Exercise Training in Metabolic and Bariatric Surgery: An Overview of Systematic Reviews

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Abstract

Understanding how to incorporate exercise into metabolic and bariatric surgery programs to optimize treatment outcomes is of great interest, as evidenced by 11 reviews published on this topic in 2022 alone. Accordingly, the current overview of reviews was conducted to create a single cohesive resource to aid clinicians and researchers by exploring the effects of pre- and postoperative exercise training on health outcomes. A literature search of seven electronic databases was performed (updated 09/2023) and 25 reviews met preset PICOS eligibility criteria and were included: 4 exploring preoperative exercise training, 14 postoperative, and 7 both. Comparing reviews, outcome results were organized as concordant, discordant, or inconclusive, and then categorized into “what we currently know”, “what we think we know” and “what we still don’t know”. According to systematic reviews, “we currently know” that postoperative exercise training has a (1) positive effect on weight, waist circumference, 6-minute walking test distance and muscle strength and (2) non-significant effects on lean body/fat-free mass, diastolic blood pressure, fasting insulin/glucose, total cholesterol, low density lipoprotein and triglycerides. Despite the abundance of research, much still needs to be done in terms of enhancing methodological rigor and reporting to achieve greater confidence in our conclusions; recommendations for next research steps are made.

Keywords: Umbrella review; Physical activity; Obesity

Introduction

In accordance with the growing prevalence of obesity (body mass index [BMI] ≥30 kg/m^2) globally, metabolic and bariatric surgery (MBS) is being increasingly performed.[1] Worldwide the estimated number of adults living with obesity has increased from 500 million in 2008 to 671 million in 2016,[2] where concurrently, the approximate number of MBS procedures increased from 344,221 in 2008 to 696,191 in 2018.[3] Notably, MBS generally offers a multitude of health benefits beyond weight loss to adults living with obesity such as improved health related quality of life,[4] improved insulin sensitivity,[5] and reduced type 2 diabetes and cardiometabolic risk factors.[5] However, like all obesity treatments, MBS also has limitations.[6] For example, MBS procedures are associated with decreased bone mineral density, and a major challenge for adults post-MBS is the maintenance of the weight loss, and health benefits.[5,7] In fact, a large cohort study (N = 1406) found that following Roux-en-Y gastric bypass 67% of adults experienced weight recurrence ≥ 20% of their maximum weight loss five years after reaching nadir weight.[8] Consequently, adjunct interventions, including exercise, have been explored to support the positive impacts of MBS.[5]

The benefits of exercise and physical activity have been established in adults pre and post MBS, and numerous systematic reviews have concluded that exercise training in this population (1) is feasible and acceptable,[9] (2) reduces cardiometabolic risk factors[10] and body weight,[11–14] (3) increases muscle strength[13,15] and cardiorespiratory fitness,[10,13,16,17] and (4) improves the maintenance of bone mineral density.[13,18] Notably, these types of reviews are on the rise with eight meta-analyses[9,11,15,16,18–21] and three systematic reviews[22–24] exploring exercise intervention (including exercise training and physical activity counselling) pre- and post-MBS published in 2022 alone. Such amassed information can be incredibly difficult to navigate; thus, an overview of these reviews is necessary to serve as a valuable resource summarizing evidence-based knowledge for researchers and clinicians to support adults undergoing MBS. The present research focuses on exercise training (i.e., prescribed and often supervised exercise) rather than physical activity counselling (i.e., interventions to increase motivation to engage in physical activity through behavioural change techniques)[25] and takes on the task of conducting this overview of systematic reviews with the intention of addressing the following questions: (1) What are the anthropometric, body composition, functional capacity, physical activity, muscle strength, cardiometabolic, quality of life, psychological, and surgical outcomes of exercise training pre- and post-MBS? (2) Are there any exercise training characteristics (i.e., modality, duration, timing) associated with better health outcomes? (3) What is the feasibility and acceptability of exercise training in adults awaiting, or who have undergone MBS? Additionally, this overview of systematic reviews was undertaken to: (1) synthetize available evidence on these questions, (2) identify concordance/discordance between the systematic reviews results, along with their strengths and limitations and (3) explore potential explanations for discordant findings between systematic reviews, if present. This work will help to identify the gaps in the literature that can be addressed through future prospective clinical trials in order to establish physical activity guidelines for MBS patients.

Materials and Methods

The current overview of reviews was registered in PROSPERO (CRD42022360120) in 2022 (minor amendments are addressed in the Supplementary File, see Appendix A) and reported in accordance with the Preferred Reporting Items for Overviews of Reviews (PRIOR) reporting guidelines (see Supplementary File Appendix B for checklist).[26]

Eligibility Criteria

In order to guide the search process, key elements of the research question were identified a priori using the Population, Intervention, Comparison, Outcomes and Study Design (PICOS) framework (details provided in Table 1).[27,28] Of note, publications that were not available in English or French were not considered for inclusion. Further, reviews including studies that combined exercise training with additional intervention strategies (e.g., dietary, therapeutic etc.) were only included in the present review if their control group was matched such that they received the same intervention without the exercise training component (e.g., exercise + protein vs only protein). Additionally, reviews that included only studies focusing on behavioral intervention to promote physical activity, without prescribed exercise training, were excluded. In addition, publications that reviewed exercise training delivered both pre- and post-MBS were only included if the results were synthesized, or could be interpreted, separately for the two time points.

[insert Table 1 near here]

Information Sources and Search Strategy

A search strategy was created by a research librarian (VL) and conducted on November 21st, 2022, in MEDLINE (Ovid), Embase (Ovid), PsycInfo (Ovid), Cochrane Database of Systematic Reviews (Ovid), CINAHL (EBSCOhost), SPORTDiscus (EBSCOhost), and Scopus (see Supplementary File Appendix C for full search details). No limits to language or publication date were applied. The main search concepts comprised of terms related to MBS, exercise, and systematic reviews. An updated search was performed by VL using the same strategy on September 1st, 2023 for reviews published since the initial search. Reference lists from eligible systematic reviews were manually checked by two reviewers (MA and AB) to identify other potentially relevant systematic reviews.

Study Selection

Bibliographical records were extracted and imported into Covidence software (Veritas Health Innovation, Melbourne, Australia), and duplicates were eliminated using the Covidence platform's duplicate identification feature. Next, two reviewers (MA and AD, then AB and JH for the update) independently screened all records by titles and abstracts for eligibility, and then screened the full texts. Disagreements were resolved by AB, and for the updated search two reviewers (AB and JH) met to discuss and reach a consensus on the included articles. Reviews were not excluded on the basis of overlapping PICOS criteria as the aim of this overview was to summarize the full body of available evidence.

Data Extraction

The data extraction was completed using Microsoft Excel by a single reviewer (IZS) and verified by a second reviewer (MA). Another reviewer (AB) synthesized the data into tables which were verified by a fourth reviewer (JH). Relevant details were extracted from the article text and supplementary files; the list of extracted variables is summarized in accordance with their subject (i.e., the review or the primary articles) in Table 2. Data was also extracted from available tables in the case where (1) results text included a synthesis of combined pre- and postoperative exercise training details or combined intervention types (e.g., exercise and diet interventions) and/or (2) outcomes that were discussed in the text required further elaboration (e.g., if the review text discusses a single primary article where weight loss significantly improved after exercise training, the article tables could then be explored to determine the additional number of studies that show no significant difference on weight loss). Similarly, sub analysis results were extracted from meta-analyses when available. Data was extracted from articles and reported *as is,* i.e., additional efforts were not made to locate missing/discrepant data or, when not reported, to assess the risk of bias for included primary articles or the level of confidence of conducted analyses.

[insert Table 2 near here]

Risk of Bias of Included Systematic Reviews

The methodological quality of each review was assessed independently by two reviewers (AB and MA) using the AMSTAR 2 rating scale,[29] and disagreements were resolved by a third reviewer (YW). The authors critical item list was followed, however, item 7 was removed in agreement with Ferguson et al[30] because providing a list of excluded original articles with reasons for exclusion is not required by the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) reporting guidelines.[31] Additionally, as done in Chaput et al,[32] item 16 was modified such that conflict of interest was only required to be reported for the review, and not the review plus all included articles. As per AMSTAR 2 criteria, the present review rated the methodological quality as high, moderate, low or critically low.[29]

Data Synthesis

Outcome data were summarized as they were presented in the reviews and no further statistical analyses on the data were performed. All results were organized based on exercise training timing (i.e., pre- or postoperative). A summary of (1) review characteristics, (2) details on the primary studies' population and intervention and (3) concordant and discordant findings as a function of the outcome (for the most recent reviews published in the last 5 years, i.e., in or after 2018), are presented narratively. Further, tables were synthesized to detail individual review characteristics and findings, as well as methodological details. Further, results for each outcome were synthesized into tables and conclusions were drawn for each review where (1) "+"/ "-" =

100% concordance (within a systematic review) or a meta-analysis revealing a significant positive or negative effect, (2) "(+)"/"(-)" = ≥ 67% (i.e., 2/3) concordance within a systematic review for a significant positive or negative effect, (3) "?" = discordant findings within a systematic review, (4) "(NS)" = ≥ 67% concordance within a systematic review for a non-significant effect and (5) "NS" = 100% concordance (within a systematic review) or a meta-analysis revealing a non-significant effect; conclusions for individual reviews were identified as inconclusive if (1) there was only one primary article included, (2) there were multiple primary articles included but they derived from the same original study (i.e. same cohort) or (3) results combined pre- and post-MBS results. In addition, results from subanalyses were organized into a table by characteristic (i.e., training type, starting time, duration and prescribed exercise/week) and subcategories (e.g. endurance vs resistance vs combined endurance/resistance), then significant positive effects were identified.

Further, as many primary articles are likely to present in multiple systematic reviews and meta-analyses, it is important to assess the degree of overlap.[33,34] To do so, several steps outlined by Hennessey and Johnson[34] were followed. First, Microsoft excel was used to produce citation matrices in accordance with instructions detailed by Pieper et al.[33], and second the corrected cover area (CCA) was calculated across two primary matrices as a function of the exercise training timing (i.e., pre- or postoperative) and across various secondary matrices as a function of outcome (not including subanalyses). The overlap of studies was interpreted as slight when the CCA was 0-5%, moderate when 6-10%, high when 11-15% and very high when >15%.[33]

Next, one of the authors (JH) created a flow diagram (which evolved through discussion with another author [AB]) in order to determine whether the findings were (a) concordant, (b) discordant with potential explanations, (c) discordant without a known reason or (d) inconclusive, between multiple reviews (see Supplementary File Appendix P). Prior to categorizing a conclusion for each outcome, individual review conclusions were removed from the outcome table if they were a meta-analysis that included multiple primary articles from the same original study and/or the results were combined for exercise training delivered pre- and postoperatively. Additionally, conclusions for outcomes at one-year post-MBS follow up were removed as they all only considered one study.[35] Using the flow diagram, two of the authors (AB and JH) independently categorized the results and then met to reach a consensus. Next, for outcomes with discordant conclusions between multiple reviews, (1) study aims, search strategies and PICOS (population, intervention, comparison, outcomes, and study) selection criteria were explored to determine potential reasons for discordance and (2) priority was given to more comprehensive and recent reviews for interpretation of discordant findings.[34]. Finally, the same flow diagram was followed by two researchers (JH and AB) who independently categorized the findings as "what we currently know", "what we think we know' or "what we still don't know" and met to reach a consensus. The "what we currently know" and "what we think we know" categories represent findings where (a) there was concordance between multiple reviews, (b) there was a single review with conclusive findings (i.e., + or NS), (c) there was discordance between reviews with a potential reason and concordance between reviews for a subgroup, or (d) there was discordance between reviews but a review(s), with concordant/conclusive findings, was prioritized due to being more recent and comprehensive; what differentiates them is that "what we currently know" means one or more meta-analyses were conducted with 3+ studies and "what we think we know" means no meta-analysis was conducted or included meta-analyses had less than three studies. The remaining findings fall into the "what we still don't know" category. Finally, the conclusions were disseminated to all authors to gain their perspective and feedback on the interpretation of results.

Results

The PRISMA flow diagram is presented in Supplementary File Appendix D. A total of 1803 records were identified through database searches and 950 remained after removal of duplicates. Following screening of titles and abstracts, 53 articles were retrieved for full-text review and 25 were eligible for inclusion (see supplementary file Appendix E for studies that were excluded with reasoning). Consequently, 25 articles were included in the current overview of which four looked only at preoperative exercise training,[16,19,23,24] 14 looked only at postoperative exercise training,[10–12,14,15,17,18,20,21,36–40] and seven looked at both[9,13,22,41–44]. Notably, one article[13] was found to be an updated version of another article by the same primary author and principle investigator[40]; thus, in accordance with Hennessey and Johnson,[34] both are reported but only the most recent was considered in the interpretation of outcome conclusions. For the included reviews, methodological details, a summary of the AMSTAR2 ratings, a summary of the corrected covered area calculations, and author conclusions on potential reporting or publication bias per outcome (including GRADE certainty of evidence when applicable) are available in the supplementary file (Appendix F, G, H, and O respectively).

Preoperative Exercise Training

Four meta-analyses[9,16,19,42] and seven systematic reviews[13,22–24,41,43,44] explored the impact of preoperative exercise training (characteristics summarized in the supplementary file Appendix I). Five of the reviews were classified as low quality[9,22,24,41,42] whereas the remainder were critically low quality[13,16,19,23,43,44]; note, for both preoperative and postoperative exercise training reviews, the critical flaws leading to such low assessed quality were commonly a lack of reporting of a comprehensive literature search strategy and inappropriate use of statistics to combine results for meta-metanalyses (i.e., the combined analysis of randomized control trails [RCTs] with non-randomized control trials [NRCTs] without providing rationale or conducting sensitivity analyses). There was a very high (18%) overlap of primary articles between the reviews and three primary articles that appeared in more than half of the reviews (i.e., 6/11[45,46] or 7/11[35]). The reviews reflected a total of 21 primary articles (see Supplementary File Appendix J for references and their inclusion in the reviews) with a range of one to 13 original studies (i.e., unique cohorts) per review.

All reviews focused on adults awaiting MBS, however, one review specified it had to be patients' first MBS[19] and another that the MBS care had to be delivered by a team with member representation from three or more disciplines (e.g., surgeon, nurse, nutritionist, physical therapist etc.)[42]. Six of the reviews included only exercise training [9,13,19,41,43,44] whereas five also considered physical activity counselling[16,22–24,42]. Of the 11 reviews, eight listed the requirement for a control group, one stated that the included primary articles could have a control group or not, and two did not identify comparator requirements. Additionally, except one review that looked solely at feasibility and acceptability outcomes,[9] all the reviews included a combination of anthropometric, body composition, functional capacity, physical activity, muscle strength, cardiometabolic, quality of life, psychological, and surgical outcome measures. Four reviews only included RCTs[16,19,22,42] and six reviews included a combination of RCTs and NRCTs, uncontrolled clinical trials or intervention trials[9,13,23,24,41,43].

The reviews had sample sizes ranging from 46-305 and their primary articles ranged from 0-100% women, aged 28-54 years with a BMI of 41.5-51.4 kg/m^2. The exercise training included endurance, resistance, combined endurance/resistance, high intensity interval training (HIIT) and aquatic exercises, of low to vigorous intensity, that lasted 2-52 weeks. Exercise sessions occurred 1-7 times per week and lasted 25-219 minutes per session. Finally, exercise training ranged from unsupervised to fully supervised (not reported in $N = 1$)[24] with mainly usual care control groups (not reported in $N = 3$)[41,43,44].

Outcomes

Table 3 summarizes results for preoperative exercise training as a function of outcome. Next, results are organized as concordant, discordant or inconclusive based on comparisons between multiple reviews. Concordance for a significant positive effect was found for 6-minute walking test distance. Concordance for a non-significant effect was found for blood pressure. Discordance was found for VO_2max and maximal aerobic capacity, muscle strength and functional capacity, body weight/ body mass index/ weight loss and quality of life. Conclusive results could not be determined for length of hospital stay and fat-mass, as there was only one primary article included in each review. Comparisons could not be made for fat-free mass, lean body-mass, resting heart rate, glucose and lipid metabolism, physical activity or adverse surgical events, as there were not multiple reviews with conclusive findings for the same outcome/ outcome measure.

[insert Table 3 near here]

Postoperative Exercise Training

Fourteen meta-analyses[9–15,17,18,20,21,36,37,42] and six systematic reviews[22,38,39,41,43,44] explored the impact of postoperative exercise training (characteristics summarized in the supplementary file Appendix K) with two classified as moderate quality,[18,20] nine low quality,[9,14,15,22,36–38,41,42] and nine critically low quality[10–13,17,21,39,43,44]. Between the reviews, there was a very high (19%) overlap of primary articles with seven primary articles[47–53] appearing in ≥50% of the reviews (10/20,[48,49] 11/20,[51,53] 12/20,[50] 13/20,[47] and 14/20[52]). A total of 42 primary articles were captured in the reviews (see Supplementary File Appendix L for references and their inclusion in the reviews), with a range of 3 to 21 original studies per review.

All reviews considered adults who have undergone MBS. Further, one review specified that the MBS had to be delivered by a multidisciplinary (3+ disciplines) team[42]. Exercise training was the only intervention in all but two reviews[11,37] which also considered physical activity counselling, whole-body electrical myostimulation (in association with dynamic exercise), physiotherapy and respiratory training interventions. Three reviews required the exercise training to have a duration of at least one month,[12,21,39] and another a minimum of three months[18]; further, one review required the exercise training to have a resistance exercise component,[38] and another allowed for interventions that combined exercise with diet supplementation[30]. Of the 20 reviews, 12 listed the requirement for a control group, one had control participants receive a placebo supplementation, one stated the articles could utilize a control group or not, and six did not specify any comparator requirements. Moreover, a majority of the reviews included a combination of body composition, anthropometric, muscle strength, functional capacity, physical activity, quality of life, cardiometabolic, psychological, and surgical outcome measures; contrastingly, some reviews chose to focus on one outcome category including weight loss[37] and specifically weight loss > 12 months[36], feasibility and acceptability,[9] muscle strength,[15] bone mineral density,[18] cardiorespiratory fitness[17] and cardiometabolic risk factors[10,21]. A majority of the reviews explored a combination of RCTs and NRCTs or prospective trials (N = 12[9,10,13,15,17,18,22,37,38,41–43])[a] whereas only seven explored only RCTs[11,12,14,20,21,36,39].

The sample sizes of the reviews ranged from 64-638 and their primary articles ranged from 55-100% women, aged 18-65 years with a BMI of 29.6-49.8 kg/m^2. The exercise training included endurance, resistance, combined endurance/resistance, HIIT, respiratory and balance training, of low to vigorous intensity. The exercise training began immediately-7 years post-MBS and lasted 4-104 weeks. Exercise sessions occurred 1-5 times per week and lasted 5-110 minutes per session. Supervision was reported in 13 reviews[9,10,12,13,15,18,22,36–38,41–43] and ranged from unsupervised to fully supervised. Six reviews did not report details on the control groups,[17,38,39,41,43,44] however the remainder reported mainly usual care.

Outcomes

Table 4 summarizes results for postoperative exercise training as a function of outcome. Next, comparisons are made between multiple reviews and results are organized as concordant, discordant, or inconclusive. Concordance for a significant positive effect was found for bone mineral density, muscle strength, and waist circumference. Concordance for a non-significant effect was found for lean body mass, diastolic blood pressure, quality of life, variables related to glucose (fasting insulin and glucose, and homeostatic model assessment for insulin resistance [HOMA-IR]) and lipid metabolism (total cholesterol, triglycerides, and low-density lipoprotein cholesterol). Discordance was found for body weight/ body mass index, fat-free mass, VO_2max, 6-minute walking test distance, fat mass, resting heart rate, systolic blood pressure, and high-density lipoprotein cholesterol. Comparisons could not be made for weight loss ≥ 12 months post-

[a] da Silva et al[17] incorrectly claimed to only explore RCTs when 4/7 included primary articles were in fact NRCTs.

MBS, or the remaining glucose metabolism outcome measures (hemoglobin A1C [HbA1c], insulin sensitivity, acute insulin response to glucose [AIRg], disposition index [Di], single-point insulin sensitivity estimator [SPISE], and glucose effectiveness), as there was only a single systematic review exploring each.

[insert Table 4 near here]

Sub-Analyses. All sub-analysis outcomes are summarized in the Supplementary File (See Appendix M).

Exercise Training Type. Four meta-analyses compared exercise training that included (1) endurance (E) and combined endurance/resistance (E/R) exercises,[21] (2) E, combined E/R and resistance (R),[12,14] (3) E, R, combined E/R and alternative exercises,[37] and (4) programmed, supervised and combined programmed and supervised exercise training[37]. Discordance was found for the effect of combined E/R on weight related variables (body weight/ body mass index / weight loss).[12,14,37] Significant benefits were found for the effect of combined E/R exercise training on systolic blood pressure and triglycerides in one meta-analysis.[21] .

Exercise Training Start Time. Four meta-analyses compared exercise training beginning (1) < 6 months to > 6 months post-MBS,[12,21] (2) < 3 months to > 3 months post-MBS,[37] and (3) < 6 months to > 12 months post-MBS to varying start times[14]. Discordance was found for the effect of exercise training starting < 6 months post-MBS on weight related variables.[12,14] Additional sets of multiple reviews using the same time frame and outcome variables were not found, however, within the meta-analyses significant positive effects were found for (1) exercise training starting > 6 months post-MBS on systolic blood pressure,[21] and (2) exercise training starting > 6 months and > 12 months post-MBS on body weight[12,14] and BMI[12].

Exercise Training Duration. Three meta-analyses compared exercise training lasting ≤ 12 weeks to > 12 weeks,[12,21] or ≤ 16 weeks to > 16 weeks[37]. The only significant finding was that one meta-analysis determined that exercise training lasting > 12 weeks significantly improved systolic blood pressure.[21]

Exercise Training Time/Week. One meta-analysis compared exercise training with ≤ 150 mins/week of prescribed exercise to those with > 150 min/week and found no significant differences on weight loss.[37]

Feasibility and Acceptability

Only one meta-analysis[9] reported on feasibility and acceptability data. The main feasibility and acceptability outcomes presented by Baillot and colleagues[9] are summarized in Table 5 and an expanded summary (including pre and post-MBS analyses and control group analyses is presented in the supplementary file Appendix N). As well, of the 16 studies that reported on adverse events from exercise: (a) nine reported none, (b) four reported occasional pain, fatigue, or dyspnea, (c) two reported hypoglycemia or hypotension, and (d) one reported a back bruise after a fall. Further, subanalyses revealed no significant differences for feasibility and acceptability measures based on exercise timing (i.e., pre- or post-MBS) or exercise duration (i.e., ≤ 12 weeks or > 12 weeks).

[insert Table 5 around here]

Overarching Results/Conclusions

[insert Figure 1 around here]

The categorizations of outcome conclusions into “what we currently know”, “what we think we know” and “what we still don’t know” in accordance with the flow diagram (See supplementary file Appendix P) are summarized in Figure 1. The process of categorizing the findings was elaborate and thus, details are provided in an expanded discussion in the supplementary file (Appendix Q). Note, a simplified visual summary of all of the outcome conclusions and their respective classification into the three categories is also provided in the supplementary file (Appendix R); viewing this summary in parallel with the discussion is recommended regardless of which discussion you choose to follow.

Discussion

Within the last decade, 25 systematic reviews and meta-analyses have explored the benefits of exercise training delivered pre- and post-metabolic and bariatric surgery (MBS) and have come to varied conclusions. Thus, the current overview aimed to summarize this evidence-based knowledge into a single cohesive resource to aid clinicians and researchers. Specifically, the data were synthesized to examine: (1) the effect of exercise training pre- and postoperatively, (2) whether there are exercise training characteristics that led to better health outcomes and (3) the feasibility and acceptability of exercise training with adults awaiting or who have undergone MBS.

Effects of Exercise Training

Exploring reviews focused on postoperative exercise training revealed a greater number of reviews (11 vs 20), total number of primary articles (21 vs 42), range of original studies per review (1 to 13 vs 3 to 21), and concordance between reviews (2 variables vs 10), compared to those focused on preoperative exercise training.

What We Currently Know

Preoperative Exercise Training. No outcome was classified into this category due to the absence of at least one meta-analysis with 3+ studies. Thus, more original studies, and subsequently more comprehensive meta-analyses, are needed to explore the impact of exercise training during the preoperative period.

Postoperative Exercise Training. There was concordance between reviews on exercise training revealing (1) a positive effect on waist circumference and muscle strength and (2) a nonsignificant effect on lean-body mass, diastolic blood pressure, fasting insulin/glucose, total cholesterol, triglycerides, and low-density lipoprotein cholesterol.

Further, although there was discordance between reviews, the removal of specific systematic reviews (see Appendix R, outcomes Post10-12 for details) resulted in concordance between the remaining reviews on exercise training revealing: (1) a positive effect on body weight/BMI and 6-minute walking test distance, and (2) a non-significant effect on fat-free mass.

Two recent overviews of reviews revealed similar findings for the effect of exercise training on adults with overweight or obesity.[54,55] Specifically, exercise training was found to have a (1) significant positive effect on weight loss and muscle strength, and (2) a non-significant effect on lean-body mass (LBM). Importantly, within the overview of reviews[54] for LBM, two meta-analyses comparing exercise to control groups revealed significantly more weight loss in the exercise group but no significant differences in lean-body mass change between groups; with this in mind, for the current overview, it is possible that the significant positive effect of post-MBS exercise training on body weight and the non-significant effect on LBM actually reflects a preservation of LBM that would otherwise be lost to factors such as protein deficiency post-MBS. Further studies are required to determine the impact of protein supplementation on LBM preservation post-MBS.[56] For diastolic blood pressure, glucose and lipid metabolism, it is possible than any changes due to exercise are overshadowed by the drastic improvement as a result of MBS.

What We Think We Know

Preoperative Exercise Training. Concordance between reviews revealed a significant positive effect of exercise training on 6-minute walking test distance. Although, discordance between reviews exploring exercise training was found for BMI, the removal of reviews including physical activity counselling (PAC) resulted in concordance for a significant positive effect. Notably, in PAC, compared to prescribed exercise training, the amount of exercise performed is likely lower, may not include as much vigorous exercise, and is often unsupervised, which may explain why the inclusion of PAC interventions above does not lead to a significant effect on weight variables. It is important that authors explicitly mention the type of exercise intervention (i.e., exercise training, PAC, etc.) in their conclusions to avoid misinterpretation. As more data becomes available, a comprehensive meta-analysis on the impact of preoperative exercise intervention on weight related variables should be conducted utilizing intervention type (e.g., exercise training, PAC etc.) as a moderating variable.

Discordance between reviews led to the prioritization of the meta-analysis revealing a non-significant effect of exercise training on quality of life (QoL) and a significant positive effect of exercise intervention (included a PAC intervention) on VO_2max (see Appendix R, outcomes Pre4-5 for details). In a recent meta-analysis, it was found that exercise training improves QoL in adults with overweight or obesity; thus, it is possible that exercise training could positively impact QoL in adults awaiting MBS but that the prioritized meta-analysis[19] was not adequately powered to detect the effect (k=3, n=53). Consequently, future studies should explore the impact of pre-MBS exercise training on QoL as a primary study aim.

Next, a single review revealed (1) a non-significant effect of exercise training on fat-free mass, and (2) a significant positive effect of exercise intervention (including two physical activity counselling interventions) on physical activity.

Postoperative Exercise Training. Concordance between reviews revealed a significant positive effect of exercise training on bone mineral density (see Appendix R, outcome Post1 for details). For fat mass, VO_2max, systolic blood pressure, and high-density lipoprotein cholesterol, a deeper interpretation of the findings conjures a necessity to rank, or at least consider, the value of different study designs. For all these variables, the discordance could be partially or fully explained by looking at reviews that solely considered RCTs, versus those that also included NRCTs in addition to RCTs (herein called mixed reviews). Specifically for all these variables, RCT-only reviews and mixed reviews exploring exercise training concluded opposite effects with RCT-only reviews revealing (1) a significant positive effect on systolic blood pressure, and (2) a non-significant effect on fat mass, VO_2max, high-density lipoprotein cholesterol, and resting heart rate (after prioritizing the recent and comprehensive meta-analysis). Although RCTs provide the most reliable evidence, conducting them can be impractical and their findings may be unrepresentative of real-world settings[57]; resultingly, NRCTs are commonly used to fill the gap, but their findings need to be interpreted with caution since they are more prone to bias and overestimation of effects.[57] Within the reviews incorporated into the outcome tables, about 41% of the meta-analyses and 50% of the systematic reviews included both RCTs and NRCTs. In a framework presented by Sarri and colleagues[57], explicit steps were shared to synthesize data from both NRCTs and RCTs together, however, neither of the mixed meta-analyses[10,13] statistically or narratively explored any differences between the impact of RCTs and NRCTs on the reported effects on the variables above. Thus, the findings originating from RCT-only reviews were prioritized. Considering the contrasting mixed review findings, however, led to the downgrading of the conclusions from what we currently know.

Finally, a single meta-analysis found a non-significant effect of exercise training on weight loss ≥ 12 months post-MBS (see Appendix R, outcome Post19). Knowing that weight recurrence is a common occurrence post-MBS,[8] and following exercise training in adults with overweight and obesity,[54] future research should employ strategies to encourage the maintenance of weight loss postoperatively.

At first glance, some of these findings may appear to be counter intuitive. For example, it appears odd that exercise training postoperatively would have positive effects on BMI and body weight, while having non-significant effects on fat-mass and fat-free mass. As well, the absence of a significant effect on VO_2max is surprising since exercise training of all types (i.e., E, R, combined E/R, HIIT) is well know to improved VO_2max in adults with obesity.[55] In the interpretation of the results, it is important to consider that the assessment of body composition and certain fitness measures (e.g., VO_2max) are not as reliable, have not been validated, and/or have barriers to it's use (e.g., weight limit of equipment, high cost for gold-standard methods, and difficulty reaching peak exertion) in populations with obesity.[58,59] Thus, these results should be interpreted with caution and additional high quality studies, utilizing gold standard methods, could aid in reaching conclusive results.

What We Still Don't Know

Preoperative Exercise Training. The effect of pre-MBS exercise training on blood pressure, muscle strength, fat mass, length of hospital stay, glucose and lipid metabolism, lean-body mass, resting heart rate, and surgery-related adverse events is still unknown (see Table 3 and supplementary file Appendix R, outcome Pre2,6,10, and 13). For muscle strength, future research should aim to collect a variety of previously used outcome measures that are consistent with the exercise performed in the training, e.g., sit to stand test, arm curl, one rep maximum (1-RM) for upper and lower muscles, dynamometer and handgrip testing etc.; increasing the available data would allow for a meta-analysis to be performed, using measurement type as a moderating variable, in order to tailor the application of the research findings in clinical settings.

Postoperative Exercise Training. The effect of post-MBS exercise training on QoL and various glucose metabolism measures (i.e., HOMA-IR, HbA1c, insulin sensitivity, AIRg and Di, SPISE and glucose effectiveness), is still unknown (see Table 4 and supplementary file Appendix R, outcomes Post7,8, and 18).

As a final point, no conclusions could be made on the long-term impacts of exercise training (pre- or post-MBS) on any variable as only one primary article[35] included an extended follow-up (1 year). Distinctly, "extended" is referring to the time since exercise training, rather than since MBS, as some exercise training interventions did not even begin until 7 years post-MBS. Thus, there is still a need to determine whether any positive impacts of exercise training are sustained in the long-term.

Beneficial Characteristics of Exercise Training Programs

The second aim for the current overview was to determine whether better health outcomes could be attributed to any characteristic(s) of the exercise training. To determine this, the significant positive effects revealed through the subgroup analyses were explored. Notably, subgroup analyses were only performed on data originating from postoperative exercise training studies and while 14 meta-analyses were conducted on this subject, only four[12,14,21,37] conducted subgroup analyses, and only two[12,21] explored variables outside of body weight/BMI/weight loss.

What We Currently Know

Although there was discordance between reviews, prioritizing the more recent and comprehensive meta-analysis[12] revealed a non-significant effect of exercise training starting less < 6 months post-MBS on body weight. Moreover, a single review revealed significant positive effects of (1) combined endurance/resistance training, and training lasting > 12 weeks, on systolic blood pressure,[21] and (2) exercise training > 6 months post-MBS on body weight.[12]

What We Think We Know

Discordance between studies examining the effect of combined endurance/resistance exercise training on body weight/BMI revealed different findings for RCT-only and mixed reviews. Following the standard set above, the RCT-only meta-analyses'[12,14] finding of a significant positive effect was prioritized but the finding was downgraded from what we currently know. Additionally, a single review revealed a significant positive effect of (1) combined endurance/resistance exercise training on triglycerides (downgraded from what we currently know; see Appendix R, outcome Sub2),[21] (2) exercise training starting > 6 months post-MBS on systolic blood pressure,[21] and (3) exercise training starting > 12 months post-MBS on body weight (an even greater positive effect on body weight than those beginning within six months).[14]

What We Still Don't Know

As the subanalyses were only performed on post-MBS exercise training interventions, currently we still don't know of any training characteristics of pre-MBS exercise training interventions that lead to improved health outcomes. To determine the most effective exercise training interventions to support adults awaiting, or who have undergone MBS, there is a need to further explore the training characteristics that most benefit health outcomes through comprehensive meta-analyses. Thus, future researchers should make explicit efforts to collect, report, and analyse subgroup data. A recent overview of reviews exploring the effect of exercise training on adults with overweight and obesity gives insight into the potential impacts of exercise training modality; specifically, certain modalities had a greater positive impact than others on lean body mass loss (i.e., R > other types), VO_2max (i.e. HIIT > E = combined E/R >R) and muscle strength (i.e., R = combined E/R > E).[55] As a result, future research should explore the exercise training modality relative to the goal of the training (e.g., improving cardiorespiratory fitness versus increasing muscular strength).

Future research should also specifically explore intervention timing, intervention duration, and sustained effects on various outcomes; for example, how soon should an exercise training intervention be delivered post-MBS to result in long-term weight loss. Of note, aligning with the subanalyses results, and the substantial weight loss that occurs in the first year following MBS, exercise training may actually be more beneficial 12 months post-MBS or when weight begins to stabilize if done with the goal of preventing weight recurrence. This may also hold true for other outcomes as the changes in the year following MBS may "wash out" any less substantial changes resulting from exercise training.

Feasibility and Acceptability

Although findings by Baillot and colleagues[9] favor concluding that exercise training seems feasible and acceptable in adults awaiting, or who have undergone, MBS, they must be interpreted with caution due to the lack of reporting of these outcome variables in primary articles; specifically, adherence data is rarely reported (~11%) and attendance to sessions and drop out rates were often not reported (39% and 64% respectively). Adherence is important because while an individual may attend a session, their completion of the prescribed exercise will provide crucial information when interpreting the success of the training; our knowledge of participants' adherence to their prescribed exercise training is currently classified as "what we still don't know". Further, studies with lower attendance and higher dropout rates may represent those that did not report this data, so their omission could bias the results. Thus, the current evidence that exercise training shows high attendance rates, low drop out rates, high retention rates, and low rates and severity of exercise-related adverse events, are classified under "what we think we know". Finally, although we found reported no significant differences in any of the feasibility or acceptability measures based on exercise training timing (pre- or post-MBS) or duration (≤ 12 weeks, or > 12 weeks), these subanalyses were underpowered leading to classification of this finding as "what we still don't know". Researchers should make explicit efforts to collect and report on feasibility and acceptability data to aid in transparency and potential explanations for the impacts, or lack thereof, of exercise training.

Strengths and Limitations

The key strengths of this overview lay in the rigor of the methodology employed. First, the established PRIOR guidelines were followed to ensure complete and accurate reporting. Second, a flow diagram was created and utilized to encourage a consistency in the categorization of the findings as concordant, discordant, or inconclusive. Third, methodological details of the included reviews (and characteristics of their primary articles) were collected in order to encourage deeper comparisons. Fourth, the primary articles were investigated in order to exclude reviews that may bias the findings – e.g., those that include multiple primary articles deriving from the same cohort. Fifth, in instances of discordant findings between reviews, both study design (RCT vs NRCT) and intervention type (exercise training vs additional exercise interventions) were explored, and more recent and comprehensive reviews were prioritized. Sixth, the systematic categorization, and display, of what we currently know, what we think we know and what we still don't know was completed in order to inform both clinicians and researchers on the current state of the evidence-based knowledge. The final strength rests in the collaboration between the authors (consisting of researchers and practitioners) in the interpretation of the results in order to formulate the findings in a way that is widely informative.

However, there are also limitations of the current overview, related primarily to either the methodology or limitations of the included research, that impact the generalizability of the findings. Throughout this overview, emphasis has been placed on the conducted meta-analyses and several suggestions for future meta-analyses have been made. One limitation of the current overview is that while the magnitude of the effect sizes reported by the meta-analyses were shared within the tables, they were not considered in the interpretation of results as it goes beyond the scope of our current efforts; instead, the emphasis was placed on simply whether or not significant effects were found. Although also beyond the scope of this manuscript, it is important to consider the quality of conducted meta-analyses. Specifically, many of the meta-analyses (a) included less than three studies, (2) had a small total sample size from underpowered studies, (3) included primary articles of poor quality or high risk, and (4) were not fully transparent in the reporting of their included studies, sample sizes, heterogeneity, and level of evidence – issues common to many meta-analyses.[60] Consequently, the category has been titled “what we currently know” to demonstrate the lack of “absolute” conclusions. Moreover, within previous reviews, and the current overview, the intervention timing is divided into pre-and post-MBS, however, this fails to capture an important distinction in the time frame post-MBS; for example, defining the impact of exercise training 6-12 months postoperatively versus 12+ months postoperatively may be just as important considering the potential for weight regain and the resulting changes to adults cardiometabolic risk factors. Despite this knowledge, observing the wide range of intervention start times post-MBS (see Supplementary File Appendix K) makes conducting this comparison impractical at this time. Future research and reviews should aim to explore the impact of post-MBS exercise training on various outcomes at pre-defined time points corresponding to changes typically observed in adults postoperatively.

Further, specific to the methodology, the current overview did not (a) include a search of grey literature, (b) include articles that were not available in French of English, and (c) explore original/primary articles that were published recently and thus, not captured within the identified reviews. Specific to the reviews, first, a high degree of overlap between primary articles was identified and 3/21 and 7/42 primary articles exploring pre- and postoperative exercise intervention respectively, contributed to over 50% of the reviews; thus, certain primary articles may have influenced the outcome conclusions more heavily than others. Secondly, a large limitation exists in the quality of both the primary articles and the included reviews. Reviewing supplementary Tables S12 and S14 (see Appendix I and K), many of the primary articles included were scored as high risk of bias, or low quality, and reviewing Tables 3 and 4 in the current manuscript, many of the included reviews were scored as critically low or low quality. Notably, many of the factors impacting the quality of studies pertain to the transparency of reporting, rather than the methodology, and may result from the often compact, but necessary, page limits set for manuscript submission; authors should embrace the open sharing of additional details and data through supplementary files that would allow for deeper comparisons and interpretations of findings to be made. Finally, for many of the outcomes, the review authors could not statistically assess risk of publication bias due to the inclusion of less than 10 studies in the analysis (see Supplementary File Appendix O), and so the risk of publication bias and the “file drawer effect” affecting the current findings cannot be ruled out entirely.[57]

Conclusion

The current overview assumed the challenge of collecting, condensing, interpreting, and reporting on a large body of literature pertaining to the impacts of pre- and post-MBS exercise training on various health outcomes. A systematic approach to organizing the findings resulted in clear categories of “what we currently know”, “what we think we know” and “what we still don’t know”. “We currently know” that postoperative exercise training has a positive effect on weight, waist circumference, 6-minute walking test distance and muscle strength, but does not have significant effects on lean body/fat-free mass, diastolic blood pressure, fasting insulin/glucose, total cholesterol, low density lipoprotein and triglycerides. However, the specific training characteristics that contribute to enhanced outcomes is still unknown because the exercise training interventions were highly variable in their duration, prescribed exercise quantity, and timing. Finally, although exercise training appears to feasible and acceptable for our population of adults awaiting, or who have undergone, MBS, very little is known about participants' adherence to prescribed exercise – a factor that may explain the (in)effectiveness of exercise training in specific interventions. Despite the published research available, what we don't know still far outweighs what we do know thus demonstrating the need for more high-quality experimental studies with larger sample sizes to increase the quality of evidence. While exercise training has the potential to support patients in MBS programs, it is also important to note that maintaining the benefits of MBS requires sustained lifestyle changes and a single short duration exercise training intervention alone is unlikely to create lasting effects. Therefore, longer duration exercise training, or a combination of exercise training and physical activity counselling, may be most beneficial.

Disclosures

Author Contributions

The authors confirm the following contributions to the manuscript. Study design and conception by AB, MA, DB, DC, PP, and BG. Data collection by JH, MA, VL, and AB. Data analysis by JH, MA, YW, and AB. Draft manuscript preparation by JH. All authors were involved in the interpretation of results, provision of manuscript feedback, and approval of the final version of the manuscript.

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Supplementary Material

The supplementary materials are available as a single file uploaded alongside this manuscript.

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Table 1: Eligibility Criteria in Accordance with PICOS framework

Category	Eligibility Criteria
Population	Adults (> 18 years old) who were awaiting, or had already undergone, MBS
Intervention	Exercise training pre- and/or post-MBS of any duration, frequency, supervision (fully, partially, or non-supervised), type (i.e., endurance, resistance, HIIT etc., or any combination thereof), delivery modalities (i.e., individual or group-based), or setting (home-based, center/hospital-based etc.).
Comparator	No control group required
Outcomes	*Critical Outcomes* [a]*:* (1) changes in lean body mass, muscle mass and/ or bone mineral density, (2) changes in physical fitness including cardiorespiratory fitness and muscle strength, (3) changes in physical activity and/ or sedentary behaviors measured objectively or subjectively, (4) peri-operative outcomes (e.g., length of hospital stay, complications rate), and (5) feasibility and acceptability outcomes (e.g., adherence rates, adverse events)
	Other Important Outcomes: (1) weight loss and weight recurrence, (2) changes in fat mass, (3) changes in physical functioning including balance and coordination, (4) changes in cardio-metabolic markers including triglycerides, total cholesterol, high and low density lipoprotein cholesterol (HDL-C and LDL-C), haemoglobinA1c (HbA1c), glucose and insulin, blood pressure, (5) changes in health or weight- related quality of life and psychosocial outcomes including depression and anxiety, and (6) changes in obesity comorbidities including type 2 diabetes and hypertension.
Study Design	All self-identified meta-analyses and systematic reviews (including those only looking at RCTs and those with various primary article study designs)

Note. PICOS=Population, Intervention, Comparator, Outcomes and Study Design; MBS=Metabolic and bariatric surgery; HIIT=high intensity interval training

[a] Outcomes known to be associated with exercise training that are not improved by MBS.

Table 2: Data Extracted as a Function of the Subject (Review or Primary Studies)

Subject	Data Extracted
Systematic Review/ Meta-Analysis	Author names, publication year, countries, study design (i.e., meta-analysis or systematic review), objective, PICOS selection criteria, date and databases searched, number of primary studies included, outcomes considered and main findings (including estimated effect size, confidence intervals, sample size, heterogeneity, quality of evidence with tool used, and subgroup analyses when available), conclusions on publication or reporting bias, quality of included articles and tool used, and funding sources
Primary Articles	Population characteristics (pooled sample size, age, sex, BMI), intervention details (duration, type, frequency, intensity, session duration, supervision, and control group type),

Note. PICOS=Population, Intervention, Comparator, Outcomes and Study Design, BMI=Body mass index.

Table 3: Preoperative Exercise Training: Systematic Review Results, Considerations and Conclusions as a Function of Outcome

Authors	Effects	n	k	I^2	Studies included	Special considerations	AMSTAR	Conclusion for review[a] and across reviews[b]	
Body Weight (BW), Body Mass Index (BMI) and Weight Loss (WL) – 20% overlap of primary studies									
Jabbour 2022	**BW:** NS (*k*=3), + (*k*=2)	NR	5	NA	Baillot 2016, Funderburk 2010, Gilbertson 2020, Marcon 2011, Marcon 2017	RCT, BA,IT 1 aquatic exercise intervention	Critically Low	?	Discordant
	BMI: NS (*k*=1), + (*k*=3)	NR	4	NA	Baillot 2016, Gilbertson 2020, Marcon 2011, Marcon 2017			(+)	
Lodewijks 2022	**Pre-MBS WL:** NS (k=9), + (k=1)	NR	10	NA	Arman 2021, Baillot 2016, Baillot 2017, Bond 2015a, Bond 2015b, Creel 2016, Funderburk 2010, Gilbertson 2020, Parikh 2012, Marc-Hernandez 2019	RCT, NRCT 4 PAC intervention 1 aquatic exercise intervention 2 publications from the same study (Bond 2015a/b)	Low	(NS)	
	Post-MBS WL: NS (k=1)	NR	1	NA	Parikh 2012			**Inconclusive 1 study**	
	@1 year follow-up: + (k=1)	NR	1	NA	Baillot 2018			**Inconclusive 1 study**	
	BMI: + (k=1)	NR	1	NA	Marc-Hernandez 2019			**Inconclusive 1 study**	
	@1 year follow-up: + (k=1)	NR	1	NA	Baillot 2018			**Inconclusive 1 study**	
Durey 2022	**%WL:** MD: 0.94% [-1.61; 3.48]	142	3	70%	Bond 2017a, Creel 2016, Li 2013	RCT 2 PAC intervention 1 conference abstract (Li 2013)	Critically Low	NS	
Herrera-Santelices 2022	**BMI:** SMD: -0.71 [-1.55; 0.12] *very low*	115	4	76%	Arman 2021, Baillot 2016, Baillot 2018, Marcon 2017	RCT 2 publications from the same study (Baillot 2016/2018)	Critically Low	NS	
Schurmans 2022	**BMI @1 year follow-up:** NS (k=1)	NR	1	NA	Baillot 2018	RCT	Low	**Inconclusive 1 study**	
	WL: NS (k=1)	NR	2	NA	Bond 2015b			**Inconclusive 1 study**	
Bellicha 2021	**BW/BMI=** NS (k=1), + (k=2)	NR	3	NA	Baillot 2016, Marc-Hernandez 2019, Marcon 2017	RCT, NRCT	Critically Low	(+)	
	@1 year follow-up: + (k=1)	NR	1	NA	Baillot 2018			**Inconclusive 1 study**	
***Fat mass (FM) – 33% overlap of primary studies**									
Jabbour 2022	**%FM:** NS (*k*=1)	NR	1	NA	Baillot 2016	RCT	Critically Low	**Inconclusive 1 study**	Inconclusive
Lodewijks 2022	**FM/Visceral Fat**: + (k=1)	NR	1	NA	Marc-Hernandez 2019	NRCT	Low	**Inconclusive 1 study**	
Herrera-Santelices 2022	**%FM:** SMD: 0.38 [-0.08; 0.84] *moderate*	75	3	0%	Arman 2021, Baillot 2016, Baillot 2018	RCT 2 publications from the same study (Baillot 2016/2018)	Critically Low	NS	
Bellicha 2021	**FM:** NS (k=1), + (k=1)	NR	2	NA	Baillot 2016, Marc-Hernandez 2019	RCT, NRCT	Critically Low	**?**	
	@1 year follow-up: NS (k=1)	NR	1	NA	Baillot 2018			**Inconclusive 1 study**	
***Fat-free mass (FFM) and Lean body mass (LBM) – 33% overlap of primary studies**									

Lodewijks 2022	**FFM @1 year follow-up:** + (k=1)	NR	1	NA	Baillot 2018	RCT	Low	**Inconclusive 1 study**	NA
Herrera-Santelices 2022	**FFM:** SMD: - 0.41[-1.00; 0.18] *moderate*	46	2	0%	Arman 2021, Baillot 2018	RCT	Critically Low	NS	
Schurmans 2022	**FFM @1 year follow-up:** + (k=1)	NR	1	NA	Baillot 2018	RCT	Low	**Inconclusive 1 study**	
Bellicha 2021	**LBM:** NS (k=1) **@1 year follow-up:** + (k=1)	NR NR	1 1	NA NA	Marc-Hernandez 2019 Baillot 2018	RCT, NRCT	Critically Low	**Inconclusive 1 study** **Inconclusive 1 study**	
***VO_2max/Maximum Aerobic Capacity – 13% overlap of primary studies**									
Durey 2022	**Pre-MBS VO_2max change:** MD: 0.73 mL/kg/min [0.61; 0.86] **VO2max change at maximal follow up:** MD: mL/kg/min 0.98 [0.05; 1.90]	79 131	3 3	62% 0%	Baillot 2018, Kwok 2016, Li 2013 Baillot 2018, Creel 2016, Li 2013	RCT 1 PAC intervention 2 conference abstracts (Kwok 2016 and Li 2013)	Critically Low	+ +	Discordant
Jabbour 2022	NS (*k*=1, METS), + (*k*=1, VO_2 peak)	NR	2	NA	Baillot 2017, Marcon 2017	RCT, IT	Critically Low	?	
Bellicha 2021	NS (k=2), + (k=1) **@1 year follow-up:** NS (k=1)	NR NR	3 1	NA NA	Baillot 2016, Marc-Hernandez 2019, Marcon 2017 Baillot 2018	RCT, NRCT	Critically Low	(NS) **Inconclusive 1 study**	
6-minute walking test distance (6MWTD) – 22% overlap of primary studies									
Jabbour 2022	NS (*k*=1), + (*k*=2)	NR	3	NA	Baillot 2016, Baillot 2017, Funderburk 2010	RCT, BA 1 aquatic exercise intervention	Critically low	(+)	Concordant
Herrera-Santelices 2022	SMD: 2.59 [1.89; 3.30] *high*	61	2	0%	Arman 2021, Marcon 2017	RCT	Critically Low	+	
Schurmans 2022	+ (k=1) **@1 year follow-up:** NS (k=1)	NR NR	1 1	NA NA	Baillot 2016 Baillot 2018	RCT	Low	**Inconclusive 1 study** **Inconclusive 1 study**	
Bellicha 2021	+ (k=2) **@1 year follow-up:** + (k=1)	NR NR	2 1	NA NA	Baillot 2016, Marcon 2017 Baillot 2018	RCT	Critically Low	+ **Inconclusive 1 study**	
Muscle strength and functional capacity – 50% overlap of primary studies									
Jabbour 2022	**Sit to stand test:** NS (*k*=1), + (*k*=1) **Arm curl:** + (*k*=2) **Leg strength/muscle quality:** + (*k*=3)	NR NR NR	2 2 3	NA NA NA	Baillot 2016, Baillot 2017 Baillot 2016, Baillot 2017 Baillot 2016, Baillot 2017, Baillot 2018	RCT,BA 2 publications from the same study (Baillot 2016/2018)	Critically Low	? + +	
Bellicha 2021	NS (k=1), + (k=1) **@1 year follow-up:** NS (k=1)	NR NR	2 1	NA NA	Baillot 2016, Marc-Hernandez 2019 Baillot 2018	RCT, NRCT	Critically Low	? **Inconclusive 1 study**	

Resting heart rate (RHR) – 33% overlap of primary studies									
Schurmans 2022	NS (k=2)	NR	2	NA	Baillot 2016, Baillot 2018	RCT 2 publications from the same study (Baillot 2016/2018)	Low	**Inconclusive only 2 publications same study**	NA
Marshall 2020	MD: -3.06 bpm [-5.65; -0.47] *very low level of evidence*	111	4	0%	Pre-MBS (Baillot 2014/Baillot 2018); Post-MBS (Castello 2011, Huck 2015, [Mundberg 2018a/Mundberg 2018b, Stolberg 2018a/Stolberg 2018b])	RCT, NRCT *k*=3 (6 publications) post-MBS intervention 1 PAC intervention Mistakenly considered Baillot 2014/2018 as one study	Low	**Inclusive as pre/post-MBS results are combined**	
Blood pressure (BP) – 28% overlap of primary studies									
Schurmans 2022	NS (k=2)	NR	2	NA	Baillot 2016, Baillot 2018	RCT 2 publications from the same study (Baillot 2016/2018)	Low	**Inconclusive only 2 publications same study**	Concordant
Jabbour 2022	**DBP:** NS (*k*=2), + (*k*=1)	NR	3	NA	Baillot 2016, Funderburk 2010, Marcon 2017	RCT 1 aquatic exercise intervention	Critically Low	(NS)	
	SBP: NS (*k*=2), + (*k*=1)	NR	3	NA	”			(NS)	
Bellicha 2021	NS (k=2), + (k=1)	NR	3	NA	Baillot 2016, Marcon 2017, Marc-Hernandez 2019	RCT, NRCT	Critically Low	(NS)	
	@1 year follow-up: NS (k=1)	NR	1	NA	Baillot 2018			**Inconclusive 1 study**	
Marshall 2020	**DBP:** MD: -1.31 mmHg [-2.33; -0.29] *very low level of evidence)*	251	6	23%	Pre-MBS (Baillot 2014/ Baillot 2018); Post-MBS (Castello 2011, [Coen 2015a/Coen 2015b/Nunez-Lopez 2017/Woodlief 2015], Huck 2015, Onofre 2017, [Mundberg 2018a/Mundberg 2018b/Stolberg 2018a/Stolberg 2018b])	RCT, NRCT *k*=5 (11 publications) post-MBS intervention 1 PAC intervention Mistakenly considered Baillot 2014/2018 as one study	Low	**Inclusive as pre/post-MBS results are combined**	
	SBP: MD: -1.59 mmHg [-3.74; 0.56] *very low level of evidence*	239	5	27%	Pre-MBS (Baillot 2014/Baillot 2018); Post-MBS (Castello 2011, [Coen 2015a/Coen 2015b/Nunez-Lopez 2017/Woodlief 2015], Huck 2015, [Mundberg 2018a/Mundberg 2018b/Stolberg 2018a/Stolberg 2018b])			**Inclusive as pre/post-MBS results are combined**	
Quality of Life (QoL) – 19% overlap of primary studies									
Herrera-Santelices 2022	SMD: 0.88 [-0.23; 1.99] *moderate*	53	3	67	Arman 2021, Baillot 2018, Funderburk 2010	RCT 1 aquatic exercise intervention	Critically Low	NS	Discordant
Lodewijks 2022	+ (*k*=2, 1 for physical functioning, general health perceptions, mental health and social functioning, and 1 for all except role-emotional)	NR	2	NA	[Bond 2015a/Bond 2015b], Marc-Hernandez 2019	RCT,NRCT 1 PAC intervention study (Bond 2015a/b)	Critically Low	+	
Schurmans 2022	+ (k=1 except role-emotional domain)	NR	1	NA	Bond 2015b	RCT 1 PAC intervention	Low	**Inconclusive 1 study**	

	@1 year follow-up: NS (k=1)	NR	1	NA	Baillot 2018			**Inconclusive 1 study**	
Bellicha 2021	NS (k=1), + (k=1) **@1 year follow-up:** NS (k=1)	NR NR	2 1	NA NA	Baillot 2016, Marc-Hernandez 2019 Baillot 2018	RCT, NRCT	Critically Low	? **Inconclusive 1 study**	
Glucose and lipid metabolism – 0% overlap of primary studies									
Jabbour 2022	**SI:** NS (*k*=1) **Adipokines:** NS (*k*=1)	NR NR	1 1	NA NA	Gilbertson 2020 ”	NRCT	Critically Low	**Inconclusive 1 study** **Inconclusive 1 study**	NA
Bellicha 2021	**Glucose:** NS (k=1), + (k=1) **Lipid Profile**: NS (k=1), + (k=1)	NR NR	2 2	NA NA	Marcon 2017, Marc-Hernandez 2019 ”	RCT, NRCT	Critically Low	? ?	
Physical activity – 20% overlap of primary studies									
Lodewijks 2022	+ (k=4) **@1 year follow-up:** + (k=1)	NR NR	4 1	NA NA	Baillot 2016, Baillot 2018, [Bond 2015a/Bond 2015b], Parikh 2012 Baillot 2018	RCT, NRCT 2 PAC intervention 2 publications from the same study (Baillot 2016/2018) however mistakenly considered as separate studies	Critically Low	+ **Inconclusive 1 study**	NA
Bellicha 2021	**Habitual physical activity** **@ 1 year follow-up:** + (k=1)	NR	1	NA	Baillot 2018	RCT	Critically Low	**Inconclusive 1 study**	
Adverse events – Overlap not applicable									
Durrey 2022	RR: 6.00 [0.27; 131.34] * Post-surgery adverse events not during exercise	22	1	NA	Li 2013	RCT Conference abstract	Critically Low	**Inconclusive 1 study**	NA
Length of hospital stay – 0% overlap of primary studies									
Durrey 2022	NS ≠ bw intervention and control	22	1	NA	Li 2013	RCT Conference abstract	Critically Low	**Inconclusive 1 study**	Inconclusive
Jabbour 2022	+ (*k*=1)	NR	1	NA	Gilbertson 2020	NRCT	Critically Low	**Inconclusive 1 study**	

Note. * interpret these results with caution due to unreliable measurements in adults with obesity. RR=risk ratio, MD=mean difference, SMD=standardized mean difference, NS=non-significant, NR=not reported, NA=not applicable, k=number of studies, n=subsample size, I^2=degree of heterogeneity, MBS=metabolic and bariatric surgery RCT=randomized control trial, NCRT=non-randomized control trial, PAC=physical activity counselling. Individual review conclusions highlighted in dark grey were not factored into the overall conclusion for the outcome.

[a] + = significant benefits from a meta-analysis, or 100% concordance for significant benefits between studies in a systematic review, (+) = partial concordance (≥ 67%) for significant benefits between studies in a systematic review, ?= discordance between studies in a systematic review, (NS)=partial concordance (≥ 67%) for non-significant benefits between studies in a systematic review, NS=non-significant benefits from a meta-analysis, or 100% concordance for non-significant benefits between studies in a systematic review

[b] conclusion determined by following flow diagram (see Supplementary File Appendix P)

Table 4: Postoperative Exercise Training: Systematic Review Results, Considerations and Conclusions as a Function of Outcome

Authors	Effects	n	k	I^2	Studies included	Special considerations	AMSTAR	Conclusion for review[a] and across reviews[b]	
Weight Loss (WL) ≥ 12 months post-MBS									
Bond 2023	SMD: - 2.26 [-2.07; 1.55]	189	5	0%	Coleman 2017, Herring 2017, Marc-Hernandez 2020, Mundberg 2018a, Shah 2011	Only RCT	Low	**NS**	NA
Body Weight (BW) and Body Mass Index (BMI) – 24% overlap of primary studies									
Gasmi 2022	**BMI**: SMD: −0.93 [−1.65; −0.20]	341	5	85%	Freitas 2017, Herring 2017, Marc-Hernandez 2020, Oppert 2018, Sellberg 2019	Only RCT	Critically Low	+	Discordant
Schurmans 2022	**BMI:** + (k=3; 1 only at 24 months), NS (k=7)	NR	10	NA	Castello 2011, Castello 2013, Coen 2015a, Coen 2015b, Hassanejad 2017, Herring 2017, Huck 2015, Mundberg 2018a, Nunez-Lopez 2017, Stolberg 2018a	RCT, NRCT 5, 2, and 2 publications from 3 interventions (Carnero 2017/Coen 2015a/Coen 2015b/Nunez-Lopez 2017/Woodlief 2015; Castello 2011/2013; Mundberg 2018a/Stolberg 2018a)	Low	**(NS)**	
	BW: + (k=4; 1 only at 24 months post-MBS), NS (k=10)	NR	14	NA	Carnero 2017, Castello 2011, Castello 2013, Coen 2015a, Coen 2015b, Daniels 2018, Hassanejad 2017, Herring 2017, Huck 2015, Mundberg 2018a, Nunez-Lopez 2017, Shah 2011, Stolberg 2018a, Woodlief 2015			**(NS)**	
Boppre 2021	**BMI:** MD: -0.84 kg/m² [-1.60; -0.08]	401	7	0%	Castello 2011, Coen 2015b, Hassanejad 2017, Herring 2017, Mundberg 2018a, Oppert 2018, Shah 2011, Tardif 2020	Only RCT	Critically Low	+	
	BW: MD: -2.51 kg [-4.74; -0.27]	496	10	0%	Castello 2011, Coen 2015b, Coleman 2017, Daniels 2018, Hassanejad 2017, Herring 2017, Mundberg 2018a, Oppert 2018, Shah 2011, Tardif 2020			+	
Bellicha 2021	**BW:** MD: -1.8 kg [-3.2; -0.4]	NR	13	35%	Campanha-Versiana 2017, Castello 2011, Coen 2015b, Coleman 2017, Daniels 2018, Hassanejad 2017, Herring 2017, Huck 2015, Mundberg 2018a, Onofre 2017, Oppert 2018, Shah 2011, Stegen 2011	RCT, NRCT	Critically Low	+	
Morales-Marroquin 2020	**BW**: NS (*k*=4), + (*k*=2)	NR	6	NA	Hassanejad 2017, Herring 2017, Huck 2015, Mundberg 2018b, Oppert 2018, Stegen 2011	RCT, NRCT All interventions include a resistance training component	Low	**(NS)**	
Carretero-Ruiz 2019	**BW:** SMD: 0.15 [-0.02; 0.32]	NR	16	0%	Campanha-Versiana 2017, Casali 2011, Castello 2011, Coen 2015b, Coleman 2017, Daniels 2018, Hassanejad 2017, Herring 2017, Huck 2015, Marchesi 2015, Mundberg 2018a, Oliviera 2016, Onofre 2017, Rojhani-Shirazi 2015, Shah 2011, Stegen 2011	RCT, NRCT Respiratory (*k*=1), and physiotherapy (*k*=1) interventions 2 PAC study	Low	**NS**	

Ren 2018	**BMI:** WMD: -0.40 kg/m^2 [-0.81; 0.00] *Moderate level of evidence*	259	5	44%	NR	Only RCT	Low	+	
	BW: WMD: -1.94 kg [-3.18; -0.69] *Moderate level of evidence*	347	8	51%	Castello 2011, Coen 2015b, Coleman 2017, Daniels 2018, Hassanejad 2017, Herring 2017, Mundberg 2018a, Shah 2011			+	
Waist Circumference (WC) – 20% overlap of primary studies									
Gasmi 2022	SMD: -0.18 [−0.79; 0.43] Based on final data intervention vs. control groups not pre-post difference	42	2	0%	Herring 2017, Marc-Hernandez 2020	Only RCT	Critically Low	**NS (different measure)**	Concordant
Boppre 2021	MD: -4.14 cm [-8.16; -0.12]	201	4	9%	Castello 2011, Coen 2015a, Herring 2017, Shah 2011	Only RCT	Critically Low	+	
Ren 2018	WMD: -5.25 cm [-10.48; -0.03] *Low level of evidence*	198	4	94%	NR	Only RCT	Low	+	
***Fat Mass (FM) – 24% overlap of primary studies**									
Gasmi 2022	SMD: -0.08 [−0.54; 0.38]	74	3	0%	Hassanejad 2017, Marc-Hernandez 2020, Ricci 2020	Only RCT Whole-body electromyostimulation with dynamic exercise (k=1)	Critically Low	**NS**	Discordant
Boppre 2021	MD: -0.49 kg [-1.71; 2.69]	173	2	0%	Coen 2015b, Oppert 2018	Only RCT, DXA FM measurment	Critically Low	**NS**	
Bellicha 2021	MD: -2.1 kg [-3.7; -0.5]	NR	8	50%	Coen 2015b, Hassanejad 2017, Herring 2017, Huck 2015, Marchesi 2015, Oppert 2018, Shah 2011, Stegen 2011	RCT, NRCT	Critically Low	+	
Morales-Marroquin 2020	NS (*k*=4), + (*k*=2)	NR	6	NA	Campanha-Versiana 2017, Hassanejad 2017, Herring 2017, Huck 2015, Oppert 2018, Stegen 2011	RCT, NRCT All interventions include a resistance training component	Low	**(NS)**	
Ren 2018	WMD: -3.35 kg [-7.99; 1.29] *Low level of evidence*	186	3	95%	NR	Only RCT	Low	**NS**	
***Fat-Free Mass (FFM) and Lean Body Mass (LBM) – 24% overlap of primary studies**									
Roth 2022	**FFM:** Ex. vs. C = SMD: 0.39 [-0.01; 0.78] *Very Low level of evidence*	132	3	0%	Campanha-Versiana 2017, Castello 2011, Murai 2019	RCT, NRCT	Moderate	**NS**	Concordant for LBM Discordant for
	Ex+Protein vs. Protein = SMD: 0.25 [-1.15; 1.65] *Low level of evidence*	91	2	0%	Hassanejad 2017, Oppert 2018			**NS**	

	Ex + Protein + vit. D + $Ca2^{+}$ vs. Control = SMD: 5.16 [4.60; 5,71] *Moderate level of evidence*	220	1	NA	Muschitz 2016			**Inconclusive 1 study**	
Gasmi 2022	**FFM:** SMD: 0.23 [−0.31; 0.77]	54	2	0%	Hassanejad 2017, Marc-Hernandez 2020	Only RCT	Critically Low	**NS**	
Schurmans 2022	**LBM:** NS (k=5)	NR	5	NA	Castello 2011, Coen 2015a, Coen 2015b, Nunez-Lopez 2017, Shah 2011	RCT, NRCT 3 publications from 1 intervention (Coen 2015a/b, Nunez-Lopez 2017)	Low	**NS**	
	FFM: + (k=2, 1 only for combined E/R vs control and 1 only at 24 weeks), NS (k=3)	NR	5	NA	Hassanejad 2017, Herring 2017, Huck 2015, Nunez-Lopez 2017, Shah 2011			**?**	
Boppre 2021	**LBM:** MD: 0.87 [-0.65; 2.40]	201	3	0%	Coen 2015b, Oppert 2018, Shah 2011,	Only RCT	Critically Low	**NS**	
Bellicha 2021	**LBM:** MD: 0.7 kg [-0.2; 1.6]	NR	10	45%	Campanha-Versiana 2017, Castello 2011, Coen 2015b, Hassanejad 2017, Herring 2017, Huck 2015, Marchesi 2015, Oppert 2018, Shah 2011, Stegen 2011,	RCT, NRCT	Critically Low	**NS**	
Morales-Marroquin 2020	**FFM:** NS (*k*=5), + (*k*=1 only for combined E/R vs control)	NR	6	NA	Campanha-Versiana 2017, Daniels 2018, Hassanejad 2017, Herring 2017, Huck 2015, Stegen 2011	RCT, NRCT All interventions include a resistance training component	Low	**(NS)**	
Ren 2018	**FFM:** WMD: 0.53 kg [-1.88; 2.94] *Very low level of evidence*	58	2	71%	NR	Only RCT	Low	**NS**	
Bone Mineral Density (BMD) – 58% overlap of primary studies									
Roth 2022	Ex vs. C, SMD: 0.51 [0.01; 1.01] *Moderate level of evidence*	63	1	NA	Murai 2019	RCT	Moderate	**Inconclusive 1 study**	
	Ex + Protein + vit. D + $Ca2^{+}$ vs C, SMD: 3.88 [3.43; 4.34] *Moderate level of evidence*	220	1	NA	Muschitz 2016			**Inconclusive 1 study**	
Diniz-Sousa 2022	**Total hip:** SMD: 0.37 [0.02; 0.71] *Very low certainty evidence*	340	4	50%	Campanha-Versiana 2017, Diniz-Sousa 2021, Murai 2019, Muschitz 2016	RCT, NRCT	Moderate	+	Concordant
	Lumbar spine: SMD: 0.41 [0.19; 0.62] *Low certainty evidence*	341	4	19%	”			+	
	Femoral neck: SMD: 0.63 [0.19; 1.06] *Low certainty*	112	2	0%	Diniz-Sousa 2021, Murai, 2019			+	

	evidence								
	1/3 radius: SMD: 0.58 [0.19; 0.97] *Low certainty evidence*	112	2	0%	”			+	
Bellicha 2021	SMD: 0.44 [0.21; 0.67]	NR	3	0%	Campanha-Versiana 2017, Murai 2019, Muschitz 2016	RCT, NRCT	Critically Low	+	
Morales-Marroquin 2020	+ (*k*=2)	NR	2	NA	Campanha-Versiana 2017, Murai 2019	RCT, NRCT All interventions include a resistance training component	Low	+	
***Vo2max/peak – 42% overlap of primary studies**									
Boppre 2022	**VO_2max:** MD: 0.26 L/min [-0.11; 0.63]	NR	3	0%	Mundberg 2018b, Nunez-Lopez 2017, Shah 2011	Only RCT	Critically Low	**NS**	Discordant
Schurmans 2022	**VO_2max:** + (k=4), NS (k=2)	NR	6	NA	Coen 2015a, Coen 2015b, Huck 2015, Nunez-Lopez 2017, Shah 2011, Woodlief 2015	RCT, NRCT 4 publications from 1 intervention (Coen 2015a/b, Nunez-Lopez 2017, Woodlief 2015)	Low	**(+)**	
Bellicha 2021	**VO_2max:** SMD: 0.70 [0.35; 1.06]	NR	8	42%	Coen 2015a, Huck 2015, Marchesi 2015, Mundberg 2018b, Onofre 2017, Oppert 2018, Shah 2011, Stegen 2011,	RCT, NRCT	Critically Low	+	
Carretero-Ruiz 2021	**VO_2max/peak relative to body weight:** ES: 0.67 [0.29; 1.06] (MD: 1.25 ml/kg/min [0.48; 2.02])	N	6	23%	Auclair 2021, Huck 2015, Marchesi 2015, Onofre 2017, Shah 2011, Stegen 2011	RCT, NRCT	Critically Low	+	
	VO_2max/peak: ES: 0.32 [0.07; 0.57]	NR	5	0%	Auclair 2021, Coen 2015a, Mundberg 2018b, Onofre 2017, Stegen 2011			+	
Da Silva 2019	**VO_2max:** SMD: 0.43 [0.16; 0.70]	215	7	0%	Coen 2015a, Huck 2015, Marchesi 2015, Nunez-Lopez 2017, Onofre 2017, Shah 2011, Stegen 2011	Only RCT 2 publications from 1 intervention (Coen 2015a, Nunez-Lopez 2017)	Critically Low	+	
6 Minute Walking Test Distance (6MWTD) – 33% overlap of primary studies									
Schurmans 2022	NS (k=3)	NR	3	NA	Castello 2011, Castello 2013, Coleman 2017	RCT 2 publications from 1 intervention (Castello 2011/2013) Caveat: unclear conclusions in both	Low	**NS**	Discordant

						review and original study articles			
Bellicha 2021	SMD: 1.46 [0.27; 2.66]	NR	5	89%	Castello 2011, Coleman 2017, Hassanejad 2017, Herring 2017, Stegen 2011	RCT, NRCT	Critically Low	+	
Ren 2018	WMD: 29.67 m [25.97; 33.37] *Low level of evidence*	65	2	0%	Castello 2011, Coleman 2017	Only RCT	Low	+	
Muscle Strength – 27% overlap of primary studies									
Vieira 2022	**1-RM Upper muscle=** ES: 0.71 [0.41; 1.01] *Very low level of evidence*	NR	4	0%	Campanha-Versiana 2017, Gil 2021, Hassanejad 2017, Stegen 2011	RCT, NRCT	Low	+	Concordant
	1-RM Lower muscle= ES: 1.37 [0.84; 1.91] *Very low level of evidence*	NR	5	46%	Campanha-Versiana 2017, Daniels 2018, Gil 2021, Kelley 2019, Stegen 2011			+	
	Sit-to stand= ES: 0.60 [0.20–1.01] *Very low level of evidence*	NR	8	69%	Coleman 2017, de Oliviera 2021, Gil 2021, Hassanejad 2017, Kelley 2019, Lamarca 2021, Mundberg 2018b, Stegen 2011			+	
	Dynamometer= ES: 0.46 [0.06–0.87] *Very low level of evidence*	NR	4	31%	Diniz-Sousa 2021, Kelley 2019, Lamarca 2021, Mundberg 2018b			+	
	Handgrip test= ES: 0.11 [-0.42–0.63] *Very low level of evidence*	NR	6	73%	de Oliviera 2021, Gallé 2020, Herring 2017, Huck 2015, Noack-Segovia 2019, Stegen 2011			NS	
Schurmans 2022	+ (k=1)	NR	1	NA	Daniels 2018	RCT	Low	**Inconclusive 1 study**	
Bellicha 2021	SMD: 0.82 [0.48; 1.16]	NR	8	42%	Campanha-Versiana 2017, Coleman 2017, Daniels 2018, Hassanejad 2017, Herring 2017, Mundberg 2018b, Oppert 2018, Stegen 2011	RCT, NRCT	Critically Low	+	
Morales-Marroquin 2020	+ (*k*=5, 1 only for combined E/R v control and 1 for exercise+protein supplementation)	NR	5	NA	Campanha-Versiana 2017, Daniels 2018, Hassanejad 2017, Herring 2017, Oppert 2018	RCT, NRCT All interventions include a resistance training component	Low	+	
Resting Heart Rate (RHR) – 30% overlap of primary studies									
Boppre 2022	MD: -2.05 bpm [-6.64; 2.54]	NR	3	0%	Castello 2011, Herring 2017, Mundberg 2018a	Only RCT	Critically Low	**NS**	Discordant
Schurmans 2022	NS (k=3)	NR	3	NA	Castello 2013, Huck 2015, Mundberg 2018a	RCT	Low	**NS**	
Carretero-Ruiz 2021	ES: -0.44 [-0.75; -0.02] (MD: -3.93 bpm [-6.54; 1.31])	NR	5	0%	Castello 2011, Huck 2015, Herring 2017, Marchesi 2015, Mundberg 2018a	RCT, NRCT	Critically Low	+	

Marshall 2020	MD: -3.06 bpm [-5.65; -0.47] *Very low level of evidence*	111	4	0%	Pre-MBS (Baillot 2018/Baillot 2014); Post-MBS (Castello 2011, Huck 2015, [Mundberg 2018a/Mundberg 2018b/Stolberg 2018a/Stolberg 2018c])	RCT, NRCT *k*=1 (2 publications) pre-MBS intervention Mistakenly considered Baillot 2014/2018 as one study	Low	**Inclusive as pre/post-MBS results are combined**
Ren 2018	WMD: -4.39 bpm [-8.11; -0.68] *Low level of evidence*	94	3	0%	NR	Only RCT	Low	+
Blood Pressure (BP) – 33% overlap of primary studies								
Boppre 2022	**SBP** MD: − 5.33 mmHg [-8.99; -1.66] *Moderate certainty evidence*	314	6	0%	Auclair 2021, Castello 2011, Coen 2015b, Herring 2017, Munderberg 2018a, Shah 2011	Only RCT	Critically Low	+
	DBP MD: -2.66 mmHg [-6.72; 1.40]	NR	6	59%	”			**NS**
Schurmans 2022	**SBP:** NS (k=4) + (k=1)	NR	5	NA	Castello 2011, Coen 2015a, Herring 2017, Huck 2015, Mundberg 2018a	RCT	Low	**(NS)**
	DBP: NS (k=2), + (k=2, 1 only at 24 months post-MBS)	NR	4	NA	Castello 2011, Coen 2015a, Mundberg 2018a, Shah 2011			**?**
Carretero-Ruiz 2021	**SBP:** ES: -0.16 [-0.40; 0.08] (MD = -2.65 mmHg [-7.32; -1.11])	NR	5	0%	Coen 2015b, Herring 2017, Huck 2015, Mundberg 2018a, Shah 2011	RCT, NRCT	Critically Low	**NS**
	DBP: ES: -0.12 [-0.446, 0.21] (MD: -1.41 mmHg [-5.56, 2.75])	NR	5	34%	”			**NS**
Bellicha 2021	**SBP:** MD: -4.2 mmHg [-9.3; 1.0]	NR	4	47%	Coen 2015b, Herring 2017, Huck 2015, Shah 2011	RCT, NRCT	Critically Low	**NS**
	DBP: MD: -2.3 mmHg [-8.5; 3.9]	NR	4	77%	”			**NS**
Marshall 2020	**SBP:** MD: -1.59 mmHg [-3.74; 0.56] *Very low level of evidence*	239	5	27%	Pre-MBS (Baillot 2014/2018); Post-MBS (Castello 2011, [Coen 2015a/Coen 2015b/Nunez-Lopez 2017, Woodlief 2015], Huck 2015, [Mundberg 2018a/Mundberg 2018b/Stolberg 2018a/Stolberg 2018c])	RCT, NRCT *k*=1 (2 publications) pre-MBS intervention Mistakenly considered Baillot 2014/2018 as one study	Low	**Inclusive as pre/post-MBS results are combined**
	DBP: MD: -1.31 mmHg [-2.33; -0.29] *Very low level of evidence*	251	6	23%	Pre-MBS (Baillot 2014/2018); Post-MBS (Castello 2011, [Coen 2015a/Coen 2015b/Nunez-Lopez 2017, Woodlief 2015], Huck 2015, Onofre 2017, [Mundberg 2018a/Mundberg 2018b/Stolberg 2018a/Stolberg 2018c])			**Inclusive as pre/post-MBS results are combined**
Ren 2018	**SBP:** WMD: -4.12 mmHg [-6.68; -1.55] *Low level of evidence*	229	4	6%	NR	Only RCT	Low	+

Concordant for DBP
Discordant for SBP

	DBP: WMD: -3.56 mmHg [-8.61; 1.48] *Very low level of evidence*	229	4	83%	”			**NS**	
Quality of Life (QoL) – 33% overlap of primary studies									
Schurmans 2022	NS (k=2) except for general health domain	NR	2	NA	Shah 2011, Stolberg 2018b	Only RCT	Low	**NS**	Concordant
Bellicha 2021	**Physical.:** MD: -2.5 [-5.1; 0.2]	NR	2	0%	Oppert 2018, Shah 2011	Only RCT	Critically Low	**NS**	
	Mental: MD: 3.9 [-0.5; 8.3]	NR	2	0%	”			**NS**	
Glucose Metabolism – 30% overlap of primary studies									
Boppre 2022	**Insulin:** MD: -1.58 µIU/mL [-5.14; 1.98]	NR	4	71%	Coen 2015b, Dantas 2020, Mundberg 2018a, Shah 2011	Only RCT	Critically Low	**NS**	Concordant
	Glucose: MD: 0.94 mg/dL [-3.31; 5.19]	NR	4	0%	”			**NS**	
	HOMA-IR: MD: 1.39 [-1.30; 4.08]	NR	2	89%	NR			**NS**	
	HbA1C: MD: -0.65 mmol/mol [-2.22; 0.93]	NR	2	0%	NR			**NS**	
Schurmans 2022	**Insulin sensitivity:** + (k=3) NS (k=1)	NR	4	NA	Coen 2015a, Coen 2015b, Nunez-Lopez 2017, Woodlief 2015	RCT 4 publications from 1 intervention (Coen 2015a/b, Nunez-Lopez 2017, Woodlief 2015)	Low	**Inconclusive all 4 publications same study**	
	AIRg and Di: + (k=1), NS (k=1)	NR	2	NA	Coen 2015b, Woodlief 2015			**Inconclusive only 2 publications same study**	
	SPISE: NS (k=1)	NR	1	NA	Mundberg 2018[a]			**Inconclusive 1 study**	
	HOMA-IR: NS (k=2)	NR	2	NA	Mundberg 2018a, Nunez-Lopez 2017			**NS**	
	Glucose effectiveness: + (k=1)	NR	1	NA	Coen 2015b			**Inconclusive 1 study**	
Bellicha 2021	**HOMA-IR** SMD: 0.14 [-0.10; 0.38]	NR	2	0%	Coen 2015b, Mundberg 2018a	RCT	Critically Low	**NS**	
Marshall 2020	**Fasting insulin**.MD: 4.88 pmol/L [-2.09; 11.84] (low level of evidence)	180	2	0%	[Coen 2015a/Coen 2015b/Nunez-Lopez 2017/Woodlief 2015], [Mundberg 2018a/Mundberg 2018b/Stolberg 2018a/Stolberg 2018c]	RCT	Low	**NS**	
	Fasting glucose MD: 0.05 mmol/L [-0.14; 0.24] (low level of evidence)	180	2	0%	”			**NS**	
Lipid Metabolism – 27% overlap of primary studies									
Boppre 2022	**TC** MD: -3.08 mg/dL [-12.04; 5.87]	NR	5	0%	Coen 2015b, Dantas 2020, Mundberg 2018a, Shah 2011, Tardif 2020	Only RCT	Critically Low	**NS**	Concordant for TG.LD
	HDL MD: 0.61 mg/dL [-3.05; 4.28]	NR	5	26%	”			**NS**	

	LDL MD: -8.17 mg/dL [-20.35; 4.00]	NR	5	57%	”			**NS**
	TG MD: -8.38 mg/dL [-19.81; 3.04]	NR	5	0%	”			**NS**
Schurmans 2022	**Blood lipids:** NS (k=1), + (k=1 for HDL-C)	NR	2	NA	Coen 2015a, Mundberg 2018a	RCT,	Low	**Inconclusive unclear variables**
Carretero-Ruiz 2021	**HDL** ES: 0.22 [0.01; 0.43]	NR	6	0%	Coen 2015b, Dantas 2020, Marchesi 2015, Mundberg 2018b, Shah 2011, Tardif 2020	RCT, NRCT	Critically Low	+
Bellicha 2021	**LDL** SMD: -0.18 [-0.46; 0.09]	NR	3	0%	Coen 2015b, Mundberg 2018a, Shah 2011	RCT, NRCT	Critically Low	**NS**
	HDL SMD: 0.10 [-0.16; 0.37]	NR	4	0%	Coen 2015b, Marchesi 2015, Mundberg 2018a, Shah 2011			**NS**
	TG SMD: 0.01 [-0.26; 0.27]	NR	4	0%	”			**NS**
Marshall 2020	**TG** MD: 0.01 mmol/L [-0.15; 0.16] (low level of evidence)	180	2	0%	[Coen 2015a/Coen 2015b/Nunez-Lopez 2017/Woodlief 2015], [Mundberg 2018a/Mundberg 2018b, Stolberg 2018a/Stolberg 2018c]	RCT	Low	**NS**
	HDL MD: -0.00 mmol/L [-0.01; 0.01] (low level of evidence)	180	2	0%	”			**NS**
	LDL MD: -0.06 mmol/L [-0.21; 0.09] (low level of evidence)	180	2	0%	”			**NS**
	TC MD: -0.08 mmol/L [-0.26; 0.11] (low level of evidence)	180	2	0%	”			**NS**

Note. * interpret these results with caution due to unreliable measurements in adults with obesity. RR=risk ratio, MD=mean difference, SMD=standardized mean difference, NS=non-significant, NR=not reported, NA=not applicable, *k*=number of studies, *n*=subsample size, I^2=degree of heterogeneity, MBS=metabolic and bariatric surgery RCT=randomized control trial, NCRT=non-randomized control trial, PAC=physical activity counselling. Individual review conclusions highlighted in dark grey were not factored into the overall conclusion for the outcome.

[a] + =significant benefits from a meta-analysis, or 100% concordance for significant benefits between studies in a systematic review, (+) =partial concordance (≥ 67%) for significant benefits between studies in a systematic review, ? =discordance between studies in a systematic review, (NS) =partial concordance (≥ 67%) for non-significant benefits between studies in a systematic review, NS =non-significant benefits from a meta-analysis, or 100% concordance for non-significant benefits between studies in a systematic review.

[b] conclusion determined by following flow diagram (see Supplementary File Appendix P).

Table 5: Pooled Percentage Feasibility and Acceptability Data from Baillot et al, 2022 [9]

Effects	k	arms	I^2	Studies included
Attendance rate (exercise arm): 84.3% [77.0; 90.7]	8	10	0%	Baillot 2016, Castello 2011, Herring 2017, Huck 2015, Lamarca 2021, Marcon 2017, Murai 2019, Picó-Servant 2019
Dropout rate (exercise arm): 5.0% [1.1; 10.5]	18	19	60%	Arman 2021, Baillot 2016, Castello 2011, Coen 2015b, Coleman 2017, Daniels 2017, Gilbertson 2020, Herring 2017, Marc-Hernandez 2019, Marc-Hernandez 2020, Marchesi 2015, Marcon 2017, Murai 2019, Onofre 2017, Oppert 2018, Picó-Servant 2019, Shah 2011, Tardif 2020
Enrollment rate (both groups): 43% [30; 57]	18	18	94%	Arman 2021, Baillot 2016, Campanha-Versiani 2017, Castello 2011, Coen 2015b, Coleman 2017, Diniz Souza 2020, Gilbertson 2020, Hassanejad 2017, Herring 2017, Lamarca 2021, Marc-Hernandez 2020, Marcon 2017, Mundberg 2018a, Murai 2019, Onofre 2017, Oppert 2018, Tardif 2020
Refusal rate (both groups) 22.6% [10.0; 38.2]	16	16	95%	Arman 2021, Baillot 2016, Campanha-Versiani 2017, Castello 2011, Diniz Souza 2020, Gilbertson 2020, Hassanejad 2017, Herring 2017, Lamarca 2021, Marc-Hernandez 2020, Marcon 2017, Mundberg 2018a, Murai 2019, Onofre 2017, Oppert 2018, Tardif 2020
Retention rate (exercise arm): 87.1% [79.6; 93.0]	23	26	80%	Arman 2021, Baillot 2016, Campanha-Versiani 2017, Castello 2011, Coen 2015b, Coleman 2017, Daniels 2017, Gilbertson 2020, Herring 2017, Lamarca 2021, Marc-Hernandez 2019, Marc-Hernandez 2020, Marchesi 2015, Marcon 2017, Mundberg 2018a, Murai 2019, Muschitz 2016, Onofre 2017, Oppert 2018, Picó-Servant 2019, Shah 2011, Stegen 2011, Tardif 2020

Note. All effects were pooled percentages. Sample size was not reported in any of the analyses and all analyses included both randomized and non-randomized control trials. k =number of primary articles, I^2=measure of heterogeneity.

Figure 1: Summary of Outcome Conclusions Pre- and Post-MBS

Operational Definitions

Exercise training = physical activity that was planned, structured, and repeated (mainly endurance and/or resistance training)

Physical activity counselling = interventions to increase motivation to engage in physical activity through behavioural change techniques

What We Currently Know

Effects of Exercise Training

Post MBS Exercise Training

Exercise training
→ + body weight/BMI
→ + waist circumference
→ + 6-minute walking test
→ + muscle strength
→ NS lean body/fat-free mass[a]
→ NS diastolic blood pressure
→ NS fasting insulin/glucose
→ NS total cholesterol, triglycerides, or low-density lipoprotein

Beneficial Characteristics of Exercise Training Programs

Exercise training that combines endurance/ resistance and/or exercise training that lasts > 12 weeks
→ + systolic blood pressure

Exercise training starting < 6 months post MBS
→ NS body weight/BMI

Exercise training starting > 6 months post MBS
→ + body weight/BMI

What We Think We Know

Effects of Exercise Training

Pre MBS Exercise Training

Exercise training
→ + 6-minute walking test
→ + BMI
→ NS fat-free mass[a]
→ NS quality of life

Exercise intervention (i.e., exercise training + physical activity counselling)
→ + VO_2max
→ + physical activity

Post MBS Exercise Training

Exercise training
→ + bone mineral density
→ + systolic blood pressure
→ NS fat mass
→ NS VO_2max
→ NS high-density lipoprotein
→ NS resting heart rate
→ NS weight loss ≥12 months post MBS

Beneficial Characteristics of Exercise Training Programs

Exercise training that combines endurance/ resistance
→ + body weight/BMI
→ + triglycerides

Exercise training starting > 6 months post MBS
→ + systolic blood pressure

Exercise training starting ≥ 12 months post MBS
→ + body weight/BMI (compared to starting within 6 months post)

Feasibility and Acceptability

Exercise training has:
- ↑ attendance rates
- ↑ retention rates
- ↓ drop out rates
- ↓ risk of serious exercise adverse events

What We Still Don't Know

Effects of Exercise Training

Pre MBS Exercise Training

Impact of exercise training:
- blood pressure
- muscle strength
- fat mass
- length of hospital stay
- lean body mass[a]
- resting heart rate
- glucose/lipid metabolism
- adverse surgical events

Post MBS Exercise Training

Impact of exercise training:
- quality of life
- HOMA-IR, HbA1c, insulin sensitivity, AIRg and Di, SPISE and glucose effectiveness

Pre and Post MBS Exercise Training

Impact of exercise training:
- in the long-term (i.e., > 12 months) on any variable

Feasibility and Acceptability

- adherence rates to prescribed exercise training programs
- impact of exercise training characteristics (i.e., timing, modality, duration etc.) on feasibility and acceptability outcomes

Note. The flow diagram used to categorize each outcome, and a summary of these categorizations, are both presented in the supplementary file (Appendix P and R respectively). The second column is titled "what we think we know" to demonstrate the lack of absolute conclusions. BMI=body mass index, HOMA-IR=homeostatic model assessment for insulin resistance, HbA1c=hemoglobin A1C, AIRg=acute insulin response to glucose, Di=disposition index, SPISE=single-point insulin sensitivity estimator.

[a] lean body mass=weight of your muscles, bones, ligaments, tendons, and internal organs, while fat free mass=total body mass – fat mass