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REVIEW

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Can exercise promote additional benefits on body composition in patients with obesity after bariatric surgery? A systematic review and meta-analysis of randomized controlled trials

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Abstract

Background: Bariatric surgery is the most effective treatment for patients with severe obesity, but success rates vary substantially. Exercise is recommended after bariatric surgery to reduce weight regain but the effectiveness remains undetermined on weight loss due to conflicting results. It is also unclear what should be the optimal exercise prescription for these patients. A systematic review and meta-analysis of randomized controlled trials on the effects of exercise on body weight (BW), anthropometric measures, and body composition after bariatric surgery was performed.

Methods: PubMed/MEDLINE®, EBSCO®, Web of Science® and Scopus® databases were searched to identify studies evaluating exercise effectiveness.

Results: The analysis comprised 10 studies ($n = 487$ participants). Exercise favored BW (–2.51kg; $p = 0.02$), waist circumference (–4.14cm; $p = 0.04$) and body mass index (–0.84kg·m^{-2}; $p = 0.02$) reduction but no improvements in body composition. Combined exercise interventions were the most effective in reducing BW (–5.50kg; $p < 0.01$) and body mass index (–1.86kg·m^{-2}; $p < 0.01$). Interventions starting >6-months after bariatric surgery were more successful in reducing BW (–5.02kg; $p < 0.01$) and body mass index (–1.62kg·m^{-2}; $p < 0.01$).

Conclusion: Exercise, combined exercise regimens and interventions starting >6-months after bariatric surgery were effective in promoting BW, waist circumference and body mass index reduction. Exercise following bariatric surgery does not seem to favor body composition improvements.

KEYWORDS
bariatric surgery, body composition, exercise training

Abbreviations: A, aerobic exercise; BMI, body mass index; BS, Bariatric surgery; BW, body weight; C, combined exercise; FM, fat mass; LM, lean mass; WC, waist circumference.

1 | INTRODUCTION

Bariatric surgery (BS) is the most effective treatment for patients with severe (body mass index (BMI) > 35kg·m^{-2}) and, particularly, clinically severe obesity (BMI > 40 kg·m^{-2}),[1] leading, on average, to over than 35% weight loss (WL) at the long term.[2] Alterations in gastrointestinal anatomy and hormonal secretion lead to changes in energy balance and hunger control mechanisms,[3] promoting thereby sustained WL and amelioration of several obesity related comorbidities.[4–6] Consequently, the number of BS performed worldwide has risen substantially from 579,517 in 2014[7] to 833,687 in 2019,[8] with the Roux-en-Y gastric bypass and the gastric sleeve being the most frequently performed procedures. Nevertheless, a significant number of patients experience weight regain and comorbidities relapse following BS.[9] For these, the only treatment option available is revisional BS, which is riskier,[10] less effective compared to primary BS[11] and contributes to a significant increase in health care costs associated with obesity treatment. Effective secondary prevention measures for favoring WL and prevent weight regain following BS are therefore needed.[12] Lifestyle modification, such as diet and exercise, are on the basis of obesity management. Exercise improves metabolic health and contributes to weight reduction and therefore is part of post-BS patients follow-up recommendations.[13] Indeed, a previous study has shown that increases in leisure time physical activity favor WL following BS.[14] However, most patients remain insufficiently active and fail to reach the amount of recommended physical activity.[15,16] Participation in structured exercise interventions is therefore a possible strategy to overcome this problem. However, available evidence surprisingly suggests that exercise is ineffective in favoring post-BS WL.[17] These results might, however, be influenced by exercise induced increases in lean mass (LM) and do not necessarily reflect a failure of post-BS exercise interventions on favoring obesity remission. Therefore, to better determine the role of exercise in favoring obesity remission in these patients, it is necessary to investigate other parameters other than just body weight (BW) that can adequately reflect changes in body composition and that are more robust indicators of all-cause and cardiovascular mortality.[18] This information would allow clinicians to clearly determine the potential role of structured exercise interventions on post-BS WL and long-term WL maintenance and to adequately manage patient's post-operative care.

This systematic review and meta-analysis aimed to answer the following research question - can exercise favor WL and promote additional benefits on body composition compared to those elicited solely by BS? To answer this question, previous randomized controlled trials (RCTs), in which post-BS patients participated in structured exercise interventions as part of post-BS care, were systematically reviewed and meta-analyzed. The effects on BW, waist circumference (WC) and body composition in opposition to usual post-BS care were compared. A secondary aim was to determine the characteristics of exercise interventions (mode, duration, and onset after BS) that were more likely to favor WL and body composition benefits.

2 | METHODS

2.1 | Design

This study followed the PRISMA guidelines for systematic reviews and meta-analyses.[19] The study protocol was registered through PROSPERO (CRD42020161175).

2.2 | Eligibility criteria

This systematic review and meta-analysis has included RCTs of adults with severe obesity that underwent BS for example, sleeve gastrectomy (SG), Roux-en-Y gastric bypass (RYGB), adjustable gastric banding (GB) or biliopancreatic diversion with duodenal switch (BPD-DS). Participants were allocated into two groups; control group (CG) received usual follow-up medical care and exercise group (EG) participated in an exercise intervention with a minimum of 1-month duration in addition to the usual medical follow-up. Supervised and semi-supervised training protocols were included and no restrictions were applied on exercise mode, which was predominantly aerobic, resistance or combined, and on intensity, intervention duration and the onset after surgery. Moreover, only studies in which BC was assessed by dual-energy X-ray absorptiometry (DXA) were included in fat mass (FM) and LM analysis. Only articles published in English between 2000 and 2020 were searched. Exclusion criteria were: i) patients aged under 18 years, ii) sample size <10 subjects, iii) reporting data at only one time point either before or after surgery. All studies that met the eligibility criteria were selected for further review and analysis.

2.3 | Search strategy

PubMed/MEDLINE®, EBSCO®, Web of Science® and Scopus® databases were systematically searched to identify potential studies corresponding to the eligibility criteria. Search strategy was designed by all authors, conducted by the first author and included the following terms in different combinations: "obesity", "bariatric surgery", "exercise training", "physical activity" and "body composition". The last search was conducted in November 2020. Manual inspection of the references from selected articles was also performed to identify potential studies of interest not retrieved from the primary database search.

2.4 | Studies selection and quality of assessment

First, all published articles identified through the systematic literature search were individually screened independently by all authors and those of potential interest were saved to an Endnote database (Endnote X9, Thomson Reuters, San Francisco, California). Independent databases were then combined, and duplicate records deleted. Afterward, selected abstracts were analyzed and those matching our criteria were selected. Finally, the full texts were analyzed and relevant data was extracted. Disagreements and ambiguity were resolved by discussion and consensus among authors. Whenever multiple studies reporting results on the same outcome derived from the same research project were identified, for example, same authors, affiliation, and study design, only the one presenting the most relevant data was included in the analysis to avoid data overlap. Selected studies were submitted to a methodological rigor assessment by the first author using the Physiotherapy Evidence Database scoring (PEDro) scale (0–10). The total PEDro score is reached by adding points for example, 1 or 0 to items 2 to 11. The final score is classified as <4 "poor"; 4 to 5 "fair"; 6 to 8 "good" and 9 to 10 "excellent".[20]

2.5 | Data extraction

The following data was extracted by the first author from the final pool of selected articles using a pre-established form: authors, publication date, country, study design, sample size, type of BS, exercise intervention type, duration, and onset after BS, outcomes and results of CG and EG, for example, mean and standard deviation of the variables of interest. Remaining reviewers checked the extracted data and disagreements were resolved by discussion and consensus. No authors were contacted to obtain further information.

2.6 | Data synthesis

Relevant outcomes on anthropometrics and BC were extracted from individual studies: BW, BMI, WC, FM and LM.

Studies that reported overlapping data were: i) Castello et al. 2013[21] and Castello et al. 2011[22]; ii) Coen et al. 2015,[23] Coen et al. 2015,[24] Nunez-Lopez et al. 2017[25] and Woodlief et al. 2015[26]; iii) Stolberg et al. 2018,[27] Stolberg et al. 2018,[28] Mundbjerg et al. 2018[29] and Mundbjerg et al. 2018.[30] In accordance with the previously mentioned criteria, from the studies above referred, only three[22,24,29] were included in the final analysis.

Data from Castello et al. 2011[22] was transformed from standard error (SE) into standard deviation (SD) using the formula:

$$SD = SE * \sqrt{N}$$

Daniels et al. 2017[31] presented absolute values for each subject and, therefore, it was necessary to calculate the mean and SD in CG and EG. Mean differences (MD) and SD between groups from baseline and post-intervention were determined using the package "meta" (version 4.11-0) for the R statistical software (version 3.6.0, R Foundation for Statistical Computing, Vienna, Austria).

2.7 | Statistical analysis

A meta-analysis of random effects was performed for each outcome selected. Pooled effect sizes (ES) were presented as unstandardized MD with 95% confidence interval (95%CI). Heterogeneity was assessed by the I^2 statistic and qualitatively classified according to the Cochrane[31] benchmarks: $I^2 = 0$–40% not important, $I^2 = 30$–60% moderate, $I^2 = 50$–90% substantial or $I^2 = 75$–100% considerable. An overall analysis was performed to explore the exercise effects, and afterward a sub-analysis by exercise intervention mode, for example, aerobic exercise versus resistance exercise versus combined exercise, time of onset post-BS, for example, (<6 months vs. >6 months) and exercise intervention duration time, for example, (<12 weeks vs. >12 weeks).

When a high I^2 was identified, a sensitivity analysis was conducted to detect if any particular study was responsible for a large proportion of I.[2] Publication bias was assessed through visual funnel plot inspection and by Egger's linear regression method test.[32] All analyses were performed with the package "meta" (version 4.11-0) and R statistical software (version 3.6.0). Overall effect (Z-test) was considered statistically significant at p-value <0.05.

3 | RESULTS

3.1 | Systematic review

Twenty-five full-text articles[21–30,33–47] out of 3842 references matching our search criteria were selected and analyzed. Of these, 8 studies[34,35,37,38,41–43,45] were further excluded because they did not present data enabling a final analysis. Studies that reported overlapping data were excluded[21,23,25–28,30] and because of that, 10 studies[22,24,29,33,36,39,40,44,46,47] that met the inclusion and quality criteria were included (Figure 1).

Studies were conducted in six continents, five in North America, one in South America, three in Europe and one in Western Asia. A total number of 487 patients was included, of which 414 (85%) were women, 73 (15%) men and 273 (56%) were allocated to exercise interventions.

Regarding the type of surgery performed, 5 studies[22,24,29,33,44] included only patients that underwent RYGB, 236,40 RYGB, SG or GB, 139 RYGB or SG, 146 RYGB or GB and 147 SG or BPD-DS. Regarding the type of exercise protocol used, 3 studies included exclusively interventions with aerobic exercise,[22,24,46] 2 with resistance,[33,44] 4 with combined[29,36,40,47] and 1 study with both aerobic and combined exercises.[39]

Aerobic sessions lasted 40–60 min, with a 3–5 days/week frequency and a 12–26 weeks duration. Load intensity monitoring strategies differed among studies. One study monitored aerobic exercise intensity through maximum heart rate percentage reached in a prior test. In this case the intensity during the sessions was set between 50 and 70% HR peak.[22] In another study intensity was defined between 60 and 70% based on maximal HR.[24] Maximum oxygen

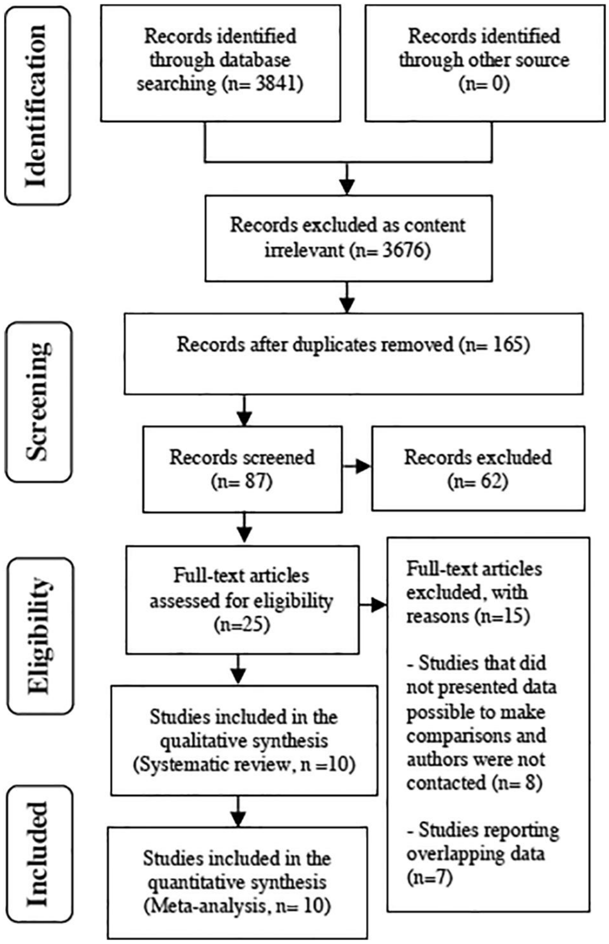

FIGURE 1 Flow diagram indicating the number of studies retrieved in the literature search, and the final number of studies included in the meta-analysis

uptake[46] was used in a third study to define exercise intensity, which in his case was set between 50 and 70%. In another study exercise intensity was defined based on Borg scale of perceived exertion and set between 12 and 14 (moderate intensity).[39] Aerobic exercises included in these studies were treadmill walking, stationary or outdoor cycling and outdoor walking. In one study, the session was partially supervised,[46] 3 studies reported semi-supervised sessions[24,36,39] and five studies reported supervised sessions.[22,29,33,40,44] Of all studies, only two reported that the sessions were monitored by exercise instructors or physiotherapists.[22,39]

In resistance training, sessions duration ranged between 60[44] and 80 min,[33] with a 3 days/week frequency[33,44] and a total duration of 12[31] to 18[44] weeks. Intensity was defined according to one-repetition maximum test[33,44] and ranged between 50 and 80%. Resistance training was performed mostly with free weights or weight machines, for example, squats, lunges, leg press, leg curl, leg extension, lat pull down, shoulder press, bench press, bent or seated rows, vertical traction, and abdominal crunch and was directed towards major muscle groups.[33,44] These sessions were always supervised. However, studies have not reported if the sessions were monitored by an exercise specialist.

Combined interventions ranged from 40[29] to 60 min[36,40,47] duration, with a frequency between 2[29] and 3-5[36,39,40,47] days/week and a total duration between 12[39,40,47] and 26 weeks.[29,36] Aerobic intensity was prescribed based on maximum oxygen uptake 50 to 70%[29,47] or rate of perceived exertion 12 to 14.[29,39,40] In one study[36] the aerobic intensity was not reported. The majority of the studies that included combined interventions did not report how the resistance component intensity was evaluated or how the training load progression was performed. Only one study[40] reported that a moderate intensity for resistance exercises was expressed as 60% of the one-repetition maximum test. High heterogeneity was noted in aerobic exercises in combined interventions, with studies reporting from treadmill walking, rowing and stair climbing[29] to free living aerobic activities measured by a pedometer,[37] such as walking outdoor or localized exercise group classes in fitness centers.[29,40] In patients that performed aerobic and resistance training at a fitness center no information regarding type or intensity was given. Exercise sessions in combined interventions were manly supervised[29,39,40] and only one partially supervised.[36] Most of the studies started the exercise training within the first 6 months after BS[22,24,33,39,44,46,47] and 3 studies between 6 and 24 months.[29,36,40] Compliance to the exercise intervention ranged from 56%[22,29,36] to 95%[40] with an average of 70.5 ± 18.3% and dropouts were reported in only three studies[22,46,47] namely 15%,[46] 34%[22] and 40%.[47]

Regarding anthropometric variables, from the 10 studies analyzed only 2[39,40] showed that exercise participation enhanced BW reduction after BS. On WC, only two[22,40] out of 6 studies[24,46] showed benefits with exercise participation, while on BMI only 2[22,40] out of 7 studies showed that exercise provided additional benefits. Two studies[39,40] showed that exercise contributed to further reductions in FM after BS. Most of the studies showed that exercise after BS was ineffective in preventing LM losses,[22,24,40,44,46] with only one study,[39] which included combined exercises, showing LM losses attenuation with exercise participation.

According to the PEDro scale, six studies were classified as fair (5 out of 10 scores) and 4 as having good methodological quality (6 out of 10). Table 1 presents additional information about design, PEDro score, sample size, type of BS, main findings, and general appreciation.

3.2 | Meta-analysis

The effect of exercise participation plus BS versus BS alone on the anthropometric and BC outcomes are shown in supplementary Table 1. Of all the variables analyzed, exercise participation after BS contributed to significant reductions on BW (−2.51kg; 95%CI −4.74;−0.27; $z = -2.20$; $p = 0.03$), WC (−4.14cm; 95%CI −8.16,−0.12; $z = -2.02$; $p = 0.04$) and BMI (−0.84kg·m^{-2}; 95%CI −1.60,−0.08; $z = -2.16$; $p = 0.03$). Exercise participation after BS has not induced significant benefits on FM and LM compared to BS alone (Figure 2).

Sub-analyses to investigate the effectiveness of different exercise modes on the anthropometric and BC outcomes (Table 2) showed that only combined regimens were associated with

TABLE 1 Summary of the selected studies

Author, Study design, PEDro Score (Coding)	Surgery type	Sample size: Exercise group	Sample size: Control group	Exercise Intervention; Duration; Onset Post-BS and Supervision Type	Outcomes used and instruments	Main findings
Castello, et al. (2011)[22] RCT; 5 (fair)	RYGB	*n* = ♀ 11; Age: 38.0 ± 4.0	*n* = ♀ 10; Age 36.0 ± 4.0	Aerobic; supervised; Followed for 3 months; Onset 1 month after BS;	BW: Weight scale (kg) WC: Tape 0.1 cm BMI: Kg/m^2	BW: ND; WC: ↓; BMI: ND
Daniels et al. (2017)[33] RCT; 6 (good)	RYGB	*n* = ♀ 8; Age 44.9 ± 10.2	*n* = ♀ 8; Age 44.9 ± 10.2	Resistance; supervised Followed for 3 months; Onset 2 months after BS	BW: Air displacement plethysmography (kg)	BW: ND
Hassannejad, et al. (2017)[39] RCT 6 (good)	RYGB, SG	(A) *n* = ♀ 15, ♂ 5; (B) *n* = ♀ 14, ♂ 6; Age: 35.4 ± 8.1	*n* = ♀ 16, ♂ 4; Age: 36.7 ± 6.2	A) Aerobic and B) combined; Semi-supervised; Followed for 3 months; Onset 1 month after BS	BW, FM and LM: Body impedance (kg) BMI: Kg/m^2	BW: ↓;BMI: ND
Shah, et al. (2011)[46] RCT 5 (fair)	RYGB, GB	*n* = ♀ 18, ♂ 3; Age: 47.3 ± 10.0	*n* = ♀ 11, ♂ 1; Age: 53.9 ± 8.8	Aerobic; partially-supervised; Followed for 3 months; Onset 3 months after BS;	BW: Weight scale (kg) WC: Tape 0.1 cm LM: DXA (kg)	BW: ND; WC: ND; FM and LM: ND
Coen, et al. (2015)[24] RCT 5 (fair)	RYGB	*n* = ♀ 54, ♂ 8; Age: 41.3 ± 9.7	*n* = ♀ 59, ♂ 7; Age: 41.9 ± 10.3	Aerobic; semi-supervised; Followed for 6 months; Onset 1 and 3 months after BS	BW: Weight scale (kg) WC: Tape 0.1 cm BMI: Kg/m^2 FM and LM: DXA (kg)	BW: ND WC: ND BMI: ND FM: And LM: ND
Herring, et al. (2017)[40] RCT 6 (good)	RYGB, SG, GB	*n* = ♀ 11, ♂ 1; Age: 44.3 ± 7.9	*n* = ♀ 11, ♂ 1; Age: 52.4 ± 8.1	Combined; supervised; Followed for 6 months; Onset 1 and 3 months after BS	BW: Bioelectrical impedance WC: Tape 0.1 cm BMI: Kg/m^2	BW: ↓; WC: ↓; BMI: ↓.
Mundbjerg, et al. (2018)[29] RCT 5 (fair)	RYGB	*n* = ♀ 21, ♂ 11; Age: 42.3 ± 9.4	*n* = ♀ 21, ♂ 7; Age: 42.4 ± 9.0	Combined; supervised; Followed for 6-months; Onset 6-months after BS;	BW: Weight scale (kg) BMI: Kg/m^2	BW: ND; BMI: ND
Coleman, et al. (2017)[36] RCT 5 (fair)	RYGB, SG, GB	*n* = ♀ 22, ♂ 4; Age: NR	*n* = ♀ 21, ♂ 4; Age: NR	Combined; semi-supervised; Followed for 6-months; Onset 6 and 24-months after BS;	BW: Weight scale (kg)	BW: ND
Oppert, et al. (2018)[44] RCT 6 (good)	RYGB	*n* = ♀ 23; Age: 40.9 ± 10.8	*n* = ♀ 22; Age: 43.9 ± 10.7	Resistance; supervised; Followed for 6-months; Onset 1 and a half month after BS	BW: Weight scale (kg) BMI: Kg/m^2 FM and LM: DXA (kg)	BW: ND BMI: ND FM and LM: ND

TABLE 1 (Continued)

Author, Study design, PEDro Score (Coding)	Surgery type	Sample size: Exercise group	Sample size: Control group	Exercise Intervention; Duration; Onset Post-BS and Supervision Type	Outcomes used and instruments	Main findings
Tardif, et al. (2020)[47] RCT 5 (fair)	SG, bpd-DS	n = ♀ 26; ♂ 8; Age: 41.6 ± 11.7	n = ♀ 11; ♂ 4; Age: 39.3 ± 10.7	Combined; supervised; Followed for 12-weeks; Onset 3-months after BS	BW: Weight scale (kg) BMI: Kg/m^2	BW: ND; BMI: ND

Note: Age is expressed as means ± SD. Symbols: decreased (↓) and increased (↑).

Abbreviations: Female (♀female,); male (♂male,); BMI, body mass index; BPD-DS, biliopancreatic division with duodenal switch; BW, body weight; CG, control group; DXA, dual-energy X-ray absorptiometry; EG, experimental group; FM, fat mass; LM, lean mass; NR, not reported; ND, no differences between groups were observed; RCT, randomized controlled trial; RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy; WC, waist circumference (WC).

additional benefits, contributing to a significant reduction on BW (−5.02kg; 95%CI −8.13;−1.90; z = −3.16; p < 0.01) and BMI (−1.62kg·m^{-2}; 95%CI −2.72;−0.59; z = −2.88; p < 0.01), while both aerobic and resistance training regimens had no significant effect (supplementary Figures S1 and S2).

Interventions with <6-months onset after BS do not seem to contribute to reduce any of the analyzed outcome measures as shown in supplementary Table 2. In opposition, interventions starting after the first 6 months post-BS were associated with a significant reduction on BW (−5.25kg; 95%CI −8.52;−1.97; z = −3.14; p < 0.01) and BMI (−1.84kg·m^{-2}; 95%CI −3.04;−0.64; z = −3.01; p < 0.01). A sub-analysis of BC outcomes was not possible due to insufficient data (supplementary Figures S4, S5).

A sub-analysis for exercise intervention duration was also performed and is shown in supplementary Table 3, in which interventions were divided into 2 categories: ≤12 weeks and >12-weeks duration. Most of the studies included interventions longer than 12 weeks. Both interventions with either ≤12 or >12 weeks duration were not associated with significant improvements in any of the selected anthropometric or BC outcomes after BS (supplementary Figure S6, S7).

3.3 | Publication bias

There was no significant publication bias on BS plus exercise intervention versus BS alone, as demonstrated by the funnel plot symmetry and the Egger's test result adjusted to BW. Bias coefficient is −3.00 (intercept) and p-value is higher (p = 0.708) (Figure 3).

3.4 | Sensitivity analysis

Substantial I^2 values presented on the exercise main analysis and exercise protocol duration, for example, (>12 weeks) sub-analysis, decreased after removing one study at a time.[40] However, the pooled effect for both was not statistically significant (p = 0.66) (supplementary Figure S8).

4 | DISCUSSION

This study aimed to conduct a systematic review and meta-analysis of RCTs on the benefits of exercise training for BW reduction and BC improvement in post-BS patients. A secondary aim was to determine the exercise intervention characteristics more likely to induce beneficial effects. Our results showed that patients with severe obesity who underwent BS and afterwards participated in a structured exercise intervention had a higher reduction on BW (−2.51 kg), WC (−4.14 cm) and BMI (−0.84 kg·m^{-2}) compared to patients undergoing standard medical follow-up care alone. Exercise however does not seem to significantly improve BC as it not contributed to further reduction on FM nor prevented LM losses.

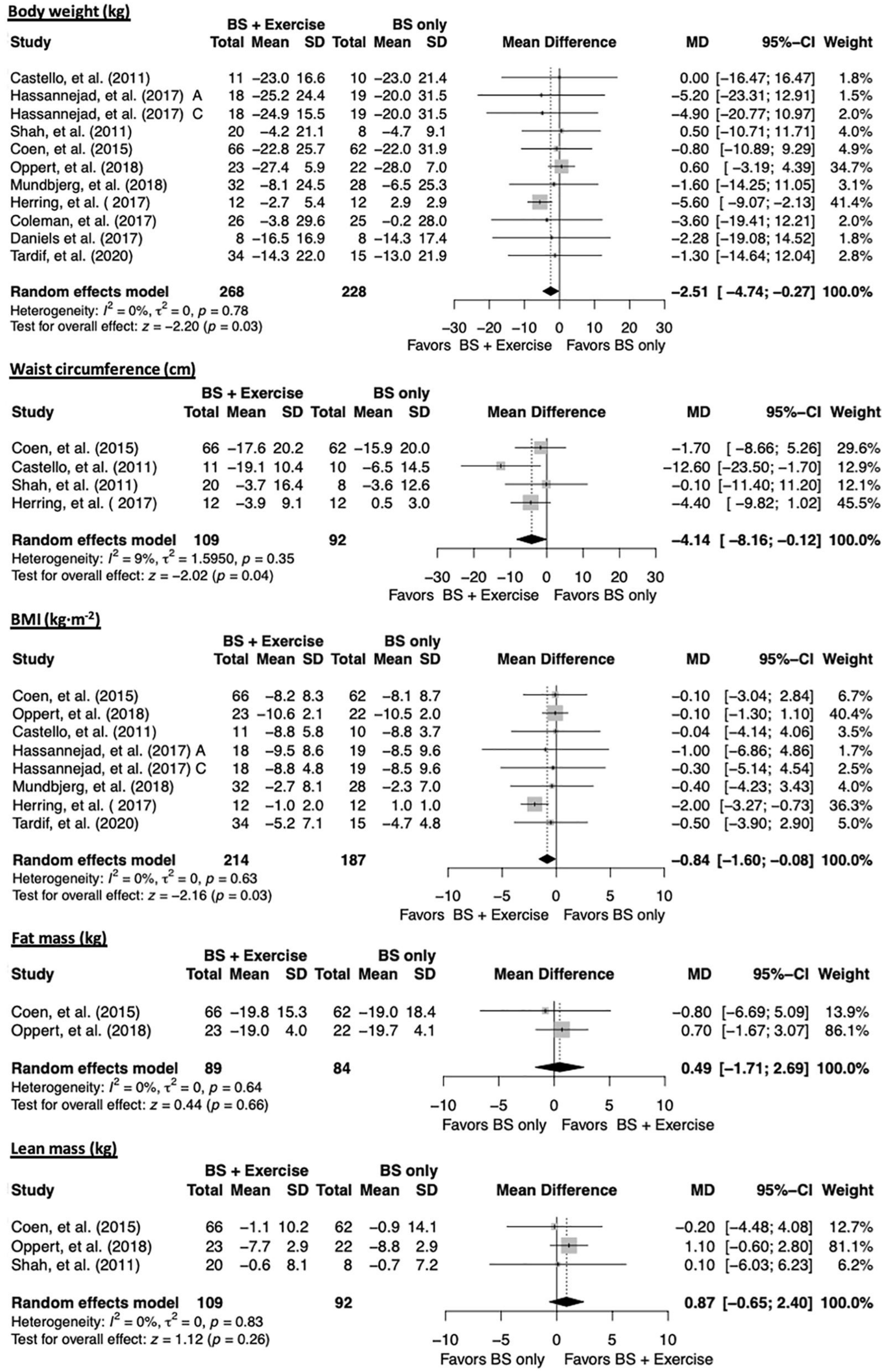

FIGURE 2 Effects of exercise interventions after BS. Note: Data are presented as mean ± SD, mean difference (MD), 95% confidence interval (95%-CI), statistical significance (p < 0.05). Abbreviation: Bariatric surgery (BS), aerobic exercise (A) and combined exercise (C)

Our main analysis showed that post-BS patients benefited from engaging in structured exercise interventions in terms of reduction BW, BMI, and WC. BW reduction after BS alone was, on average, −22.5 kg and exercise participation contributed to an additional −2.5 kg weight reduction, corresponding roughly to an additional 11% loss associated with exercise. A previous systematic review[48]

TABLE 2 Sub-analyses of the effects of different exercise modes on anthropometry and body composition

		BS + aerobic exercise versus BS only		
Outcomes	**N**	**MD (95% CI)**	**I^2 (*p*)**	**Z (*p*)**
Body weight (kg)	4	−0.80 (−7.19; 5.58)	0% (0.96)	−0.25 (0.80)
Waist circumference (cm)	3	−4.30 (−11.30; 2.70)	39% (0.20)	−1.20 (0.23)
BMI (kg•m-2)	3	−0.21 (−2.42; 2.00)	0% (0.96)	−0.19 (0.85)
Lean Mass (kg)	2	−0.10 (−3.61; 3.41)	0% (0.94)	−0.06 (0.95)
		BS + resistance exercise versus BS only		
Outcomes	**N**	**MD (95% CI)**	**I^2 (*p*)**	**Z (*p*)**
Body weight (kg)	2	0.46 (−3.24; 4.16)	0% (0.74)	0.24 (0.81)
		BS + combined exercises versus BS only		
Outcomes	**N**	**MD (95% CI)**	**I^2 (*p*)**	**Z (*p*)**
Body weight (kg)	5	−5.02 (−8.13; −1.90)	0% (0.95)	−3.16 (**<0.01**)
BMI (kg•m-2)	4	−1.62 (−2.72; −0.59)	0% (0.70)	−2.88 (**<0.01**)

Note: Data are presented in mean difference (MD), confidence interval (CI), heterogeneity and *p*-value I^2 (*p*), test for overall effect and *p*-value Z (*p*) and statistical significance $p < 0.05$.

Abbreviations: BMI, body mass index; BS, bariatric surgery; N, number of studies.

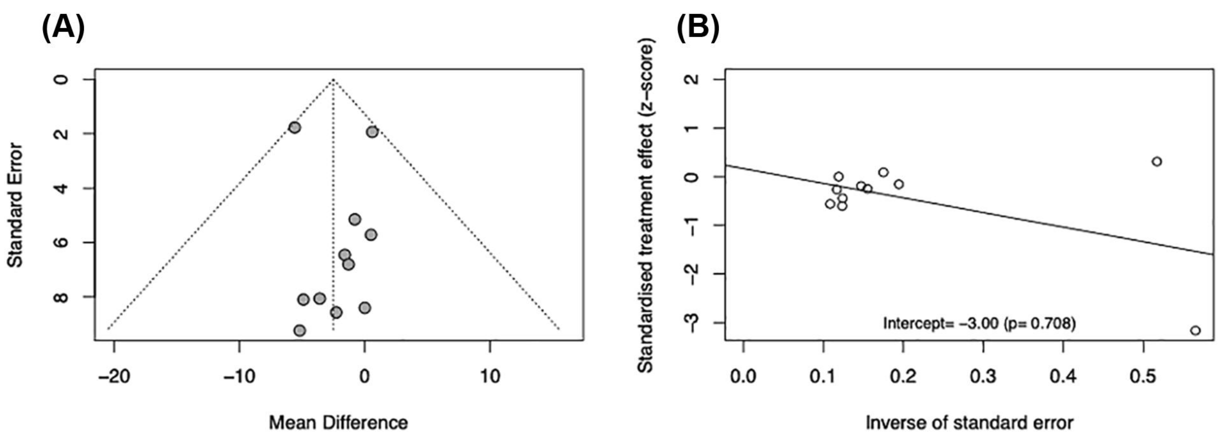

FIGURE 3 Assessment of potential publication bias by funnel plot (A) and Linear regression test of funnel plot For Review Only asymmetry (B), adjusted to body weight

has also suggested that exercise effectively improved several anthropometric parameters in post-BS patients and prior meta-analyses[49,50] showed that exercise led to additional BW reductions ranging from −1.9 kg[50] to −2.4 kg,[49] which is in accordance with our own findings. WC and BMI are important treatment targets for monitoring the reduction of obesity-related adverse health outcomes.[51] Our results showed that patients that engaged in exercise after BS had higher WC reductions of about −4.14 cm, which represents an additional reduction of roughly −33% of the −12.4 cm WC reduction caused by BS alone. These findings are in line with the results from a previous study showing additional exercise associated WC reductions of about −5.25 cm in post-BS patients.[50] Therefore, since WC is so strongly associated with cardiovascular[52,53] and all-cause mortality,[54] this additional WC reduction associated with exercise participation has the potential to contribute to a substantial mortality risk reduction in post-BS patients.

Our analysis showed that BS led to a BMI reduction of −6.8 kg·m^{-2} and that exercise contributed to an additional reduction of −0.84 kg·m^{-2} or 12.3%, which is higher than what has been reported in a previous study.[50] This value is small compared to the BS magnitude effect on BMI but considering the steep relationship with mortality risk increase,[55] even small decreases in BMI can result in a significant mortality risk reduction.

BW reductions after BS are not only the result of significant reductions in FM, but also of substantial LM[56] and bone mass[57] losses. These important changes in BC can negatively impact on physical function,[1] metabolic regulation[58] and long-term risk of weight regain.[59] Our results showed that, exercise participation tends to further reduce FM (−1.40 Kg; 95%CI −4.84; 2.03) and prevent LM losses (0.87 Kg; 95%CI −0.65; 2.24), but differences did not reach statistical significance. Moreover, these results contrast with the findings of a previous meta-analysis showing that exercise in post-BS patients contributed to an additional −2.7 kg FM losses.[49] These differences can be attributed to our option to include only studies in which BC was assessed by DXA, unlike the previous study[49] from which less robust bioimpedance and skinfold thickness measures were also pooled.

Study results employing aerobic, resistance and combined interventions were pooled and compared to investigate the different exercise mode effects on post-BS anthropometry and BC. Results showed that combined interventions had the greatest benefits on WL (−5.02 kg) and BMI reductions (−1.62 $kg{\cdot}m^{-2}$) compared with BS alone. Unfortunately, there was only one study that assessed the combined exercise effect on WC and BC[40] meeting our inclusion criteria and therefore precluding a formal evidence analysis.

Aerobic interventions, for which there was a higher number of available studies, have not shown an effective contribution on BW or BMI reductions after BS. In addition, despite a trend for aerobic interventions to favor WC reduction, the effect did not reach statistical significance.

Regarding resistance interventions, pooled results from only 2 studies suggested that resistance exercise was not effective on BW reduction after BS. These results are in agreement with the findings reported in a previous meta-analysis[50] showing that combined exercise interventions were the most effective on BW reduction (−3.12 kg), with both aerobic and resistance interventions per se presenting no benefits. It was not possible to compare different exercise prescription effects on BC because the number of available studies was too low.

In most studies patients underwent exercise training within 6 months after BS. However, results suggested that interventions starting >6 months after BS are more effective in favoring BW (−5.25 kg) and BMI (−1.84 $kg{\cdot}m^{-2}$) reductions, while no effect was identified on any of the anthropometric and BC variables in exercise interventions starting <6 months after BS. Unfortunately, there were no studies assessing interventions starting exercise >6 months on WC and BC meeting our inclusion criteria. A trend for higher exercise interventions efficacy starting >6 to 12 months compared to interventions starting soon after BS has also been reported in a previous study.[50] This can be interpreted based on the fact that the great amount of WL after BS is achieved during the first post-surgical year, namely during the first 6 months.[60] Therefore, it is conceivable that the effects of exercise become most noticeable when the effects of BS on BW start to wane.

Considering the importance of exercise dose and the effects on health,[61] one of the questions to be answered was if longer-duration interventions induced more benefits compared to shorter duration interventions. Results suggested that protocol duration was not a critical factor since no improvements were found on the variables assessed when studies were pooled according to duration. Nevertheless, trends of BW, WC and FM reductions and LM increases were more evident with longer exercise protocols. This can reflect a higher efficacy of longer protocols or a lower attrition rate for patients that are more responsive or motivated to exercise and therefore that have a lower tendency to dropout in longer exercise interventions.[62] Findings from a previous study[17] are also in line with this result by showing that interventions lasting >16 weeks tend to reduce BW in post-BS patients.

A previous study has shown that post-BS patients daily physical activity levels are an important variable for the success of BS WL.[14] However, despite the recommendation to become physically more active after surgery, most patients remain sedentary.[15,16,63] Results from our study show that promoting the integration in structured exercise interventions is an effective alternative to address the problem of reduced daily physical activity following BS, since it seems to favor weight and WC decreases. Although supervised interventions seem to achieve the best results,[64] the burden to commit with a fixed sessions schedule that implies additional commuting and competes with other daily responsibilities raises significant logistic problems that, in patients that initially had low drive to exercise, may contribute to the high dropout rates observed. It would therefore be important to determine the effectiveness of home-based exercise interventions which, by the higher flexibility and lower logistic demands could also be an interesting strategy to address the problem of low post-BS daily physical activity.[65] Home-based interventions would also potentially contribute to foster patient's autonomy regarding exercise habits and contribute to maintenance of a physically active lifestyle after the end of the intervention.

5 | LIMITATIONS

The present study has some potential limitations mostly related with the lack of an adequate exercise intervention protocol description in several of the pooled studies. It would be inconceivable to assess a drug effect without knowing the dose taken by the patient, but this happens often in studies involving exercise prescription. Particularly for combined exercise protocols, several studies lacked information reporting exercise intensity and how progression was controlled. Furthermore, most of the included studies lacked information regarding how training loads were controlled and adjusted throughout the study as well as a measure of the adherence between the actual training loads and what was initially planned for the intervention. There is also a scarcity of evidence on the effects of resistance exercise in post-BS patients.

Only a limited number of studies reported compliance rate (4 out of 10) and dropout (3 out of 10). The wide variability in compliance to the exercise intervention (56%–95%) may have influenced data interpretation and intervention effectiveness. In addition, the high heterogeneity among studies on several outcome variables and the fact that participants were mostly females could reduce the external validity of the results since an increasing number of male patients are undergoing BS. Considering these limitations, high-quality, adequately powered and representative of both genders RCTs are required to better determine the potential exercise benefits for health gains optimization after BS.

6 | CONCLUSIONS

According to RCTs available evidence, patients with severe obesity that undergo BS should be encouraged to engage in structured exercise programs as this favors BW, BMI, and WC reduction. The magnitude of the exercise effect is not overwhelming, but it can be clinically relevant, and this should be discussed with patients for adequate expectations management. The available evidence, however, does not support the use of exercise to enhance FM reductions or prevent LM losses. Regarding the exercise prescription, combined exercise interventions and those starting >6 months after BS should be favored.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Giorjines Boppre, Florêncio Diniz-Sousa, Lucas Veras, Hélder Fonseca, José Oliveira: study concept and design. Giorjines Boppre, Florêncio Diniz-Sousa, Lucas Veras, Hélder Fonseca, José Oliveira: data analyses. Giorjines Boppre: statistical analysis. Giorjines Boppre, Hélder Fonseca, José Oliveira: drafting of manuscript. Giorjines Boppre, Florêncio Diniz-Sousa, Lucas Veras, Hélder Fonseca, José Oliveira: revision of the manuscript. All authors read and approved the final manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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