UHASSELT
KNOWLEDGE IN ACTION

Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Exercise Interventions for Preserving Fat-Free Mass Post-Bariatric Surgery: A Systematic Review

Niels Kerkhofs
Senne Prenen
Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie, afstudeerrichting revalidatiewetenschappen en kinesitherapie bij musculoskeletale aandoeningen

PROMOTOR :
Prof. dr. Kenneth VERBOVEN

2023
2024

UHASSELT
KNOWLEDGE IN ACTION

www.uhasselt.be
Universiteit Hasselt
Campus Hasselt:
Martelarenlaan 42 | 3500 Hasselt
Campus Diepenbeek:
Agoralaan Gebouw D | 3590 Diepenbeek

Faculteit Revalidatiewetenschappen

master in de revalidatiewetenschappen en de kinesitherapie

Masterthesis

Exercise Interventions for Preserving Fat-Free Mass Post-Bariatric Surgery: A Systematic Review

Niels Kerkhofs
Senne Prenen

Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie, afstudeerrichting revalidatiewetenschappen en kinesitherapie bij musculoskeletale aandoeningen

PROMOTOR :

Prof. dr. Kenneth VERBOVEN

Situation

This research is situated in the broad research domain of health promotion and movement. Resulting from its characteristics corresponding with the promotion of a healthy lifestyle, together with a clarification of the benefits of multiple types of movement on health outcomes post bariatric surgery.

The systematic review aims to provide relevant information regarding the most optimal exercise intervention for patients who received bariatric surgery. Especially those patients who are deemed at risk for developing sarcopenic obesity. This area of expertise within physiotherapy has not been thoroughly researched and thus this review provides an excellent opportunity to assist clinicians to provide optimal support for their patients.

The following systematic review as part of a Masters' thesis, is not linked to an existing research project within the research group of Prof. Dr. Verboven. It originated from a research question provided to Prof. Dr. Kenneth Verboven by two Masters' students (Kerkhofs Niels and Prenen Senne). Both students performed and took part in the screening of the necessary articles retrieved through an extensive research strategy. Concurrently, the other steps in conducting the following systematic review were performed by both students equally, doing both individual work necessary according to the protocol for a systematic review as well as work in duo to find and describe links in evidence necessary for interpreting the literature.

Exercise Interventions for Preserving Fat-Free Mass Post-Bariatric Surgery: A Systematic Review

Prenen S, Kerkhofs N, Verboven K[1,2]

[1] *REVAL Research Institute, Faculty of Rehabilitation Sciences and Physiotherapy, Hasselt University, Hasselt, Belgium*

[2] *Biomedical Research Institute, Faculty of Medicine and Life Science, Hasselt University, Hasselt, Belgium*

1. Abstract

Background: Excessive loss in fat-free mass (FFM) following bariatric surgery poses a risk for the development of sarcopenic obesity, potentially impacting long-term health outcomes in individuals with morbid obesity. This systematic review aims to evaluate the efficacy and feasibility of exercise interventions in preserving FFM.

Method: A systematic search in accordance with the PRISMA guidelines was conducted on PubMed and Scopus. Two independent reviewers screened records for eligibility. Studies investigating the impact of exercise programs on FFM either pre- or post-bariatric surgery were included. Quality assessment was performed using the Cochrane ROB2-assessment tool and ROBINS-I.

Results: Out of 296 screened articles, 14 studies met the inclusion criteria. Most studies (n=13) incorporated a post-bariatric exercise intervention (mean intervention duration ±16 weeks), one study encompassed a pre-bariatric exercise program. Fifty percent of studies exhibited a low risk of bias. The analysis of results reported ten studies displaying better preservation of FFM when comparing the intervention group to the control group.

Discussion and conclusion: Overall, exercise interventions effectively preserved FFM (mean: -6.15%) in most studies, particularly through supervised programs combining aerobic and resistance training. Discrepancies in intervention feasibility were noted, with drop-out ranging from 0-74%. Due to insufficient data, no conclusions could be drawn about the role of sex in exercise prescription.

In conclusion, a multimodal supervised exercise program should be implemented post-bariatric surgery to effectively preserve FFM. More research is needed to understand the influence of sex on exercise outcomes post-bariatric surgery.

Key words: Bariatric Surgery, Fat-Free Mass, Exercise

2. Introduction

Obesity is a widespread and well-known health problem in our modern society. The World Health Organization (WHO) defines obesity as a body mass index (BMI) greater than or equal to 30 kg/m². In 2022, 1/8th of the world's adult population lived with obesity (*Obesity and overweight*, 2024). Bariatric surgery (BS) is known to be an effective treatment for severe obesity, being associated with positive health outcomes such as significant weight loss and improved metabolic health (Gloy et al., 2013; le Roux & Heneghan, 2018). Research by Thereaux et al. (2019) revealed a reduced mortality risk over a seven year follow-up for individuals choosing BS compared to non-bariatric surgery patients. Investigating disparities in BS utilisation, Mousapour et al. (2021) found no significant differences between men and women when comparing excessive weight reduction during the first 36 months after surgery (Mousapour et al., 2021). Concurrently, Aly et al. (2020) reported a notable sex disparity in BS utilisation, with a higher proportion of female patients seeking surgical intervention, despite male patients presenting at an older age with more comorbidities. Nevertheless, BS demonstrates comparable efficacy in inducing weight loss across sexes, with both male and female patients attaining approximately 20% reduction in body weight three months post-surgery (Fuchs et al., 2015; Le Foll et al., 2020). While BS, particularly gastric bypass, effectively induces weight loss, it also carries risks of long-term adverse events such as hospital admissions due to nutritional disorders, significant fat-free mass (FFM) loss, and post-surgery complications like renal failure (Guida et al., 2018; Maciejewski et al., 2012; Thereaux et al., 2019)**.** This underlines the need to identify predictors to mitigate adverse events post-bariatric surgery. Considering this, sarcopenic obesity emerges as a significant predictor of adverse events due to its association with an up to 41% increase in mortality risk (Atkins & Wannamathee, 2020; Maciejewski et al., 2012; Molero et al., 2020). Moreover, Herring et al. (2016) highlight that rapid weight loss post-BS is accompanied by a significant loss of FFM, constituting up to 50% of the total weight lost, emphasising that this decline in FFM is an undesirable outcome of BS. This reduction in FFM can lead to a substantial decrease in total muscle mass and strength (Herring et al., 2016).

According to Vieira et al. (2022), the prevalence of sarcopenic obesity among patients who underwent BS is about 23%, which warrants a strong emphasis on preserving FFM post-surgery as muscle mass is an essential component for the overall protein metabolism. A recent meta-analysis by Nuijten et al. (2022) revealed that BS led to a loss of FFM, accounting for up to 22% of total body weight loss. This impacts long-term health status, influencing functional capacity, bone strength, thermogenesis, and metabolic health. Excessive reduction in FFM, may lead to the development or aggravation of sarcopenia (sarcopenic obesity), cardiometabolic disorders, or frailty (Nuijten et al., 2022). Of interest, a notable reduction in FFM can have adverse effects on the body's resting metabolic rate (Ebbeling et al., 2012, in Schiavo et al., 2017). In line, a decrease in FFM also leads to patients being more susceptible to regain weight after surgery (Ravussin et al., 1988, in Schiavo et al., 2017).

Henceforth, the management and preservation of FFM must be considered paramount to optimise long-term health outcomes in individuals with morbid obesity, which can be achieved with exercise intervention. Notably, the specifics of this intervention and the optimal commencement time for patients remain ambiguous (Livhits et al., 2010)**.** Consideration must be given to sex when examining diverse exercise interventions. Existing literature indicates a notable disparity in FFM reduction post-bariatric surgery, with males exhibiting a more pronounced decrease than females, with a loss of up to 20.8%. These findings underline the importance of understanding sex-specific responses to exercise interventions post-bariatric surgery and raise the question whether tailored exercise regimens are needed to address this discrepancy (Guida et al., 2018). Literature reveals a substantial knowledge gap regarding the most effective exercise intervention, either pre- or post-operative, to achieve optimal preservation of FFM while reducing fat mass following BS in individuals with (morbid) obesity. Additionally, there is a limited understanding of the role of sex when defining exercise intervention characteristics. Therefore, this systematic review investigates which type of exercise intervention is the most effective and feasible for preserving FFM, considering potential sex differences in BS candidates.

3. Method

3.1 Research question

The current systematic review was conducted in accordance with the PRISMA guidelines. The research question of this systematic review is the following: "What is the most effective and feasible exercise intervention for preserving fat-free mass in patients undergoing bariatric surgery?". This systematic review aims to review research concerning exercise interventions specifically tailored for this particular patient population, focusing on identifying the most effective and feasible approach. This systematic review defines efficacy as the inverse amount of BS-induced muscle mass loss, while feasibility will be defined as the percentage of drop-outs. Nonetheless, it is important to note that potential BS complications can influence feasibility; therefore, it will be combined with the attendance rate where applicable. A secondary objective of this review is to identify potential sex-specific variations in the prescription of exercise interventions. The hypothesis posits that the optimal intervention for preserving FFM following bariatric surgery would entail the implementation of a moderate-intensity aerobic exercise modality coupled with a strength training program.

3.2 Literature search

PubMed and Scopus were the primary databases searched for relevant literature. The initial search was conducted on the 12th of June 2023, with an updated search on the 28th of April 2024 to include the most recent evidence. Two independent reviewers performed both searches. There were no restrictions regarding the publication date of the articles. The comprehensive search strategy for both PubMed and Scopus employed for this systematic review is presented in Supplementary Table 1a and Supplementary Table 1b, respectively. This query was specifically designed following a PICO (Table 1) created to answer the research question of this systematic review. Retrieved papers underwent a title/abstract screening by the same independent reviewers (PS and KN), followed by a full-text screening for those papers passing the first screening stage. Any disagreements were resolved by discussion with a third independent reviewer (VK) (Figure 1). A modification was made to the search query for Scopus, which involved the addition of the search term "Fat-Free Mass" and its associates to refine the search and obtain more focused results within this extensive database.

3.3 Eligibility criteria

Publications included in this systematic review were limited to those meeting the predefined inclusion criteria, which were as follows: 1) Publication in English language, 2) Studies involving human participants, 3) Age range: 18-65 years, 4) Studies examining the effects of exercise intervention on fat-free mass (FFM), 5) Studies investigating all forms of exercise intervention, irrespective of pre-/post-operative timing. The exclusion criteria encompass the following: 1) Studies combining dietary and exercise interventions except when they exclusively entail a group subjected solely to exercise intervention, 2) Intervention does not start within the early phase (≤ 3 months post-BS) or late phase (>2 years post-BS), and 3) Studies lacking information on sex distribution, as well as 4) Non-individual research such as (systematic) reviews and meta-analysis.

3.4 Quality assessment

To assess the risk of bias in all included randomised controlled trial studies, the Cochrane ROB2-assessment tool was used. The quality of each study was assessed based on the following domains: risk of bias arising from the randomisation process, risk of bias due to deviations from the intended interventions (effect of assignment to intervention and effect of adhering to intervention), missing outcome data, risk of bias in measurement of the outcome, and risk of bias in selection of the reported result. The outcomes obtained from the Cochrane ROB2 assessment tool are summarised by a colour-coded ranking (Figure 2). To assess the quality of all included observational studies, the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) was used. The STROBE is a checklist of items that should be included in reports of observational studies. Lastly, the Risk Of Bias In Non-randomized Studies – of Interventions (ROBINS-I) assessment tool was used to assess the risk of bias in non-randomized studies. The scores of the Cochrane ROB2-assessment, ROBINS-I, and STROBE were used to consider the quality of evidence when interpreting the included articles. Any disagreements were resolved by discussion with a third independent reviewer (VK).

3.5 Data extraction and synthesis

Two reviewers (PS and KN) independently extracted data from all included studies, any disagreements were discussed and resolved by a third independent reviewer (VK). The extracted data from the studies were categorised into primary and secondary outcomes. The primary outcomes encompassed the examination of three variables: 1) Changes in FFM, including the relative preservation percentage, together with method(s) of FFM measurement; 2) attendance and/or drop-out rate defined as the number of drop-outs for non-BS-complication-related reasons as well as the percentage of completed sessions respectively, and 3) exercise intervention characteristics, according to the FITT-principle. The secondary outcomes encompassed: 1) timing of intervention, including pre-operative, post-operative, or a combination of both; 2) sex distribution; 3) duration of the intervention period; 4) body composition variables: amount of total weight loss, and 5) Type of bariatric surgery. When required, data conversion was used to facilitate accurate analysis and comparative interpretation of results among different studies. For instance, standard errors (SE) were converted to standard deviations when necessary. A formula was employed to quantify the preservation of FFM as a percentage to address the potential heterogeneity in results arising from variations in baseline participant characteristics among individual studies. The formula utilised consisted of the following calculation: $((FFM_{baseline} - FFM_{post\text{-}intervention}) / FFM_{baseline}) \times 100$. This approach facilitates a more standardised interpretation of the results within the context of this review.

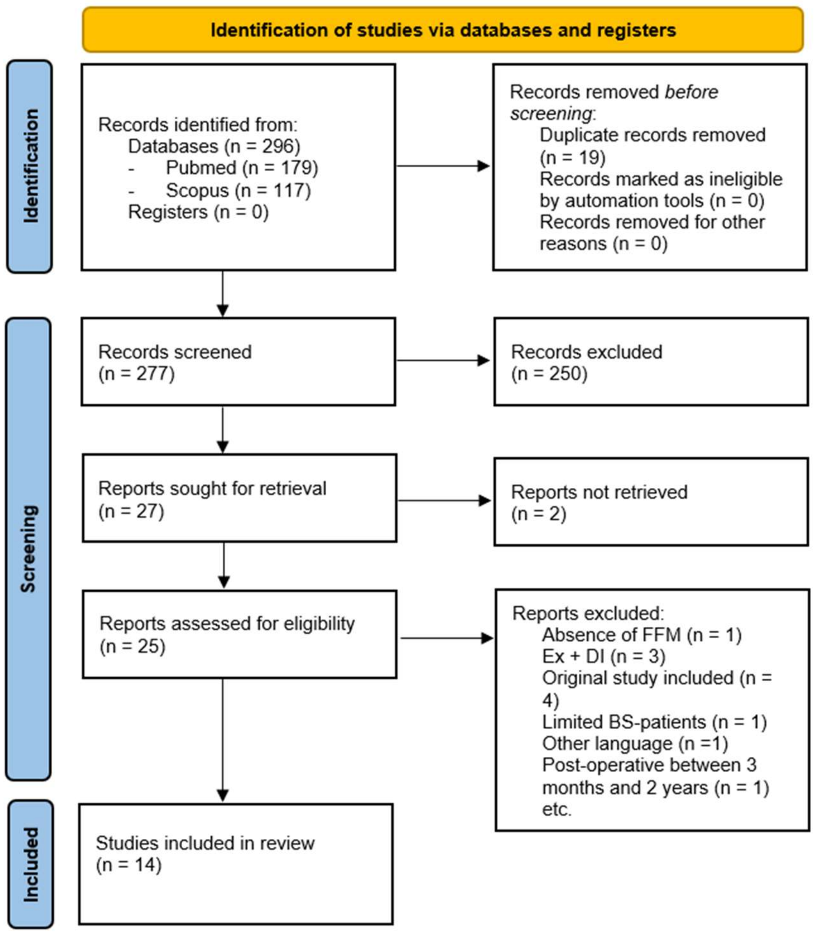
4. Results

4.1 Study selection results

The systematic search concluded a total of 296 articles, with 179 sourced from PubMed and 117 from the Scopus database (Figure 1). Subsequently, 19 duplicates were removed. The remaining 277 articles were screened based on title and abstract, excluding 250 publications. Eight articles needed screening by a third reviewer. The most prevalent reasons for exclusion were the absence of an exercise intervention (n=159), no research on FFM (n = 39), the lack of relevance to bariatric surgery (n=23), and the sole incorporation of a combined exercise and dietary intervention (n=19). Full-text screening identified 14 articles that met all inclusion criteria.

Figure 1

PRISMA Flowchart



Note. PRISMA flowchart of search strategy outcomes and screening process.

FFM, Fat-Free Mass.

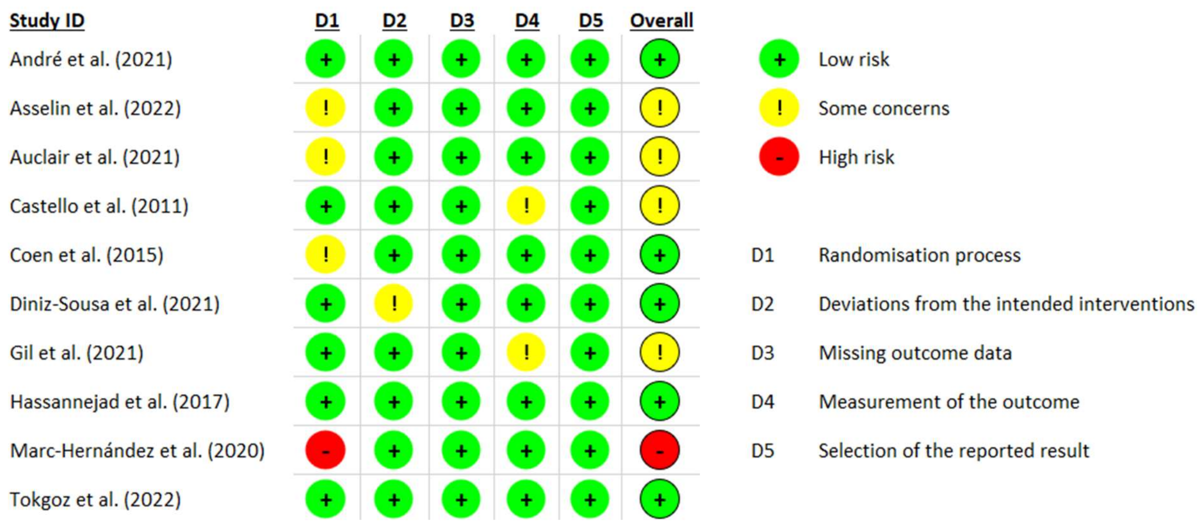
4.2 Quality assessment results

According to the ROB2 assessment tool, 50% of the included studies incorporated in the intention-to-treat analysis demonstrated a low risk of bias, and 40% of studies exhibited some concerns regarding the risk of bias. Conversely, the remaining 10% were judged to have a high risk of bias.

The primary contributors to a high risk of bias or the manifestation of some concerns were predominantly associated with the randomisation process, wherein six studies exhibited a low risk of bias in this domain. Notably, the remaining domains that elicited some concerns in the included studies were related to deviations from the intended intervention and measurement of the outcome (Figure 2).

Figure 2

Risk of Bias Assessment of Included Articles by Use of ROB2-tool



The ROBINS-I assessment tool was used for four non-randomised studies. The studies of Lamarca et al. (2021), and Huck (2015), both received a moderate risk of bias. A serious risk of bias was found in the studies of Morana et al. (2018), and Stegen et al. (2011). These scores resulted from high drop-out ratios and lack of blinding, respectively.

4.3 Data extraction results

<u>Primary outcome measures</u>

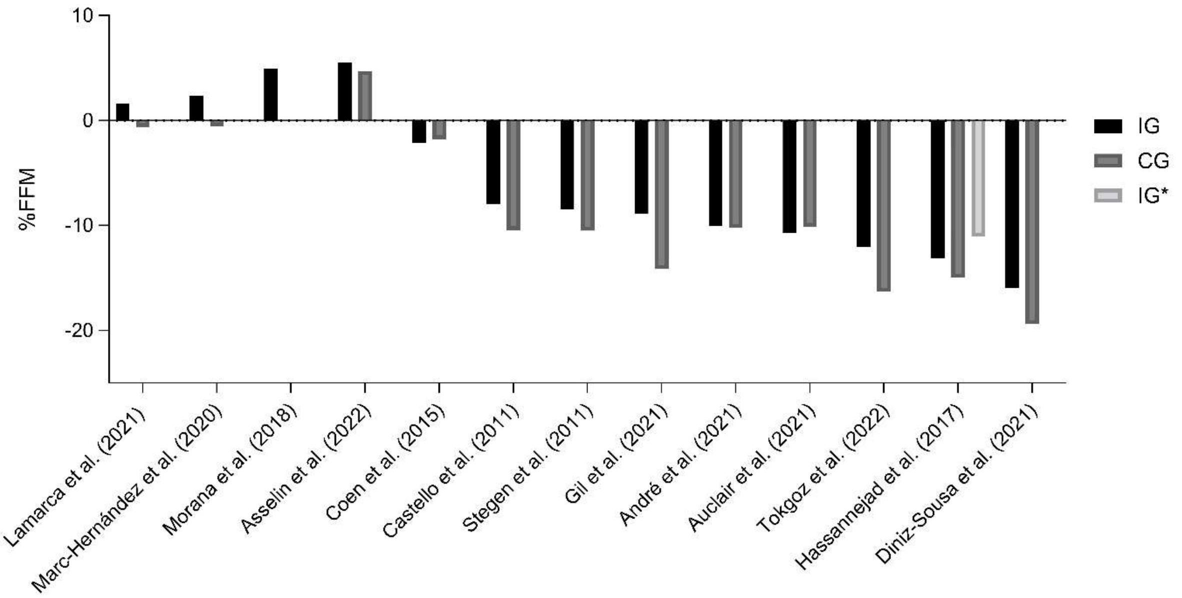
Effect on fat-free mass: Nine of the included studies observed a significant reduction in FFM when comparing pre- and post-intervention measurements in both the control group (CG) and the intervention group (IG). In contrast, the studies conducted by Lamarca et al. (2021), and

Marc-Hernández et al. (2020) show a loss of FFM in the CG and an absolute non-significant increase ($p = 0.072$) in the IG. The only studies reporting a significant increase in FFM in the IG are the studies of Asselin et al. (2022) and Morana et al. (2018), which found an increase of 5.5% and 4.9% compared to pre-intervention values, respectively, for the IG and 4.7% for the CG in the study of Asselin et al. (2022). The study conducted by Morana et al. (2018) did not include a control group. The study by Tokgoz et al. (2022), which incorporated an intervention program prior to surgery, reported a decrease in FFM of 12.09% in the IG and 16.32% in the CG. Huck (2015) found no significant reduction in FFM between pre- and post-intervention measurements in both the CG and IG. His study was excluded from further discussion, due to lack of baseline information necessary to calculate %FFM (Figure 3).

Lastly, three studies note a significant difference in the between-group results of the CG and IG concerning FFM (Diniz-Sousa et al., 2021; Gil et al., 2021; Hassannejad et al., 2017). The IG retained more FFM in the studies conducted by Diniz-Sousa et al. (2021), and Gil et al. (2021). Hassannejad et al. (2017) only found a significant difference between the CG and their secondary IG (aerobic+strength) (Figure 3). Of interest, nine of the 14 studies used bio-electrical assessments of FFM. In contrast, three studies used a Dual-energy X-ray Absorptiometry (DXA) method (Coen et al., 2015; Diniz-Sousa et al., 2021; Gil et al., 2021). Auclair et al. (2021) used bioelectrical impedance balance, whereas skinfold measurements were used by Castello et al. (2011). An overview of all the data per individual study can be found in Table 2.

Figure 3

Variation in Fat-Free Mass (FFM) Preservation Across Included Studies



Note. Presentation of %FFM results, ranked by preservation of FFM ascending to descending order; IG, intervention group; IG*, secondary intervention group; CG, control group; %FFM, percentage of preservation of fat-free mass.

Attendance and drop-out rates: Across all studies, the mean drop-out rates were 26.71% (SD: ±21.04) and 17.69% (SD: ±13.13) for the IG and CG, respectively. Huck (2015) was excluded from the statistical analysis due to insufficient information regarding drop-out rates. The drop-out rates for the CG ranged from 0-37.5% (Asselin et al., 2022; Castello et al., 2011), while a range of 0-74% was noted for the IG (Asselin et al., 2022; Morana et al., 2018). Six articles exhibited a higher drop-out rate for the IG than the CG (André et al., 2021; Auclair et al., 2021; Coen et al., 2015; Hassannejad et al., 2017; Lamarca et al., 2021; Tokgoz et al., 2022). Statistical analysis of drop-out rates shows no significant difference between CG and IG (p=0.216). Attendance percentages were explicitly reported in only three of the included articles, consistently ranging from 39-84% (Diniz-Sousa et al., 2021; Gil et al., 2021; Huck, 2015) (Table 2).

To examine the relationship between intervention duration and drop-out rate, a comparison was made between the mean and individual drop-out rates of all included studies within the IG. Intervention periods with a duration of six months or longer seem to have a higher percentage of drop-outs than the mean drop-out ratio. A higher discrepancy is found between drop-out rates of studies performing an intervention shorter than ten weeks. Most frequent reasons of drop-out were refusal to continue the intervention, lack of adherence to intervention, lack of time, and personal reasons. Huck (2015) also mentioned surgery-related health complications.

Type of intervention: Seven studies comprised a combination of resistance training (RT) and either endurance training (ET) or aerobic exercise (AE) (Asselin et al., 2022; Auclair et al., 2021; Gil et al., 2021; Hassannejad et al., 2017; Marc-Hernández et al., 2020; Morana et al., 2018; Stegen et al., 2011). AE modalities are regarded as equal to ET modalities in the context of this systematic review. An exception to this is the study of Marc-Hernández et al. (2020), which includes High-Intensity Interval Training (HIIT) as a part of an ET program. Two studies exclusively utilised an RT program (Huck, 2015; Lamarca et al., 2021). Three studies solely utilised an AE program (Castello et al., 2011; Coen et al., 2015; Tokgoz et al., 2022). Another study incorporated a mixed training program, described as combining high-impact, balance, and strength exercises (Diniz-Sousa et al., 2021). Furthermore, one study implemented an RT program in combination with whole-body electromyostimulation during the intervention (André et al., 2021).

The most prevalent frequency of training sessions was three times per week, with a maximum of five sessions per week (n=11). The RT component was typically composed of three sets of eight to twelve repetitions of dynamic load exercises targeting all major muscle groups, with increasing intensity ranging from 60% to 75% of One-Repetition Maximum (1-RM). AE encompassed continuous aerobic training on a cycle ergometer and/or treadmill, such as running or walking. The intensity of AE ranged from 60% to 75%, utilising various variables such as VO_2peak, Heart Rate Reserve (HRR), or Heart Rate Max (HRmax). Two studies incorporated an interval training form (Asselin et al., 2022; Castello et al., 2011), while another study included a form of HIIT (Marc-Hernández et al., 2020).

Among these interventions, only one training program was classified as semi-supervised, indicating that only a limited number of sessions were supervised (Coen et al., 2015). Additionally, one study reported using a non-supervised training program (Hassannejad et al., 2017). A more detailed description of individual interventions of all included studies can be found in Table 3.

Secondary outcome measures

***Sex distribution*:** Overall, it can be noted that a higher percentage of women participated in the included studies. Three studies solely focused on women (Asselin et al., 2022; Castello et al., 2011; Gil et al., 2021). In contrast, the other studies do include male participants. Still, it is seen that this generally only accounts for a small percentage of the total number of participants (ranging from 8.8 to 27.0%). Studies did not include any sex-specific data regarding the evolution of FFM (Table 2).

***Timing of intervention*:** All included studies reported a post-bariatric exercise intervention, with only one study examining the effect of a pre-bariatric exercise intervention initiated three to six months before surgery (Tokgoz et al., 2022). The most common initiation of the intervention occurred between one and three months post-bariatric surgery. Two articles reported an exceptionally postponed initiation of the intervention, ranging from two to seven years post-bariatric surgery (Lamarca et al., 2021; Marc-Hernández et al., 2020). In contrast, two articles reported an early start of the post-bariatric intervention within the first week after the surgical procedure (André et al., 2021; Hassannejad et al., 2017) (Table 2).

***Duration of intervention period*:** The most applied duration of interventions is found to be 12 weeks. Seven of the 14 included studies use this duration for their interventions (Asselin et al., 2022; Auclair et al., 2021; Castello et al., 2011; Hassannejad et al., 2017; Huck, 2015; Lamarca et al., 2021; Stegen et al., 2011). However, there is a noticeable heterogeneity in the duration of intervention periods, ranging from six weeks to eleven months (André et al., 2021; Diniz-Sousa et al., 2021) (Table 2).

***Body composition variables: amount of total weight loss (kg)*:** Three articles lacked sufficient information regarding the extent of total weight loss after surgery (André et al., 2021; Gil et al., 2021; Morana et al., 2018). One study reported a similar weight loss after surgery between groups (Castello et al., 2011), while three studies identified a higher absolute weight loss in the CG (Diniz-Sousa et al., 2021; Stegen et al., 2011; Tokgoz et al., 2022). In contrast, seven studies reported a greater absolute weight loss (in kilograms) in the IG compared to the CG (Table 2).

Type of bariatric surgery**:** Five out of the 14 studies combined two types of surgery in their inclusion criteria (Asselin et al., 2022; Auclair et al., 2021; Diniz-Sousa et al., 2021; Hassannejad et al., 2017; Huck, 2015). In total the included studies describe four different types of bariatric surgery, namely Roux-en-Y gastric bypass (RYGB), sleeve gastrectomy (SG), duodenal switch (DS), and gastric banding (GB). The most common included variant is RYGB, which has been included in ten out of the 14 included studies. The least commonly included surgical options are DS and GB; these forms were only included in one study (Auclair et al., 2021). Lastly, SG has been included in seven studies (Asselin et al., 2022; Auclair et al., 2021; Diniz-Sousa et al., 2021; Hassannejad et al., 2017; Marc-Hernández et al., 2020; Morana et al., 2018; Tokgoz et al., 2022) (Table 2).

5. Discussion

Overall, most studies (n=9) found a significant reduction in FFM in CG and IG. A significant difference in FFM between groups was only found in three studies. The mean drop-out rates across all studies were 26.71% and 17.69% for the IG and CG, respectively. Half of the included studies performed a multi-modality intervention, with most of them (n=6) opting for supervision during their interventions.

5.1 Reflection on study quality

No studies were excluded based on study quality, as they provided pertinent information for discussion. However, it remains important to interpret the findings of studies with a high risk of bias cautiously. Specifically, Marc-Hernández et al. (2020), Morana et al. (2018), and Stegen et al. (2011), were identified as having a high risk of bias.

5.2 Reflection on findings in relation to research question

The significance of preserving FFM becomes particularly important when considering patients' overall quality of life and functional capacity post-BS. While the initial reduction in body mass enhances the quality of life for obese individuals, an associated decline in overall FFM may attenuate this improvement (Campbell & Vallis, 2014). An evaluation of exercise intervention parameters is essential for discovering and exploring associations between these variables and potential drop-outs. Given that the drop-out rate of a programme can influence its effectiveness depending on the analysis used (Bell et al., 2013).

Our findings suggest that including a resistance training component targeting all major muscle groups is of uttermost importance. It is recommended that the intensity of this training regimen be set to approximately 8-12 repetition maximum (RM) to effectively stimulate hypertrophy. This is confirmed by the review of Hansen et al. (2020), which highlights the efficacy of resistance exercise in preservation of lean tissue mass. This becomes important in light of the potential development of sarcopenic obesity, which is associated with a higher risk of mortality and decreased functional capacity (Atkins & Wannamathee, 2020).

Concurrently, the role of aerobic exercise must not be overlooked in program design. Only one study among those demonstrating a positive effect on FFM did not incorporate aerobic training. Consequently, it can be inferred that integrating aerobic exercise is crucial for designing the most effective exercise training program for FFM preservation. This assertion is supported by a 2010 systematic review, which suggests that weight loss induced by aerobic exercise effectively maintains FFM, primarily due to individuals losing less body weight overall (Weinheimer et al., 2010). Concurrently, Bellicha et al. (2021) suggest that integrating AE and RT proves beneficial for weight maintenance among overweight or obese adults. Our study confirms these findings, demonstrating that the most significant weight loss while preserving FFM occurs in multi-modal intervention programs combining RT and AE. Nonetheless, single-modality programs focusing solely on AE also achieve a substantial reduction in total body weight. These outcomes align with the observations of Bellicha et al. (2021), which indicate that AE is more effective than RT for overall weight loss, while RT stands out as the optimal exercise modality for preserving lean body mass. When evaluating modalities for feasibility, discrepancies in results emerge. Both single- and multi-modality interventions show a wide range of drop-outs. It can thus be concluded that the type of exercise modality is unlikely to considerably affect drop-out ratios and potential effects on FFM preservation.

No observable pattern emerges in the potential relationship between intervention duration, and its effectiveness in preserving FFM. Both longer and shorter (less than 12 weeks) intervention durations positively affected overall FFM preservation, with neither surpassing the other. This suggests that the duration of an intervention holds no significance in designing or prescribing exercise interventions for post-BS patients. This finding aligns with the absence of a clear relationship between intervention duration and drop-out rates. Hence, it indicates that intervention duration does not contribute to the effectiveness of the intervention in terms of preservation and feasibility of completing exercise. Our findings are in accordance with those of Votruba et al. (2000), whose review underlines the discrepancy in exercise duration. Some results advocate for a minimum 12-week duration, while others achieve similar outcomes with only six weeks of intervention (Votruba et al., 2000). However, it appears imperative to maintain engagement in some form of exercise or physical activity post-intervention, as evidence indicates that a sustained increase in physical activity subsequent to an exercise intervention may contribute to weight maintenance and FFM preservation in individuals with obesity (Waters et al., 2013).

Moreover, examining potential discrepancies in FFM preservation between patients in the late phase (> 2 years) post-BS and those in the early phase post-BS (≤ 3 months) is of clinical significance. Our results reveal that studies involving patients in the late phase post-surgery demonstrate superior FFM preservation in the IG compared to the CG (Lamarca et al., 2021; Marc-Hernández et al., 2020) (Figure 3). This finding has been confirmed by Davidson et al. (2018), who showed that FFM is either maintained or decreases minimally between one and five years post-BS. This underlines the importance of implementing an exercise intervention within the first year post-BS to preserve FFM. Furthermore, the role of a pre-bariatric surgery (pre-BS) exercise program and its potential benefits should not be overlooked. Our findings suggest that a pre-BS exercise program may lead to better preservation of FFM comparing to the CG, although this effect was not statistically significant ($p= 0.052$) (Tokgoz et al., 2022). A recent meta-analysis by Durey et al. (2022) found a slight increase in cardiorespiratory fitness resulting from pre-BS exercise interventions. This improvement in cardiorespiratory fitness could potentially contribute to a decrease in all-cause mortality in both the general and clinical populations. However, the results of the meta-analysis remain inconclusive, making it difficult to draw definitive conclusions. Since this systematic review included only one study investigating the effect of pre-BS exercise interventions, it is not possible to reach a conclusive determination on this topic.

Ten out of fourteen studies highlighted the superiority of the IG in preserving FFM over time, both before and after BS. Upon closer inspection of the results, it is noteworthy that nearly all studies (n=12) demonstrating enhanced FFM preservation post-BS incorporated a supervised training regimen. Much heterogeneity was noted considering the drop-out rates of included supervised studies. It can thus be assumed that supervision is not a confounding variable for the feasibility of these interventions. This assumption is supported by the study of Dalager et al. (2015), which shows that supervision is not a predictor of compliance or any health, behaviour and performance outcomes of interventions. However, it should be noted that since supervision seems to increase the preservation of FFM, integrating it into the exercise protocol will still be regarded as preferable.

Even though the frequency of training sessions remained relatively consistent across all included studies, it did not appear to significantly impact the drop-out rate. It can however be concluded that frequency can act as an important modifiable factor for reaching the volume necessary to achieve muscle hypertrophy (Bernárdez-Vázquez et al., 2022). Evidence shows that it may be unrealistic for post-BS patients to maintain public health recommendations, however a frequency of three to four sessions per week was found to be more feasible (Coleman et al., 2017). Overall, a large heterogeneity can be seen between the drop-out rates, regardless of intervention duration. Therefore, the most used frequency of three sessions per week will be recommended as this has been backed up by previous feasibility research.

Nevertheless, combining all of these factors, the significance of individualised exercise programmes facilitated by shared decision-making and healthcare professionals' implementation of the self-determination theory should not be underestimated, as demonstrated by Edmunds et al. (2007) and Joosten et al. (2008). Therefore, eliciting intrinsic motivation in patients, coupled with the principles of shared decision-making, will play a crucial role in both adherence and drop-out rates when designing exercise interventions.

Understanding how to optimise the design of exercise programs pre- or post-bariatric surgery is crucial. However, alongside exploring these dynamics, it is equally imperative to acknowledge the demographic landscape in which these interventions operate.
The demographic distribution among participants in the included studies reveals a notable predominance of females, with a proportion of 85%. This trend towards higher proportions of up to 80% of female patients in bariatric surgery has been confirmed by Aly et al. (2020). Previous research indicates that male patients typically experience greater loss of FFM post-operatively. This phenomenon may be attributed to several factors, including the larger preoperative FFM observed in male patients and differences in muscle fibre composition between sexes. Specifically, men tend to exhibit significantly larger areas of type II muscle fibres, which are more susceptible to atrophy during periods of decreased energy intake, such as the post-operative period (Miller et al., 1993; Nuijten et al., 2020). Concurrently, a deeper understanding of BS and exercise benefits, particularly considering the distinct physiological responses exhibited by women during the menopausal phase, is essential. During menopause there is a decline in ovarian hormones, notably oestrogen, leading to a decrease in fat oxidation during prolonged exercise, given that oestrogen is naturally lipolytic (Isacco et al., 2012). Therefore, it was sought to identify potential adjustments for exercise interventions to account for differences based on whether the patient is male or female and their menopausal status. A conclusion on this subject could not be made in accordance with available data as the proportion of male participants, as well as distinct data between sexes was found to be

insufficient. Consequently, the precise magnitude of sex-related influences on exercise and energy restriction remains ambiguous, both within the scope of our findings and in previous literature.

5.3 Reflection on strengths and limitations of the review

This study contributes to a vital yet underexplored research area by combining evidence from diverse individual studies into a well-defined and comprehensive article. The basis of this review supports on well-defined inclusion and exclusion criteria, coupled with an assessment of the methodological quality of the incorporated studies. Notably, a strength of this study lies in adhering to the PRISMA guidelines for systematic reviews to ensure a transparent and standardised approach to the review process. In contrast, this study also suffers several weaknesses. The search was conducted using only two databases. Expanding the search to include multiple databases could potentially yield a greater number of relevant articles and enhance the comprehensiveness of the review, thereby aiding in more thoroughly addressing the research question. At the same time, including both observational and pilot studies could introduce potential bias. These weaknesses warrant consideration and acknowledgement to accurately process and interpret the outcomes of the study. Finally, certain articles lacked essential data required for obtaining more valuable insights into exercise prescription either pre- or post-bariatric surgery. Despite efforts to contact researchers, some did not respond to our inquiries.

5.4 Recommendations for future research

Future research should aim to address the current gaps in understanding the effectiveness of pre-bariatric surgery exercise interventions, as the available data remains inconclusive. Additionally, there is a critical need for further investigation into the complex interplay between sex, exercise, and energy restriction, particularly in the post-bariatric surgery context.

6. Conclusion

Generally, the key aspects of rehabilitation after bariatric surgery can be characterised according to the following principles. An effective intervention program should integrate RT targeting all major muscle groups, as this modality has been identified as the most effective for preserving lean muscle mass. Specifically, RT should consist of three sets of eight to twelve repetitions to stimulate hypertrophy of the trained muscles. Additionally, AE should be performed concurrently with RT, as the greatest amount of weight loss has been observed with this combination of modalities. When considering the type of exercise modality, it can be inferred that the exercise type alone is unlikely to significantly affect drop-out ratios. Concurrently, there does not appear to be a relationship between the duration of the intervention period and the drop-out rate. Consequently, both the type and duration of exercise intervention should be individualised by the clinician to match the capabilities and preferences of the patient. A frequency of three sessions per week has been found to be viable for improving hypertrophy in post-BS patients. The intervention should be supervised, as this has yielded better results in terms of FFM preservation. A shared decision-making process should facilitate the design of an individualised exercise program.

Regarding a potential sex-related influence on exercise outcomes in pre- and post-BS patients, no conclusion could be made following insufficient data on this topic. For the same reason, the effect of pre-BS interventions remains inconclusive.

Acknowledgements

The authors would like to mention their gratitude to Prof. Dr. Kenneth Verboven for his continued support and guidance throughout the process of their Master's thesis. Similarly, the reviewers are grateful to Dr. Gil, PhD, and colleagues, as well as Dr. Fonseca, PhD, and colleagues, for their generous provision of the necessary data.

7. References

Aly, S., Hachey, K., & Pernar, L. I. M. (2020). Gender disparities in weight loss surgery. *Mini-invasive Surgery*, *4*, 21. https://doi.org/10.20517/2574-1225.2019.57

André, L. D., Basso-Vanelli, R. P., Ricci, P. A., Di Thommazo-Luporini, L., de Oliveira, C. R., Haddad, G. F., Haddad, J. M., Parizotto, N. A., de Vieira, R., Arena, R., & Borghi-Silva, A. (2021). Whole-body electrical stimulation as a strategy to improve functional capacity and preserver lean mass after bariatric surgery: a randomized triple-blind controlled trial. *Int J Obes (Lond)*, *45*(7), 1476-1487. https://doi.org/10.1038/s41366-021-00812-7

Asselin, M., Vibarel-Rebot, N., Amiot, V., & Collomp, K. (2022). Effects of a 3-Month Physical Training on Cortisol and Testosterone Responses in Women After Bariatric Surgery. *Obes Surg*, *32*(10), 3351-3358. https://doi.org/10.1007/s11695-022-06225-3

Atkins, J. L., & Wannamathee, S. G. (2020). Sarcopenic obesity in ageing: cardiovascular outcomes and mortality. *British Journal of Nutrition*, *124*(10), 1102-1113. https://doi.org/10.1017/S0007114520002172

Auclair, A., Harvey, J., Leclerc, J., Piché, M. E., O'Connor, K., Nadreau, É., Pettigrew, M., Haykowsky, M. J., Marceau, S., Biertho, L., Hould, F. S., Lebel, S., Biron, S., Julien, F., Bouvet, L., Lescelleur, O., & Poirier, P. (2021). Determinants of Cardiorespiratory Fitness After Bariatric Surgery: Insights From a Randomised Controlled Trial of a Supervised Training Program. *Can J Cardiol*, *37*(2), 251-259. https://doi.org/10.1016/j.cjca.2020.03.032

Bell, M. L., Kenward, M. G., Fairclough, D. L., & Horton, N. J. (2013). Differential dropout and bias in randomised controlled trials: when it matters and when it may not. *Bmj*, *346*, e8668. https://doi.org/10.1136/bmj.e8668

Bellicha, A., van Baak, M. A., Battista, F., Beaulieu, K., Blundell, J. E., Busetto, L., Carraça, E. V., Dicker, D., Encantado, J., Ermolao, A., Farpour-Lambert, N., Pramono, A., Woodward, E., & Oppert, J.-M. (2021). Effect of exercise training on weight loss, body composition changes, and weight maintenance in adults with overweight or obesity: An overview of 12 systematic reviews and 149 studies. *Obesity Reviews*, *22*(S4), e13256. https://doi.org/https://doi.org/10.1111/obr.13256

Bernárdez-Vázquez, R., Raya-González, J., Castillo, D., & Beato, M. (2022). Resistance Training Variables for Optimization of Muscle Hypertrophy: An Umbrella Review [Mini Review]. *Frontiers in Sports and Active Living*, *4*. https://doi.org/10.3389/fspor.2022.949021

Campbell, T. M., & Vallis, L. A. (2014). Predicting fat-free mass index and sarcopenia in assisted-living older adults. *AGE*, *36*(4), 9674. https://doi.org/10.1007/s11357-014-9674-8

Castello, V., Simões, R. P., Bassi, D., Catai, A. M., Arena, R., & Borghi-Silva, A. (2011). Impact of aerobic exercise training on heart rate variability and functional capacity in obese women after gastric bypass surgery. *Obes Surg*, *21*(11), 1739-1749. https://doi.org/10.1007/s11695-010-0319-4

Coen, P. M., Tanner, C. J., Helbling, N. L., Dubis, G. S., Hames, K. C., Xie, H., Eid, G. M., Stefanovic-Racic, M., Toledo, F. G., Jakicic, J. M., Houmard, J. A., & Goodpaster, B. H. (2015). Clinical trial demonstrates exercise following bariatric surgery improves insulin sensitivity. *J Clin Invest*, *125*(1), 248-257. https://doi.org/10.1172/jci78016

Coleman, K. J., Caparosa, S. L., Nichols, J. F., Fujioka, K., Koebnick, C., McCloskey, K. N., Xiang, A. H., Ngor, E. W., & Levy, S. S. (2017). Understanding the Capacity for Exercise in Post-Bariatric Patients. *Obesity Surgery*, *27*(1), 51-58. https://doi.org/10.1007/s11695-016-2240-y

Dalager, T., Bredahl, T. G. V., Pedersen, M. T., Boyle, E., Andersen, L. L., & Sjøgaard, G. (2015). Does training frequency and supervision affect compliance, performance and muscular health? A cluster randomized controlled trial. *Manual Therapy*, *20*(5), 657-665. https://doi.org/https://doi.org/10.1016/j.math.2015.01.016

Davidson, L. E., Yu, W., Goodpaster, B. H., DeLany, J. P., Widen, E., Lemos, T., Strain, G. W., Pomp, A., Courcoulas, A. P., Lin, S., Janumala, I., Thornton, J. C., & Gallagher, D. (2018). Fat-Free Mass and Skeletal Muscle Mass Five Years After Bariatric Surgery. *Obesity*, *26*(7), 1130-1136. https://doi.org/https://doi.org/10.1002/oby.22190

Diniz-Sousa, F., Veras, L., Boppre, G., Sa-Couto, P., Devezas, V., Santos-Sousa, H., Preto, J., Vilas-Boas, J. P., Machado, L., Oliveira, J., & Fonseca, H. (2021). The Effect of an Exercise Intervention Program on Bone Health After Bariatric Surgery: A Randomized Controlled Trial. *J Bone Miner Res*, *36*(3), 489-499. https://doi.org/10.1002/jbmr.4213

Durey, B. J., Fritche, D., Martin, D. S., & Best, L. M. J. (2022). The Effect of Pre-operative Exercise Intervention on Patient Outcomes Following Bariatric Surgery: a Systematic Review and Meta-analysis. *Obesity Surgery*, *32*(1), 160-169. https://doi.org/10.1007/s11695-021-05743-w

Ebbeling, C. B., Swain, J. F., Feldman, H. A., Wong, W. W., Hachey, D. L., Garcia-Lago, E., & Ludwig, D. S. (2012). Effects of Dietary Composition on Energy Expenditure During Weight-Loss Maintenance. *JAMA*, *307*(24), 2627-2634. https://doi.org/10.1001/jama.2012.6607

Edmunds, J., Ntoumanis, N., & Duda, J. L. (2007). Adherence and well-being in overweight and obese patients referred to an exercise on prescription scheme: A self-determination theory perspective. *Psychology of Sport and Exercise*, *8*(5), 722-740. https://doi.org/https://doi.org/10.1016/j.psychsport.2006.07.006

Fuchs, H. F., Broderick, R. C., Harnsberger, C. R., Chang, D. C., Sandler, B. J., Jacobsen, G. R., & Horgan, S. (2015). Benefits of Bariatric Surgery Do Not Reach Obese Men. *Journal of Laparoendoscopic & Advanced Surgical Techniques*, *25*(3), 196-201. https://doi.org/10.1089/lap.2014.0639

Gil, S., Kirwan, J. P., Murai, I. H., Dantas, W. S., Merege-Filho, C. A. A., Ghosh, S., Shinjo, S. K., Pereira, R. M. R., Teodoro, W. R., Felau, S. M., Benatti, F. B., de Sá-Pinto, A. L., Lima, F., de Cleva, R., Santo, M. A., Gualano, B., & Roschel, H. (2021). A randomized clinical trial on the effects of exercise on muscle remodelling following bariatric surgery. *J Cachexia Sarcopenia Muscle*, *12*(6), 1440-1455. https://doi.org/10.1002/jcsm.12815

Gloy, V. L., Briel, M., Bhatt, D. L., Kashyap, S. R., Schauer, P. R., Mingrone, G., Bucher, H. C., & Nordmann, A. J. (2013). Bariatric surgery versus non-surgical treatment for obesity: a systematic review and meta-analysis of randomised controlled trials. *BMJ : British Medical Journal*, *347*, f5934. https://doi.org/10.1136/bmj.f5934

Guida, B., Cataldi, M., Busetto, L., Aiello, M. L., Musella, M., Capone, D., Parolisi, S., Policastro, V., Ragozini, G., & Belfiore, A. (2018). Predictors of fat-free mass loss 1 year after laparoscopic sleeve gastrectomy. *Journal of Endocrinological Investigation*, *41*(11), 1307-1315. https://doi.org/10.1007/s40618-018-0868-2

Hansen, D., Decroix, L., Devos, Y., Nocca, D., Cornelissen, V., Dillemans, B., & Lannoo, M. (2020). Towards Optimized Care After Bariatric Surgery by Physical Activity and

Exercise Intervention: a Review. *Obesity Surgery*, *30*(3), 1118-1125. https://doi.org/10.1007/s11695-020-04390-x

Hassannejad, A., Khalaj, A., Mansournia, M. A., Rajabian Tabesh, M., & Alizadeh, Z. (2017). The Effect of Aerobic or Aerobic-Strength Exercise on Body Composition and Functional Capacity in Patients with BMI ≥35 after Bariatric Surgery: a Randomized Control Trial. *Obes Surg*, *27*(11), 2792-2801. https://doi.org/10.1007/s11695-017-2717-3

Herring, L. Y., Stevinson, C., Davies, M. J., Biddle, S. J., Sutton, C., Bowrey, D., & Carter, P. (2016). Changes in physical activity behaviour and physical function after bariatric surgery: a systematic review and meta-analysis. *Obesity Reviews*, *17*(3), 250-261. https://doi.org/https://doi.org/10.1111/obr.12361

Huck, C. J. (2015). Effects of supervised resistance training on fitness and functional strength in patients succeeding bariatric surgery. *J Strength Cond Res*, *29*(3), 589-595. https://doi.org/10.1519/jsc.0000000000000667

Isacco, L., Duché, P., & Boisseau, N. (2012). Influence of Hormonal Status on Substrate Utilization at Rest and during Exercise in the Female Population. *Sports Medicine*, *42*(4), 327-342. https://doi.org/10.2165/11598900-000000000-00000

Joosten, E. A. G., DeFuentes-Merillas, L., de Weert, G. H., Sensky, T., van der Staak, C. P. F., & de Jong, C. A. J. (2008). Systematic Review of the Effects of Shared Decision-Making on Patient Satisfaction, Treatment Adherence and Health Status. *Psychotherapy and Psychosomatics*, *77*(4), 219-226. https://doi.org/10.1159/000126073

Lamarca, F., Vieira, F. T., Lima, R. M., Nakano, E. Y., da Costa, T. H. M., Pizato, N., Dutra, E. S., & de Carvalho, K. M. B. (2021). Effects of Resistance Training With or Without Protein Supplementation on Body Composition and Resting Energy Expenditure in Patients 2-7 Years PostRoux-en-Y Gastric Bypass: a Controlled Clinical Trial. *Obes Surg*, *31*(4), 1635-1646. https://doi.org/10.1007/s11695-020-05172-1

Le Foll, D., Lechaux, D., Rascle, O., & Cabagno, G. (2020). Weight loss and quality of life after bariatric surgery: a 2-year longitudinal study. *Surg Obes Relat Dis*, *16*(1), 56-64. https://doi.org/10.1016/j.soard.2019.10.010

le Roux, C. W., & Heneghan, H. M. (2018). Bariatric Surgery for Obesity. *Medical Clinics of North America*, *102*(1), 165-182. https://doi.org/https://doi.org/10.1016/j.mcna.2017.08.011

Livhits, M., Mercado, C., Yermilov, I., Parikh, J. A., Dutson, E., Mehran, A., Ko, C. Y., & Gibbons, M. M. (2010). Exercise Following Bariatric Surgery: Systematic Review. *Obesity Surgery*, *20*(5), 657-665. https://doi.org/10.1007/s11695-010-0096-0

Maciejewski, M. L., Winegar, D. A., Farley, J. F., Wolfe, B. M., & DeMaria, E. J. (2012). Risk stratification of serious adverse events after gastric bypass in the Bariatric Outcomes Longitudinal Database. *Surg Obes Relat Dis*, *8*(6), 671-677. https://doi.org/10.1016/j.soard.2012.07.020

Marc-Hernández, A., Ruiz-Tovar, J., Aracil, A., Guillén, S., & Moya-Ramón, M. (2020). Effects of a High-Intensity Exercise Program on Weight Regain and Cardio-metabolic Profile after 3 Years of Bariatric Surgery: A Randomized Trial. *Sci Rep*, *10*(1), 3123. https://doi.org/10.1038/s41598-020-60044-z

Miller, A. E. J., MacDougall, J. D., Tarnopolsky, M. A., & Sale, D. G. (1993). Gender differences in strength and muscle fiber characteristics. *European Journal of Applied Physiology and Occupational Physiology*, *66*(3), 254-262. https://doi.org/10.1007/BF00235103

Molero, J., Moizé, V., Flores, L., De Hollanda, A., Jiménez, A., & Vidal, J. (2020). The Impact of Age on the Prevalence of Sarcopenic Obesity in Bariatric Surgery Candidates. *Obesity Surgery*, *30*(6), 2158-2164. https://doi.org/10.1007/s11695-019-04198-4

Morana, C., Collignon, M., & Nocca, D. (2018). Effectiveness of a Functional Rehabilitation Program After Bariatric Surgery: a Pilot Study. *Obes Surg*, *28*(8), 2321-2326. https://doi.org/10.1007/s11695-018-3154-7

Mousapour, P., Tasdighi, E., Khalaj, A., Mahdavi, M., Valizadeh, M., Taheri, H., Hosseinpanah, F., & Barzin, M. (2021). Sex disparity in laparoscopic bariatric surgery outcomes: a matched-pair cohort analysis. *Scientific Reports*, *11*(1), 12809. https://doi.org/10.1038/s41598-021-92254-4

Nuijten, M. A. H., Eijsvogels, T. M. H., Monpellier, V. M., Janssen, I. M. C., Hazebroek, E. J., & Hopman, M. T. E. (2022). The magnitude and progress of lean body mass, fat-free mass, and skeletal muscle mass loss following bariatric surgery: A systematic review and meta-analysis. *Obesity Reviews*, *23*(1), e13370. https://doi.org/https://doi.org/10.1111/obr.13370

Nuijten, M. A. H., Monpellier, V. M., Eijsvogels, T. M. H., Janssen, I. M. C., Hazebroek, E. J., & Hopman, M. T. E. (2020). Rate and Determinants of Excessive Fat-Free Mass Loss After Bariatric Surgery. *Obesity Surgery*, *30*(8), 3119-3126. https://doi.org/10.1007/s11695-020-04654-6

Obesity and overweight. (2024, 01/03/2024). World Health Organization. https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

Ravussin, E., Lillioja, S., Knowler, W. C., Christin, L., Freymond, D., Abbott, W. G. H., Boyce, V., Howard, B. V., & Bogardus, C. (1988). Reduced Rate of Energy Expenditure as a Risk Factor for Body-Weight Gain. *New England Journal of Medicine*, *318*(8), 467-472. https://doi.org/doi:10.1056/NEJM198802253180802

Schiavo, L., Scalera, G., Pilone, V., De Sena, G., Iannelli, A., & Barbarisi, A. (2017). Preservation of Fat-Free Mass After Bariatric Surgery: Our Point of View. *Obesity Surgery*, *27*(4), 1071-1073. https://doi.org/10.1007/s11695-017-2586-9

Stegen, S., Derave, W., Calders, P., Van Laethem, C., & Pattyn, P. (2011). Physical fitness in morbidly obese patients: effect of gastric bypass surgery and exercise training. *Obes Surg*, *21*(1), 61-70. https://doi.org/10.1007/s11695-009-0045-y

Thereaux, J., Lesuffleur, T., Czernichow, S., Basdevant, A., Msika, S., Nocca, D., Millat, B., & Fagot-Campagna, A. (2019). Long-term adverse events after sleeve gastrectomy or gastric bypass: a 7-year nationwide, observational, population-based, cohort study. *Lancet Diabetes Endocrinol*, *7*(10), 786-795. https://doi.org/10.1016/s2213-8587(19)30191-3

Tokgoz, G., Arman, N., Seyit, H., & Karabulut, M. (2022). Effects of pre-surgical aerobic dance-based exercise on lower extremity in people with morbid obesity awaiting bariatric surgery: Randomized controlled study. *Clin Obes*, *12*(4), e12529. https://doi.org/10.1111/cob.12529

Vieira, F. T., Godziuk, K., Lamarca, F., Melendez-Araújo, M. S., Lima, R. M., Prado, C. M., de Carvalho, K. M. B., & Dutra, E. S. (2022). Sarcopenic obesity diagnosis by different criteria mid-to long-term post-bariatric surgery. *Clin Nutr*, *41*(9), 1932-1941. https://doi.org/10.1016/j.clnu.2022.07.006

Votruba, S. B., Horvitz, M. A., & Schoeller, D. A. (2000). The role of exercise in the treatment of obesity. *Nutrition*, *16*(3), 179-188. https://doi.org/https://doi.org/10.1016/S0899-9007(99)00264-6

Waters, D. L., Vawter, R., Qualls, C., Chode, S., Armamento-Villareal, R., & Villareal, D. T. (2013). Long-term maintenance of weight loss after lifestyle intervention in frail, obese older adults. *The Journal of nutrition, health and aging*, *17*(1), 3-7. https://doi.org/https://doi.org/10.1007/s12603-012-0421-5

Weinheimer, E. M., Sands, L. P., & Campbell, W. W. (2010). A systematic review of the separate and combined effects of energy restriction and exercise on fat-free mass in middle-aged and older adults: implications for sarcopenic obesity. *Nutrition Reviews*, *68*(7), 375-388. https://doi.org/10.1111/j.1753-4887.2010.00298.x

8. Appendix

Table 1

PICO related to the Research Question

Acronym	Definition	Description
P	Patient or problem	Patients who underwent bariatric surgery (including both male and female)
I	Intervention	Exercise intervention of any kind
C	Comparison	Other exercise interventions or Usual care
O	Outcome(s)	Effects on fat-free mass and feasibility

Note. Utilisation of PICO enables a viable extraction of descriptors that can be used in several databases.

Table 2
Study and Participant Characteristics

Reference, (author(s), [year])	Primary			Secondary				
	Effects on FFM (after bariatric surgery) and measurement	Relative effect on FFM (%)	Attendance and/or Drop-out rate (%)	Gender distribution (female/male)	Timing of intervention	Duration of intervention period	Amount of weight loss (kg)	Bariatric surgery type
André et al. (2021)	↓ LM[a] Measurement: BIA	CG: -10.25 IG: -10.05	Attendance: N/A Drop-out: CG: 5.26 IG: 15.00	30/9	post-BS (6.7 ± 3.7 days)	6 weeks	N/A	RYGB
Asselin et al. (2022)	↑ LM[b] Measurement: BIA	CG: +4.70 IG: +5.50	Attendance: N/A Drop-out: CG: 0.00 IG: 0.00	20/0	post-BS (6 weeks)	3 months	CG: 27.30 IG: 28.10	RYGB, SG
Auclair et al. (2021)	↓ FFM[a] Measurement: BIB	CG: -10.13 IG: -10.74	Attendance: N/A Drop-out: CG: 15.00 IG: 17.50	45/13	post-BS (3 months)	3 months	CG: 34.20 IG: 37.00	SG, DS
Castello et al. (2011)	↓ LM[a] Measurement: skinfold thickness	CG: -10.45 IG: -7.94	Attendance: N/A Drop-out: CG: 37.50 IG: 31.25	32/0	post-BS (1 month)	12 weeks	CG: 23.00 IG: 23.00	RYGB

Table 2

Study and Participant Characteristics

	Primary			Secondary				
Reference, (author(s), [year])	Effects on FFM (after bariatric surgery) and measurement	Relative effect on FFM (%)	Attendance and/or Drop-out rate (%)	Gender distribution (female/male)	Timing of intervention	Duration of intervention period	Amount of weight loss (kg)	Bariatric surgery type
Coen et al. (2015)	↓ LM[a] Measurement: DXA	CG: -1.80 IG: -2.18	Attendance: N/A Drop-out: CG: 9.68 IG: 33.33	113/15	post-BS (1-3 months)	6 months	CG: 22.00 IG: 22.80	RYGB
Diniz-Sousa et al. (2021)	↓ LM[a] Measurement: DXA	CG: -19.40 IG: -15.94 †	Attendance: 39.00 Drop-out: CG: 28.57 IG: 26.79	50/11	post-BS (1 month)	11 months	CG: 40.40 IG: 38.10	RYGB, SG
Gil et al. (2021)	↓ FFM[b] Measurement: DXA	CG: -14.16 IG: -8.86 † †	Attendance: 83.00 Drop-out: CG: 32.50 IG: 30.00	80/0	post-BS (3 months)	6 months	N/A	RYGB
Hassannejad et al. (2017)	↓ FFM[a] Measurement: BIA	CG: -14.98 IG (A): -13.11 IG (AS): -11.06 †	Attendance: N/A Drop-out: CG: 5.00 IG (A): 10.00 IG: (AS): 10.00	45/15	post-BS (<1 week)	12 weeks	CG: 20.00 IG (A): 25.10 IG (AS): 24.90	RYGB, SG

Table 2

Study and Participant Characteristics

	Primary			Secondary				
Reference, (author(s), [year])	Effects on FFM (after bariatric surgery) and measurement	Relative effect on FFM (%)	Attendance and/or Drop-out rate (%)	Gender distribution (female/male)	Timing of intervention	Duration of intervention period	Amount of weight loss (kg)	Bariatric surgery type
Huck (2015)	↓ FFM Measurement: BIA	N/A	Attendance: 84.00 Drop-out: CG: N/A IG: N/A	12/3	post-BS (<1 year)	12 weeks	CG: 5.60 IG: 8.80	RYGB, GB
Lamarca et al. (2021)	↑ FFM Measurement: BIA	CG: -0.64 IG: +1.62	Attendance: N/A Drop-out: CG: 34.62 IG: 61.77	106/13	post-BS (2-7 years)	12 weeks	CG: -0.06 IG: 1.61	RYGB
Marc-Hernández et al. (2020)	↑ FFM Measurement: BIA	CG: -0.57 IG: +2.37	Attendance: N/A Drop-out: CG: 20.00 IG: 9.09	14/4	post-BS (37 months)	20 weeks	CG: -1.50 IG: 1.20	SG
Morana et al. (2018)	↑FFM[c] Measurement: BIA	CG: N/A IG: +4.90	Attendance: N/A Drop-out: CG: N/A IG: 74.00	19/4	post-BS (2 months)	10 weeks	N/A	SG

Table 2

Study and Participant Characteristics

Reference, (author(s), [year])	Primary			Secondary				
	Effects on FFM (after bariatric surgery) and measurement	Relative effect on FFM (%)	Attendance and/or Drop-out rate (%)	Gender distribution (female/male)	Timing of intervention	Duration of intervention period	Amount of weight loss (kg)	Bariatric surgery type
Stegen et al. (2011)	↓ FFM[c] Measurement: BIA	CG: -10.50 IG: -8.50	Attendance: N/A Drop-out: CG: 22.20 IG: 20.00	11/4*	post-BS (1 month)	12 weeks	CG: 26.60 IG: 22.70	RYGB
Tokgoz et al. (2022)	↓ MW[c] Measurement: BIA	CG: -16.32 IG: -12.09	Attendance: N/A Drop-out: CG: 0.00 IG: 23.53	31/3	pre-BS (3-6 months)	8 weeks	CG: 28.00 IG: 27.70	SG

Note. BIA, Bioelectrical Impedance Analysis; BIB, Bioelectrical Impedance Balance; BMI, Body Mass Index; CG, Control Group; DS, Duodenal Switch; DXA, Dual-energy X-ray Absorptiometry; FM, Fat Mass; FFM, Fat-Free Mass; GB, Gastric Banding; IG, Intervention Group; IG(A), Intervention Group (Aerobic); IG(AS), Intervention Group (Aerobic+Strength); LM, Lean Mass; MW, Muscle Weight; N/A, Not Applicable; post-BS, post-Bariatric Surgery; pre-BS, pre-Bariatric Surgery; RYGB, Roux-en-Y gastric bypass; SD, Standard Deviation; SG, Sleeve Gastrectomy; SMM, Skeletal Muscle Mass.

[a]$p \leq 0.05$ (intragroup), [b]$p \leq 0.01$ (intragroup), [c]$p \leq 0.001$ (intragroup), † $p \leq 0.05$ (significantly different from CG), † † $p \leq 0.01$ (significantly different from CG), * Only accounting for 15 patients included in analysis, four drop-outs were reported without information on sex.

Table 3
Description of Interventions in Included Studies

Reference, (author(s), [year])	Intervention
André et al. (2021)	Supervised training sessions (5x/week). *WB-EMSG*: 20-30 min, low intensity, 10-14 loaded dynamic exercises (squats, trunk flexion, upper limb exercises, and isometric abdomen contractions), use of EMS (rectangular wave by a symmetrical bipolar electric pulse). *ShamG*: exercise regimen mirrored to WB-ESMG group without EMS.
Asselin et al. (2022)	Supervised training program ET + RT (3x/week). ET: warm-up 3 min, 3x10 min at 60-75% VO2peak on cycle-ergometer or treadmill with alternating 3 min active recovery, cooling-down 3 min. RT: 30 min strength exercise for all large muscle groups.
Auclair et al. (2021)	Supervised training program AE + RT (3x/week). 3-5 min warm-up and cooling-down, 35 min at 60-75% HRR or 5-7 on modified BORG-scale performed on an ergometer. RT: 25 min, 3 sets of 10-12 reps for all major muscle groups. Control received usual care and general PA advice
Castello et al. (2011)	Supervised training program AE (3x/week). AE: warm-up 10 min (stretching and treadmill walking), 40 min treadmill walking with increasing intensity (50-70% HRmax) in 4 blocks, cooling-down 10 min (stretching and diaphragmatic breathing. Continuous monitoring of HR and BP.
Coen et al. (2015)	Semi-supervised training program AE (3-5x/week). AE: minimum 30 min of cycling (stationary or outdoors) or walking (treadmill or outdoors), at 60-70% of HRmax. Daily training time could be continuous or intermittent. Progression from 10-15min per session during the initial 4 weeks to 120min per week until the end of the intervention. Both groups attended 6 health education sessions.
Diniz-Sousa et al. (2021)	Supervised training program MT (3x/week). MT: 5 min warm-up, 10 min high-impact (running, jumping), 10 min balance (static and dynamic), 10 min high-impact, 35 min of RT performed for 2-3 sets with 4-12 reps (large trunk muscle groups, abdominal wall muscles, lower back muscles), 5 min cooling-down.
Gil et al. (2021)	Supervised training program RT + AE (3x/week). RT: 8-12 reps, 3 sets, all large muscle groups (leg-press, leg extensions, half squat, bench press, lat pulldown, seated row, calf raises), progressive load increase. AE: 30-60 min of treadmill walking at 50% of the difference between the ventilatory aerobic threshold and respiratory compensation point with progressive increase in time every 4 weeks.
Hassanejad et al. (2017)	Non-supervised training program AE + RT (3-5x/week). Aerobic and Aerobic + strength training groups. AE: 150-200 min weekly walking regimen with gradually increased walking speed, 12-14 on the Borg-scale. RT: 3x in addition to AE, 20-30 min of exercises with elastic bands focusing on shoulders and hips. No specific exercise regimen was prescribed to the control group.
Huck (2015)	Supervised training program RT (2-3x/week). RT: 10 min warm-up, 45 min circuit training consisting of 8-10 exercises targeting major muscle groups at 60-75% 1-RM, 8-12 reps for 1-3 sets (progressively increased), 5 min cooling-down. At the end of the training program, various training modalities (e.g., bodyweight exercises, free weights, etc.) are introduced.

Table 3
Description of Interventions in Included Studies

Reference, (author(s), [year])	Intervention
Lamarca et al. (2021)	Supervised training program RT (3x/week): RT: 10 min warm-up, 60 min of exercises targeting all major muscle groups (e.g. chest press, knee extension, hamstring curl, leg press, etc.), 8-12 reps for 3 sets, 6-8 points on OMINI-RES scale.
Marc-Hernández et al. (2020)	Supervised training program RT + ET (2-4x/week). RT: focussing on different muscle groups each session for the total involvement of 5 major muscle groups (hamstrings, pectorals, quadriceps, latissimus dorsi, and gastrocnemius). ET consisted of AE and HIIT. AE: 50 min performed on cycle-ergometers, elliptical machines, or treadmills with HR monitoring. HIIT: 5 min warm-up at 40-60% VO2max, 20 min with 30 sec bouts at 60-95% VO2max with active recovery at 40% VO2max, 3 min cool-down at 40% VO2max. HIIT is always combined with RT and flexibility exercises for a total of 50 min.
Morana et al. (2018)	Supervised training program RT + ET (2x/week). RT: rowing machine for engaging of UL and LL + core strengthening exercises. ET: 30 min on cycle ergometer in first sessions, 30 min on cycle ergometer and treadmill or elliptical bike in later sessions. Intensity at 60% HRmax. Addition of proprioception training with HUBER device and manual therapy. Progression was registered.
Stegen et al. (2011)	Supervised training program RT + ET (3x/week). 10 min warm-up and 10 min cooling-down. RT: 25 min of strength exercise targeting elbow and knee flexion and extension, 10-15 reps for 2-3 sets (gradual increase). ET: 10 min of cycling on a stationary bicycle, 10 min of treadmill walking, and 10 min of stepping at 60-75% HRR (gradual increase).
Tokgoz et al. (2022)	Supervised training program AE (2x/week). All parts of the aerobic exercise were accompanied by music. AE: 10 min warm-up (flexibility exercises) at 40-50% HRmax, loading phase (50-70% HRmax in the first 4 weeks, 60-80% HRmax in the last 4 weeks), lasting 40 minutes, involved exercises with an increasing rhythm, 10 min cooling-down at 40-50% HR max).

Note. WB-EMSG, Whole-Body Electromyostimulation Group; ShamG, Sham Group; EMS, Electrical Muscle Stimulation; ET, Endurance Training; RT, Resistance Training; AE, Aerobic Exercise; HRmax, maximal Heart Rate; UL, Upper Limb; LL, Lower Limb; HR, Heart Rate; HIIT, High-Intensity Interval Training; MT, Mixed Training; HRR, Heart Rate Reserve; PA, Physical Activity; 1-RM, One-Repetition Maximum.

Supplementary Table 1a

Search Query Details for PubMed - Comprehensive Search Terms and Filters

Concepts	Search Terms[a]	Hits
#1 Exercise intervention	"Exercise" OR "Physical Activity" OR "Exercise Therapy" OR "Exercise Training" OR "Resistance Training" OR "Aerobic Exercise" OR "High-Intensity Interval Training" OR "Strength Training" OR "Cardiovascular Exercise" OR "Endurance Training" OR "Flexibility Training" OR "Functional Training" OR "Balance Training"	60,349
#2 Bariatric surgery	"Bariatric Surgery" OR "Gastric Bypass" OR "Sleeve Gastrectomy" OR "Gastric Banding" OR "Biliopancreatic Diversion" OR "Duodenal Switch" OR "Metabolic Surgery" OR "Weight Loss Surgery"	2,274
#1 AND #2	(("Exercise" OR "Physical Activity" OR "Exercise Therapy" OR "Exercise Training" OR "Resistance Training" OR "Aerobic Exercise" OR "High-Intensity Interval Training" OR "Strength Training" OR "Cardiovascular Exercise" OR "Endurance Training" OR "Flexibility Training" OR "Functional Training" OR "Balance Training") AND ("Bariatric Surgery" OR "Gastric Bypass" OR "Sleeve Gastrectomy" OR "Gastric Banding" OR "Biliopancreatic Diversion" OR "Duodenal Switch" OR "Metabolic Surgery" OR "Weight Loss Surgery"))	179

Note. Comprehensive search query results, categorised by concepts along with their respective number of hits on PubMed.

[a]The search query was filtered to include Randomized Controlled Trials and Observational Studies.

Supplementary Table 1b

Search Query Details for Scopus - Comprehensive Search Terms and Filters

Concepts	Search Terms[a]	Hits
#1 Exercise intervention	(TITLE-ABS-KEY (("Exercise" OR "Physical Activity" OR "Exercise Therapy" OR "Exercise Training" OR "Resistance Training" OR "Aerobic Exercise" OR "High-Intensity Interval Training" OR "Strength Training" OR "Cardiovascular Exercise" OR "Endurance Training" OR "Walking"))) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE,"English"))	779,128
#2 Bariatric surgery	TITLE-ABS-KEY (("Bariatric Surgery" OR "Gastric Bypass" OR "Sleeve Gastrectomy" OR "Gastric Banding" OR "Biliopancreatic Diversion" OR "Duodenal Switch" OR "Metabolic Surgery" OR "Weight Loss Surgery")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE,"English"))	33,577
#3 Fat-Free mass	TITLE-ABS-KEY ("Fat free mass" OR "lean body mass" OR "skeletal muscle mass") AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (LANGUAGE,"English"))	25,161
#1 AND #2 AND #3	(TITLE-ABS-KEY (("Exercise" OR "Physical Activity" OR "Exercise Therapy" OR "Exercise Training" OR "Resistance Training" OR "Aerobic Exercise" OR "High-Intensity Interval Training" OR "Strength Training" OR "Cardiovascular Exercise" OR "Endurance Training" OR "Walking")) AND TITLE-ABS-KEY (("Bariatric Surgery" OR "Gastric Bypass" OR "Sleeve Gastrectomy" OR "Gastric Banding" OR "Biliopancreatic Diversion" OR "Duodenal Switch" OR "Metabolic Surgery" OR "Weight Loss Surgery"))) AND TITLE-ABS-KEY ("Fat free mass" OR "lean body mass" OR "skeletal muscle mass") AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English"))	117

Note. Comprehensive search query results, categorised by concepts along with their respective number of hits on Scopus.

[a]The search query was limited to articles and publications in the English language.