Physical Activity Intervention in Overweight/Obese Children and Adolescents: Endurance and / or Resistance Training?

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Introduction

Childhood obesity and its related metabolic complications are associated with insufficient physical activity, excessive sedentary time, unhealthy eating behaviors, these factors all constituting an unhealthy lifestyle[1, 2]. Primary prevention programs, often based on interventions in schools, promote the positive effects of physical activity and healthy eating behaviors[3, 4]. These interventions targeting the general population are effective for the prevention of excessive body fat accumulation, and better physical fitness in children and adolescents[3, 4]. However, youth with obesity often requires more structured programs. Most studies so far have suggested that increased physical activity level combined with reduced energy intake can improve body composition and health in general in overweight or obese children and adolescents[5]. Until recently, physical activity interventions were mostly based on endurance exercise combined or not with dietary interventions, and it is only recently that resistance training has gained interest. Endurance exercise, also termed aerobic exercise, refers to exercise performed for extended period of time, at low to moderate intensities and that relies primarily on the aerobic metabolism[6]. Resistance exercise also called strength or weight training or weight lifting, involves muscular strength and mainly consists in isometric, isotonic, or isokinetic exercises. Resistance training is designed to develop greater resistance in order to develop muscle strength and anaerobic endurance. Resistance exercise has been long proscribed in children and adolescents and was thought to be at high risk of musculoskeletal injuries or negative effects on the maturation process given the mechanical constraints. In the case of obesity, resistance training was not advised considering that the resulting energy expenditure is low, and would thus have little effect on adiposity [7]. Only recently, number of studies have shown that resistance training can be performed safely and be beneficial to obese youth when cautiously supervised by professional and following established guidelines[8-10]. Since it is particularly difficult for obese youth to engage in physical activity[11], it is necessary to find exercise prescriptions favoring their adherence, and resistance training may be efficient in this way. Our purpose in this chapter is to provide an overview of the current knowledge on the effectiveness of endurance and/or resistance exercises in weight loss interventions in overweight and obese children and adolescents.

Endurance or resistance interventions?

The Word Health Organization currently recommends at least 60 minutes of moderate to vigorous physical activity, with exercise that strengthen muscles and bones at least 3 days/week, and many studies implement programs with similar amount of exercise. Structured aerobic exercise programs with sessions 3 to 5 times a week, of moderate intensity up to 60 minutes are the more commonly implemented weight-loss interventions in children and adolescents [12, 13], and have been shown to be effective in inducing short-term Body Mass Index, Fat Mass, Blood Pressure and Triglycerides improvements[14]. Aerobic exercise training is usually proposed to obese youth but an important limitation is their poor compliance to this type of exercise[15]. The less aerobically taxing nature of resistance training may offer a more accepted form of physical activity in these children and adolescents[16]. Indeed, endurance exercises are often not well tolerated by obese youth because of the additional body mass they have to carry on compared with their normal weight peers[17]. As described by McGuigan et al., aerobic exercise programs may not be well tolerated by obese/overweight youth as their important body weight increases the intensity of weight bearing activities which will increase their rate of perceived exertion and favor their drop-out[18]. Moreover, the low aerobic fitness level of obese youth[19] limits the intensity at which endurance exercise can be performed, contrarily to resistance exercises during which the high muscle mass of obese youth is an advantage rather than a disadvantage [20]. Resistance exercise training may thus represent a good option to improve the adherence to physical activity intervention in obese youth[16]. Resistance exercise training has long been discouraged in children and adolescents because of the fear of musculoskeletal injury [21]. It is now clear that resistance training can safely be done by children and adolescents[22-24], and there is a growing interest for this type of exercise in obese youth [16, 25-28]. Obese youth are frequently shown to have higher muscle mass comparatively to normal weight youth, and consequently have better performances during exercise involving strength and power. Obese youth may thus adhere more to resistance exercise programs, with favorable effects on their self-confidence and esteem[16]. Regarding the benefits of this type of exercise, a moderate intensity and progressive resistance exercise 10-week program (with a 1-year follow-up) in 7 -12 years old obese children was shown to have similar health benefits compared with adults[26]. Although resistance training may offer a great alternative to increase the rate of adherence to exercise programs, its exact impacts on obese children and adolescents' body composition, physical fitness and metabolic health remain to be clarified and compare to what is found using endurance training.

Effects on body composition

It is well documented that endurance training decreases body weight, BMI, waist circumference and body fat in obese children and adolescents[29-34]. Exercise in the low to moderate intensity domain (below the 2nd ventilatory threshold) will maximize fat oxidation, and are thought to decrease lipid storage and increase fat mass loss. The amount of fat used as a substrate also increases with the duration of exercise. Based on the fatmax or Lipox max model (see box 2) proposed by Brooks and Mercier[35], the efficacy of training at the Lipox max intensity has been tested in obese youth[29]. Beneficial results were observed for body weight and body composition, and a 2-month aerobic training (45 minutes per day) set at the participants' individual lipox max combined with a -300 kcal hypocaloric diet improved the lipox max intensity by 12.5% and their cross-over point by 17% (see box 2) 29. These results highlight the capacity of such interventions to improve the ability for fat oxidation during exercise in obese youth. Ben Ounis et al. also reported an increased capacity to oxidize fat during exercise in obese children, after a 2-month intervention set at the Lipox max with 90 minutes of exercises per day, 4 days a week[34]. Lately, Lee et al. compared the effect of a 3-month physical activity program of either 180min/week aerobic or resistance exercises in 12-18 years old girls on adiposity, and showed that despite the lack of body mass loss in both groups, the endurance programs induced significant decrease in visceral adipose tissue (-15.68 ± 7.64 cm²) and intrahepatic lipid (-1.70 ± 0.74 %)[36]. In contrast, fat mass, intramuscular and visceral adipose tissue and intrahepatic lipids decreased but not significantly with resistance training[36]. After a 12-week resistance program (2 sessions/week, session length: 1 hour) overweight obese adolescents), Van der Heijden et al. reported an increased body weight in 15 years old girls, but 80% of this increase was caused by an increase in lean mass (from 55.7 to 57.9 kg mean)[37], which confirms previous results that showed an increase in lean body mass after a 6-week resistance training in obese children[28]. However, Van der Heijden et al. did not observe any decrease of visceral, hepatic nor intramyocellular fat content[38]. In contrast, with the same amount of physical activity but with only aerobic exercise, total, visceral and hepatic fat content decreased significantly and were accompanied by increased peripheral and hepatic insulin sensitivity[37, 39]. Based on a similar program duration, Van der Heijden and colleagues showed that an aerobic exercise only intervention did not affect IMCL-fat content whereas hepatic fat content declined from 8.9±3.2 to 5.6±1.8% and visceral fat from 54.7±6.0 to 49.6±5.5 cm^2 [37].

Sgro et al. explored the effect of resistance training duration on body composition in 7-12 years old children training 3 times a week for either 8, 16 or 24 weeks. The results indicated an improvement of the children body composition after 8 weeks of training with particularly a 5 to 7% reduction of body fat while it was decreased by about 8.1% after 16 week of intervention [17]. This confirms previous results showing that by 8 weeks of resistance program (3 sessions per week) significant body composition improvement occurs [18]. Similarly, 8 weeks of resistance training (3 days a week) have been shown to reduce body fat in both overweight and obese children [18, 25]. Others found slightly different results with prepubertal children following a 12-week high repetition, moderate intensity resistance training (2 sessions of 75 min /week) where body weight, lean body mass and lean body mass index ($kg/height^2$) increased, without any changes in terms of fat mass percentage[40].

Based on a systematic analysis, Dietz et al. underlined that resistance training in obese youth is associated with increased BMI and body weight but no modification of total fat mass [20]. Treuth et al. even observed an increased fat mass after a resistance-based intervention but this is to our knowledge the only study to report this type of result[27]. Looking at the available evidence, resistance training has the potential to favor decreased fat mass only when associated with energy intake restriction [7, 16, 28]. Moreover, while dietary restrictions are usually prescribed as weight loss strategies in overweight and obese children and adolescents, resistance-based programs offer a great opportunity to counteract the reduction of the basal metabolic rate and decreased fat-free mass associated with diet-only induced-weight loss [5]. In addition to its effects on fat mass and lean mass, resistance exercise also has beneficial effects on bone [41, 42]. Increased bone mineral content was observed after a 6-week resistance training with exercises performed at 70 to 85% of individuals' 1 maximal repetition while fat mass percentage was unchanged [43].

Lately, several studies compared the effect of aerobic training alone with programs combining both endurance and resistance exercises. Campos et al. studied 42 post-pubertal obese adolescents who followed a weight loss program with psychological cares, dietary restriction and endurance exercise or a combination of resistance and endurance exercise. Although both programs resulted in decreased Body Mass Index, central visceral and subcutaneous fat, fasting insulin concentration and insulin resistance index (HOMA index), only the combination of aerobic and resistance exercises induced improvements of the Bone Mineral Content, adiponectin concentration and lean mass [44]. According to the authors, combining endurance and resistance training modalities has a protective role for the bone altogether with improvement of adipokines productions, reducing the inflammatory state induced by excess adiposity [44].

Although resistance training contributes to the increase in muscle mass, evidences of the effects on body fat are more limited [25, 45], despite the importance of decreasing fat mass and especially central fat mass to improve physical and metabolic fitness of the obese youth (Table 1). It is also important to note that aerobic exercise combined with moderate energy restriction in obese adolescents is sufficient to preserve the muscle mass of the legs, but not in the arms [46, 47]. This is most likely because carrying a high body weight represent a constraint similar to that of resistance exercise for the lower limbs, but not the upper body in obese youth. Thus, the physical activity practitioner may choose to recommend different types of exercise for the upper and lower body (resistance or aerobic), depending whether the obese patient is in a state of energy deficit or not.

	Body weight	BMI	Fat Mass	Lean Mass	Visceral Adipose Tissue	Intra-muscular fat	Inta-hepathic Lipid
Endurance	↓	↓	↓	↓	↓	↓	↓
Resistance	↑	↑	↔	↑	↔	↔	↔

Table 1. *Sum up of the effects of Endurance vs. Resistance training programs on obese youth's body composition.*

Effects on cardiorespiratory and musculoskeletal fitness

Cardiorespiratory fitness, also called aerobic fitness or aerobic capacity describes the ability of the respiratory and circulatory systems to function together to supply adequate amount of oxygen to supply the body with the required energy to sustain dynamic exercise[48]. Endurance exercise training is thought to be the most beneficial for cardiorespiratory fitness. Musculoskeletal fitness describes the ability of the muscular and skeletal systems to sustain physical work without undue fatigue[48]. Resistance exercise training is the most efficient form of exercise to improve musculoskeletal fitness through improved muscle strength and power in obese youth [49]. Briefly, resistance training improves muscle strength and hypertrophy in adolescents [50, 51], including those with obesity [17, 18, 52].

Mc Guigan et al. observed increased muscle power and muscle strength after an 8-week resistance training composed of 3 sessions per week in obese youth [18]. In their previously cited study, Alberga et al. showed that a 12-week resistance program, with a high number of repetitions performed at a moderate intensity, twice a week during 75 min resulted in improved arm and leg strength [40]. Although Sgro et al. did not observed any improvement in physical fitness after 8 weeks of resistance training (3 times a week), their results showed that 16 or 24 weeks of intervention was able to induce a significant improvement of the children's anaerobic capacities (+10,5% minimum using static jump test)[17]. According to Van der Heijden et al., a 12-week resistance training (2*1h/week in 15 years old obese adolescents) led to a significant strength gain in both lower and upper muscle groups [37]. This research team also reported in another study that a 12-week aerobic exercise training (4x30min/week at least at 70% VO2peak) was able to increase by 13±2% the aerobic fitness of prepubertal obese children [37].

While Sung et al. described resistance training as a safe and effective alternative for weight loss programs among youth in order to reduce the severity of obesity-associated cardiorespiratory risk factors[7], there is little evidence indicating that resistance training interventions improves CRF [5, 43, 53, 54]. In their review, Alberga et al. concluded that in order to improve cardiorespiratory fitness in obese youth, exercises programs need to include aerobic exercise training [52].

What about the metabolic profile?

Although the loss of fat mass is the main target when implementing dietary and/or physical activity programs among overweight and obese youth, it is necessary to first target the metabolic complications associated with excess weight that could be clustered as a pediatric metabolic syndrome[1, 2]. The actual literature mainly presents results regarding the impact of endurance training on overweight and obese children's metabolic profile.

In a recent systematic-review looking at the effect of exercise training on lipid profile in overweight and obese youth[55] programs based on aerobic training alone were effective on lipid profile, with moderate effects on Low Density Lipoprotein Cholesterol (LDL-C) and large effects on triglycerides (TG) levels, with a typical exercise dose of 3 sessions/week of 60 min and a maximal intensity of 75% of maximal heart rate. In a series of studies and based on the prescription of exercise at the Fatmax (or Lipoxmax) intensity, Ben Ounis et al. showed the positive effect of 2-month aerobic interventions on HOMA-IR, TG, LDL-C and total cholesterol, on the adiponectin concentration, inflammatory markers, and the growth factor IGF-1 and its binding protein IGFBP-3 30-32. Aerobic exercise training also has beneficial effects on glucose metabolism as Nassis et al. showed that 12 weeks of aerobic exercise training with 3 sessions/ week resulted in improved insulin sensitivity of 13.1 ± 1.8 years old overweight/obese girls [56], despite no significant change in body weight, body fat, adipokines concentrations or inflammatory factors [56].

A recent meta-analysis points out that aerobic exercise (for at least 60min 3 times a week) is able to reduce LDL-C and TG concentrations, and that the combination of aerobic and resistance training provides additional benefits, such as increased HDL-C[55]. When resistance and aerobic exercises are combined, programs can have a positive effect on HDL-C if the session last at least 60 minutes for a minimal intensity of 75% of the maximal aerobic capacities [55]. When compared to the effect of dietary restriction alone, Suh et al. showed that endurance or resistance training similarly improve insulin sensitivity index in overweight Asian adolescents [55, 57]. In adults however, aerobic exercise training only has been shown to induce greater improvements of the insulin sensibility compared with resistance exercise training[58, 59]. Looking at the effect of endurance combined with resistance exercise training, versus endurance exercise training alone, De Piano et al. reported that in obese adolescents with non-alcoholic fatty liver disease a 1-year program combining resistance and aerobic sessions favored a better improvement of insulin and alanine transaminase concentrations, HOMA index, adiponectin and leptin concentrations as well as lower melanin-concentrating hormones (MCH) compared to endurance alone [60].

Resistance training alone has been shown to reduce insulin resistance and to improve their glycemic control in obese youth[61] independently of body weight changes in overweight adolescents[61]. Other authors have reported beneficial effects of resistance training, such as decreased resting heart rate, systolic blood pressure, TG and insulin concentrations and increased HDL-C levels after a 6-week resistance program in obese children (3 times a week set at 70 to 85% of the children's maximal capacities)[43]. As previously mentioned with aerobic exercise training, the improvement in insulin sensitivity, hepatic insulin sensitivity (+24±9%) and metabolic control of glycogenolysis are not related to change in adiposity or visceral, hepatic and IMCL fat content after a 12-week resistance program in obese youth[38]. By comparison, in prepubertal children the same research team showed that a 12-week aerobic program (4 sessions of 30 minutes each at least) in prepubertal obese children resulted in decreased insulin resistance and reduced fasting insulin concentration[37]. The following table (Table 2) sums up the impact of both endurance and resistance training programs on obese youth's metabolic profile.

	Insulin sensitivity	LDL-C	HDL-C	Triglycerides	CHO-Total	Blood Pressure
Endurance	↑	↓	↔	↓	↓	↓
Resistance	↑	-	↑	↓	-	↓

Table 2. *Impact of endurance vs. resistance programs on the metabolic profile in obese youth.*

Discussion and recommendations

There are now good evidences that resistance exercise can be included in programs for the treatment of obesity in children and adolescents. The World Health Organization and many national and international organizations focusing on physical fitness, such as the National Strength and Conditioning Association[62] or the United States Physical Activity Guidelines for Youth[63] recommend the use of resistance training in children and adolescents. The type of exercise should involve an activity of whole body and be performed at moderate to submaximal intensities with 2-3 sets of 8 to 20 repetitions over a period of a least 8 weeks [10, 20, 21, 64]. With this type of exercise, the level of compliance is high (about 84%) and a low rate of injuries in children and adolescents [20]. It should however be noticed that similar compliance rate between 80 to 100% can also be reached for aerobic exercise interventions[13].

Both endurance and resistance trainings offer beneficial effects to the health of overweight and obese children and adolescents. Looking at their respective benefits, we recommend a combination of resistance and aerobic exercise, more likely to bring the most benefits, rather than resistance or aerobic exercise alone [65]. Practitioners are encouraged to follow the classical general recommendations for exercises prescriptions in children and adolescents based on 60 minutes or more of Physical activity every day suggesting that the main core of the 60 minutes should be moderate to vigorous activities with muscle and bone strengthening about 3 times a week.

BOX 1

Endurance training

Endurance training (also termed aerobic or cardio training) refers to exercise programs at low-to-moderate intensities that relies primarily on the aerobic metabolism. Since the term aerobic literally means "living in the air", it is easy to understand that aerobic exercises rely on the use of oxygen to furnish the energy needed during the completion of the exercise thanks to the aerobic metabolism process [66].

Resistance training

Also called strength or weight training, resistance training involves the use of muscular strength to work against a resistive force or move a weight. It mainly consists in isometric, isotonic, or isokinetic exercises designed to gradually develop greater resistance in order to induce muscular contractions which develop strength, anaerobic endurance, and size of skeletal muscles.

BOX 2

Fat max (or Lipox max)

The Fatmax or lipoxmax represents the exercise intensity that elicits the higher lipid oxidation rate. In obese youth, fatmax typically occurs at 53.3 ± 12.2% of VO2max[67].

The Crossover point

During incremental intensity exercise, carbohydrate oxidation progressively increases while lipid oxidation decreases to reach a point where the carbohydrate oxidation represents 70% of energy expenditure and fat oxidation represent 30%. This point is called the cross-over point. Studies in obese adults showed that the cross over point occurs at lower intensity than in normal weight subjects, reflecting a decreased ability of muscle to use fat as a substrate [68]. A number of studies have shown that the cross over point can be shifted to higher intensity (indicating improvement of the muscle's ability to oxidize fat) with exercise training performed at submaximal intensity in obese youth [29].

References

1. Aguilar-Salinas CA, Rojas R, Gomez-Perez FJ, Franco A, Olaiz G, Rull JA, et al. [The metabolic syndrome: a concept in evolution]. Gac Med Mex. 2004; 140 Suppl 2: S41-8.
2. Thivel D, Malina RM, Isacco L, Aucouturier J, Meyer M, Duche P. Metabolic syndrome in obese children and adolescents: dichotomous or continuous? Metab Syndr Relat Disord. 2009; 7: 549-55.
3. Lazaar N, Aucouturier J, Ratel S, Rance M, Meyer M, Duche P. Effect of physical activity intervention on body composition in young children: influence of body mass index status and gender. Acta Paediatr. 2007; 96: 1315-20.
4. Thivel D, Isacco L, Lazaar N, Aucouturier J, Ratel S, Dore E, et al. Effect of a 6-month school-based physical activity program on body composition and physical fitness in lean and obese schoolchildren. Eur J Pediatr. 2011; 170: 1435-43.
5. Watts K, Jones TW, Davis EA, Green D. Exercise training in obese children and adolescents: current concepts. Sports Med. 2005; 35: 375-92.
6. Plowman SA, Smith DL. Exercise Physiology for Health, Fitness, and Performance 2007.
7. 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: 407-10.
8. Faigenbaum AD, Kraemer WJ, Blimkie CJ, Jeffreys I, Micheli LJ, Nitka M, et al. Youth resistance training: updated position statement paper from the national strength and conditioning association. J Strength Cond Res 1996; 23: 60-79.
9. Falk B, Tenenbaum G. The effectiveness of resistance training in children. A meta-analysis. Sports Med. 1996; 22: 176-86.
10. American Academy of Pediatrics COmmittee on Sports Medicine and Fitness. Strength training by children and adolescents. Pediatrics. 2001; 107: 1470-2.

11. Faith MS, Leone MA, Ayers TS, Heo M, Pietrobelli A. Weight criticism during physical activity, coping skills, and reported physical activity in children. Pediatrics. 2002; 110: e23.

12. Daniels SR, Arnett DK, Eckel RH, Gidding SS, Hayman LL, Kumanyika S, et al. Overweight in children and adolescents: pathophysiology, consequences, prevention, and treatment. Circulation. 2005; 111: 1999-2012.

13. Kelley GA, Kelley KS. Effects of aerobic exercise on non-high-density lipoprotein cholesterol in children and adolescents: a meta-analysis of randomized controlled trials. Prog Cardiovasc Nurs. 2008; 23: 128-32.

14. Balas-Nakash M, Benitez-Arciniega A, Perichart-Perera O, Valdes-Ramos R, Vadillo-Ortega F. The effect of exercise on cardiovascular risk markers in Mexican school-aged children: comparison between two structured group routines. Salud Publica Mex. 2010; 52: 398-405.

15. Martin JE, Dubbert PM, Katell AD, Thompson JK, Raczynski JR, Lake M, et al. Behavioral control of exercise in sedentary adults: studies 1 through 6. J Consult Clin Psychol. 1984; 52: 795-811.

16. Sothern MS, Loftin JM, Udall JN, Suskind RM, Ewing TL, Tang SC, et al. Safety, feasibility, and efficacy of a resistance training program in preadolescent obese children. Am J Med Sci. 2000; 319: 370-5.

17. Sgro M, McGuigan MR, Pettigrew S, Newton RU. The effect of duration of resistance training interventions in children who are overweight or obese. J Strength Cond Res. 2009; 23: 1263-70.

18. 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. J Strength Cond Res. 2009; 23: 80-5.

19. Owen CG, Nightingale CM, Rudnicka AR, Sattar N, Cook DG, Ekelund U, et al. Physical activity, obesity and cardiometabolic risk factors in 9- to 10-year-old UK children of white European, South Asian and black African-Caribbean origin: the Child Heart And health Study in England (CHASE). Diabetologia. 2010; 53: 1620-30.

20. Dietz P, Hoffmann S, Lachtermann E, Simon P. Influence of exclusive resistance training on body composition and cardiovascular risk factors in overweight or obese children: a systematic review. Obes Facts. 2012; 5: 546-60.

21. Faigenbaum AD. Strength training for children and adolescents. Clin Sports Med. 2000; 19: 593-619.

22. Faigenbaum AD, Loud RL, O'Connell J, Glover S, Westcott WL. Effects of different resistance training protocols on upper-body strength and endurance development in children. J Strength Cond Res. 2001; 15: 459-65.

23. Faigenbaum AD, Milliken LA, Westcott WL. Maximal strength testing in healthy children. J Strength Cond Res. 2003; 17: 162-6.

24. Faigenbaum AD, Westcott WL, Loud RL, Long C. The effects of different resistance training protocols on muscular strength and endurance development in children. Pediatrics. 1999; 104: e5.

25. Benson AC, Torode ME, Fiatarone Singh MA. The effect of high-intensity progressive resistance training on adiposity in children: a randomized controlled trial. Int J Obes (Lond). 2008; 32: 1016-27.

26. Sothern MS, Loftin JM, Udall JN, Suskind RM, Ewing TL, Tang SC, et al. Inclusion of resistance exercise in a multidisciplinary outpatient treatment program for preadolescent obese children. South Med J. 1999; 92: 585-92.

27. Treuth MS, Hunter GR, Figueroa-Colon R, Goran MI. Effects of strength training on intra-abdominal adipose tissue in obese prepubertal girls. Med Sci Sports Exerc. 1998; 30: 1738-43.

28. 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: 667-72.

29. Brandou F, Dumortier M, Garandeau P, Mercier J, Brun JF. Effects of a two-month rehabilitation program on substrate utilization during exercise in obese adolescents. Diabetes Metab. 2003; 29: 20-7.

30. Ben Ounis O, Elloumi M, Amri M, Zbidi A, Tabka Z, Lac G. Impact of diet, exercise end diet combined with exercise programs on plasma lipoprotein and adiponectin levels in obese girls. J Sports Sci Med. 2008; 7: 437-45.

31. Ben Ounis O, Elloumi M, Ben Chiekh I, Zbidi A, Amri M, Lac G, et al. Effects of two-month physical-endurance and diet-restriction programmes on lipid profiles and insulin resistance in obese adolescent boys. Diabetes Metab. 2008; 34: 595-600.

32. Ben Ounis O, Elloumi M, Lac G, Makni E, Van Praagh E, Zouhal H, et al. Two-month effects of individualized exercise training with or without caloric restriction on plasma adipocytokine levels in obese female adolescents. Ann Endocrinol (Paris). 2009; 70: 235-41.

33. Ben Ounis O, Elloumi M, Zouhal H, Makni E, Denguezli M, Amri M, et al. Effect of individualized exercise training combined with diet restriction on inflammatory markers and IGF-1/IGFBP-3 in obese children. Ann Nutr Metab. 2010; 56: 260-6.

34. Ben Ounis O, Elloumi M, Zouhal H, Makni E, Lac G, Tabka Z, et al. Effect of an individualized physical training program on resting cortisol and growth hormone levels and fat oxidation during exercise in obese children. Ann Endocrinol (Paris). 2011; 72: 34-41.

35. Brooks GA, Mercier J. Balance of carbohydrate and lipid utilization during exercise: the “crossover” concept. J Appl Physiol (1985). 1994; 76: 2253-61.

36. Lee S, Deldin AR, White D, Kim Y, Libman I, Rivera-Vega M, et al. Aerobic exercise but not resistance exercise reduces intrahepatic lipid content and visceral fat and improves insulin sensitivity in obese adolescent girls: a randomized controlled trial. Am J Physiol Endocrinol Metab. 2013; 305: E1222-9.

37. van der Heijden GJ, Wang ZJ, Chu ZD, Sauer PJ, Haymond MW, Rodriguez LM, et al. A 12-week aerobic exercise program reduces hepatic fat accumulation and insulin resistance in obese, Hispanic adolescents. Obesity (Silver Spring). 2010; 18: 384-90.

38. Van Der Heijden GJ, Wang ZJ, Chu Z, Toffolo G, Manesso E, Sauer PJ, et al. Strength exercise improves muscle mass and hepatic insulin sensitivity in obese youth. Med Sci Sports Exerc. 2010; 42: 1973-80.

39. van der Heijden GJ, Toffolo G, Manesso E, Sauer PJ, Sunehag AL. Aerobic exercise increases peripheral and hepatic insulin sensitivity in sedentary adolescents. J Clin Endocrinol Metab. 2009; 94: 4292-9.

40. Alberga AS, Farnesi BC, Lafleche A, Legault L, Komorowski J. The effects of resistance exercise training on body composition and strength in obese prepubertal children. Phys Sportsmed. 2013; 41: 103-9.

41. Heinonen A, Sievanen H, Kannus P, Oja P, Pasanen M, Vuori I. High-impact exercise and bones of growing girls: a 9-month controlled trial. Osteoporos Int. 2000; 11: 1010-7.

42. Morris FL, Naughton GA, Gibbs JL, Carlson JS, Wark JD. Prospective ten-month exercise intervention in premenarcheal girls: positive effects on bone and lean mass. J Bone Miner Res. 1997; 12: 1453-62.

43. Lau P, YU C, Lee A, Sung R. The physiological and psychological effects of resistance training on chinese obese adolescents. Journal of Exercise Science and Fitness. 2004; 2: 115-20.

44. Campos RM, de Mello MT, Tock L, da Silva PL, Corgosinho FC, Carnier J, et al. Interaction of bone mineral density, adipokines and hormones in obese adolescents girls submitted in an interdisciplinary therapy. J Pediatr Endocrinol Metab. 2013; 26: 663-8.

45. Falk B, Eliakim A. Resistance training, skeletal muscle and growth. Pediatr Endocrinol Rev. 2003; 1: 120-7.

46. Dao HH, Frelut ML, Oberlin F, Peres G, Bourgeois P, Navarro J. Effects of a multidisciplinary weight loss intervention on body composition in obese adolescents. Int J Obes Relat Metab Disord. 2004; 28: 290-9.

47. Dao HH, Frelut ML, Peres G, Bourgeois P, Navarro J. Effects of a multidisciplinary weight loss intervention on anaerobic and aerobic aptitudes in severely obese adolescents. Int J Obes Relat Metab Disord. 2004; 28: 870-8.

48. Heyward VH. Advanced fitness assessment and exercise prescription. 4th edn. Champaign, IL 2002.

49. Maffiuletti NA, Ratel S, Sartorio A, Martin V. The impact of obesity on in vivo human skeletal muscle function. Curr Obes Rep. 2013; 2: 251-60.

50. Kraemer WJ, Fry AC, Frykman PM, Conroy B, Hoffman J. Resistance training and youth. Ped Exe Science. 1989: 336-50.

51. Webb DR. Strength training in children and adolescents. Pediatr Clin North Am. 1990; 37: 1187-210.

52. Alberga AS, Sigal RJ, Kenny GP. A review of resistance exercise training in obese adolescents. Phys Sportsmed. 2011; 39: 50-63.

53. Maziekas MT, LeMura LM, Stoddard NM, Kaercher S, Martucci T. Follow up exercise studies in paediatric obesity: implications for long term effectiveness. Br J Sports Med. 2003; 37: 425-9.

54. Davis JN, Tung A, Chak SS, Ventura EE, Byrd-Williams CE, Alexander KE, et al. Aerobic and strength training reduces adiposity in overweight Latina adolescents. Med Sci Sports Exerc. 2009; 41: 1494-503.

55. Escalante Y, Saavedra JM, Garcia-Hermoso A, Dominguez AM. Improvement of the lipid profile with exercise in obese children: a systematic review. Prev Med. 2012; 54: 293-301.

56. Nassis GP, Papantakou K, Skenderi K, Triandafillopoulou M, Kavouras SA, Yannakoulia M, et al. Aerobic exercise training improves insulin sensitivity without changes in body weight, body fat, adiponectin, and inflammatory markers in overweight and obese girls. Metabolism. 2005; 54: 1472-9.

57. Suh S, Jeong I, Kim MY, Kim YS, Shin S, Kim SS, et al. Effects of Resistance Training and Aerobic Exercise on Insulin Sensitivity in Overweight Korean Adolescents: A Controlled Randomized Trial. Diabetes Metab J. 2011; 35: 418-26.

58. 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: 2463-8.

59. 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: 122-31.

60. 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: 1313-24.

61. 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: 1208-15.

62. Faigenbaum AD, Kraemer WJ, Blimkie CJ, Jeffreys I, Micheli LJ, Nitka M, et al. Youth resistance training: updated position statement paper from the national strength and conditioning association. J Strength Cond Res. 2009; 23: S60-79.

63. Neumark-Sztainer D, Story M, Hannan PJ, Rex J. New Moves: a school-based obesity prevention program for adolescent girls. Prev Med. 2003; 37: 41-51.

64. Stratton G, Jones M, Fox KR, Tolfrey K, Harris J, Maffulli N, et al. BASES position statement on guidelines for resistance exercise in young people. J Sports Sci. 2004; 22: 383-90.

65. LeMura LM, Maziekas MT. Factors that alter body fat, body mass, and fat-free mass in pediatric obesity. Med Sci Sports Exerc. 2002; 34: 487-96.

66. Cooper DM, Kaplan MR, Baumgarten L, Weiler-Ravell D, Whipp BJ, Wasserman K. Coupling of ventilation and CO2 production during exercise in children. Pediatr Res. 1987; 21: 568-72.

67. Aucouturier J, Rance M, Meyer M, Isacco L, Thivel D, Fellmann N, et al. Determination of the maximal fat oxidation point in obese children and adolescents: validity of methods to assess maximal aerobic power. Eur J Appl Physiol. 2009; 105: 325-31.

68. Perez-Martin A, Dumortier M, Raynaud E, Brun JF, Fedou C, Bringer J, et al. Balance of substrate oxidation during submaximal exercise in lean and obese people. Diabetes Metab. 2001; 27: 466-74.

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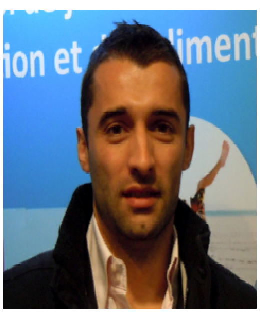

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