High intensity training in obesity: a Meta-analysis

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Summary

Introduction

High Intensity training (HIT) is a time-effective alternative to traditional exercise programs in adults with obesity, but the superiority in terms of improving cardiopulmonary fitness and weight loss has not been demonstrated.

Objective

to determine the effectiveness of HIT on cardiopulmonary fitness and body composition in adults with obesity compared to traditional (high volume continuous) exercise.

Methods

A systematic search of the main health science databases was conducted for randomized controlled trials comparing HIT with traditional forms of exercise in people with obesity. Eighteen studies were included in the meta-analysis. The (unstandardized) mean difference of each outcome parameters was calculated and pooled with the random effects model.

Results

HIT resulted in greater improvement of cardiopulmonary fitness (VO_{2max}) (MD 1.83, 95% CI 0.70, 2.96, p<0.005; I^2=31%) and a greater reduction of %body fat (MD -1.69, 95% CI -3.10, -0.27, p=0.02, I^2=30%) compared to traditional exercise. Overall effect for BMI was not different between HIT and traditional exercise.

Conclusion

Training at high intensity is superior to improve cardiopulmonary fitness and to reduce %body fat in adults with obesity compared to traditional exercise. Future studies are needed to design specific HIT programs for the obese with regard to optimal effect and long-term adherence.

Keywords: Obesity, High intensity training, Exercise.

Introduction

Physical inactivity is one of the major factors associated with obesity, and a low physical fitness is an independent risk factor for mortality. Exercise is an effective strategy to reduce weight and to improve health (1). The World Health Organization recommends at least 150 minutes of moderate intensity, or at least 75 minutes of vigorous-intensity physical activity for healthy adults in a week (2). However, the majority of the adults with obesity are not able to achieve this target due to different barriers, such as lack of motivation, lack of time and physical limitations (3–6). In addition, psychological factors like depression, anxiety and body image dissatisfaction are important limitations in people with obesity to perform exercise in public (7). High intensity training (HIT) is a time-effective alternative to traditional exercise programs which mostly involves a low to moderate intensity training of long duration. HIT is defined as exercise performed at an intensity of > 65% of maximal capacity (8). In general,

HIT is often performed with intensities above 80% of maximal capacity and therefore an interval training is often used in order to maintain the exercise performance (8). High Intensity Interval Training (HIIT), a specific form of HIT, is characterized by brief repetitions of high intensity exercise (30s-min) alternated with periods of rest or low-intensity exercise (1-5 min) (9,10). Recent studies showed that HIIT is effective to increase cardiopulmonary fitness (11,12) and to improve insulin sensitivity (12). Also, several studies have shown similar or better results with regard to weight reduction after a HIIT intervention compared to high volume, continuous training (13–15). Traditionally for weight loss, a medium intensity, high volume training is advised to increase fat oxidation. HIIT can effectuate weight reduction by promoting fat oxidation in a shorter time period, but also mechanisms like increased post exercise fat oxidation and a decreased post exercise appetite could play a role (15). Besides, some studies showed that HIIT is perceived to be more enjoyable than moderate intensity continuous exercise, also in the obese (16,17). This may improve the adherence to exercise and promote health benefit over a longer period. Up until now, the superiority of HIT in terms of improving cardiopulmonary fitness or weight reduction compared to moderate intensity continuous training has not been shown yet in persons with obesity. Most of the studies demonstrating weight reduction with HIT are not performed in an obese study population and there is a lot of variation in exercise protocols used in these studies. Therefore, it is currently not possible to make recommendations on the optimal type of exercise in adults with obesity. The aim of this review and meta-analysis was to determine the effectiveness of HIT on cardiopulmonary fitness and body composition in adults with obesity compared to traditional forms of exercise (lower intensity, high volume continuous). Secondly, we were interested in the effect of HIIT compared to traditional forms of exercise on these outcomes.

Methods

This review is based on PRISMA Statement for reporting systematic reviews and meta-analysis of studies that evaluate health care interventions (18).

Search strategy

A systematic search of the main health science databases (i.e. PubMed, Embase, Medline, Cochrane and Pedro) was conducted on 30 November 2015 and on 31 January 2017. The following search terms and matching synonyms were used: obesity, obese, high intensity, interval, exercise training and clinical trial. The full search strategy in each database can be found in the supplemental file (S1).

Inclusion and exclusion criteria

For this review, randomized controlled trials published after the year 2000 were included. Studies were included if the mean Body Mass Index (BMI) of the study population was above 30 kg/m^2 and if the participants were adults between 18 and 60 years. At least one of the intervention groups in the studies must have performed high intensity (interval) training (HIT or HIIT), while the control group must have performed medium or low intensity (continuous) training or normal level of physical activity. At least one of the following outcome parameters must have been reported: maximal oxygen uptake (VO$_2$max) or any of the following body composition parameters: BMI, fat mass (%), waist circumference, fat free mass, fat free mass index. Trials must have been written in English or Dutch. Studies were excluded if the details of the exercise intervention were lacking; the participations of the studies had any significant cardiovascular of neurological comorbidity; there was any significant co-intervention (psychological, drugs or nutritional) and if the duration of the intervention was shorter than 2 weeks.

Outcome measures

The primary outcome parameter was the maximal Oxygen Uptake (VO$_{2max}$) in ml/kg/min. Secondary outcome parameters were body weight (kg), Body Mass Index (BMI) (kg/m^2), waist circumference (cm) and fat mass (%).

Selection of Studies

Two authors (YT, WT) screened the articles for inclusion by using the title and abstracts. Abstracts were excluded based on the study design, age and BMI of the study population. Next, the full text of the selected articles was screened by those two researchers for inclusion based on study design, patient characteristics, intervention and outcomes. If there was a disagreement between these two authors, the third researcher (MK) made the definitive decision. The reference list of all relevant articles was screened for eligible studies for this review.

Risk management

Risk of bias for each article was assessed by two reviewers (YT and WT) independently. The recommendations in the Cochrane handbook of systematic reviews of interventions were used. Authors used the risk of bias tool

in Review Manager 5 (version RevMan 5.3; https://tech. cochrane.org/revman) software and evaluated the risk as "low risk", "unclear risk" or "high risk" for each domain (selection bias, performance bias, detection bias, attrition bias and reporting bias). Disagreements were resolved by consensus between the reviewers.

Data extraction and management

Following data were extracted from the included studies: publication year, journal, study site, study design, objectives, methods of analysis, size of study population, gender, age, type of intervention, intensity and volume of exercise training, duration of the intervention and study, VO_{2max} (before-after), BMI (before-after), body weight (before-after), waist circumference (before-after) and percentage body fat (before-after). RevMan 5.3 was used for data management. Only 4 articles reported the change from baseline with the corresponding standard deviations of the change for different outcomes. Calculation of standard deviations of the change in other articles was not possible because of missing standard error, t- and p-values. Because of the heterogeneity in time points (baseline-final value measurement), imputation of standard deviations of the change was not recommended (Cochrane Handbook for Systematic Reviews of Interventions). Therefore, a comparison of the final measurements was used, which in randomized controlled trials estimates the same effect as the comparison of changes from baseline (19). Data were extracted from the articles. The (unstandardized) mean difference of each outcome parameters was calculated and pooled with the random effects model (19).

Heterogeneity

Heterogeneity was expected in the size and characteristics of the study populations (age and gender) and in the characteristics of the interventions, such as the type of exercise, the intensity, frequency and the total intervention period. To determine the heterogeneity across the studies, the Chi^2 and I^2 tests of RevMan 5.3 were used (20). Heterogeneity was interpreted as not important when I^2 was between 0% to 40%, moderate when I^2 was 30% to 60%, substantial when I^2 was 50%-90% and considerable when I^2 was 75% to 100%. For the Chi^2 test, a p-value of 0.10 was used to determine statistical significance in heterogeneity (19).

Subgroup analysis

Subgroup analyses were performed for HIIT (interval only) for each outcome parameter if there was sufficient data

available. Additionally, subgroup analysis was performed for HIT compared to medium- or low intensity exercise training and compared to normal level of physical activity.

Sensitivity analysis

A sensitivity analysis was conducted by excluding studies with an intervention period shorter than 4 weeks. In addition, sensitivity analysis was performed by excluding studies with less than 20 participants from the analysis.

Meta-regression

If there were significant results, meta-regression analysis was performed to determine the impact of study characteristics (duration of the intervention period, intensity, intervals, repetitions, baseline BMI, age, gender and publication year) on the difference in VO_{2max} and body composition (%body fat) between the HIT and traditional interventions. Meta-regression analyses were performed in Stata v14.2 using the 'metareg' procedure taking the individual study as unit as unit of analysis. For VO_{2max}, adjusted effect sizes are reported. For % body fat, univariable ('crude') effect sizes are displayed.

Meta-regression analysis to evaluate the impact of study characteristics on the before/after changes of $VO2m_{ax}$ and % body fat within the HIT/HIIT groups could not be performed because the estimated standard error of the mean before/after change in these variables was usually not reported.

Results

Results of the search

There were 4251 records identified from the initial search of electronic databases. Two additional articles were identified through other sources. After removing the duplicates, 1865 titles were left for screening. From this list, the full text of 81 relevant articles were reviewed in detail. Finally, 18 articles were included in the meta-analysis (Figure 1).

Risk of bias in included studies

The overall quality of the included studies was low (Figure 2). Details about the randomization process and allocation concealment were lacking in almost all studies, so the risk of bias was unclear. Only 3 studies reported a blinded assessment of the outcomes (21–23). Also in 4 studies, the number of participants was low, ranging from 12-18, with the risk of overestimation or underestimation of the effect on outcome parameters (21,24–26). In most
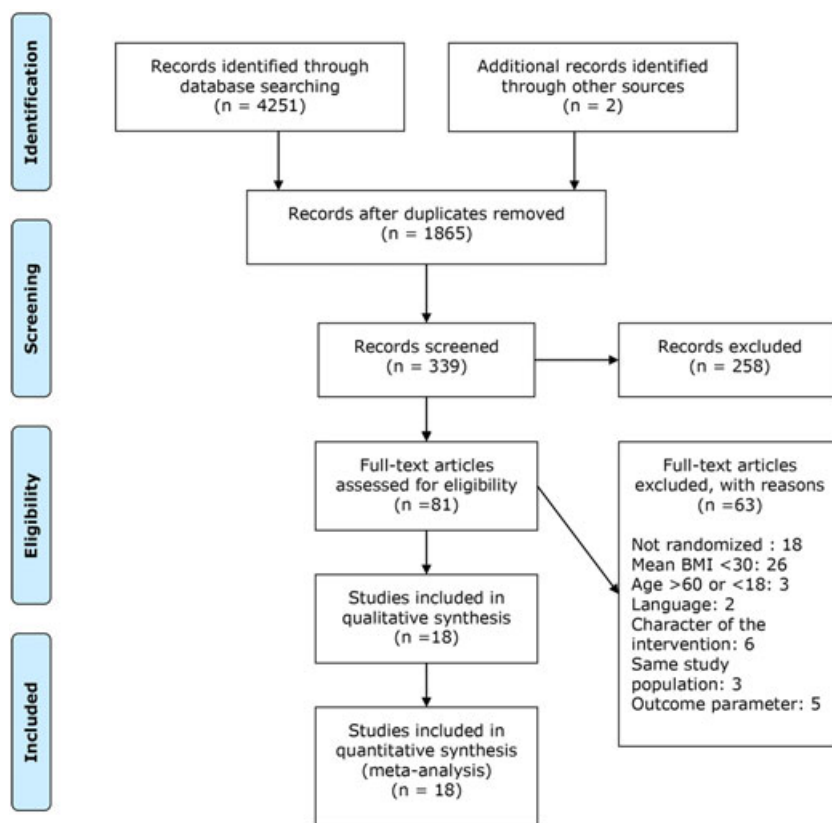
Figure 1 Flow diagram of screening and selection of articles for review.

studies, there was not enough information to determine reporting bias (Figure 2 and 3, S2).

Characteristics of the included studies

The characteristics of the 18 included studies are summarized in Table 1 and S2. A total of 854 participants were randomized in these studies. The sample size differed between 12 and 201 participants. All studies were published between 2003 and 2016. The mean age of the included patients was between 24 and 59 year and the mean BMI range was between 30-38 kg/m^2. In all included studies, obesity was defined as a BMI equal or greater to 30 kg/m^2. Twelve studies excluded participants with diabetes (I and II) (21,24,26–35), and 13 studies excluded patients with hypertension and cardiac comorbidity (21,23,24,26,28–30,32–37) . One study did not provide information about the presence of comorbidities (25).

Characteristics of the interventions

Details of the exercise interventions in each study are summarized in Table 1. Twelve studies compared HIIT with lower intensity exercise or normal level of physical activity (21,22,24–28,30,35–37). Six studies compared the effect of a continuous HIT with lower intensity exercise training (29,31,38) or normal level of physical activity (23,32,33). In two studies, there was a diet intervention included in both the intervention and control group, so the intensity of the exercise was the only difference between these groups (23,32). In the majority of the studies, participants trained 3 to 5 times a week, and the duration of the interventions varied from 2 weeks to 6 months. Different exercise modalities were cycling (24–28,30–32,34–36,38), walking/running (22,23,29,30,33,34,36–38) and boxing (21). There was considerable variation in the used HIIT protocols. The number of repetitions varied from 4 to 12 repetitions, with intervals of 10s to 4 min. The intensity of the exercise varied from 70-100% of the maximal heart rate (HR$_{max}$) (21,22,26,27,30,37), 90-100% of VO$_{2max}$ (36) or 85-200% of W$_{max}$ (24,34) . Three studies performed "all out" sprints against a resistance equivalent to 0.05 kg/body mass (25,28,35). The intensity of continuous HIT was 60-75% of VO$_{2max}$ (31,38) or 70-80% of HR$_{max}$ (23,29,32,33) . Adherence to the intervention program was above 75% in 10 of the 18 studies (21,23,25,29–32,34,36,38). One study reported a lower adherence rate

Figure 2 Risk of bias summary: review authors' judgements about each risk of bias item for each included study.

of 59% (22); one study excluded patients with an attendance of < 70% from analysis (28), and in the other 6 studies, no information was provided about adherence

(24,26,27,33,35,37). Three of the 18 studies reported adverse events related to the intensity of the exercise. In the study of Lunt et al. three participants had developed injuries in the group with maximal volitional interval training. No injuries occurred in the group with aerobic interval training or walking (22). In the study of Nicklas et al., one patient in the vigorous intensity vs. 4 patients in the moderate intensity group discontinued exercising because of time problems (2) or injuries (3) (23). In the study of Keating et al. during exercise a syncopal episode occurred in one patient in the high intensity and one patients in the low intensity group (31).

Measurements

Anthropometric parameters such as height and weight were measured in a standardized way in all studies. Cardiopulmonary fitness was measured by determining the maximal oxygen uptake (VO_{2max}) either by an incremental cycling test (24–28,30–32,34,35,38) or by the use of a treadmill for maximal exercise (21–23,29,36,37). Different protocols were used for exercise testing (39,40) but mainly a load-incremental protocol was used until volitional exhaustion and/or reaching >85% age-predicted heart rate and/or plateau of VO2max and/or a drop of the pedaling rate < 50/rpm. Body composition was measured by a bioelectrical impedance (33) or a dual energy x-ray absorptiometry (DXA) (23,24,26–28,35,37,38). In one study, the % body fat was computed from six skinfold sites using validated equations (21).

Outcome VO_2 max

Fifteen studies reported VO_{2max} as an outcome parameter. Compared to traditional exercise, HIT was significantly more effective to improve VO_{2max} (MD 1.83, 95% CI 0.70, 2.96, p<0.005; I^2=31%) (Figure 4). In addition, comparing HIIT with traditional exercise revealed a significant effect in favour of HIIT (MD=1.79, 95% CI 0.21, 3.36, p=0.03; I^2=38%) (Figure 5). Continuous HIT showed a statistical significant effect for VO_{2max} (MD 1.68, 95% CI 0.10, 3.27, p=0.04; I^2=25%).

Outcome Body composition

The overall effect for BMI, body weight, waist circumference was not different between HIT and traditional exercise (Table 2a). However, HIT resulted in a significant reduction in the percentage of body fat compared to traditional exercise (MD -1.69, 95% CI -3.10, -0.27, p=0.02, I^2=30%) (Figure 6). In addition, comparing HIIT with traditional exercise revealed a
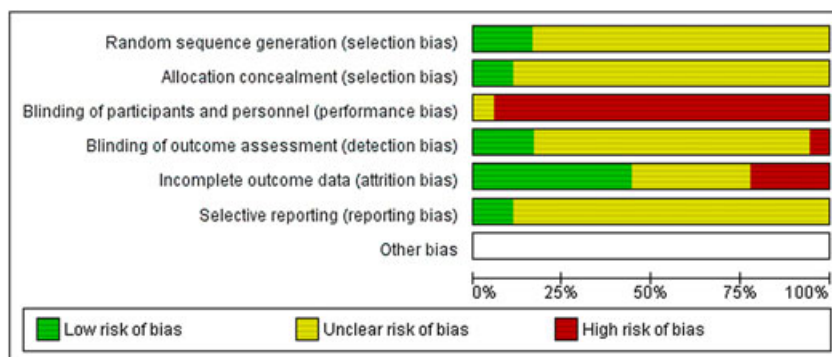
Figure 3 Risk of bias graph. Review authors' judgement about each risk of bias item presented as percentages across all included studies.

significant effect for the percentage of body fat in favour of HIIT (MD -2.01, 95% CI -3.75, -0.30, p=0.02, I^2=0%) (Table 2b).

Subgroup analysis

Subgroup analysis for HIT compared to baseline physical activity revealed a significant effect for VO_{2max} in favour of HIT (MD 4.32, 95% CI 2.39, 6.26, p<0.005; I^2=0%). Also, HIT compared to medium intensity training showed a significant effect for VO_{2max} in favour of HIT (MD 1.20, 95% CI 0.12, 2.28, p=0.03, I^2=11%).

Sensitivity analysis

Sensitivity analysis by excluding studies with an intervention period shorter than 4 weeks did not change the results for VO_{2max} or other outcomes (25,34). Also, excluding studies with less than 20 participants did not change the results for VO_{2max} or other outcomes (21,24–26).

Meta-regression

Duration of the intervention period (VO_{2max}: β=0.014, p=0.979; %body fat: β=0.16, p=0.132), intensity of intervention (VO_{2max}: β=-1.34, p=0.602; %body fat: β= -0.11, p=0.887), intervals (VO_{2max}: β=-0.04, p=0.372; %body fat: β=0.01, p=0.290), number of repetitions (VO_{2max}: β=-0.203, p=0.763; %body fat: β=-0.39, p=0.262) and baseline BMI (VO_{2max}: β= -0.66, p=0.087; %body fat: β=0.12, p=0.708) were not significantly associated with the treatment effects for VO_{2max} and %body fat between HIT and traditional intervention. In addition, studies with a younger study population (VO_{2max}: β=-0.06, p=0.721; %body fat: β=0.049, p=0.192), male study population (VO_{2max}: β= 1.93, p=0.237; %body fat: β= 0.06, p=0.960) and recent studies (VO_{2max}: β=-4.15, p= 0.093; %body fat: β=0.46 p=0.766)

were not associated with the treatment effects for VO_{2max} en %body fat.

Discussion

In this review and meta-analysis, the effectiveness of high intensity training in terms of cardiopulmonary fitness and body composition was compared to other forms of exercise in adults with obesity. Based on the results of this meta-analysis we can conclude that training at high intensity is a better method to improve cardiopulmonary fitness in the obese population than traditional, lower intensity continuous training. In addition, when high intensity interval training was compared with other forms of exercise, we found a significant better improvement of VO_{2max}.

To our knowledge, this is the first meta-analysis comparing high intensity training with other forms of exercise in adults with obesity. Previous studies in normal weight adults (BMI < 25 kg/m^2) showed significant improvements in cardiopulmonary fitness (11) after an HIIT intervention compared to medium intensity continuous training (41). In a randomized controlled trial in overweight patients with metabolic syndrome, Tjonna et al. showed a significant higher increase in VO_{2max} after HIIT compared to continuous moderate exercise (CME) (35% vs. 16%). Moreover, HIIT was superior compared to CME in reducing risk factors for metabolic syndrome, such as reduction in blood glucose and lipogenesis in adipose tissue and enhancing endothelial function. There was no difference between HIIT and CME groups with regard to weight reduction (14). Different mechanisms underlying the increase of VO2max in HIIT are an increased ATP generation by phosphocreatine degradation during HIIT and muscle glycogenolysis (15,42), improvement in vascular/endothelial function (43), an increase in cardiac output by enhanced cardiac contractility and an increased muscle oxidative capacity

Table 1 Overview of the characteristics of included studies. Data are presented in means ±SD. Abbreviations: HIIT (High intensity interval training), CON (control), SIT (sprint interval training), MICT (medium intensity continuous training), HI (high intensity), LI (low intensity), MeD (Mediterranean diet), MeDE (Mediterranean diet with exercise), AIT (aerobic interval training), MVIT (maximal volitional intensity training), WALK (walking exercise), CR (caloric restriction), CR+MI (caloric restriction + medium intensity exercise), CR+HI (caloric restriction +high intensity exercise), CMIET (continuous medium intensity exercise training), TER (traditional exercise recommendations)

Study	N	Age (y)	BMI (kg/m²)	Training	Intensity	Duration	Control	Outcome VO2max (ml.min.kg)	Outcome BMI (kg/m²)
Arad et al. 2015 (27)	28 female	HIIT: 29 ± 4, CON: 30 ±7	HIIT: 32.5 ±3.6, CON: 32.1 ±3.2	HIIT (cycling; 24 min) (3/week)	6 min warm-up 50%HRR 4x30-60s 75-90% HRR 5 min cool-down	14 weeks	Normal level of physical activity	HIIT: from 23.1 ±4.9 to 24.9±5.5, CON: from 19.7 ±6.3 to 20.9 ±4.6	HIIT: from 32.5±3.6 to 32.7 ±3.8, CON: from 32.1±3.2 to 31.6 ±3.6
Cheema et al. 2015 (21)	12, 7: female, 5: male	39 ±17	HIIT: 32.0±5.9, CON: 30.8±2.6	HIIT (Boxing; 50 min) (4/week)	5 min warm up HIIT 2:1 >75% HRR vs rest/pacing	12 weeks	50 min brisk walking (4/week)	HIIT: from 27.9 ±2.4 to 32.5 ±5.0, CON: from 29.0 ±6.4 to 28.8 ±8.0	HIIT: from 32.0 ±5.9 to 30.5 ±4.0, CON: from 30.8 ±2.6 to 30.7 ±3.0
Cocks et al. 2015 (24)	16 male	SIT: 24 ±5.7, MICT:26±5.7	SIT: 35.8 ±4.2, MICT: 33.7±4.2	SIT (cycling) (5/week)	2 min warm up (50W) 30s 200% Wmax /120s 30W 4 to 7 intervals	12 sessions	40-60 min continuous cycling -65% VO2peak (5/week)	SIT: from 33.9 ±3.4 to 36.3 ±4.5, MICT: 35.1 ±4.2 to 39.8 ±7.6	SIT: from 35.8 ±4.2 to 35.7 ±4.2, MICT: 33.7±4.2 to 33.1±4.5
Hansen et al. 2009 (38)	50 male	59 ±8	HIIT: 32.1±4.5, LIT: 32.7±3.9	HIT (walking, cycling, cross-country ski-type exercise) (3/week)	40 min continuous at 75% VO2peak	6 months	55 min continuous at 50% VO2peak	HIT: from 20.8 ±5.5 to 24.7 ±6, LIT: from 20.9 ±5 to 23.5 ±5.5	HIT: from 32.1±4.5 to 31.4 ±4.5, LIT: from 32.7 ± 4 to 32.3 ±4.5
Higgins et al 2016 (20)	60 female	20.4 ±1.5	30.3 ±4.5	SIT (cycle ergometer) (3/week)	4 min warm-up 30 s 'all out" sprints, 4 min active recovery. 5 repetitions in week 1-2, 6 repetitions in week 3-4 and 7 repetitions in week 5-6	6 weeks	20-30 min cycling at 60-70% Heart rate reserve	SIT: from 29.1 ±4.8 to 33.2 ± 4.4, MICT: from 26.9 ±4.5 to 28.8 ± 4.3	
Jakicic et al. 2003 (29)	201 female	HI/HI: 38.3 ±5.4, MI/HI: 36.8±5.3	HI: 32.8 ±3.9, MI: 32.2 ±3.9	High intensity/high duration (treadmill) (5/week)		12 months	Moderate intensity/high duration (5/week)	HI: from 20.2±2.9 to 24.5±4.8, MI: from 19.4±3.2 to 22.1±4.0	HI: from 32.9 ±3.9 to 29.5 ±4.8, MI: from 32.3 ±3.9 to 29.2 ±4.8
Jung et al. 2015 (30)	32, 27:female	51 ±10	32.9 ±6.3	HIIT (25 min)	3 min warm up	10 days + 4 weeks		HIIT: from 20.7 ±3.3 to 22.6 ±4.1	HIIT: from 29.8 ±5.5 to 29.9 ±5.1

Study	Participants	Age	Baseline BMI	Intervention	HI protocol	Duration	Comparator protocol	Outcome 1	Outcome 2
(continued)	5:male			(walking, elliptical machine, treadmill or cycling) (3/week)	10x1 min 90% HRpeak 2 min cool-down		20-50 min continuous 65% HRpeak	MICT: from 20.8 ±5.2 to 22.0 ±4.6	MICT: from 32.1 ±4.1 to 31.9 ±3.7
Keating et al. 2015 (31)	48	43.6 ±3.0	33.4 ±1.3	HI (cycling) (3/week)	30-45 min 60-70% VO2peak	8 weeks	Low to moderate intensity, high volume (Brisk walking) 45-60 min 50% VO2peak	HI: from 21.9 ±4.8 to 24.9 ±5.5 LO: from 24.9 ±3.5 to 27.2 ±2.8	HI: from 36.3 ±5.9 to 35.8± 5.9 LO: from 33.9 ±3.1 to 33.4 ±3.1
Landaeta-Diaz et al. 2012 (32)	45 30: female 15: male	MeD: 57.2 ±4.4 MeDE: 59.05 ±5.5	MeD: 38.44 ±6.5 MeDE: 37.05 ±3.22	MeDE (diet +exercise) (ergometer) (3/week)	30 min 80% HRmax	12 weeks	Diet only- calori restriction (500kcal/day)	MeDE: from 18.87 ±5.59 to 27.31 ±4.70 MeD: from 19.99 ±5.72 to 22.38 ± 6.98	MeDE: from 37.05 ±3.22 to 33.79±3.21 MeD: from 38.44 ±6.5 to 36.35 ±6.12
Lunt et al. 2013 (22)	49 36:female 13:male	WALK: 46.3 ±5.4 AIT: 48.2 ±5.6 MVIT: 50.3 ±8.0	WALK: 32.7 ±4.3 AIT: 32.1 ±3.1 MVIT: 32.4 ±2.9	AIT: aerobic interval training (walking) MVIT: maximal volitional intensity training (3/week)	AIT: 4min HIIT (85-95% HRmax)/3 min walking 4 repetitions (40 min) MVIT: 30 s volitional intensity/4 min walking 3-6 repititions (25-40 min) 10 min warming up 5 min cool-down	12 weeks	WALK: 10 min warming up 5 min cool down 33 min walk (65-75% HRpeak)	AIT: from 24.2 ±4.8 to 25.6 ±4.8 MVIT: from 25.0 ±2.8 to 25.2 ±3.4 WALK: from 26.5 ±5.3 to 25.2 ±3.6	AIT: from 32.1 ±3.1 to 32.1 ±3.0 MVIT: from 32.4 ±2.9 to 32.3 ±2.9 WALK: from 32.4 ±2.9 to 32.3 ±2.9
Mezghanni et al. 2012 (33)	31 female	25.2 ±4.8	G75: 32.9 ±1.8 G50: 34.1 ±3.6 CON: 33.2 ±1.8	High intensity aerobic training (walking and jogging)	G75: 20-55 min 75% HRR	12 weeks	Moderate intensity aerobic training G50: 20-55min 50% HRR OR Control		G75: from 32.9 ±1.8 to 30.5 ±2.4 G50: from 34.1 ±3.6 to 32.9 ±3.8 CON: from 33.2 ±1.8 to 33.3 ±1.7
Nicklas et al. 2009 (23)	112 female	CR: 58.4 ±6.0 CR+MI: 57.7 ±5.5 CR+HI: 59.0 ±5.0	CR: 33.9 ±4.0 CR+MI: 33.7 ±3.5 CR+HI: 32.9 ±3.7	Caloric restriction + high intensity exercise (treadmill) (3/week)	3-5 min warm up CR+HI: 70-75%HRR	20 weeks	CR+MI: 45-50%HRR OR CR only	CR+HI: +4.1 ± 3.7 CR+MI: +2.5 ±2.6 CR only: +2.0 ±2.6	
Robinson et al. 2015 (34)	39	52±10	HIIT: 32.9± 6.6 MICT: 31.4 ± 4.1	HIIT (cycle, treadmill, elliptical)	HIIT: 3 min warm up 4x 1:1 85-90% Wpeak/20% Wpeak	2 weeks	20-50 min of continuous activity at 32.5% Wpeak	HIIT: from 20.4 ±3.4 to 21.9 ±4.0 MICT: from 20.6 ±4.9 to 22.1 ±4.7	HIIT: from 32.9 ±6.6 to 32.6 ±6.7 MICT: from 31.4 ±4.1 to 31.3 ±4.0

Table 1. *Continued*

| Study	N	Age (y)	BMI (kg/m²)	Training	Intensity	Duration	Control	Outcome VO2max (ml.min.kg)	Outcome BMI (kg/m²)
Roxburgh et al. 2014 (36)	29 19: female 10: male	36.3 ± 6.9	CMIET+HIIT: 30.7± 6.3 CMIET: 29.6± 4.7 Control: 29.2 ±4.2	CMIET+ single bout of HIIT (treadmill and cycling) (5/week)	to 10x 1:185-90% Wpeak / 20% Wpeak Cooldown (32.5% Wpeak) 4 sessions CMIET +1 session HIIT: 60s 100%VO2max -150 s recovery 8-12 repetitions	12 weeks	CMIET: 15 min walking and 15 min cycling (45-60%HRR) Control: normal activity level. No exercise	CMIET+HIIT: from 32.7 ±9.2 to 36.0±11.5 CMIET: from 33.2±4.0 to 34.5 ±6.1 CON: from 30±4.6 to 28.3±6.5	CMIET+HIIT: from 30.7 ±6.3 to 30.6±6.1 CMIET: from 29.6±4.7 to 29.4±4.7 CON: from 29.2 ±4.2 to 29.5±4.4
Sawyer et al. 2016 (26)	18 9: female 9: male	HIT: 35.6 ±8.9 MICT: 34.8 ±7.7	HIIT: 37.4 ±6.2 MICT: 34.5 ±3.2	HIIT (cycle ergometer) (3/week)	5 min warm-up (50-60% HRmax) 10x 1 min intervals (90-95% HRmax) 5 min cool-down (50-60% HRmax)	8 weeks	5 min warm-up (50-60% HRmax) 30 min cycling at 70-75% of HRmax 5 min cool-down (50-60% HRmax)	HIIT: from 20.3 ±4.9 to 24.4 ±5.9 MICT: from 22.4 ±3.6 to 25.5 ±4.5	HIIT: from 37.4 ±6.2 to 37.4 ±6.1 MICT: from 34.5 ±3.2 to 34.5 ±3.2
Schjerve et al. 2008 (37)	40 32: female 8: male	Strength: 46.2 ± 10.6 Moderate intensity: 44.4 ±7.9 High intensity: 46.9±7.9	Strength: 34.5±5.05 Moderate intensity: 36.7±5.05 High intensity: 36.6±4.49	HIIT (treadmill, walking and running) (3/week)	10 min warm up 50-60% HRmax 4x4 min 85-95% + 3 min interval walking 50-60% HRmax 5 min cool down	12 weeks	Moderate intensity: 47 min walking 60-70% HRmax Strenght training: 15 min warm up 40-50% HRmax 4x5 90% 1RM		
Skleryk et al. 2013 (25)	16 male	38.7±5.5	33.7±5.7	Sprint interval training (SIT) (ergometer) (6 sessions)	8-12x10 s 'all out' sprints	2 weeks	Traditional exercise recommendations (TER) 30 min 65% VO2max (10 sessions)	SIT: from 29.7 ±3.7 to 29.3±5.3 TER: from 26.3±5.7 to 26.3±6.2	SIT: from 32.2±5.9 to 32.2±5.9 TER: from 35.2±5.1 to 35.2±5.1
Trilk et al. 2011 (35)	28 female	SIT: 30.1±6. CON: 31.4±5.5	SIT: 35.7±6. CON: 34.6±5.9	Sprint interval training (SIT)(ergometer) (3/week)	SIT: 4 min warm up 30 s sprint against resistance (0.05kg/kg) 4 min active recovery (low RPM at 0% body mass)	4 weeks	Normal level of physical activity	SIT: from 21.6±4.12 to 24.5±4.12 CON: from 20.5±3.4 to 20.4±3.0	
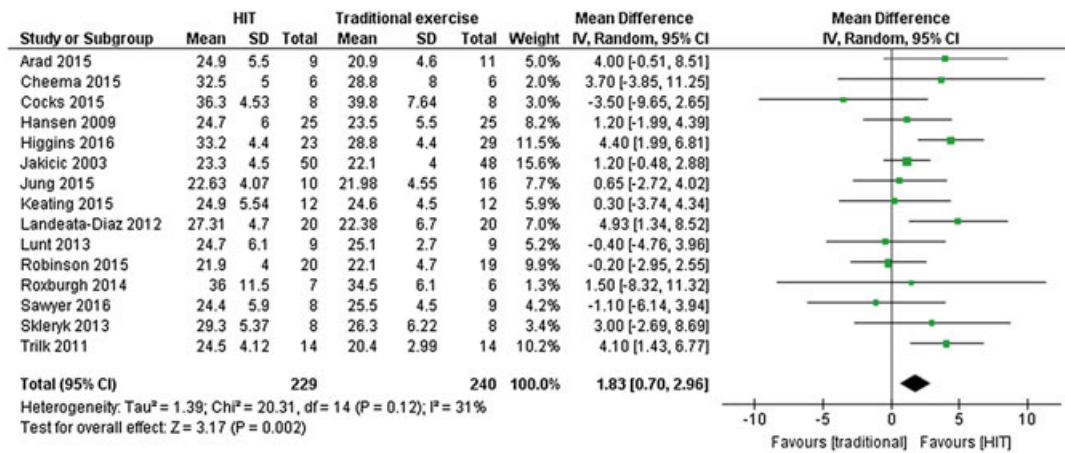
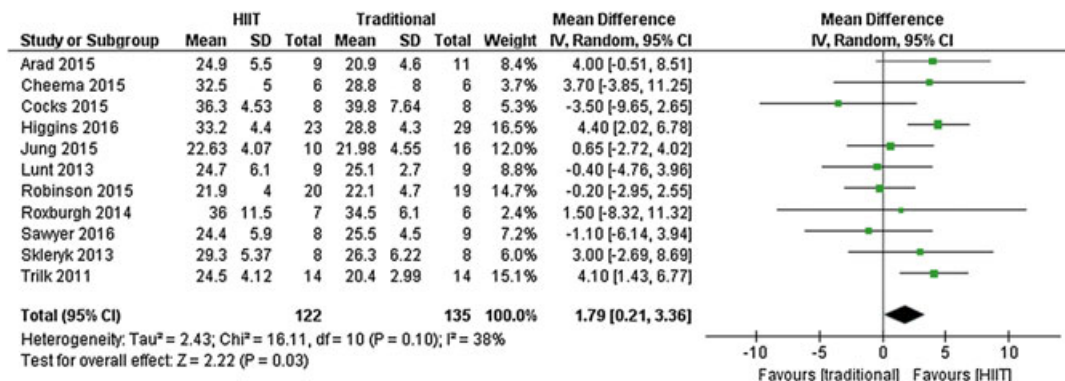**Figure 4** Forest plot of comparison: HIT vs. traditional exercise. Outcome: Maximal Oxygen Uptake (VO$_{2max}$)

Figure 5 Forest plot of comparison: HIIT vs. traditional exercise. Outcome: Maximal Oxygen Uptake (VO$_{2max}$)

Table 2 a) Effect of HIT vs. lower intensity exercise on cardiopulmonary fitness (VO$_{2max}$) and body composition. b) Effect of HIIT vs. lower intensity exercise on cardiopulmonary fitness (VO$_{2max}$) and body composition

a	study (n)	participants (n)	MD (IV, Random, 95% CI)	p-value	I^2
VO$_{2max}$ (ml/kg/min)	15	469	1.83 [0.70, 2.96]	<0.05	31%
BMI (kg/m^2)	15	437	0.20 [-1.10, 1.50]	0.76	91%
Body weight (kg)	12	386	-1.18 [-4.16, 1.80]	0.44	0%
Body fat (%)	10	296	-1.69 [-3.10, -0.27]	0.02	30%
Waist circumference (cm)	8	253	-1.04 [-4.54, 2.45]	0.56	27%
b					
VO$_{2max}$ (ml/kg/min)	11	257	1.79 [0.21, 3.36]	0.03	38%
BMI (kg/m^2)	9	177	0.37 [-1.44, 2.18]	0.69	70%
Body weight (kg)	7	153	-0.42 [-5.30, 4.47]	0.87	7%
Body fat (%)	7	157	-2.01 [-3.73, -0.30]	0.02	0%
Waist circumference (cm)	5	111	-1.63 [-6.37, 3.10]	0.87	7%

by upregulation of mitochondrial activity (10,44). However, it is unclear whether these adaptations are different in the people with obesity. With regard to body composition, this meta-analysis showed a significant reduction in the percentage of body fat in favour of HIT compared to traditional exercise. Moreover, HIIT showed the same effect compared to lower intensity continuous exercise. This finding implies a direct effect of high
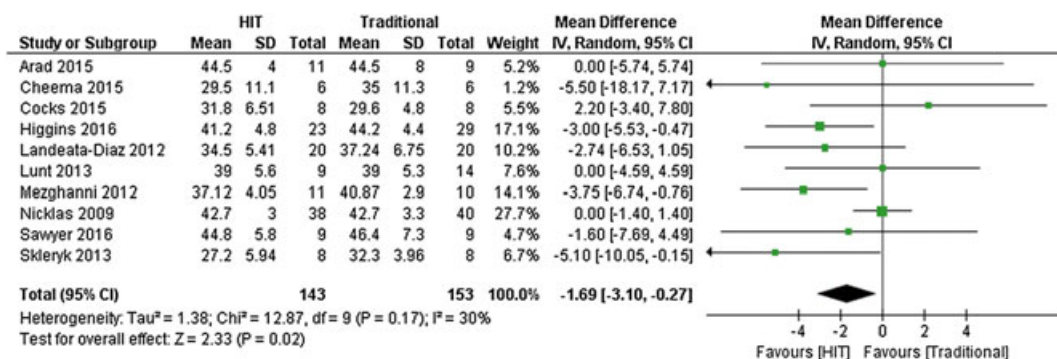
Figure 6 Forest plot of comparison: HIT vs. traditional exercise. Outcome: %body fat

intensity (interval) training on fat oxidation, and was confirmed by a previous study of Trapp et al. who showed significantly more reduction in subcutaneous fat in young healthy women who performed HIIT (3/week, 15 weeks) compared to a continuous exercise training (13). However, in the present meta-analysis, there was no difference in the amount of weight loss, BMI or waist circumference between HIT or traditional exercise. This may be explained by the absence of an accompanying significant dietary intervention. For example, in a randomized controlled trial with asthma patients with obesity, Scott et al. showed that after 10 weeks of either dietary intervention, exercise intervention or combined dietary/exercise invention, only patients who received dietary or combined intervention did have a statistically significant amount of weight loss (45). This study emphasises the importance of a dietary intervention on top of exercise. However, in this meta-analysis, studies with diet as an intervention were excluded, because the aim was to focus on the effect of HIT. Another issue is that the most included studies did not provide data on equal energy expenditure between HIT and traditional exercise forms. Only one study controlled this well, showing that sprint interval training resulted to a greater decrease of fat mass and led to a nearly 2-fold greater increase in VO_{2max} compared to medium intensity continuous training with equal exercise energy expenditure (28). Another possibility for the absence of positive effects on BMI is that the variable duration of the exercise intervention could have influenced the results. However, excluding articles with an intervention period of <4 weeks did not change the results. A recent meta-analysis of Jelleyman et al. demonstrated that HIIT was associated with modest weight loss (-1.3kg, p<0.001) compared to a non-exercising control group, but not compared to continuous training. However, the primary aim of the mentioned study was to investigate the effect of HIIT on glucose regulation (46). Although this review shows that high intensity (interval) training has

favorable effects on cardiopulmonary fitness and body composition in adults with obesity, the results should be interpreted with caution. An important limitation is that most included studies only reported the pre- and post-intervention parameters, but not the change from baseline, or the corresponding 95% CI or p-values of that change. Therefore, we were only able to compare post-intervention values. Although, only randomized controlled trials were included, there were some imbalances in baseline values between the intervention and control groups in some of the studies. The small sample sizes in these studies could be the reason for these imbalances and this could result in a bias. Nevertheless, excluding studies with small sample sizes from analysis did not change the results. Secondly, the primary outcome in some studies was different from VO2max and body composition. Moreover, small size studies may be underpowered to show a significant effect on these parameters. Different methods were used to determine outcome parameters which could lead to variation heterogeneity in outcomes and outcome assessment. Also, the risk of bias was unclear in most domains, especially with regard to selection bias (randomization/ allocation) and reporting bias. In addition, excluding comorbidities like diabetes and cardiovascular problems in these studies could result in an important selection bias. However, in this review and meta-analyses we were able to summarize the available data about high intensity (interval) exercise intervention in the obese population. There are some issues that should be considered about high intensity exercise in the obese. Performing exercise at high intensity is very demanding and could be a potential risk for knee- and other injuries in the obese. However, only three of the 18 included studies reported adverse events related to the intensity of the exercise. Also, 13 of the 18 studies excluded patients with hypertension and cardiac comorbidity, conditions that are usually present in the obese population. VO_{2max} is recognized as one of the best predictors of mortality

among cardiac patients and several studies have noted that high intensity interval training is safe and effective in cardiac patients (47,48). Moreover, some studies reported that HIIT results in greater improvements in VO$_{2max}$ compared to moderate intensity continuous training (47,49–51). Another issue is the motivation for an exercise program in persons with obesity. Depression, a negative body image and embarrassment are factors that can influence the decision to participate in an exercise program. Therefore, attention to these psychological should be given in addition to exercise training in this group of patients (7). In the included studies, most of the exercises were performed on a cycle ergometer or on a treadmill. Little is known about the effect or risk of other exercise modalities, like running (outdoor) or swimming. Future studies are needed to investigate which type of HIT is most suitable for the obese with regard to side effects, risk of injuries, but also with regard to long-term adherence and effects. In addition, patients with obesity and with different comorbidities (cardiovascular, pulmonary, diabetes) should be included in these kind of studies to investigate the feasibility and effects in this group of patients. In conclusion, HIT is, 1) superior to traditional exercise in improving cardiopulmonary fitness, which is an important indicator of health, 2) superior to traditional exercise in reducing the percentage of body fat 3) feasible and well-tolerated in persons with obesity. Larger, well-designed randomized controlled trials are required to confirm the findings and to design optimal (HIT) training programs for the obese population.

Potential Conflicts of interest

Authors declare that there are no potential conflicts of interest regarding to this manuscript

Acknowledgements

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Supporting Information

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Data S1. Supplemental file
Data S2. Supporting info item