulation of adipokine and myokine production. In *Progress in molecular biology and translational science*. 2015;135:313-36.
  39. Mathur N, Pedersen BK. Exercise as a mean to control low-grade systemic inflammation. *Mediators of inflammation*. 2008;2008.
  40. Olson TP, Dengel DR, Leon AS, Schmitz KH. Changes in inflammatory biomarkers following one-year of moderate resistance training in overweight women. *International journal of obesity*. 2007;31(6):996.
  41. Phillips MD, Patrizi RM, Cheek DJ, Wooten JS, Barbee JJ, Mitchell JB. Resistance training reduces subclinical inflammation in obese, postmenopausal women. *Medicine & Science in Sports & Exercise*. 2012;44(11):2099-110.
  42. Moraes C, Marinho SM, Da Nobrega AC, de Oliveira Bessa B, Jacobson LV, Stockler-Pinto MB,

- et al. Resistance exercise: a strategy to attenuate inflammation and protein-energy wasting in hemodialysis patients? *International urology and nephrology*. 2014;46(8):1655-62.
43. Forti LN, Van Roie E, Njemini R, Coudyzer W, Beyer I, Delecluse C, et al. Effects of resistance training at different loads on inflammatory markers in young adults. *European journal of applied physiology*. 2017;117(3):511-9.
44. Alvandi H, Salehzadeh K, Najafzade MR, Kalani AT. The effect of strength training on anti-inflammatory cytokines, cortisol and testosterone in overweight men. *European Journal of Experimental Biology*. 2014;4:296-302.
45. Prokopchuk O, Liu Y, Wang L, Wirth K, Schmidbleicher D, Steinacker JM. Skeletal muscle IL-4, IL-4R $\alpha$ , IL-13 and IL-13R $\alpha$ 1 expression and response to strength training. *Exercise immunology review*. 2007;13:67-75.
46. Ross R, Bradshaw AJ. The future of obesity reduction: beyond weight loss. *Nature Reviews Endocrinology*. 2009; 5(6):319.
47. Strasser B, Arvandi M, Siebert U. Resistance training, visceral obesity and inflammatory response: a review of the evidence. *Obesity reviews*. 2012; 13(7):578-91.
48. Gleeson M, Bishop NC, Stensel DJ, Lindley MR, Mastana SS, Nimmo MA. The anti-inflammatory effects of exercise: mechanisms and implications for the prevention and treatment of disease. *Nature reviews immunology*. 2011;11(9):607.
49. Nicklas BJ, Ambrosius W, Messier SP, Miller GD, Penninx BW, Loeser RF, et al. Diet-induced weight loss, exercise, and chronic inflammation in older, obese adults: a randomized controlled clinical trial. *The American journal of clinical nutrition*. 2004;79(4):544-51.
50. Oberbach A, Tönjes A, Klötting N, Fasshauer M, Kratzsch J, Busse MW, et al. Effect of a 4 week physical training program on plasma concentrations of inflammatory markers in patients with abnormal glucose tolerance. *European Journal of Endocrinology*. 2006;154(4):577-85.
51. Calle MC, Fernandez ML. Effects of resistance training on the inflammatory response. *Nutrition research and practice*. 2010;4(4):259-69.
52. Beavers KM, Brinkley TE, Nicklas BJ. Effect of exercise training on chronic inflammation. *Clinica chimica acta*. 2010;411(11-12):785-93.