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REVIEW

Effects of Exercise Training on Weight Loss in Patients Who Have Undergone Bariatric Surgery: a Systematic Review and Meta-Analysis of Controlled Trials

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Abstract
The combination of bariatric surgery and physical exercise has been suggested as a promising strategy to positively influence obesity, not only body weight but also all associated comorbidities. An electronic search of intervention studies was carried out in which an exercise training program was implemented after bariatric surgery. The quality of each study was assessed and the data were meta-analyzed using a random effect model. Twenty-six articles were included in the systematic review and 16 in the meta-analysis. As the main conclusion, exercise in patients who have undergone bariatric surgery does not seem to be effective in enhancing weight loss (SMD = 0.15; 95% CI = − 0.02, 0.32; p = 0.094). However, the variability in the protocols used makes it too early to reach a definite conclusion.

Keywords Bariatric surgery · Weight loss · Physical activity · Exercise

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Background

The World Health Organization considers people with class I obesity if they have a body mass index (BMI) ≥ 30 kg/m^2, class II obesity if they have a BMI ≥ 35 kg/m^2, and class III obesity with a BMI ≥ 40 kg/m^2 [1]. Obesity is considered a risk factor for diseases such as hypertension, heart failure, coronary heart disease [2], diabetes mellitus [2, 3], sleep apnea, and osteoarthritis [3]. Compared to normal weight, class II and III obesity are related to higher mortality rates from all causes [4]; the average survival rate is reduced by 2–4 years for people with class II obesity and by 8–10 years for people with class III obesity [5]. In economic terms, obese people have worse results in the world of work, lower wages, and higher health costs [6].

Weight and fat loss are related to improvements in obese people's health, a reduction in the inflammatory markers associated with diabetes [7], a decrease in blood pressure [8], and improvements in terms of cardiovascular diseases [7]. Bariatric surgery is an effective treatment option for reducing weight in people with morbid obesity [9], on average losing around 12% of total body weight in the 6 months after surgery, and up to 45% over 3 years [10]. Physical activity (PA) is also one of the main approaches that influences and improves people's health [11], decreasing cardiovascular risks [12] and coronary heart diseases [13]. Exercise training diminishes comorbidities related to obesity, such as asthma and sleep problems [14] as well as reducing insulin resistance, hypertension, and blood lipids [15]**.** Furthermore, PA plays an important role in the amount of weight recovered after weight loss and helps reduce weight progressively [16].

Given the increased number of people with morbid obesity [17], the proven short- and long-term effectiveness of bariatric surgery [18] and the possibilities presented by PA in relation to maintenance and improvement of risk factors suggest that PA could help those patients who suffer weight regain after bariatric surgery [19]. The present review and meta-analysis arise from the need to accurately assess whether PA following bariatric surgery has a positive effect on weight loss and to try to determine what type of exercise is most effective for that purpose. Previous systematic reviews [20, 21] and one meta-analysis [22] have studied weight loss caused by exercise following bariatric surgery, although the authors failed to take into account the specific characteristics of each training program, which can undoubtedly influence their effect.

The aims of this systematic review and meta-analysis were (a) to analyze the effects of exercise training after bariatric surgery in relation to weight loss; and, in case of being effective for a higher weight loss, (b) to determine what type of training is the most appropriate for weight loss in people undergoing bariatric surgery.

Material and Methods

Protocol and Registration

This study has been carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses, the PRISMA Statement [23], using the PRISMA checklist as a reference (Table A supplementary files), and the Cochrane Handbook for Systematic Reviews of Interventions [24]. This systematic review and meta-analysis has been registered in PROSPERO, the International Prospective Register of Systematic Reviews, with the ID CRD42018097444.

Searches

The literature search was performed systematically using the MEDLINE, EMBASE, Scopus, Cochrane, and Web of Science databases, with the deadline of May 23, 2019.

The following equation was used for the search ("Bariatric Surgery" OR "stapling stomach" OR "weight loss surgery" OR "obesity surgery" OR "weight reduction surgery" OR "Biliopancreatic Diversion" OR "Duodenal switch" OR "laparoscopic band" OR "lap band" OR "gastric band" OR "gastric banding" OR "Gastric Bypass" OR "Gastroplasty" OR "gastric sleeve" OR "sleeve gastrectomy" OR "gastric bypass surgery" OR "gastric bypass" OR "Roux-en-Y Gastric Bypass" OR "Maestro Rechargeable System" OR "gastric balloon" OR "gastric bubble" OR "ballobes balloon" OR "Greenville gastric bypass") AND ("physical exercise" OR "Physical Therapy" OR "physical activity" OR "physical education" OR "physical training" OR exercise OR fitness OR sport OR "Exercise Movement" OR "exercise program" OR "Complementary Therapies" OR "physiotherapy" OR "physio therapy" OR "therapeutic exercise" OR "Occupational Therapy" OR "Exercise therapy") AND ("body mass index change" OR "weight maintenance" OR "weight loss" OR "weight regain" OR obesity OR overweight).

Eligibility Criteria

Articles showing either the effect of physical activity on patients who had undergone bariatric surgery or which carried out an experimental intervention were included as eligible for further review.

The exclusion criteria for this systematic review were (a) papers not written in English or Spanish; (b) studies that do not report the outcome weight; (c) studies in which the intervention is performed before bariatric surgery; (d) studies in which the population investigated are non-humans; (e) studies in which participants are under 18 years old; (f) papers that combine physical activity with other types of intervention, medications, and nutrition among others; (g) retracted studies;

(h) duplicate studies; and (i) non-selectable publications, as in the case of reviews, guidelines, interviews, comments, or case studies.

The literature review was independently and simultaneously performed by two reviewers (AC and IC-R). Disagreements were sorted out either through consensus or with the participation of a third party (EG).

Data Selection

The data gathered from the selected studies were as follows: (a) the year of the study; (b) the study design; (c) the main features and the type of physical activity intervention; (d) the population's characteristics, number, sex, and age; and (e) the pre- and post-surgery weight.

Assessment of the Risk of Bias

For randomized controlled trials (RCTs), the Cochrane Collaboration's tool was used for assessing risk of bias in randomized trials [25]. This tool measures the risk of bias based on six domains: selection bias, performance bias, detection bias, attrition bias, reporting bias, and other biases. For non-randomized control trials (non-RCTs), the quality assessment tool for quantitative studies [26] was used. This tool considers seven domains: selection bias, study design, confounders, blinding, the data collection method, and withdrawals and dropouts.

To combine both tools for evaluating the risk of bias for the reviewed articles, each of the sections to be evaluated was designated as strong, moderate, or weak, and the articles were classified as having a low risk of bias (without weak ratings), a moderate risk of bias (one weak rating), or a high risk of bias (two or more weak ratings) [27, 28].

Quality assessment and data extraction were carried out independently and simultaneously by two reviewers (AC and IC-R). Any differences were sorted out either through consensus or with the participation of a third researcher (EG).

Statistical Analyses

The software used to perform the statistical analyses of the meta-analysis was StataSE V.14.0 (StataCorp LP., College Station, TX, USA). The analysis variable (the result) was the weight loss at the end of the treatment in each of the groups; the quantification of the effect was calculated through the standardized mean difference (SMD) and through the unbiased Hedges estimator [29]. Weightings and standard deviations (SDs) were extracted for each study and group before and at the end of the treatment. In the case of not having the SD values, these were imputed as the average value of each group [30]. On the other hand, the differences of the weight means and the standard deviation of the difference for each of the articles were calculated; for the latter, a correlation of 0.59 was considered between the values before and after starting the treatment [31]. A positive SMD value indicated greater weight loss in the intervention group compared to the control group. The DerSimonian-Laird random effects method was used and the 95% confidence intervals (CI) were calculated [32].

As a test to evaluate heterogeneity, we estimated the I^2 statistic [25]—values of 0% indicated non-heterogeneity, whereas values of 25%, 50%, and 75% were interpreted as having a low, moderate, and high level of heterogeneity, respectively. In addition, the Q statistic and its P value were calculated.

The publication bias was evaluated by the funnel plot and the Egger test was performed.

To complete the statistical analysis, certain details were contemplated: (I) when two or more studies obtained the data from the same database, only the main study was taken into account; (II) those papers with two intervention groups were analyzed as two individual studies; and (III) pre-operative body weight data were collected using the baseline and post-intervention data from the evaluation performed immediately after the surgery.

Subgroups analyses were carried out considering the following characteristics of the training intervention protocols: (I) the type of physical activity intervention, (II) the start of the intervention after the surgery, (III) the duration of the intervention, (IV) the type of exercise, and (V) the total exercise time per week.

Meta-regressions with random effects were employed using the aggregate level data to know the effect of the intervention and the heterogeneity in relation to (I) the average age of the participants, (II) the time per session, and (III) the length of the intervention.

Finally, a sensitivity analysis was conducted by performing the calculations again, without each of the studies, to know the robustness of that particular study.

Results

Systematic Review

Of the 10543 studies obtained in the search, 26 documents were finally selected (Fig. 1). These were carried out in different countries—10 from the United States, 6 from Brazil, 2 from Iran, 4 from Denmark, and 1 from Belgium, Sweden, Italy, and the UK, respectively. All the studies included were experimental, most of them with an RCT design (21) while 5 were non-RCTs. All 26 studies were published between 2011 and 2018 (Table 1).

The internationally accepted criteria to undergo bariatric surgery are a BMI $\geq$ 40 kg/m^2 or a BMI $\geq$ 35 kg/m^2 if comorbidities are present that put the patient's health at risk. Most of

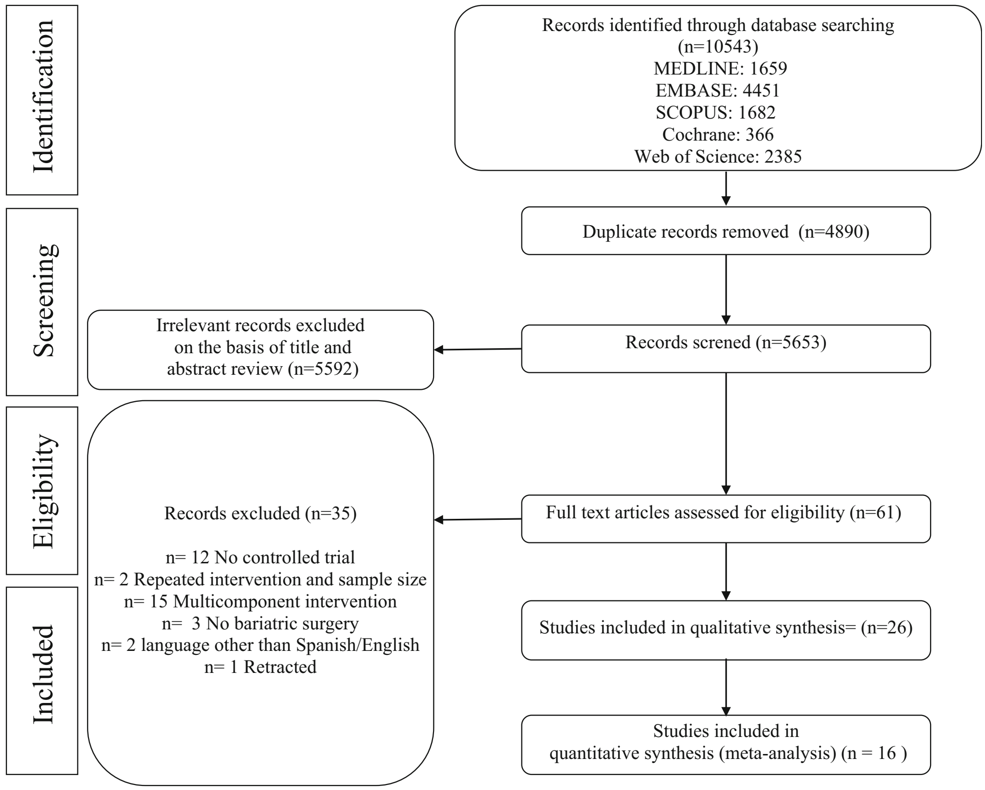

Fig. 1 Literature search preferred reporting items for systematic reviews and meta-analyses consort diagram

the selected studies included any type of surgical technique, apart from nine of them which included only laparoscopic surgery with RYGB, and one study on the sleeve gastrectomy technique. The sample size of the studies varied between 12 and 120 subjects, most of them including participants of both sexes, except for 5 studies in which only women participated.

The physical activity interventions carried out were supervised in 12 of the studies, programmed in 4, while 8 were mixed interventions, combining programmed and supervised. Only 1 study used a counseling intervention type. Aerobic exercise alone was used in 11 studies, resistance exercise alone in 2 of them, whereas a combination of both was used in 10 studies, and other alternative types of exercise in 3 studies. The reviewed studies used exercise durations between 20 and 85 min per session. The maximum length of the intervention was 40 weeks and the shortest was 1 week. The start of the intervention varied between 5 days and 24 months after surgery.

Risk of Bias

Regarding the risk of bias, as can be seen in Tables 2 and 3, from the 26 studies analyzed, 10 of them (38.5%) show a high risk of bias, 6 (23.1%) show a moderate risk of bias, and the other 10 (38.5%) show a low risk of bias. Analyzing the sections considered in both assessment tools individually, we can observe that all non-RCTs ($n = 5$, 100%) present deficiencies (i.e., scored as weak) in the blinding domain study, while in the case of RCTs, 38.1% ($n = 8$) and 14.3% ($n = 3$) show detection bias and performance bias, respectively. Among the non-RCT studies, deficiencies in the selection bias and the design of the study were present in 40% of the studies ($n = 2$) compared to 5.3% ($n = 1$) showing selection bias among the RCTs.

Meta-Analyses

The pooled SMD estimate did not show a greater significant weight loss in favor of the intervention (exercise) group, with a small effect size and no significant differences (SMD = 0.15; 95% CI = − 0.02, 0.32; $p = 0.094$), as well as low heterogeneity ($I^2 = 0\%$; $p = 0.999$) (Fig. 2).

Subgroup Analyses

When considering the specific characteristics of the physical activity intervention (i.e., type of intervention, start of the intervention after surgery, duration, type of exercise, and total time per week), none of the subgroups analyses showed a significant difference in favor of the control group or the intervention group, with heterogeneity being very low in all cases ($I^2 = 0.0\%$) (Table 4).

Meta-Regressions

The meta-regression analyses showed no heterogeneity based on the participants' mean age ($p = 0.902$), nor on the length of

Table 1 Studies included in the systematic review

Reference	Country	Study design	Population Characteristics				Intervention		
			Age	Sample size (%W)	BMI	Pre-surgery weight	Type of population	Type of intervention/Start of intervention	Physical activity characteristics
Campanha-Versiani et al. 2017 [42]	Brazil	NON-RCT	I.G: 37.2 ± 9.3 C.G: 37.0 ± 10.8	I.G: 30 (83%) C.G: 30 (83%)	I.G: 42.5 ± 4 C.G: 41.7 ± 4.6	I.G: 111.2 ± 10.8 C.G: 112.7 ± 14	Have undergone bariatric surgery	I.G: Physical activity supervised 3 months after surgery	I.G: Resistance + Endurance training - 36 weeks - 2 days/week - 85 min - 1–3 sets - 10–12 reps - Load correspondent to 10 RM - 70 to 80% HRmax
Carnero et al. 2017 [43]	USA	RCT	I.G: 39.4 ± 9.7 C.G:41.7 ± 9.8	I.G: 46 (91.3%) C.G: 50 (86%)	I.G: 45.8 ± 7.4 C.G: 44.4 ± 7.5	I.G: 127.9 ± 23.9 C.G: 122.6 ± 27.3	Not diabetic Have undergone bariatric surgery	I.G: Physical activity supervised/programme 11 weeks after surgery	I.G: Cycling or walking endurance training - 26 weeks (6 months) - 3–5 days/week - Minimum of 120 m/week
Casali et al. 2011 [44]	Brazil	RCT	I.G: 37.6 ± 10.9 C.G: 35.1 ± 10.7	I.G: 15 (73.3%) C.G: 15 (73.3%)	I.G: 42.8 ± 4.2 C.G:43.6 ± 3.9	I.G:115.2 ± 19 C.G: 120.3 ± 14.1	Have undergone bariatric surgery	I.G: Physical activity supervised 1 day after surgery	I.G: Respiratory training - 4 weeks - Daily 29 days - 30 min - 40% of MIP
Castello et al. 2011 [45]	Brazil	RCT	I.G: 38.0 ± 4 C.G: 36.0 ± 4	I.G: 16 (100%) C.G: 16 (100%)	I.G: 45.64 ± 1.54 C.G: 44.46 ± 0.96	I.G: 117.6 ± 4 C.G: 117 ± 6	Women who have undergone bariatric surgery	I.G: Physical activity supervised 1 months after surgery	I.G: Endurance training - 12 weeks - 3 days/week - 60 min - 50 to 70% HR peak
Castello-Simoes et al. 2013 [46]	Brazil	RCT	I.G: 32.0 ± 4.0 C.G: 31 ± 2.0	I.G: 16 (100%) C.G: 16 (100%)	I.G: 45.5 ± 1.7 C.G: 43.6 ± 1	I.G: 115 ± 6.9 C.G: 113 ± 4.7	Women who have undergone bariatric surgery	I.G: Physical activity supervised 1 months after surgery	I.G: Endurance training - 12 weeks - 3 days/week - 60 min - 50 to 70% HR peak
Coen et al. 2015 [47]	USA	RCT	I.G: 41.3 ± 9.7 C.G: 41.9 ± 10.3	I.G: 66 (89.4%) C.G: 62 (87.1%)	I.G: 38.8 ± 6.1 C.G: 38.3 ± 6.9	I.G: 127.2 ± 22.6 C.G:121.8 ± 25.7	Have undergone bariatric surgery	I.G: Physical activity supervised/programme Between 1 and 3 months after surgery	I.G: Endurance training - 26 weeks (6 months) - 3 to 5 days/week - 30 min - 60 to 70% HR
Coen et al. 2015 (2) [48]	USA	RCT	I.G: 41.6 ± 9.3 C.G: 42.1 ± 9.9	I.G: 51 (88%) C.G: 50 (84.3%)	I.G: 38.8 ± 5.6 C.G: 38.1 ± 6.9	I.G:108.2 ± 20.2 C.G:106.8 ± 25.4	Have undergone bariatric surgery Volunteered to undergo muscle biopsy before and after the intervention	I.G: Physical activity supervised/programme Between 1 and 3 months after surgery	I.G: Endurance training - 26 weeks (6 months) - 3 to 5 days/week - 30 min - 60 to 70% HR
Coleman et al. 2016 [49]	USA	RCT	I.G: 52.0 ± 10.9 C.G: 46.6 ± 12.0	I.G: 26 (84%) C.G: 25 (84.6%)	I.G: 45.0 ± 7.6 C.G: 44.5 ± 5.5	I.G: 90.8 ± 23.0 C.G: 93.4 ± 19.8	Have undergone bariatric surgery	I.G: Physical activity supervised/programme Between 6 and 24 months after surgery	I.G: Endurance + resistance training - 26 weeks (6 months) + 26 weeks of maintenance

Table 1 (continued)

Reference	Country	Study design	Population Characteristics: Age	Sample size (%W)	BMI	Pre-surgery weight	Intervention: Type of population	Type of intervention/Start of intervention	Physical activity characteristics
									- 5 dayd/week - 60 min
Creel et al. 2016 [50]	USA	RCT	C.G: 44.2 ± 11.0 I.G1: 41.8 ± 10.8 I.G2: 43.6 ± 12.2	C.G: 50 (84.0%) I.G1: 52 (84.6%) I.G2: 48 (83.3%)	C.G: 47.6 ± 8.0 I.G1: 48.4 ± 9.5 I.G2: 46.9 ± 7.8	132.1 ± 2.7	Morbidly obese Have undergone bariatric surgery	I.G1: Physical activity programme NR I.G2: Physical activity counseling NR	I.G1: Walking endurance - 26 weeks (6 months) - 7 days/week - Up to 10,000 steps per day I.G2: Walking endurance - 26 weeks (6 months) - 7 days/week
Daniels et al. 2018 [51]	USA	RCT	44.9 ± 10.2	I.G: 8 (100%) C.G: 8 (100%)	NR NR	I.G: 134.8 ± 23.6 C.G: 135.4 ± 17.1	Women who have undergone RYGB	I.G: NR 8 weeks post-surgery	I.G: Resistance training - 12 weeks - 3 days/week - 60–80 min - Period 1: 8–10 exercise; 1 set; 10–15 reps; 50–60% RM - Period 2: Progressive increased of volume; 10–15 reps; 50–60% to 70–80% RM - Period 3: Maintains sets of period 2; 8–10 reps; > 80% RM
Hassannejad et al. 2017 [52]	IRAN	RCT	I.G. 1: 33.3 ± 8.4 I.G. 2:35.5 ± 8.1 C.G:36.7 ± 6.2	I.G. 1: 20 (75%) I.G. 2: 20 (70%) C.G: 20 (80%)	I.G. 1: 47.9 ± 6.7 I.G. 2: 42.9 ± 3.9 C.G: 46.6 ± 6.9	I.G. 1: 129.6 ± 19.2 I.G. 2: 119.8 ± 15.3 C.G: 122.4 ± 24.9	Patients with BMI ≥ 35 Have undergone bariatric surgery	I.G. 1: Physical activity programme I.G. 2: Physical activity programme During first week after surgery	- The first 4 weeks, in both groups, patients should walk 150 min/week with a progressive increase in intensity I.G. 1: Endurance training - 5–12 weeks - 3–5 days/week - 150–200 min/week - 12–14 Borg Scale I.G. 2: Endurance + resistance training - 5–12 weeks - 3–5 days/week - 150–200 min/week - 12-14 Borg Scale Resistance training - 3 days/week - 20–30 min - Elastic bands with different resistances
Herring et al. 2017 [52]	UK	RCT	I.G: 44.3 ± 7.9 C.G:52.4 ± 81	I.G: 12 (91.7%) C.G: 12 (91.7%)	I.G: 38.2 ± 6.1 C.G: 39.4 ± 4.3	I.G: 106.5 ± 16.4 C.G: 106 ± 17.5	Inactive people Have undergone RYGB	I.G: Physical programme 12–24 months after operation	I.G: Resistance + Endurance training - 12 weeks - 3 days/week - 60 min - 2 exercise per session

Table 1 (continued)

Reference	Country	Study design	Population Characteristics: Age	Sample size (%W)	BMI	Pre-surgery weight	Intervention: Type of population	Type of intervention/Start of intervention	Physical activity characteristics
									- 3 sets - 12 reps - 60% RM 64–77% HRmax
Huck 2015 [53]	USA	NON-RCT	I.G: 53.6 ± 8.2 C.G: 44.0 ± 9.7	I.G: 7 (85.7%) C.G: 8 (75%)	I.G: 37.7 ± 6.3 C.G: 32.7 ± 4.2	I.G: 101.6 ± 19.8 C.G: 92.5 ± 15.5	Have undergone bariatric surgery	I.G: Physical programme NR	I.G: Small groups resistance training - 12 weeks - 2 days/week first 6 weeks and 3 days/week last 6 weeks - 60 min 60% to 75% RM
López et al. 2017 [54]	USA	RCT	I.G:38.5 ± 16.3 C.G: 43 ± 12.6	I.G: 11 (81.8%) C.G: 11 (81.8%)	I.G: 39.5 ± 6.7 C.G: 40.8 ± 7.9	I.G: 106.9 ± 19.9 C.G: 111.1 ± 21.3	Have undergone laparoscopic RYGB	I.G: Physical programme/programme Between 1 to 3 months after surgery	I.G: Endurance training - 26 weeks (6 months) - 3 to 5 days/week - 30 min - 60 to 70% HR
Marchesi et al. 2015 [55]	Italy	NON-RCT	I.G: 43.1 C.G:39.1	I.G: 10 (100%) C.G: 10 (100%)	I.G:29.57 C.G:30.07	I.G: 81.3 C.G: 80.2	Women who have undergone bariatric surgery	I.G: Physical activity supervised/programme Between 1 to 3 years after surgery	I.G: Endurance training - 40 weeks - 3 days/week for 6 first months and 4 days/week last 4 months - 60 min - 3 first months 55–65% and 65–75% HRmax, middle 3 months 55–65% and 65–85% HRmax and last 4 months 60–70% and 70–90% HRmax
Mundbjerg et al. 2018 [56]	Denmark	RCT	I.G: 42.3 ± 9.4 C.G: 42.4 ± 9	I.G: 32 (66.6%) C.G: 28 (75%)	I.G: 43.1 ± 6.7 C.G:42.8 ± 5.5	I.G:129.1 ± 19.9 C.G:123.7 ± 22	Have undergone RYGB	I.G: Physical activity supervised 6 months after surgery	I.G: Resistance + Endurance training - 26 weeks - 2 days/week - 40 min - Borg Sacale 15 to 17/ 50 to 70% VO_2max Encouraged to do 210 m/w of extra exercise
Mundbjerg et al. 2018 (2) [57]	Denmark	RCT	42.3 ± 9.1	I.G: 32 (66.6%) C.G: 28 (75%)	43 ± 6.1	126.6 ± 20.9	Have undergone RYGB	I.G: Physical activity supervised 6 months after surgery	I.G: Resistance + endurance training - 26 weeks - 2 days/week - 40 min - Borg Scale 15 to 17/ 50 to 70% VO_2max encouraged to do 210 min/week of extra exercise
Oliveira et al. 2016 [58]	Brazil	RCT	I.G: NR C.G: NR	I.G: 20 (%NR) C.G: 23 (%NR)	I.G: 44.7 ± 4.7 C.G: 46.4.7 ± 5.4	I.G: 113.6 ± 12.3 C.G: 122.4 ± 19.6	Have undergone bariatric surgery	I.G: Physical activity supervised 1 months after surgery (30 days)	I.G: Resistance + breathing training - 4 weeks (30 days)

Table 1 (continued)

Reference	Country	Study design	Population Characteristics: Age	Sample size (%W)	BMI	Pre-surgery weight	Intervention: Type of population	Type of intervention/Start of intervention	Physical activity characteristics
									- 2 days/week - 40 min - 15 reps per exercise
Onofre et al. 2017 [59]	Brazil	NON-RCT	I.G: 40.3 ± 10.7 C.G:39.5 ± 7.2	I.G: 6 (100%) C.G:6 (100%)	I.G: 46.1 ± 7.0 C.G: 44.9 ± 9.0	I.G: 118.4 ± 21.6 C.G: 117.6 ± 7.2	Women with Obesity type II or III who have undergone bariatric surgery	I.G: Supervised training 3 months after surgery	I.G: Resistance + endurance training - 12 weeks - 3 days/week - 60 min - 60–80% RM - 40–60% intercalated with 85–90% HRR reserve
Rojhani-Shirazi et al. 2015 [60]	Iran	RCT	I.G: 36.1 ± 6.7 C.G: 36.6 ± 7.8	I.G: 16 (%NR) C.G: 16 (%NR)	I.G: 40.5 ± 5.4 C.G: 44.0 ± 7.2	I.G: 109.1 ± 13.4 C.G: 117.3 ± 22.2	Have undergone sleeve gastrectomy To be between 20 and 50 years old	I.G: Physical activity programme 5 days after surgery	I.G: Balance training - 4 weeks - 4 days/week - 45 min
Shah et al. 2011 [61]	USA	RCT	I.G: 47.3 ± 10.0 C.G:53.9 ± 8.8	I.G: 21 (90%) C.G: 12 (92%)	I.G: 42.4 ± 6.9 C.G: 41.0 ± 3.7	I.G: 110.3 ± 16.6 C.G: 101.4 ± 8.7	Class 2 obesity Have undergone bariatric surgery	I.G: Physical activity supervised/programme More than 3 months after surgery	I.G: Endurance training - 12 weeks - 5 days/week - 60 min - 60% to 70% VO_2max
Stegen et al. 2011 [62]	Belgium	NON-RCT	I.G: 39.9 ± 9.9 C.G: 43.1 ± 5.6	I.G: 8 (87.5%) C.G: 7 (57.1%)	I.G: 45.3 ± 2.7 C.G: 40.4 ± 8.1	I.G: 130.8 ± 17.8 C.G: 126.5 ± 24.7	Have undergone RYGB	I.G: Physical activity supervised 1 months after surgery	I.G: Resistance + endurance training - 12 weeks - 3 days/week - 75 min - 60%-75% RM - 60% to 75% HRR reserve
Stolberg et al. 2018 [63]	DENMARK	RCT	I.G: 43.0 ± 9.4 C.G:42.8 ± 9.4	I.G: 32 (65.6%) C.G: 28 (75%)	I.G: 33.3 ± 6.2 C.G: 34.1 ± 5.4	126.6 ± 20.9	Have undergone laparoscopic RYGB	I.G: Physical activity supervised/counseling 6 months after surgery	I.G: Resistance + endurance training - 26 weeks - 2 days/week - 40 min - Endurance: moderate intensity
Stolberg et al. 2018 (2) [64]	DENMARK	RCT	I.G: 42.4 ± 9.0 C.G:42.3 ± 9.4	I.G: 32 (65.6%) C.G: 28 (75%)	I.G: 33.3 ± 6.2 C.G: 34.1 ± 5.4	126.6 ± 20.9	Have undergone laparoscopic RYGB	I.G: Physical activity supervised/counseling 6 months after surgery	I.G: Resistance + endurance training - 26 weeks - 2 days/week - 40 min - Endurance: moderate intensity
Wiklund et al. 2015 [65]	Sweden	RCT	I.G: 39.9 ± 11.7 C.G: 44.6 ± 12.9	I.G: 30 (53.3%) C.G:25 (56%)	I.G: 45.4 ± 8.0 C.G: 42 ± 2.4	I.G: 123.8 ± 15.2 C.G: 133.7 ± 31.3	Have undergone laparoscopic RYGB	I.G: Physical activity programme During first week after surgery	I.G: Walking endurance training - 1 week - 7 days/week
Woodlief et al. 2015 [66]	USA	RCT	I.G. Low-ex: 39 ± 2 I.G. Med-ex: 43 ± 2	I.G. Low-ex: 18 I.G. Med-ex: 19	I.G. Low-ex: 38.9 ± 1.6 I.G. Med-ex: 37.8 ± 1.5	I.G. Low-ex: 127.8 ± 3.8 I.G. Med-ex: 120.9 ± 3.5	Have undergone bariatric surgery	I.G: Physical activity supervised/programme Between 1 and 3 months after surgery	I.G: Endurance training - 26 weeks (6 months) - 3 to 5 days/week - 30 min

Table 1 (continued)

Reference	Country	Study design	Population Characteristics				Intervention		
			Age	Sample size (%W)	BMI	Pre-surgery weight	Type of population	Type of intervention/Start of intervention	Physical activity characteristics
			I.G. High-ex: 41 ± 2	I.G. High-ex:19	I.G. High-ex: 39.7 ± 1.4	I.G. High-ex: 132.7 ± 6.9			- 60 to 70% HR
			C.G: 43 ± 2	C.G: 42	C.G: 38.5 ± 0.9	C.G: 123.9 ± 4.4			

RCT randomized controlled trial, *NON-RCT* non-randomized controlled trial, *I.G* intervention group, *C.G* control group; NR: Not reported; HR: Heart Rate; RM: Repetition Maximum; VO_2max: Maximum oxygen consumption; D/W: Day per Week; BMI: Body Mass Index; RYGB: Roux-en-Y gastric bypass. M/W: Minutes per week; MIP: maximum inspiratory pressure. %W: percentage of women in each study or group

the intervention ($p = 0.377$) or the time devoted to each exercise session ($p = 0.807$) (Table 5).

Sensitivity Analysis and Publication Bias

Once the impact of each study was verified in the final result, eliminating each study individually, no changes were observed in the overall results. As seen in the funnel plot (Fig. 3) and once the Egger test was performed, there was no evidence of significant publication bias risk ($p = 0.208$).

Discussion

Our systematic review and meta-analysis provide insight into how a physical activity program performed after bariatric surgery can affect weight loss. The data obtained from the analysis of a total of 749 pooled bariatric surgeries did not show significant positive results in favor of exercise for people who underwent bariatric surgery. No significant results were found in terms of weight loss in favor of physical exercise after bariatric surgery when compared to the usual postoperative care.

Three previous systematic reviews [20, 21, 33] concluded that exercise following bariatric surgery is positive in increasing weight loss and improving other factors such as muscle loss or cardiovascular risk. Similarly, a recent meta-analysis [22] obtained significant results in favor of physical exercise, in contrast to our results, which are slightly positive for the intervention group, although not significant. This might be because some of the studies included in these previous reviews carried out multi-component interventions; meaning that physical exercise was accompanied by something else. Also, discrepancy between our results and those from previous systematic reviews and meta-analysis may be due to the fact that other authors directly calculated the difference in means between the groups, instead of calculating the difference in the standardized means. In addition, the number of articles included in our meta-analysis is higher than in previous weight-loss reviews, and the studies included in this meta-analysis only performed exercise, without any other type of intervention, such as diet or psychological support.

The results obtained in our systematic review and meta-analysis slightly disagree with the conclusions of previous reviews, showing no significant differences in favor of physical exercise once the bariatric surgery has been completed successfully. The effect (standardized mean difference, SMD) does not achieve statistical significance, which could indicate that (i) longer/more intense/better designed physical exercise programs are needed to elicit greater weight loss after bariatric surgery, or (ii) physical

Table 2 The Cochrane collaboration's tool for assessing the risk of bias in randomized trials

RCTs	Selection bias	Performance bias	Detection bias	Attrition bias	Reporting bias	Other bias	Risk of bias
Carnero et al. 2017 [43]	Strong	Strong	Strong	Moderate	Strong	Strong	Low
Casali et al. 2011 [44]	Moderate	Moderate	Weak	Moderate	Moderate	Strong	Moderate
Castello et al. 2011 [45]	Moderate	Weak	Weak	Moderate	Moderate	Strong	High
Castello-Simoes et al. 2013 [46]	Moderate	Weak	Weak	Moderate	Moderate	Strong	High
Coen et al. 2015 [47]	Strong	Moderate	Strong	Strong	Strong	Strong	Low
Coen et al. 2015 (2) [48]	Strong	Moderate	Strong	Strong	Strong	Strong	Low
Coleman et al. 2017 [49]	Strong	Moderate	Moderate	Weak	Moderate	Strong	Moderate
Creel et al. 2016 [50]	Strong	Weak	Moderate	Weak	Moderate	Strong	High
Daniels et al. 2018 [51]	Strong	Strong	Strong	Moderate	Strong	Strong	Low
Hassannejad et al. 2017 [52]	Strong	Moderate	Weak	Strong	Strong	Strong	Moderate
Herring et al. 2017 [67]	Strong	Moderate	Weak	Strong	Strong	Strong	Moderate
López et al. 2017 [54]	Strong	Strong	Moderate	Moderate	Strong	Strong	Low
Mundbjerg et al. 2018 [56]	Strong	Strong	Moderate	Strong	Strong	Strong	Low
Mundbjerg et al. 2018 (2) [65]	Strong	Strong	Moderate	Strong	Strong	Strong	Low
Oliveira et al. 2016 [58]	Moderate	Moderate	Weak	Weak	Weak	Moderate	High
Rojhani et al. 2016 [60]	Moderate	Moderate	Weak	Weak	Moderate	Moderate	High
Shah et al. 2011 [61]	Strong	Moderate	Moderate	Moderate	Weak	Strong	Moderate
Stolberg et al. 2018 [63]	Strong	Strong	Moderate	Strong	Strong	Strong	Low
Stolberg et al. 2018 (2) [64]	Strong	Strong	Moderate	Strong	Strong	Strong	Low
Wiklund et al. 2015 [65]	Weak	Moderate	Weak	Weak	Weak	Strong	High
Woodlief et al. 2015 [66]	Strong	Moderate	Strong	Strong	Strong	Strong	Low

RCTs randomized controlled trials

exercise after bariatric surgery must be accompanied by long-term changes in eating habits [16].

In a previous randomized controlled trial by Creasy et al. [34], obese/overweight participants lost on average 3.8 ± 3.0 kg when performing supervised physical activity, compared to an average weight loss of 5.1 ± 3.3 kg among those who were in the programmed (unsupervised) physical activity group. In our meta-analysis, the data reveal a non-significant trend toward greater weight reduction in those studies carrying out programmed (unsupervised) physical activity. This may occur due to an improvement in the psychological processes, self-efficacy, and autonomous motivation produced by performing physical activity after bariatric surgery [35].

Regarding the type of exercise, aerobic training shows the highest effect size, although this is also not significant. In contrast, previous studies on obese and overweight people (not bariatric patients) showed that a combination of resistance and aerobic training is the most effective way to lose weight [36]. Furthermore, a minimum of 150 min/week of moderate intensity physical activity has been proposed for developing and maintaining fitness [37]. In our results, however, the greatest weight loss was observed (although again not significant) in those interventions lasting less than 150 min/week. These two results might be related to the scarcity of studies containing sufficient samples combining aerobic and resistance exercise that entailed more than 150 min/week of exercise in patients who had undergone bariatric surgery. In addition, the studies did not control other factors that may affect weight loss, such as sleep, physical activity outside the program, or

Table 3 The quality assessment tool for quantitative studies

Non-RCTs	Selection bias	Study design	Confounders	Blinding	Data collection	Withdrawals/ drop-outs	Risk of bias
Campanha-Versiani et al. 2017 [42]	Weak	Moderate	Strong	Weak	Strong	Strong	High
Huck et al. 2015 [53]	Moderate	Moderate	Moderate	Weak	Strong	Strong	Moderate
Marchesi et al. 2015 [55]	Moderate	Weak	Strong	Weak	Strong	Moderate	High
Onofre et al. 2017 [59]	Weak	Moderate	Moderate	Weak	Strong	Strong	High
Stegen et al. 2011 [62]	Moderate	Weak	Strong	Weak	Strong	Strong	High

Non-RCTs non-randomized controlled trials

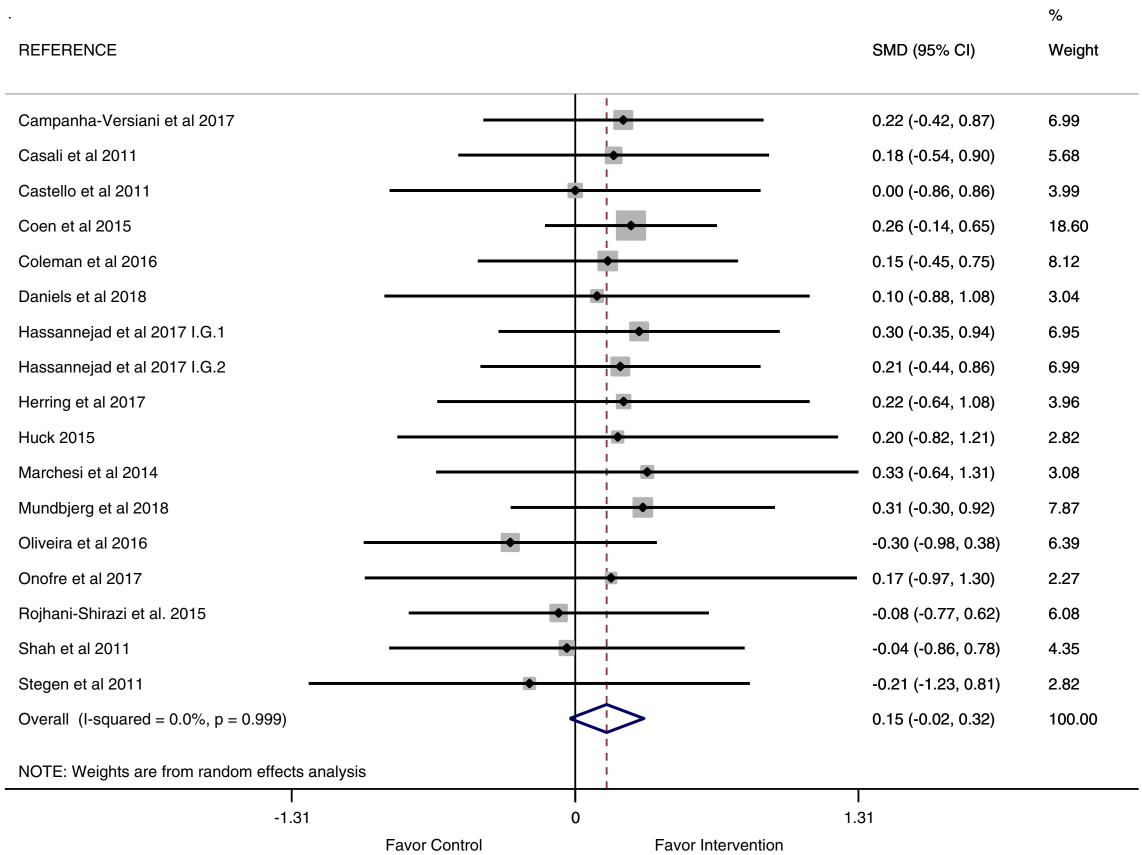

Fig. 2 Forest plot of the weight loss standardized mean difference between the control group and the intervention group. *SMD* standardized mean difference, *CI* confidence interval

Table 4 Stratified analysis according to the characteristics of the exercise program

Subgroups analysis	Control group vs. intervention group				
	Number of studies	Pooled SMD (95%CI)	I^2	X^2	*P*
Type of intervention					
Physical activity programmed	3	0.153 (− 0.229, 0.535)	0.0	0.63	0.434
Physical activity supervised	9	0.101 (− 0.160, 0.363)	0.0	2.53	0.447
Physical activity programmed/supervised	4	*0.202 (− 0.091, 0.495)*	*0.0*	*0.50*	*0.176*
Start of intervention after the surgery					
≤ 3 months	11	0.123 (− 0.081, 0.328)	0.0	3.21	0.238
> 3 months	5	*0.199 (− 0.128, 0.526)*	*0.0*	*0.55*	*0.234*
Duration of the intervention					
≤ 16 weeks	12	0.064 (− 0.166, 0.294)	0.0	2.64	0.587
> 16 weeks	5	*0.248 (− 0.008, 0.504)*	*0.0*	*0.18*	*0.057*
Type of exercise					
Aerobic training	5	*0.209 (− 0.073, 0.490)*	*0.0*	*0.77*	*0.146*
Resistance training	2	0.147 (− 0.559, 0.853)	0.0	0.02	0.683
Aerobic/resistance combination	7	0.189 (− 0.085, 0.463)	0.0	0.79	0.176
Alternative training	3	− 0.075 (− 0.476, 0.327)	0.0	0.90	0.715
Time of exercise					
≤ 150 min/week	4	*0.165 (− 0.110, 0.441)*	*0.0*	*2.24*	*0.240*
> 150 min/week	13	0.134 (− 0.084, 0.352)	0.0	1.64	0.228

SMD standardized mean difference, *CI* confidence interval

Positive SMD values indicate a higher score in outcomes favoring the intervention group

Results in italic are those that show a higher SMD

Table 5 Meta-regression of weight loss with mean age, length of intervention, and time per session

	Mean age			Length of intervention			Time per session		
	I^2	β (95% CI)	*p*	I^2	β (95% CI)	*p*	I^2	β (95% CI)	*P*
SMD weight loss	0%	− 0.002 (− 0.042, 0.037)	*0.902*	0%	0.006 (− 0.008, 0.002)	*0.377*	0%	− 0.001 (− 0.013, 0.01)	*0.807*

CI confidence interval, *SMD* standardized mean difference

nutritional habits, which may condition the study results in relation to weight loss.

Physical activity interventions in obese people lasting less than 16 weeks were associated with increased energy expenditure but not with a reduction in body weight [38, 39]. According to our analysis, interventions lasting more than 16 weeks seem to produce greater weight loss, although this effect was not statistically significant compared to the control groups (no exercise). This might occur due to the increase in energy expenditure and the induction of lipolysis [40]. Some evidence suggests that weight loss could be higher if physical activity were combined with dietetic education, caloric reduction, or changes in eating habits [38, 40].

Limitations

Certain limitations that may have affected the results should be considered. First of all, some studies (five of them) did not report the standard deviation for body weight after the intervention. Secondly, not having the correlation between pre- and post-measures to estimate the standard deviation of the difference—it was for this reason that 0.59 was used. Thirdly, the samples, the inclusion/exclusion criteria, and the follow-up time varied greatly across studies. Moreover, there was a moderate risk of bias for the studies included. Finally, we could not analyze the exercise intensity performed in the reviewed programs because it was not possible to unify the criteria.

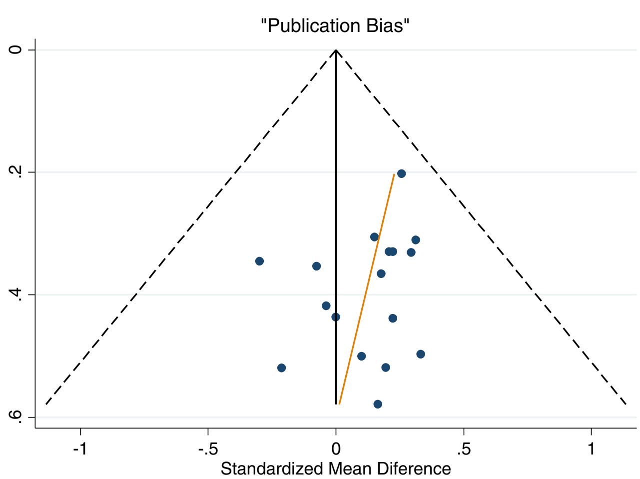

Fig. 3 Funnel plot with Egger test

Conclusions

Based on the results of our meta-analysis, one can conclude that exercise training in patients who have undergone bariatric surgery does not seem to be effective in achieving greater weight loss compared to the usual post-operative care, and no particular training is more effective than another for losing weight in patients who have undergone bariatric surgery. There is, however, a consensus that large enough RCTs of exercise have yet to be done—so doing meta-analyses of early, small cohorts can be misleading. The reviewed studies used different surgery types, exercise types, exercise durations, and interventions were in general poorly reported, making them difficult to be properly combined. It may be too early to make any conclusions, and reporting null findings could possibly dissuade people from adding exercise to their post-operative lifestyle changes, which could take them away from the myriad of positive effects of exercise. Even if the lack of effects on weight loss could be rigorously confirmed, exercise after bariatric surgery may help maintain lean body mass, improve cardiovascular health, psychological well-being, and increase adherence to training, among other benefits [41].

Future Directions

This line of research, which combines bariatric surgery and exercise training, should continue in order to elucidate the most appropriate type of exercise, as well as to determine the design and implementation of training programs with greater frequency, volume, intensity, and/or with different types of exercises, in such a way that is most appropriate for this population. Studies are also necessary in which patients begin to train straight after surgery to take advantage of the window of opportunity for behavioral change as soon as possible, not only to achieve greater weight loss but also to improve other parameters that affect these patients' health status such as muscle mass loss, cardiovascular parameters, biochemical markers, and respiratory parameters, among others. As demonstrated in our weight loss meta-analysis, all these research areas require better designed (and better reported) studies with sufficient sample sizes.

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Compliance with Ethical Standards

Ethics Approval and Consent to Participate Not applicable.

Conflict of Interest The authors declare that they have no conflict of interest.

Abbreviations 95% CI, 95% confidence intervals; BMI, Body mass index; C.G, Control group; D/W, Days per week; HR, Heart rate; I.G, Intervention group; M/W, Minutes per week; MIP, Maximum inspiratory pressure; non-RCTs, Non-randomized control trials; NR, Not reported; PA, Physical activity; RCTs, Randomized controlled trials; RM, Repetition maximum; RYGB, Roux-en-Y gastric bypass; SDs, Standard deviations; SMD, Standardized mean difference; VO2max, Maximum oxygen consumption

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