Original Article

Influence of Exclusive Resistance Training on Body Composition and Cardiovascular Risk Factors in Overweight or Obese Children: A Systematic Review

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Key Words

Adiposity • Strength training • Childhood • Cardiovascular health

Abstract

Objective: Since the last decade, a significant increase in the prevalence of overweight and obesity among children has been reported. Low aerobic fitness and a low compliance with endurance sports in such children are theoretical reasons to favor the use of resistance training in intervention studies, even though positive effects of resistance training on morbidity without accompanying dietary modifications are a matter of debate. In this review we summarize the studies that have shown the isolated effect of resistance training on body composition and cardiovascular risk factors in overweight and obese children. **Method:** We systematically reviewed interventional studies that exclusively applied resistance training to overweight and obese 3- to 18-year-old children. Outcome measurements were body composition or cardiovascular risk factors. **Results:** Only six studies passed the inclusion criteria. All studies preferred an individually planned and supervised whole-body resistance training of moderate to submaximal intensity during treatment. The mean compliance was 84%. Four studies reported significant changes in body composition, with an increase in fat free mass and BMI, along with a decrease in fat mass. Three studies analyzed the effect of resistance training on cardiovascular risk factors, and only one study reported a significant decrease in systolic blood pressure. **Conclusion:** An individually planned and supervised whole-body resistance training of moderate to submaximal intensity in children seems to be safe and tends to show positive effects on body composition. Similar to interventions based on en-

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duration exercise alone or in combination with dietary modifications, the effects on cardiovascular risk factors cannot be substantiated. In consequence, we suggest to substantiate the effect of resistance training on cardiovascular risk factors in overweight and obese children in upcoming randomized controlled trials with high case numbers, applying both resistance training only and resistance training in combination with dietary intervention to get knowledge about whether resistance training alone is effectual in the treatment of overweight and obesity in youth or if a combination of resistance training and dietary interventions is actually needed.

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Introduction

Overweight and obesity in childhood have reached enormous epidemic dimensions worldwide [1–3] and are strong predictors of obesity in adulthood [4]. Moreover, overweight and obesity in childhood do not only correlate with a low fitness level [5] but are also associated with risk factors for cardiovascular and other chronic diseases [6]. Torrance et al. [7], for instance, showed the negative influence of obesity on blood pressure and its determinants in children. Cardiovascular dysfunctions associated with obesity have become an enormous problem for the public health care system with substantial downstream healthcare costs [8].

Current models of obesity intervention include increased physical activity, modification of eating habits and psychosocial interventions [9]. The most frequently implemented exercise-based interventions for children are structured aerobic exercise programs (walking, jogging, skating, cycling, dancing) 3–5 times a week of moderate to submaximal intensity up to 60 min a day [10, 11] which are reported to have positive short-term effects on BMI, % fat mass, blood pressure, and triglycerides [12]. Additionally, Nassis et al. [13] showed an improvement of insulin sensitivity and an increase of cardiorespiratory fitness after 12 weeks of aerobic exercise in overweight and obese girls. Maggio et al. [14] reported for the first time that beneficial effects of exercise training on obesity and cardiovascular risk markers in children are sustained 2 years after the intervention.

A drawback of endurance-based exercise interventions is the relatively poor compliance in cohorts of children, mainly because of the problem of getting this age group sufficiently motivated for this type of training intervention [15]. Additionally, the low aerobic fitness level of overweight and obese children [5] limits the intensity at which such exercise interventions should be conducted. In contrast, interventions based on resistance training will most probably be well tolerated achieving a high level of compliance, since children with a higher body mass will on average be able to lift higher weights than peers that are normal weight [16]. Resistance training may therefore be an interesting alternative for respective lifestyle interventions since both compliance and intensity of the particular training sessions could be improved in overweight and obese persons. According to recommendations given by the American Academy of Pediatrics [17], resistance training for children and adolescents has to be supervised by competent personnel, be progressively planned, be of moderate intensity, address all major muscles, and include a warm-up and cool-down component. Some studies have already suggested that resistance training is able to reduce overweight and obesity as well as insulin resistance and helps to improve glycemic control in children [18] and adults [19–21]. In overweight and obese adults, beneficial effects of resistance training on cardiovascular risk factors have already been well documented [22–24]. In a randomized controlled trial (RCT) of 34 obese women, Idoate et al. [22] reported a significant decrease of regional visceral fat after a combined intervention with resistance training

and diet. Significant decreases in visceral fat mass after a treatment based on resistance training without any dietary modifications have been shown in women [23] as well as in men [24]. Furthermore, in a meta-analysis of RCTs, Cornelissen et al. [25] concluded that resistance training of moderate intensity is not contraindicated and has positive effects on high blood pressure in adult people.

In children, several studies have investigated the combined effect of a diet and exercise intervention on obesity [16, 26, 27]. Benson et al. [28] have systematically reviewed the combined intervention of resistance training and dietary modifications, resistance training and aerobic exercise as well as isolated resistance training on metabolic fitness in overweight and obese children. Besides the gain of muscular strength, health-related benefits on body composition, cardiorespiratory fitness, blood lipids, bone mineral density, and insulin sensitivity were reported. Benson et al. [28] were by the time not able to differentiate which kind of intervention is the most effective and practical intervention for the respective population. So far the influence of an intervention by resistance training alone on cardiovascular risk factors in overweight and obese children has not yet been reviewed. However, such information would be interesting given that in adults it has already been shown that mortality due to impaired cardiovascular risk factors is increased in the population of overweight and obese persons and that obesity in youth is highly correlated with the prevalence of heart diseases in adulthood [6, 29]. For the population of adults, interventions using only resistance training have been shown to influence cardiovascular risk factors positively [25].

Our purpose in the present study is to analyze the effect of interventions with isolated resistance training in overweight and obese children on anthropometric measurements, such as body mass, body fat, fat free mass or BMI, and cardiovascular risk factors. As outcome measurements regarding cardiovascular risk, we integrated all studies that reported effects on the following well established predictors: blood pressure [30], total cholesterol level (TC), ratio of low-density (LDL) and high-density lipoproteins (HDL) [31–33], visceral fat [34], waist circumference (WC), and waist-to-hip ratio (WHR) [35, 36]. The aim of this systematic review is to ascertain whether resistance training alone can be regarded as a sufficiently effective treatment.

Material and Methods

Inclusion and Exclusion Criteria

In this systematic review all studies had to successfully pass the following inclusion criteria: Studies had to be published in English; cohorts had to be children or adolescents (ages under 18 years); the intervention had to be based exclusively on resistance training with free weights (dumbbells and barbells), machines, or a combination of these. All kind of endurance-based training was only accepted as warm-up or cool-down periods and not as part of the main intervention. An intervention combining resistance training and diet was not accepted because the role of resistance training alone is the focus of this review. Results had to relate to body composition (mass, BMI, percentage fat, total fat mass, and fat free mass) and cardiovascular risk factors including blood pressure, WC, WHR, visceral fat, TC, LDL, and HDL.

Search Protocol

We conducted a comprehensive literature search for full-length manuscripts with the MEDLINE (1950–2010) and SPORTS Discus (1830–2010) online databases using the following subject headings and their logical combinations: ‘resistance training’, ‘strength training’, ‘weight training’, ‘dumbbell training’, ‘exercise’, ‘child’, ‘children’, ‘childhood’, ‘adolescents’,

Fig. 1. Flow chart of study selection process.

‘obesity’, ‘obese’, ‘adiposity’, ‘overweight’, ‘BMI’, ‘body weight’, ‘body mass’, ‘body composition’, ‘risk factors’, ‘blood pressure’, ‘cholesterol’, ‘waist circumference’, ‘waist-to-hip ratio’, ‘lipids’, ‘lipoproteins’.

The whole search term was created as follows: (‘resistance training’ OR ‘strength training’ OR ‘weight training’ OR ‘dumbbell training’ OR exercise) AND (child OR children OR childhood OR adolescents) AND (obesity OR obese OR adiposity OR overweight) AND (BMI OR ‘body weight’ OR ‘body mass’ OR ‘body composition’ OR ‘risk factors’ OR ‘blood pressure’ OR cholesterol OR ‘waist circumference’ OR ‘waist-to-hip ratio’ OR lipids OR lipoproteins). This search revealed 4,353 articles that were further limited to clinical trials in English, in humans, and in children (0–18 years) as well as to studies in males and females that had been terminated until November 5, 2010. We also checked the reference lists of the published articles in order to screen for relevant articles which have not been identified by our primary search, but no additional articles have been found.

Table 1. Cohort and intervention characteristics

Author, year	Study design	Sample	Age	Exercise mode, intervention	Strength test method	Resistance training equipment	Duration	Compliance
VanDer Heijden, 2010 [37]	UCT	n = 12 6 boys 6 girls BMI ≥ 95th percentile	mean age: 15,5 years	supervised resistance training 2 days a week, 1 h warm-up, resistance training, cool down week 1-2: 2-3 sets, 8-12 reps, 50% 3 RM week 3-12: increasing weights till 3 sets, 15-20 reps, 80-85% 3 RM	3 RM	free weights, machines, cables, physioball	12 weeks	96%
McGuigan, 2008 [38]	UCT	n = 48 22 boys 26 girls BMI ≥ 85th percentile	7-12 years mean age: 9,7 years	undulating, supervised, periodized resistance training; high volume, moderate intensity: 3 days a week day 1: 3 sets 8-10RM day 2: 3 sets 10-12RM day 3: 3 sets 3-5 reps	1 RM	dumbbells, elastic bands, medicine balls, weighted bags	8 weeks	76%
Naylor, 2008 [39]	NRCT	n = 23 T: 13 C: 10 Obese BMI > 30 kg/m ²	mean age: t: 12,2 years c: 13,6 years	T: supervised circuit group resistance training: 3 days a week, 1 h warm-up, resistance training, cool down 10 stations, 2 sets, 8 reps C: no exercise intervention	1 RM	weight-stack machines	8 weeks	T: 85,4%
Benson, 2008 [40]	RCT	n = 78 T: 22 boys 15 girls C: 24 boys 17 girls overweight/obese	10-15 years mean age: 12,2 years	T: high-intensity progressive resistance training: 2 days a week 11 exercises (5 upper body, 4 lower body, 2 abdominal muscles), 2 sets, 8 repetitions C: <no exercise intervention	RPE 6-20 scale	free weights, ankle weights	8 weeks	77%

Table 1 continued on next page

Table 1. Continued

Author, year	Study design	Sample	Age	Exercise mode, intervention	Strength test method	Resistance training equipment	Duration	Compliance
Shaibi, 2006 [18]	RCT	n= 22 boys T: 11 C: 11 BMI ≥ 85th percentile	mean age: t: 15,1 years c: 15,6 years	T: progressive resistance training: moderate intensity, higher volume 2 days a week week 1–4: 1 set, 10–15 reps week 5–10: 2 sets, 13–15 reps week 11–16: 3 sets, 8–12 reps C: no exercise intervention	1 RM	free weights, machines	16 weeks	79%
Treuth, 1998 [41]	NRCT	n= 22 girls T: 11 C: 11 BMI ≥ 95th percentile	7–10 years	T: circuit based whole body strength training: moderate intensity, session 1–3: 50% 1 RM, raise every 2-week period, still comfortable; 3 days a week, 20 min 2 sets, 12–15 repetitions six upper-body exercises, one lower-body exercise C: no exercise intervention	1 RM	machines	5 months	92%

C = Control-group; NRCT = non-randomized controlled trial; RCT = randomized controlled trial; reps = repetitions; RM = repetition maximum; RPE = rating of perceived exertion; T = treatment-group; UCT = uncontrolled trial.

Table 2. Resistance training program of each study

Author, year	Day	Order	exercise	sets	reps	tempo	rest
VanDer Heijden, 2010 [37]	1, 2	1	chest press or push-ups	week 1+2: 2	week 1+2: 8–12	controlled	not reported
		2	seated row or overhead press	week 3–12: 3	week 3–12: 15–20		
		3	triceps extension				
		4	biceps curls				
		5	lateral raises				
		6	squats or lunges				
		7	deadlift or leg curl				
		8	calf raises				
		9	bridges on physioball				
		10	abdominal				
McGuigan, 2008 [38]	1	1	squat	3	8–10	controlled	90 s
		2	press	3	8–10		
		3	upright row	3	8–10		
		4	lunge	3	8–10		
		5	push-up	3	max		
		6	arm-curl	3	8–10		
		7	triceps dip	3	8–10		
		8	abdominal	3	12–15		
	2	1	squad	3	10–12	controlled	60 s
		2	deadlift	3	10–12		
		3	chest fly	3	10–12		
		4	front raise	3	10–12		
		5	row	3	10–12		
		6	calf raise	3	10–15		
		7	triceps extension	3	10–12		
		8	abdominal	3	10–15		
	3	1	jump	3	5	fast	3 min
		2	high pull	3	3		
		3	press	3	5		
		4	upright row	3	5		
		5	squat jump	3	3		
		6	lying press	3	5		
		7	broad jump	3	3		
		8	abdominal	3	10		
Naylor, 2008 [39]	1, 2, 3	1–10	not reported	2	8	not reported	1 min

Table 2 continued on next page

With this procedure we identified 237 potentially relevant articles (fig. 1). Therefrom, we excluded all review articles (34), all intervention studies not using an exercise-based intervention for treating obesity, e.g. studies dealing with pharmaceuticals and surgeries (134), as well as studies in children dealing with a treatment based on endurance exercise and/or dietary (34). Of the remaining 35 studies, only 6 full articles reported a treatment using resistance training exclusively and its effects on either markers of body composition or cardiovascular risk factors as defined above.

Table 2. Continued

Author, year	Day	Order	exercise	sets	reps	tempo	rest
Benson, 2008 [40]	1, 2	1	biceps screw curl	2	8	controlled	not reported
		2	triceps extension	2	8		
		3	one arm dumbbell row	2	8		
		4	dumbbell front raise	2	8		
		5	bench press	2	8		
		6	standing leg abduction	2	8		
		7	standing leg curl	2	8		
		8	calf raise and lower back	2	8		
		9	squat	2	8		
		10	abdominal crunch	2	8		
		11	abdominal reverse crunch	2	8		
Shaibi, 2006 [18]	1	1	leg press	week 1–4: 1	week 1–4: 10–15	controlled	1–2 min
		2	dead lift	week 5–10: 2	week 5–10: 3–15		
		3	biceps curl	week 11–16: 3	week 11–16: 8–12		
		4	triceps extension				
		5	shoulder press				
	2	1	bench press	week 1–4: 1	week 1–4: 10–15	controlled	1–2 min
		2	lat pull-down	week 5–10: 2	week 5–10: 3–15		
		3	leg extension	week 11–16: 3	week 11–16: 8–12		
		4	leg curl				
		5	calf raise				
Treuth, 1998 [41]	1, 2, 3	1	bench press	2	12	controlled	short rests
		2	military press	2	12		
		3	biceps curl	2	12		
		4	lat pull-down	2	12		
		5	triceps extension	2	12		
		6	abdominal (sit-up)	2	12		
		7	leg press	2	15		

reps = repetitions.

Results

Among the six included studies [18, 37–41] were two RCTs [18, 40] two non-randomized controlled trials (NRCT) [39, 41] and two uncontrolled trials (UCT) [37, 38].

Cohort and Intervention Characteristics

The sample sizes for the studies ranged from 12 to 78 [37, 40] with a mean sample size of 34 for all six studies. Three studies investigated mixed cohorts of boys and girls [37, 38, 40], one only girls [41], one only boys [18], and one study did not give any information whatsoever about the gender [39]. All children included in the studies had to be either overweight or obese. In four studies the children were pointed out as overweight or obese using the 85th [18, 38] or 95th [37, 41] BMI percentile. One study used the BMI limit over 30 kg/m² [39], and one study just reported overweight and obese children, without giving any further specifications with regard to their definition of overweight and obesity [40]. The subjects' ages ranged from a mean age of 9 years [41] up to a mean age of 16 years [18] (table 1).

All studies arranged a whole-body resistance training workout with the children including exercises for the legs, chest, back, shoulders, arms, and abdominal muscles. Five studies preferred a supervised resistance training of moderate intensity in the treatment groups [18, 37–39, 41], and only one study used a progressive resistance training intervention of high intensity [40]. All treatment groups worked out 2 [18, 37, 40] or 3 times a week [37, 39, 41], executing 2 or 3 sets with 8–20 repetitions. Two studies [37, 39] indicated a warm-up period prior to and a cool-down period after the resistance training. Three studies [18, 37, 38] created a split resistance training especially for the treatment: Van der Heijden et al. [37] started out with 2–3 sets and 8–12 repetitions at an intensity of 50% of the 3-repetition maximum (RM) during the first 2 weeks. From week 3–8, they increased the intensity progressively and finally concluded the treatment with 3 sets of 15–20 repetitions at 80–85% of 3 RM in the weeks 9–12. In contrast, Shaibi et al. [18] started the first 4 weeks with 1 set of 10–15 repetitions followed by weeks 5–10 with 2 sets of 13–15 repetitions each and completed the training program with 3 sets of 8–12 repetitions from weeks 11–16. Further, McGuigan et al. [38] split the 3 days of intervention into 2 training days of controlled resistance training with three sets of 8–12 repetitions and a 3rd day of explosive jumps and high training loads with 3 sets of 3–5 repetitions. Apart from this one fast/explosive working day applied by McGuigan et al. [38], all studies reported a preference for a slower and maybe more controlled way of absolving the individual exercise movements. The resting period between the sets ranged from 60 s to 3 min [37] (table 1, table 2). The control groups of all four controlled trials [39–41] carried out no intervention by exercise whatsoever. To determine the individual intensity and progression of resistance training for each child, four studies used the 1 RM [18, 38, 39, 41], one the 3 RM [37], and another the rating of perceived exertion (RPE) 6–20 scale [39]. In five studies, free weights or a combination of free weights and machines [36–40] were used to perform the exercises during training. Only Treuth et al. [41] exclusively used machines. The duration of the intervention phases ranged from 8 weeks [38–40] to 5 months [41] with a lowest compliance for attendance of 76% [38] up to a maximum compliance with 96% [37]. The mean compliance of all six studies presented in the review is 84% (table 1).

Outcome Measurements

Table 3 presents all reported outcome measurements and their given unit, with pre- to post-intervention changes of each outcome measurement being described by the standard deviation (SD). Significant time effects from pre- to post-intervention of the treatment and control groups and group differences between treatment and control groups are presented with the respective p values.

Five studies [18, 37–39, 41] used dual-energy x-ray absorptiometry (DEXA) to calculate fat mass and fat free mass. Benson et al. [40], however, were not able to perform DEXA. Instead they used the bioelectrical impedance analysis (BIA).

All studies [18, 37–41] presented results on body mass, percentage fat, total fat mass, and fat free mass; only one study failed to report results on BMI [41]. Van der Heijden et al. [37] showed a significant increase of body mass and BMI as well as a significant increase in fat free mass after the intervention. Three studies [18, 38, 39] showed a significant decrease in percentage fat and a significant increase of fat free mass. Benson et al. [40] pointed out significant differences between the treatment and the control group, with a significant higher increase of the BMI in the control group as well as an increase of percentage fat in the control group and a simultaneous decrease in the treatment group. Finally, in the study of Treuth et al. [41], both the treatment group as well as the control group showed significant increases in body mass, total fat mass and fat free mass, combined with significant differences between the groups.

Table 3. Outcome measurements

Author, year	Type of change	Mass, kg	BMI, kg/m ²	% Fat method	Total fat mass, kg	Fat free mass, kg	SBP, mm HG	TC, mmol/l	LDL, mmol/l	HDL, mmol/l	Visceral fat, cm ²	WC + WHR
VanDer Heijden, 2010 [37]	pre: post time effect	97.0 (3.8) 99.6 (4.2) p < 0.01	35.3 (0.7) 36.1 (0.9) p < 0.01	DEXA DEXA NS	39.7 (1.9) 40.3 (2.3) NS	55.7 (2.8) 57.9 (3.0) p < 0.01	-	8.3 (0.4) 8.7 (0.5) NS	5.0 (0.4) 5.3 (0.4) NS	2.3 (0.1) 2.3 (0.1) NS	58.0 (4.0) 55.0 (4.0) NS	-
McGuigan, 2008 [38]	pre: post time effect	55.2 (10.0) 56.3 (10.1) NS	25.6 (3.1) 25.9 (3.2) NS	DEXA DEXA p < 0.05	22.5 (5.7) 21.3 (5.6) NS	32.2 (5.5) 33.9 (5.3) p < 0.05	-	-	-	-	-	-
Naylor, 2008 [39]	pre: post T	84.9 (6.5) 85.5 (6.6)	32.5 (1.9) 31.9 (2.0)	DEXA DEXA	43.1 (3.5) 42.8 (3.6)	41.2 (3.7) 42.1 (3.0)	120 (2) 116 (3)	-	-	-	-	-
C		82.1 (8.3) 82.5 (8.3)	30.2 (2.6) 30.0 (2.6)	not reported not reported	not reported not reported	Not reported Not reported	122 (2) 122 (2)					
time effect		NS	NS	T: p < 0.01	T: NS	T: p < 0.05	T: P < 0.05 C: NS					
Benson, 2008 [40]	pre: post T	59.2 (19.9) 60.7 (20.0)	24.0 (5.4) 24.0 (5.5)	BIA BIA	not reported not reported	44.1 (10.9) 45.6 (11.4)	-	4.2 (1.0) 4.3 (1.1)	2.4 (0.7) 2.3 (0.9)	1.4 (0.4) 1.5 (0.4)	-	-
C		51.7 (10.7) 53.7 (10.3)	22.1 (3.6) 22.3 (3.5)	21.2 (8.6) 22.4 (8.1)		40.5 (6.3) 41.4 (6.3)		4.3 (0.7) 4.2 (0.7)	2.5 (0.6) 2.4 (0.6)	1.5 (0.3) 1.4 (0.2)		
group difference		NS	p < 0.05	p < 0.05		NS		NS	NS	NS		

Table 3 continued on next page

Table 3. Continued

Author, year	Type of change	Mass, kg	BMI, kg/m ²	% Fat method	Total fat mass, kg	Fat free mass, kg	SBP, mm HG	TC, mmol/l	LDL, mmol/l	HDL, mmol/l	Visceral fat, cm ²	WC + WHR
Shaibi, 2006 [18]	pre:post											
	T	90.0 (5.7)	32.5 (1.6)	DEXA	31.4 (3.4)	54.4 (3.2)	-	-	-	-	-	-
	C	91.9 (5.6)	32.8 (1.6)		30.1 (3.2)	58.1 (3.1)						
		98.3 (6.9)	34.6 (2.0)		30.8 (3.5)	62.3 (3.2)						
		100.0 (6.5)	35.0 (2.0)		30.7 (3.2)	64.3 (3.0)						
	time effect	T: NS	T: NS	T: P < 0.05	T: NS	T: P < 0.05						
	group difference	C: P < 0.05	C: NS	C: NS	C: NS	C: P < 0.05						
		NS	NS	NS	NS	p < 0.05 between % change of each group						
Treuth, 1998 [41]	pre:post											
	T	46.6 (9.4)	-	DEXA	18.1 (6.8)	27.1 (3.2)	-	-	-	-	-	-
	C	50.6 (10.3)			19.6 (6.9)	29.2 (3.6)						
		29.1 (2.8)			8.0 (1.8)	20.2 (2.1)						
		32.0 (3.0)			9.0 (1.8)	22.1 (2.2)						
	time effect	T: P < 0.001		T: NS	T: P < 0.001	T: P < 0.001						
	group difference	C: P < 0.001		C: NS	C: P < 0.05	C: P < 0.001						
		p < 0.05		p < 0.001	p < 0.001	p < 0.001						

BIA = Bioelectrical impedance analysis; C = control-group; DEXA = dual-energy x-ray absorptiometry; NS = not significant; SBP = systolic blood pressure T =, treatment-group.

The influence of resistance training on a specific cardiovascular risk factor was only investigated by three studies [37, 39, 40]. Two studies [37, 40] showed non-significant increases of TC in the treatment group, whereas one study reported [40] a non-significant decrease of TC in the control group. Additionally, one study reported an increase in LDL with no change in HDL [37], whereas another study [40] showed a decrease in LDL concentration in the treatment and in the control group. These changes were not significant.

One study [37] reported a non-significant decrease in visceral fat mass. The only significant change of a cardiovascular risk factor, due to the intervention, was found in the study of Naylor et al. [39], which did show a significant decrease in systolic blood pressure after the intervention. Systolic blood pressure has not been measured in the other studies.

Unfortunately, neither WHR nor WC was measured in any of the studies dealing with isolated resistance training in overweight and obese children and adolescents.

Discussion

All studies favored a whole body resistance training of moderate to submaximal intensity with 2–3 sets of 8–20 repetitions over a period of 8 weeks to 5 months for the treatment. This agrees largely with several recommendations found in the literature [17, 42, 43] that propose an appropriately designed resistance training of moderate intensity performed under the supervision of competent personnel in order to be safe and beneficial for children and adolescents. The consistently high compliance numbers for resistance training and the mean compliance of 84% underline the low rate of injuries of resistance training in childhood. Regarding aerobic exercise interventions in children, compliances between 80 and 100% were reported [11]. Although both resistance training and aerobic exercise intervention studies show high compliance numbers for exercise, there still is the question how realistic these numbers really are. The interventions performed in the studies were done under absolutely standardized conditions by supervised personnel. These conditions seem not to be given in real life and therefore not to be realistic for treating overweight and obesity in children.

All studies reported an increase in BMI or body weight. These outcomes on BMI are similar to studies that focused on a combined intervention of resistance training and dietary modifications [16, 26, 27] and stress the importance of resistance training in the therapy of overweight and obesity in children and adolescents. Although, BMI in children and adolescents varies by age and gender [44] and although some of the studies have assessed BMI changes in adolescents of a considerable age range, none of the studies reported the data in a way such that BMI standard deviation scores (BMI-SDS) values could be calculated by us [18, 37–41]. Unfortunately, this lowers the validity of the results of systematic reviews to a larger extent than the validity of the results of the original contributions. Reviews would additionally require a between-study standardization for the different age groups since they vary considerably between studies as in our case. To ensure higher validity of intervention studies and their potential reviews in overweight and obese children, future studies should use standardized age- and sex-specific BMI cut-offs to further create SDS [45]. The use of age and sex standardized scores should be common practice when studying overweight and obesity in both children [46] and adolescents [47].

Although three studies found a significant decrease in percentage fat, not even one study reported a significant decrease in total fat mass. Interestingly, Treuth et al. [41] even reported a significant increase in total fat mass. This effect is mainly the result of an increase of muscle mass in consequence to adaptation to resistance training. Even though the intervention of Treuth et al. [41] was conducted over a period of 5 months, thus constituting the

longest training period of all interventions referred to in this review, they were unable to show any positive effects on body composition. These findings, however, might primarily be due to a sampling bias, since only girls were included in the study, and these represented the youngest intervention study population (7–10 years), as well [41].

The aforementioned lack of decrease in fat mass is in contrast to studies which included a combined intervention of resistance training and dietary modification for treatment [16, 26, 27]. In consequence, a treatment of isolated resistance training appears to be insufficient for the reduction of fat mass in overweight and obese children. Future interventions that aim at a reduction of fat mass or body mass will have to combine resistance training with dietary modifications.

A practical reason against the usage of isolated resistance training for intervention is that participants will observe no or very little weight loss which will most likely abate their training enthusiasm. This lack of clearly observable progress will almost certainly lower their long-term compliance with resistance training interventions.

Only five outcome measurements in three studies were reported to affect cardiovascular risk factors in children; just one study [39] showed a significant effect on systolic blood pressure. The literature presents noticeably more data on adults [25]; so further scientific research is needed to substantiate the effect of resistance training on cardiovascular risk factors in overweight and obese children and adolescents.

It is apparent that positive changes in body composition and cardiovascular health were found after the interventions; nonetheless, the limitations in study design (of 6 studies only 2 were RCTs [18, 40]) plus the heterogeneous reports do not really allow current conclusions on the isolated role of resistance training. The lack of controlled trials and randomization as well as the low sample sizes, with a mean sample size of 37 in this systematic review, make a statistically safe interpretation of the results, and thus a subsequent validation of the exercise regimes used for the treatments, difficult.

Based on the revised recommendations for improving the quality of trials of Mosher et al. [48], future studies should be RCTs, including both a treatment group with isolated resistance training exercise and a treatment group combining resistance training with dietary modifications, since studies on adults have shown that resistance training and dietary modifications are beneficial to treat overweight and obesity [49]. Moreover, future studies on children and adolescents should analyze the effects of resistance training and dietary modifications on TC, systolic blood pressure, visceral fat as well as WHR and WC, as markers of cardiovascular health, to allow a more precise statement whether or not resistance training is able to improve cardiovascular risk factors in overweight and obese children. The measurements of these variables are easily to be accomplished and inexpensive, and these factors are even more relevant concerning mortality than the BMI alone.

Disclosure Statement

The authors declare to have no conflict of interest.

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