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Effectiveness of exercise training after bariatric surgery-a systematic literature review and meta-analysis

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13 **Effectiveness of exercise training after bariatric surgery – A systematic literature review**
14 **and meta-analysis**

15

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26

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32

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42 **Potential conflict of interest**

43 Authors declare that they have no conflict of interest.

44 **Abstract**

45 We aimed to conduct a systematic review and meta-analysis of controlled trials assessing
46 exercise training programs in patients with obesity undergoing bariatric surgery. We
47 systematically searched exercise training studies performed after bariatric surgery published
48 up to June 2017. Studies reporting changes in body composition, physical fitness, functional
49 capacity, objectively-measured physical activity, quality of life or relevant health outcomes
50 were included. The review protocol is available from PROSPERO (CRD42017069380).
51 Meta-analyses were conducted using random-effects models when data were available from at
52 least 5 articles. Twenty articles were included, describing 16 exercise training programs, of
53 which 15 were included in the meta-analysis. Overall, exercise training was associated with
54 higher weight loss (mean difference: -2.4 kg, 95% CI: -4.2;-0.6, $I^2=49%$, n=12), higher fat
55 mass loss (-2.7 kg, 95% CI: -4.5;-1.0, $I^2=50%$, n=8), improved VO_2 max and functional
56 walking (standardized mean difference: 0.86, 95% CI: 0.29;1.44, $I^2=57%$, n=6; 1.45, 95% CI:
57 0.32;2.58, $I^2=89%$, n=6, respectively). Exercise training was not associated with lean body
58 mass changes. In conclusion, exercise training programs performed after bariatric surgery
59 were found effective to optimize weight loss and fat mass loss and to improve physical
60 fitness, although no additional effect on lean body mass loss were found.

61 **Introduction**

62

63 Bariatric surgery is increasingly performed in patients with severe obesity worldwide and in
64 Europe¹. Bariatric surgery leads to marked weight loss, decreased morbidity and mortality,
65 and improved quality of life and physical function²⁻⁴. Clinical guidelines emphasize the need
66 for lifestyle changes, including regular physical activity, to enhance health benefits⁵.

67 Objectively-measured physical activity data indicate that most patients undergoing obesity
68 surgery have insufficient levels of physical activity⁶, suggesting important potential benefits
69 of physical activity interventions in these patients.

70

71 Emerging evidence suggests that physical activity might provide important health benefits
72 after obesity surgery. A positive relationship between self-reported physical activity and the
73 amount of weight loss has been described in a previous review published in 2011⁷. However,
74 evidence came from observational studies only. Two recent reviews published in 2015,
75 synthesizing findings from 5⁸ and 8⁹ intervention studies published at that time, suggested that
76 exercise performed before or after surgery might improve physical fitness and metabolic
77 health, without additional benefits on anthropometry and body composition^{8,9}. However, both
78 controlled and non-controlled studies were included, which represents a major bias given that
79 bariatric surgery in itself is associated with decreased fat mass and lean body mass¹⁰,
80 improved cardiorespiratory fitness⁴ and decreased muscle strength⁴. In addition, the number
81 of studies was insufficient to conduct a meta-analysis. Most recently, a number of controlled
82 trials have described the effects of exercise training on various outcomes related to body
83 composition, physical capacity or health status¹¹⁻²⁰. Therefore, a systematic updated overview
84 of this topic, complemented by a meta-analysis, is relevant.

85

86 The aim of this review was to propose an updated overview and meta-analysis of the
87 effectiveness of exercise training in patients with severe obesity undergoing bariatric surgery.

88

89 **Materials and Methods**

90

91 **Literature search, selection of studies and data extraction**

92 The systematic review protocol is available from PROSPERO (PROSPERO 2017:
93 CRD42017069380). The literature search was performed in June 2017, using four electronic
94 databases (PubMed, Web of Science, Cochrane Library and EMBASE). Combinations of
95 terms related to bariatric surgery ("bariatric surgery", "obesity surgery", "metabolic surgery",
96 "Roux-en-Y", "gastric bypass", "sleeve gastrectomy", "gastric banding", "duodenal switch")
97 and to physical activity ("physical activity", "exercise", "sedentary", "endurance", "resistance
98 training", "aerobic", "fitness", "muscle strength", "physical capacity") were used in the search.
99 The reference lists of included articles and review articles were also scanned for further
100 eligible studies. The initial inclusion criterion was the implementation of an exercise training
101 program in adult patients with obesity undergoing bariatric surgery. Other inclusion criteria
102 were: 1) articles written in English, 2) controlled trials comparing patients undergoing
103 bariatric surgery receiving either usual care or usual care and exercise training 3) patients
104 undergoing gastric bypass, sleeve gastrectomy, gastric banding, biliopancreatic diversion or
105 duodenal switch 4) intervention conducted after bariatric surgery, 5) pre- to post-intervention
106 changes reported for at least one of the following outcomes: anthropometry or body
107 composition, objectively-measured physical activity or physical capacity, health-related
108 quality of life, relevant other health outcomes.

109 The characteristics of included articles were extracted by one reviewer (AB) and checked by a
110 second reviewer (JMO), and included: authors, journal, year of publication, study design,

111 sample size, surgical procedure, description of intervention, outcomes, assessment tools, times
112 of measurement and main findings. Emphasis was placed on the description of intervention.
113 The TIDierR checklist (including 12 items: brief name, why, what materials and procedures,
114 who provided, how, where, when and how much, tailoring, modification of intervention
115 throughout trial, strategies to improve or maintain intervention fidelity and extent of
116 intervention fidelity) was used for description of interventions both in exercise and control
117 groups²¹.

118

119 **Quality assessment**

120 The methodological quality of included studies was scored using the Physiotherapy Evidence
121 Database (PEDro) scale (<https://www.pedro.org.au/>)²². The PEDro scale has been used
122 extensively to assess rehabilitation programs and exercise training interventions^{9, 23}. The
123 PEDro scale is an 11-item checklist (specification of eligibility criteria, random allocation,
124 concealed allocation, baseline comparability, blind subjects, blind therapists, blind assessor,
125 adequate follow up, intention-to-treat-analysis, between groups comparisons, point estimates
126 and variability) receiving a “yes” or “no” rating. The total score ranges from 0 to 10 since the
127 first item is not included in the calculation. Trials with a score < 4 were classified as poor-
128 quality, 4-5 as fair-quality, 6-8 as good-quality, and ≥ 9 as excellent-quality⁹. Quality of each
129 included study was assessed independently by two reviewers (AB, JMO). When opinions
130 differed, consensus was reached through discussion.

131

132 **Reporting of findings**

133 We reported changes in anthropometry, body composition, physical fitness, functional
134 capacity, objectively-measured physical activity, quality of life and health outcomes after
135 exercise training for each individual study (Table S1). Physical fitness included

136 cardiorespiratory fitness (assessed by a maximal exercise test) and maximal muscle strength.
137 Functional capacity was assessed with field-based fitness assessments (e.g. 6-minute walk
138 test, sit-to-stand test, half-squat test, arm curl test, chair sit-and-reach test, 8- foot up-and-go).
139 Functional walking refers to the distance walked during walking tests. To facilitate the
140 synthesis of results, we grouped related metabolic outcomes into broader categories, e.g.
141 fasting or post-prandial glucose and insulin, HOMA-IR, insulin sensitivity, insulin
142 responsiveness were grouped into a category named “glucose metabolism”; or total, LDL- or
143 HDL-cholesterol and triglycerides into the “lipid profile” category.
144 When several follow-up measurements were conducted, we reported results from the first
145 assessment after the end of the exercise training. When results of a single trial were reported
146 in several studies (e.g. the trial by Coen et al.²⁴ was followed by a series of studies^{12, 18, 25, 26}),
147 we selected results from the parent trial or from the study with the largest sample size.

148

149 **Data analysis**

150 We performed meta-analyses using Review Manager version 5.3 when data were available
151 from at least 5 studies. We reported the mean and standard deviation (SD) of absolute changes
152 in body mass, fat mass, lean body mass, VO₂max and functional walking (results of walking
153 tests). Absolute changes were calculated as differences between arithmetic means before and
154 after intervention. Transformation methods were used for studies that did not provide the SD
155 of absolute change but provided the exact p-value for intra-group or inter-group analyses, as
156 suggested by the Cochrane Handbook for systematic reviews of interventions²⁷. One study
157 was not included in the meta-analysis due to insufficient data despite attempts to contact the
158 study authors.

159 Data from intention-to-treat analyses were included whenever available in included studies.

160 Pooled-effect estimates were expressed as the weighted mean difference between exercise and

161 control groups for changes in body mass, fat mass and lean body mass. For changes in
162 VO₂max and functional walking, because different walking tests were performed and
163 VO₂max was expressed in values either relative to body mass or to lean body mass, estimates
164 were expressed as the standardized mean difference. Calculations were performed using a
165 random-effects model because of the small number of studies available and their
166 methodological diversity. A p-value < 0.05 was considered statistically significant.
167 Heterogeneity was measured using the I² test²⁷.
168 When the number of studies was insufficient to perform a meta-analysis, we synthesized
169 study findings by presenting the number of studies reporting (1) an improvement (i.e. if a
170 significant positive effect of exercise was found for at least one outcome, and no deterioration
171 was found) or (2) no change (i.e. if no significant difference in any direction was found
172 between exercise and control groups).

173

174 **Results**

175

176 **Study characteristics and quality**

177 Among the 3,504 articles initially identified, 20 were included in our review (Figure 1). The
178 main characteristics of the 20 articles are presented in Table 1. Five articles reported results of
179 the same intervention study^{12, 18, 25, 26, 28} and one study compared two interventions¹⁵. Sixteen
180 distinct intervention studies were therefore included. Studies were published between 2011
181 and 2017. Five studies were conducted in the USA, 3 in Brazil, 2 in Iran and UK and 1 in
182 Austria, Belgium and Italy. Studies were randomized (9 studies) or non-randomized (6
183 studies) controlled trials. Most studies had limited sample sizes, except for four studies that
184 included more than 50 participants^{13, 15, 17, 24}. Ten studies included both men and women, the
185 remaining studies included women only. Patients underwent Roux-en-Y gastric bypass

186 (RYGB) in 6 studies, sleeve gastrectomy in one study and either RYGB, gastric banding or
187 sleeve gastrectomy in the remaining studies. The most frequently reported outcomes were
188 anthropometry (15 studies), body composition (11 studies), physical function, VO₂max and
189 muscle strength (7, 6 and 6 studies, respectively) and health-related quality of life (6 studies).
190 Objectively-measured physical activity was reported in only 4 studies, blood pressure, glucose
191 metabolism and lipid profile in 4, 3 and 3 studies, respectively. Preoperative data were
192 collected in 6 studies.

193

194 **Study quality**

195 Study quality was rated as poor, fair and good in 2, 9 and 4 studies, respectively (Table 2). No
196 study was rated as excellent-quality. Most studies reported a measure of variability (15/15)
197 and conducted between-group comparison (14/15). About two-third to three-quarters of
198 studies were randomized, achieved similarity of groups at baseline and specified eligibility
199 criteria. About half of studies performed intention-to-treat analysis and concealed allocation
200 to experimental groups. Only one third of studies reported changes in one key outcome for at
201 least 85% of study participants. Blinding of participants, therapists or assessors could not be
202 achieved in any study, except for one that mentioned the blinding of all assessors²⁴.

203

204 **Description of interventions**

205 Interventions are described in detail in Table S2. Exercise started from 1 week after surgery²⁰
206 to 18 months after surgery²⁹. Duration of exercise training ranged from 1 month²⁰ to 24
207 months¹⁷, with a median duration of 3 months (Figure 2). Endurance training was performed
208 in 5 studies^{15, 24, 29-31}, resistance training in 2 studies^{14, 32}, a combination of endurance and
209 resistance training in 8 studies^{11, 13, 15-17, 19, 33, 34} and balance training in 1 study²⁰. Intensity of
210 exercise was usually defined in relative terms, according to maximal heart rate or maximal

211 strength. The intervention included a behavioral component in 4 studies (physical activity
212 and/or dietary counseling^{13, 29, 31, 33} and a protein, calcium and vitamin D supplementation in 1
213 study¹⁷). Exercise sessions were fully supervised (10 studies^{11, 13, 16, 19, 29-34}), partially
214 supervised (1 study²⁴) or not supervised (2 studies^{15, 17}). Supervision was not described in 1
215 study²⁰. Supervision was performed by physical activity specialists, physiotherapists, exercise
216 physiologists or experts in physical medicine. Sessions were performed in a hospital or
217 research center in 5 studies^{16, 19, 30, 31, 33}, and outdoor²⁹ or in a private training facility³² in one
218 study each. Only 1 study described that sessions were organized in groups³². One study
219 sought to increase adherence by proposing a variety of exercise modalities¹³. Most studies
220 provided no or very little information about the control group. The intervention received by
221 control patients, described in 7 studies, included physical activity and/or dietary counseling
222 sessions^{11, 13, 17, 19, 24, 31, 32}, with multivitamin and mineral supplementation indicated in 3
223 studies^{11, 17, 31}.

224

225 **Compliance**

226 The percentage of included participants who completed the study ranged from 60%¹¹ to
227 100%^{14, 19, 24} (Table S3). Only 2 studies performed analysis for completers, defined as patients
228 participating to either a minimum number of training sessions ($\geq 80\%$ ¹⁷) or a minimum
229 duration of training (≥ 120 min/week)²⁴. In these studies, completers represented around 70%
230 of all participants. Finally, 3 studies reported attendance to training sessions^{16, 32, 33} that ranged
231 from 75%³³ to 95%¹⁶.

232

233 **Effectiveness of interventions**

234

235 Overall, exercise training was associated with a higher loss in body mass (-2.4 kg, 95% CI: -
236 4.2, -0.6, $I^2=49%$, n=12 studies) and in fat mass (-2.7 kg, 95% CI: -4.5, -1.0, $I^2=50%$, n=8
237 studies) compared to the control group but was not associated with changes in lean body mass
238 (0.7 kg, 95% CI: -0.3, 1.7, $I^2=50%$, n=10 studies) (Figure 3). Exercise training was also
239 associated with an improvement in VO_2 max (standardized mean difference: 0.86, 95% CI:
240 0.29, 1.44, $I^2=57%$, n=6 studies), and in functional walking (standardized mean difference:
241 1.45, 95% CI: 0.32, 2.58, $I^2=89%$, n=6 studies) (Figure 4).

242 Sub-sample analyses were performed on VO_2 max expressed relative to body mass, reported in
243 5 studies^{19, 29, 31, 32, 34}. A mean difference of 2.87 mL/kg/min (95% CI: 0.63, 5.12, $I^2=83%$)
244 was found.

245

246 Changes in muscle strength, objectively-measured habitual physical activity, metabolic profile
247 and health related-quality of life were not included in the meta-analysis. Muscle strength
248 increased in most studies in the exercise group compared to the control group (Table 3).

249 Objectively-measured physical activity, metabolic profile (glucose metabolism, lipid profile,
250 blood pressure) and health-related quality of life were found unchanged after exercise
251 compared to control in most studies (Table 4).

252

253 **Discussion**

254

255 In this systematic review, we provided an updated overview of the effectiveness of exercise
256 training on physical fitness, body composition, objectively-measured habitual physical
257 activity, health-related quality of life and health outcomes in patients undergoing bariatric
258 surgery. The review identified 20 articles assessing the effect of 16 distinct exercise training
259 programs performed after surgery. Compared with the previous reviews by Coen et al. (2015)⁸

260 and Pouwels et al. (2015)⁹, this review added a number of recent articles published in 2016
261 and 2017 assessing a combination of endurance and resistance exercise training which, until
262 recently, had received little attention in the context of bariatric surgery. Our main finding was
263 that exercise training performed after bariatric surgery was effective to optimize weight loss
264 and fat mass loss and to improve physical fitness.

265

266 This meta-analysis provides evidence of additional benefits of exercise training on body mass
267 and body fat loss after bariatric surgery although no preservation of lean body mass was
268 found. This adds to the body of knowledge previously reviewed by Coen et al.⁸ and Pouwels
269 et al.⁹ who concluded that there was insufficient evidence for an additional effect of exercise
270 training on body composition. The amount of additional weight loss observed in our meta-
271 analysis, of approximately 2.5 kg, seems however to represent a relatively modest benefit as
272 compared to the amount of weight lost after bariatric surgery itself (i.e. around 30 to 35% loss
273 of initial weight during the first post-operative year²). The relatively small added energy
274 deficit induced by exercise may not be sufficient to substantially influence energy balance¹²,
275 especially taking into account that the post-bariatric setting is characterized by a major energy
276 deficit³⁵. Interestingly, the major part of weight loss seems to be related to loss in body fat,
277 which can be considered as a favorable effect. However, based on results of our meta-
278 analysis, exercise training was not significantly associated with changes in lean body mass,
279 compared to usual care without training. Preserving lean body mass in this context appears to
280 be particularly challenging, which might be explained, at least in part, by the dramatic
281 decrease in protein intake observed in the first months following bariatric surgery³⁵. When
282 associated with resistance training, protein supplementation is recognized as an important
283 means for preserving lean body mass during dietary-induced weight loss³⁶. The effects of

284 protein supplementation, with or without resistance training after bariatric surgery warrant
285 further investigation.

286

287 Another major finding of this meta-analysis was that exercise training further improved
288 physical fitness and physical function as assessed by walking tests. Overall, VO₂max was
289 improved in the exercise training group, compared to the control group, by a mean 2.9
290 mL/kg/min. Although not included in the meta-analysis, muscle strength also increased after
291 exercise training in most studies, whether assessed as lower-limb^{11, 14, 34} or upper-limb^{11, 15, 16,}
292 ³⁴ maximal strength. Cardiorespiratory fitness and muscle strength are predictors of mortality
293 risk both in healthy individuals and in patients with chronic diseases, including obesity³⁷⁻⁴⁰.
294 According to a meta-analysis with a combined sample size of over 100,000 participants, each
295 1-MET increase in cardiorespiratory fitness was associated with a 15% and 13% reduction in
296 all-cause and cardiovascular mortality, respectively⁴¹. The improvement in cardiorespiratory
297 fitness with exercise training observed in the present meta-analysis is therefore likely to be
298 associated with improved health status after bariatric surgery. Interestingly, additive effects
299 between low cardiorespiratory fitness and muscle strength have been reported⁴², which
300 emphasizes the need to promote both dimensions of physical fitness in patients with obesity
301 undergoing bariatric surgery.

302

303 Because of a limited number of studies and important methodological heterogeneity, we were
304 not able to compare the effects of different types of exercise training. Given the known
305 principle of specificity of exercise training, stating that the physiological adaptations to
306 exercise are specific to the type of exercise performed⁴³, we would expect that endurance
307 training would preferentially improve cardiorespiratory fitness, and that resistance training
308 would improve muscle strength. This hypothesis would, however, need to be confirmed in

309 patients undergoing bariatric surgery. Data were also insufficient to determine the minimum
310 amount of exercise needed to optimize weight loss. In secondary analyses of data from the
311 trial by Coen et al.²⁴, which investigated the effect of a semi-supervised endurance training
312 program, authors reported a significant weight and fat loss only in patients who exercised
313 most, i.e. those who exercised on average 286 minutes per week²⁵. The need to increase
314 exercise duration to promote weight loss would be in agreement with the role of physical
315 activity in general in the prevention of weight regain⁴⁴. Further analysis of the trial by Coen et
316 al²⁴ revealed that irrespective of exercise training, patients with the highest level of habitual
317 physical activity based on daily steps experienced higher body weight and body fat loss¹².
318 These findings suggest that increasing total physical activity (i.e. both exercise and incidental
319 physical activity) might be necessary to optimize weight loss and body composition changes
320 after bariatric surgery. However, direction and magnitude of change in habitual physical
321 activity after bariatric surgery is still a matter of discussion. According to recent reviews, data
322 generated from self-reported questionnaires consistently indicated an increase in physical
323 activity whereas data from objective measures indicated no change or only modest increases⁴,
324 ^{7, 8}. Of note is the fact that very few studies included in the present review assessed habitual
325 physical activity using objective methods such as accelerometry^{12, 16, 31}. Overall, these
326 findings emphasize the need for a more systematic and detailed assessment of physical fitness
327 and habitual physical activity to gain better understanding of the role of exercise training and
328 daily activities in the follow-up of bariatric surgery.

329

330 Although the overall study quality was rated as fair to good in most studies, a number of
331 studies under-reported important aspects of interventions such as the mode of delivery
332 (individual or group sessions), the potential modifications of the intervention during the
333 course of the study, or the use of strategies to improve or maintain adherence, which is a

334 frequent limitation of non-pharmacological interventions⁴⁵. Better describing the intervention
335 delivered to both the intervention and control groups would help interpret study results and
336 replicate studies in real-life settings²¹. Included studies were also characterized by important
337 variations in terms of intervention (type, duration and timing) and evaluation (timing of
338 assessment, assessment tools, data analysis and reporting). To date, data are insufficient to
339 answer important research questions, such as the effect by type of exercise, relevant
340 intervention duration or intervention timing, the additional effect of supervising exercise
341 sessions and the long term effect of exercise training. Two thirds of exercise programs lasted
342 3 months or less, which might be too short to observe a significant impact on health
343 outcomes. Interestingly, Muschitz et al.¹⁷ observed that the preservation of lean body mass
344 became significant only after 18 months of intervention, during the weight stabilization phase.
345 Long-term trials are needed to determine the most effective duration and timing of exercise
346 training programs in patients with obesity undergoing bariatric surgery.

347

348 **Conclusion**

349 Exercise training programs performed after bariatric surgery were found effective to increase
350 weight loss and fat mass loss and to improve physical fitness, although no additional effect on
351 lean body mass or health outcomes were found compared to usual care follow-up. This meta-
352 analysis provides evidence that exercise training is an effective strategy to optimize follow-up
353 care after bariatric surgery. Both health professionals and patients should be aware of the type
354 of benefits they should expect from an exercise program in this context, especially given the
355 fact that additional weight and fat loss with exercise was of relatively small magnitude.
356 Included studies were characterized by important heterogeneity, precluding an analysis by
357 type and amount of exercise. More studies are needed to identify the most effective and
358 feasible strategies and to better understand the role of daily physical activity in the follow-up

359 of bariatric surgery. Also, important aspects of interventions should be described in more
360 detail to facilitate implementation and maintenance of exercise training programs in post-
361 bariatric patients in routine clinical care.

362

363 **Conflict of Interest Disclosure Statement**

364 Authors declare that they have no conflict of interest.

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500

501 **Tables titles and legends**

502

503 **Table 1**

504 Title: Characteristics of included studies (N=20)

505 Legend: Articles are presented in chronological order and articles reporting results from the
506 same trial are presented together.

507 Abbreviations, RCT, randomized controlled trial; NRCT, non-randomized controlled trial;

508 RYGB, Roux-en-Y gastric bypass; SG, sleeve gastrectomy; GB, gastric banding; END,

509 endurance training; RES, resistance training, BALANCE, balance training; 6MWT, 6-minute

510 walk test; WC, waist circumference; TC, total cholesterol; TG, triglycerides; NA, not

511 available.

512

513 **Table 2**

514 Title: Results on study quality

515 Legend: PEDro criteria: (1) specification of eligibility criteria, (2) random allocation, (3)

516 concealed allocation, (4) baseline comparability, (5) blind subjects, (6) blind therapists, (7)

517 blind assessor, (8) adequate follow up, (9) intention-to-treat-analysis, (10) between groups

518 comparisons, (11) point estimates and variability.

519 The first criterion was not included in the calculation of the total score.

520

521 **Table 3**

522 Title: Changes in muscle strength, physical activity, quality of life and metabolic profile in

523 exercise group compared to control group

524 Legend:

525 Abbreviations, 1-RM, 1 repetition maximum or repetition-maximum or maximum weight that
526 can be used to complete 1 repetition; MVPA, moderate-to-vigorous physical activity; EE,
527 energy expenditure.

528

529 **Figures titles and legends**

530

531 **Figure 1:**

532 Title: Flow chart of the literature search

533

534 **Figure 2:**

535 Title: Timing of intervention and assessment

536 Legend: The letter “S” represents the time of surgery, the circles represent the time of
537 assessment and the lines represent the duration of the exercise training program. Some trials
538 have been reported in different articles. This figure includes only articles that present results
539 of the parent trial.

540

541 **Figure 3**

542 Title: Changes in body mass and body composition after bariatric surgery in exercise group
543 compared to control group

544 Legend: Presents the difference in change in body mass and body composition after bariatric
545 surgery between the participants in the exercise and control groups. The sample size
546 represents the number of participants who completed the trials.

547 Hassannejad 2017a: endurance training. Hassannejad 2017b: endurance and resistance
548 training

549

550

551 **Figure 4:**

552 Title: Changes in physical fitness after bariatric surgery in exercise group compared to control
553 group

554 Legend: Presents the difference in change in VO₂max and functional walking after bariatric
555 surgery between the participants in the exercise and control groups. The sample size
556 represents the number of participants who completed the trials.

557 Hassannejad 2017a: endurance training. Hassannejad 2017b: endurance and resistance
558 training

559

560 **Supporting information**

561 **Table S1:** Changes in anthropometry, body composition, objectively-measured physical
562 activity, physical fitness, quality of life and health outcomes in exercise and control groups

563 **Table S2:** Intervention description (using the TIDieR checklist)

564 **Table S3:** Compliance to exercise training program

Table 1

Authors	Country	Study design Sample size Surgery type	Intervention (in addition to usual care)	Outcomes	Measures for corresponding outcomes
Castello et al. (2011) ³⁰	Brazil	RCT n=21 W RYGB	<u>Type</u> : END, 3 sessions/week <u>Supervision</u> : total <u>Timing</u> : 3 months, starting 1 month after surgery	- Anthropometry: body weight, WC - Body composition - Physical function	- Clinical examination - Skinfolds - 6MWT
Castello-Simoes et al. (2013) ²⁸	Brazil	RCT n=19 W RYGB	<u>Type</u> : END, 3 sessions/week <u>Supervision</u> : total <u>Timing</u> : 3 months, starting 1 month after surgery	- Anthropometry: body weight - Physical function	- Clinical examination - 6MWT
Shah et al. (2011) ³¹	USA	RCT n=33 W+M RYGB, GB	<u>Type</u> : END, 5 sessions/week <u>Supervision</u> : total <u>Timing</u> : 3 months, starting 3-42 months after surgery + Behavioral intervention	- Anthropometry: body weight, WC - Body composition - Physical activity - VO ₂ max - Resting energy expenditure - Glucose metabolism: glucose, insulin - Lipid profile: TC, LDL-c, HDL-c, TG - Quality of life	- Clinical examination - DEXA - Pedometer - Maximal exercise test - Indirect calorimetry - Blood analyses, oral glucose tolerance test - Blood analyses - SF-36, IWQOL-L
Stegen et al. (2011) ³⁴	Belgium	NRCT n=15 W+M RYGB	<u>Type</u> : END + RES, 3 sessions/week <u>Supervision</u> : total <u>Timing</u> : 3 months, starting 1 month after surgery	- Anthropometry: body weight, WC - Body composition - VO ₂ peak: maximal exercise test - Muscle strength - Muscle fatigue - Physical function	- Clinical examination - Impedance - Maximal exercise test - Weight machines, handgrip dynamometer - Handgrip dynamometer - 6MWT, sit-to-stand test
Coen et al. (2015) ²⁴	USA	RCT n=128 W+M RYGB	<u>Type</u> : END 3-5 sessions/week <u>Supervision</u> : partial <u>Timing</u> : 6 months, starting 1-3 months after surgery	- Anthropometry: body weight, WC - Body composition - VO ₂ peak - Glucose metabolism: insulin sensitivity - Lipid profile: TC, LDL-c, HDL-c, TG - Blood pressure	- Clinical examination - DEXA - Maximal exercise test - Intravenous glucose tolerance test - Blood analyses - Clinical examination
Coen et al. (2015) ²⁶	USA	RCT n=101 W+M RYGB	<u>Type</u> : END 3-5 sessions/week <u>Supervision</u> : partial <u>Timing</u> : 6 months, starting 1-3 months after surgery	- Anthropometry: body weight WC - Body composition - VO ₂ peak: maximal exercise test - Glucose metabolism: insulin sensitivity	- Clinical examination - DEXA - Maximal exercise test - Intravenous glucose tolerance test

Woodlief et al. (2015) ²⁵	USA	RCT n=98 W+M RYGB	<u>Type:</u> END 3-5 sessions/week <u>Supervision:</u> partial <u>Timing:</u> 6 months, starting 1-3 months after surgery	- Intramyocellular lipids - Mitochondrial respiration - Lipid profile: TC, LDL-c, HDL-c, TG - Blood pressure - Anthropometry: body weight - Body composition - VO ₂ peak - Resting metabolic rate - Glucose metabolism: insulin sensitivity - Mitochondrial respiration - Lipid oxidation - Anthropometry: body weight - Body composition - Skeletal muscle mass - Physical activity and sedentary behavior - VO ₂ peak - Resting metabolic rate - Anthropometry: body weight, WC - Body composition - VO ₂ peak: maximal exercise test - Glucose metabolism: insulin sensitivity - MicroRNAs profiling - Lipid profile: TC, LDL-c, HDL-c, TG - Blood pressure	- Muscle biopsy - Muscle biopsy - Blood analyses - Clinical examination - Clinical examination - DEXA - Maximal exercise test - Indirect calorimetry - Intravenous glucose tolerance test - Muscle biopsy - Muscle biopsy - Clinical examination - DEXA - Computed tomography - Accelerometer - Maximal exercise test - Indirect calorimetry - Clinical examination - DEXA - Maximal exercise test - Intravenous glucose tolerance test - Arterialized blood analyses - Blood analyses - Clinical examination
Carnero et al. (2017) ¹²	USA	RCT n=96 W+M RYGB	<u>Type:</u> END 3-5 sessions/week <u>Supervision:</u> partial <u>Timing:</u> 6 months, starting 1-3 months after surgery	- Anthropometry: body weight - Body composition - Skeletal muscle mass - Physical activity and sedentary behavior - VO ₂ peak - Resting metabolic rate - Anthropometry: body weight, WC - Body composition - VO ₂ peak: maximal exercise test - Glucose metabolism: insulin sensitivity - MicroRNAs profiling - Lipid profile: TC, LDL-c, HDL-c, TG - Blood pressure	- Clinical examination - DEXA - Computed tomography - Accelerometer - Maximal exercise test - Indirect calorimetry - Clinical examination - DEXA - Maximal exercise test - Intravenous glucose tolerance test - Arterialized blood analyses - Blood analyses - Clinical examination
Nunez Lopez et al. (2017) ¹⁸	USA	RCT n=22 W+M RYGB	<u>Type:</u> END 3-5 sessions/week <u>Supervision:</u> partial <u>Timing:</u> 6 months, starting 1-3 months after surgery	- Anthropometry: body weight, WC - Body composition - VO ₂ peak: maximal exercise test - Glucose metabolism: insulin sensitivity - MicroRNAs profiling - Lipid profile: TC, LDL-c, HDL-c, TG - Blood pressure	- Clinical examination - DEXA - Maximal exercise test - Intravenous glucose tolerance test - Arterialized blood analyses - Blood analyses - Clinical examination
Huck et al. (2015) ³²	USA	NRCT n=15 W+M RYGB, GB	<u>Type:</u> RES 2-3 sessions/week <u>Supervision:</u> total <u>Timing:</u> 3 months, starting 4 months after surgery	- Anthropometry: body weight, WC - Body composition - VO ₂ max - Muscle strength - Physical function	- Clinical examination - Impedance - Maximal exercise test - Weight machines, handgrip dynamometer - Sit-to-stand test, chair sit-and-reach test
Jassil et al. (2015) ³³	UK	NRCT n=24 W RYGB, SG	<u>Type:</u> END + RES 1 session/week <u>Supervision:</u> total <u>Timing:</u> 2 months, starting 3-6 months after surgery + behavioral intervention	- Anthropometry: body weight - Physical function - Quality of life	- Clinical examination - 6MWT - Dartmouth COOP
Marchesi et al. (2015) ²⁹	Italy	NRCT n=20 W RYGB	<u>Type:</u> END, 3 sessions/week <u>Supervision:</u> total <u>Timing:</u> 10 months, starting 1-3 year after surgery + behavioral intervention	- Anthropometry: body weight, WC - Body composition - VO ₂ max - Quality of life - Lipid profile: TC, HDL-c, TG - Glucose metabolism: glucose	- Clinical examination - DEXA - Maximal exercise test - SF-36 - Blood analyses - Blood analyses

Muschitz et al. (2016) ¹⁷	Austria	RCT n=220 W+M RYGB, SG	<u>Type:</u> END + RES, 3 and 2 sessions/week + protein, calcium, vit. D supplementation <u>Supervision:</u> none <u>Timing:</u> 24 months, starting 2 week after surgery	- Anthropometry: body weight) - Body composition - Bone mineral density - Bone metabolism markers - Quality of life	- Clinical examination - DEXA - DEXA - Blood analyses - SF-36
Rojhani-Shirazi et al. (2016) ²⁰	Iran	RCT n=32 W SG	<u>Type:</u> BALANCE 4 sessions/week <u>Supervision:</u> not described <u>Timing:</u> 1 months, starting 5 days after surgery	- Anthropometry: body weight, WC - Balance control	- Clinical examination - Single leg stance, star excursion balance test, get up and go test
Campanha-Versiani et al. (2017) ¹¹	Brazil	NRCT n=37 W+M RYGB	<u>Type:</u> END + RES 2 sessions/week <u>Supervision:</u> total <u>Duration:</u> 9 months, starting 3 months after surgery	- Anthropometry: body weight - Body composition - Muscle strength - Bone mineral density - Bone turnover markers	- Clinical examination - DEXA - Weight machines - DEXA - Blood analyses
Coleman et al. (2017) ¹³	USA	RCT n=51 W+M RYGB, SG, lap band	<u>Type:</u> END + RES 2 sessions/week <u>Supervision:</u> total <u>Timing:</u> 6 months, starting 6-24 months after surgery + behavioral intervention	- Anthropometry: body weight - Physical activity - Physical function	- Clinical examination - Pedometer - 6MWT, 8-foot up-and-go, 30-s chair rise, arm curl test, chair sit-and-reach test
Daniels et al. (2017) ¹⁴	USA	RCT n=16 W RYGB	<u>Type:</u> RES 3 sessions/week <u>Supervision:</u> not described <u>Timing:</u> 3 months, starting 2 months after surgery	- Anthropometry: body weight - Body composition - Skeletal muscle mass - Muscle strength	- Clinical examination - Displacement plethysmography - MRI - Weight machines
Hassannejad et al. (2017) ¹⁵	Iran	RCT n=60 W+M RYGB, SG	<u>Type:</u> END 3-5 sessions/week or END 3-5 sessions/week + RES 3 sessions/week <u>Supervision:</u> none <u>Timing:</u> 3 months, starting 0 (END) to 5 (RES) week after surgery	- Anthropometry: body weight - Body composition - Muscle strength - Physical function	- Clinical examination - Impedance - Weight machines - Sit-to-stand test, 12-min walk-run test
Herring et al. (2017) ¹⁶	UK	RCT n=24 W+M RYGB, SG, GB	<u>Type:</u> END + RES 3 sessions/week <u>Supervision:</u> total <u>Timing:</u> 3 months, starting 12-24 months after surgery	- Anthropometry: body weight, WC - Body composition - Physical activity and sedentary behavior - Muscle strength - Physical function - Blood pressure	- Clinical examination - Impedance - Accelerometer - Handgrip dynamometer - Incremental shuttle walk test, sit-to-stand test - Clinical examination
Onofre et al. (2017) ¹⁹	Brazil	NRCT n=12 W RYGB, SG	<u>Type:</u> END + RES 3 sessions/week <u>Supervision:</u> total <u>Timing:</u> 3 months, starting 3 months after surgery	- Anthropometry: body weight, WC - VO ₂ peak	- Clinical examination - Maximal exercise test

Table 2

	Criteria											Total score	Coding
	1	2	3	4	5	6	7	8	9	10	11		
Castello et al. (2011) ³⁰	1	1	1	1	0	0	0	0	0	1	1	5	Fair
Shah et al. (2011) ³¹	1	1	0	1	0	0	0	0	1	1	1	5	Fair
Stegen et al. (2011) ³⁴	0	0	0	0	0	0	0	0	0	1	1	5	Fair
Coen et al. (2015) ²⁴	1	1	1	1	0	0	1	1	1	1	1	8	Good
Huck et al. (2015) ³²	0	0	0	1	0	0	0	0	1	1	1	4	Fair
Jassil et al. (2015) ³³	1	0	0	1	0	0	0	0	0	1	1	3	Poor
Muschitz et al. (2015) ¹⁷	1	1	1	1	0	0	0	0	1	1	1	6	Good
Marchesi et al. (2015) ²⁹	1	0	0	1	0	0	0	0	0	1	1	3	Poor
Rojhani-Shirazi et al. (2016) ²⁰	0	1	0	1	0	0	0	0	0	1	1	4	Fair
Campanha-Versiani et al. (2017) ¹¹	1	0	1	1	0	0	0	0	0	1	1	4	Fair
Coleman et al. (2017) ¹³	1	1	1	1	0	0	0	0	1	0	1	5	Fair
Daniels et al. (2017) ¹⁴	0	1	0	0	0	0	0	1	1	1	1	5	Fair
Hassannejad et al. (2017) ¹⁵	1	1	1	1	0	0	0	1	0	1	1	6	Good
Herring et al. (2017) ¹⁶	1	1	1	0	0	0	0	1	1	1	1	6	Good
Onofre et al. (2017) ¹⁹	1	0	0	1	0	0	0	1	1	1	1	5	Fair

Table 3

	Number of studies		
	Measuring the outcome	Reporting no difference between exercise and control groups	Reporting an improvement in exercise group vs. control group
Muscle strength			
Lower-limb 1-RM	3	0	3
Upper-limb 1-RM	4	1	3
Handgrip strength	3	1	2
Physical activity and energy metabolism			
MVPA	2	1	1
Daily steps	3	2	1
Mitochondrial respiration	1	0	1
Resting EE	2	2	0
Quality of life	4	4	0
Metabolic profile			
Glucose metabolism	3	2	1
Lipid profile	3	3	0
Blood pressure	4	3	1

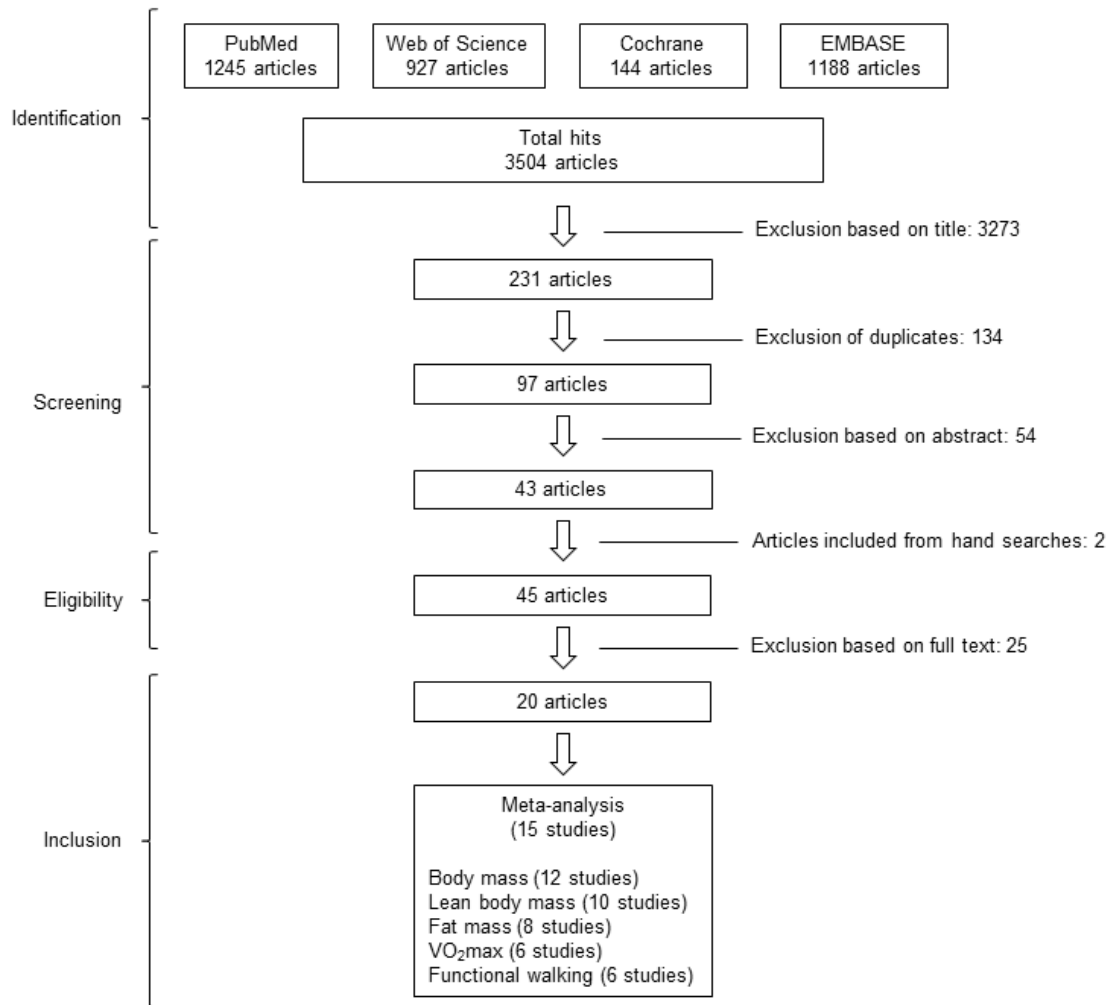


Figure 1

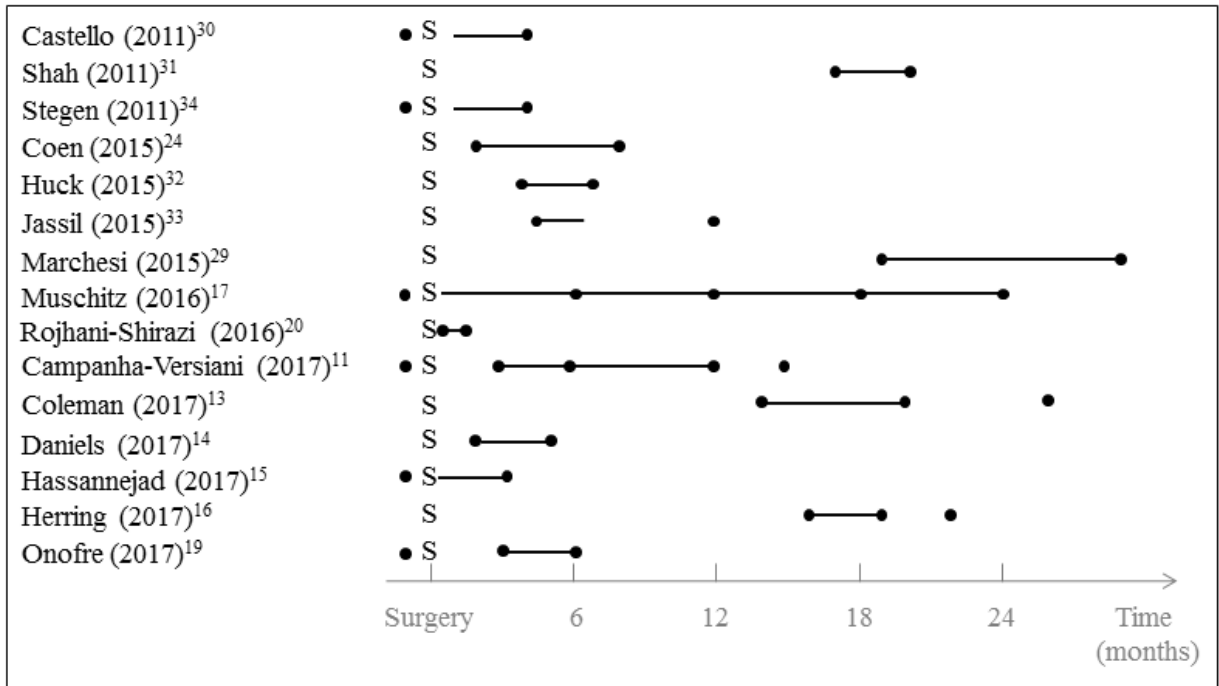
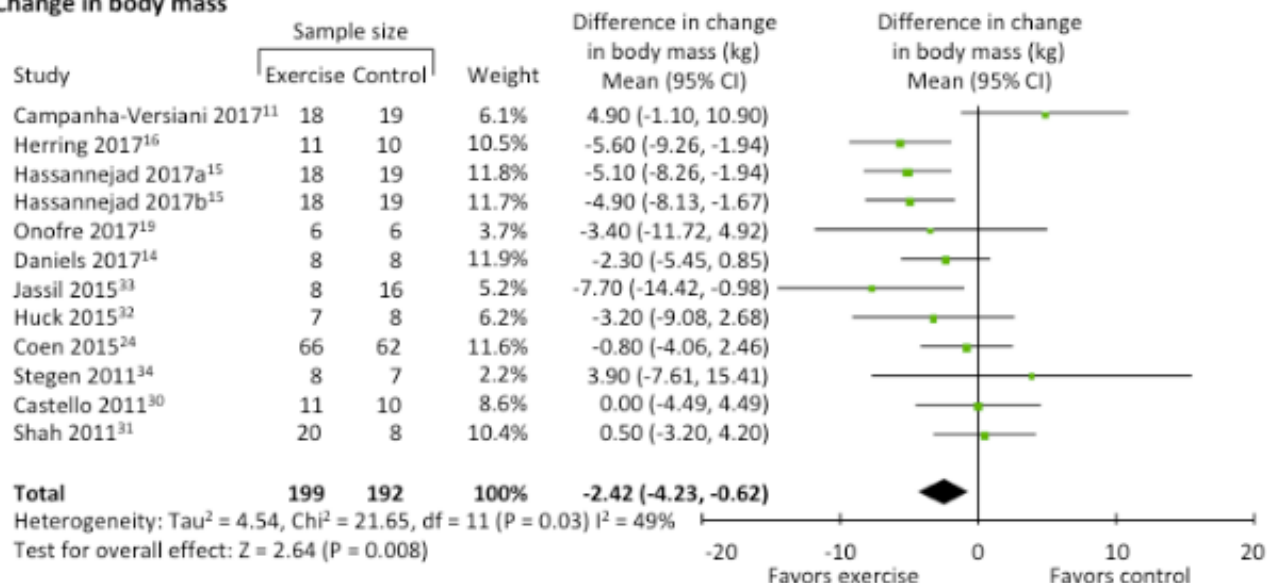
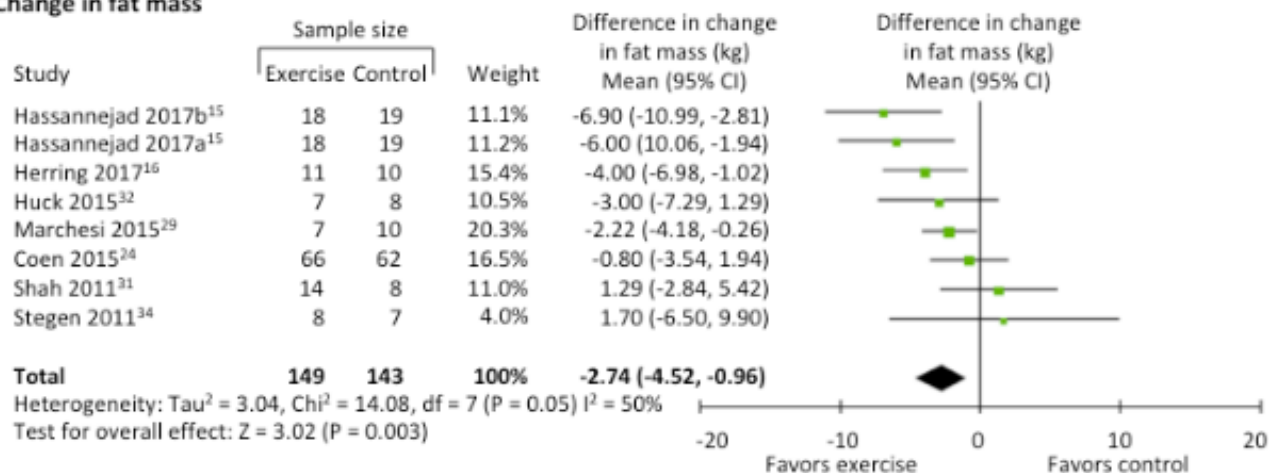


Figure 2

Change in body mass



Change in fat mass



Change in lean body mass

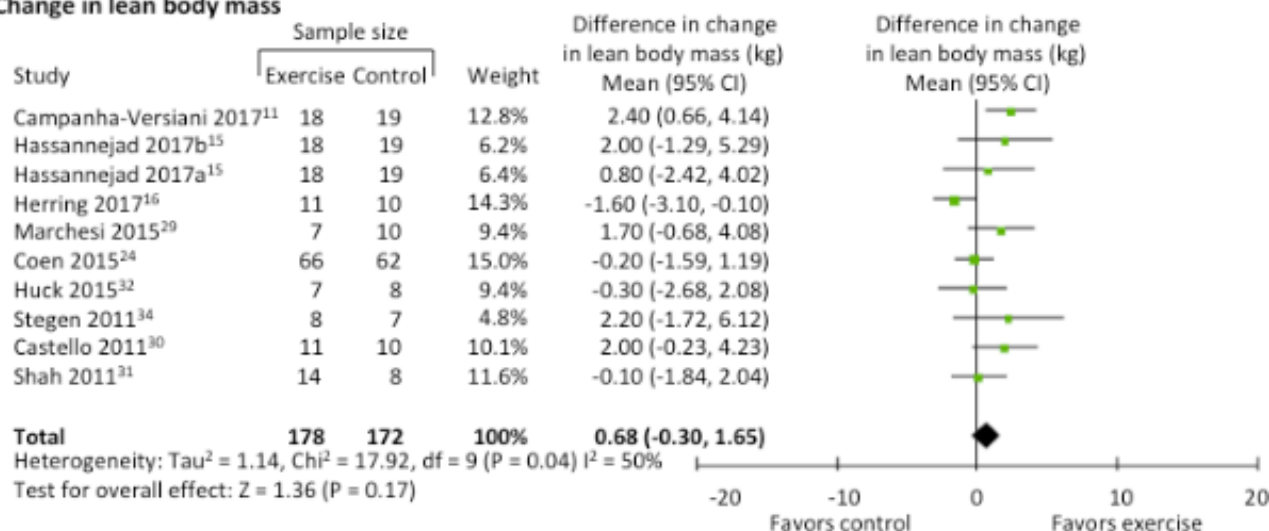
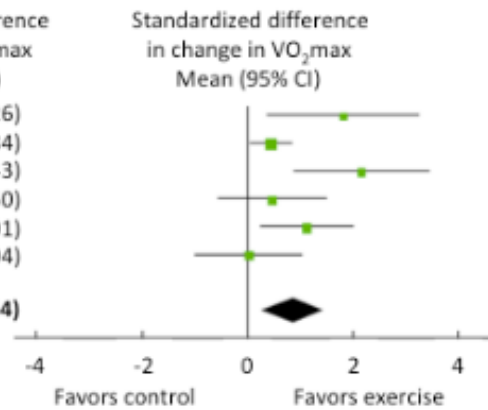


Figure 3

Change in VO₂max

Study	Sample size		Weight	Standardized difference in change in VO ₂ max Mean (95% CI)
	Exercise	Control		
Onofre 2017 ¹⁹	6	6	10.6%	1.82 (0.38, 3.26)
Coen 2015 ²⁶	50	51	27.5%	0.44(0.05, 0.84)
Marchesi 2015 ²⁹	7	10	12.3%	2.16 (0.89, 3.43)
Huck 2015 ³²	7	8	15.6%	0.47 (-0.56, 1.50)
Shah 2011 ³¹	20	8	18.1%	1.13 (0.25, 2.01)
Stegen 2011 ³⁴	8	7	15.9%	0.02 (-0.99, 1.04)
Total	98	90	100%	0.86 (0.29, 1.44)

Heterogeneity: Tau² = 0.27, Chi² = 11.71, df = 5 (P = 0.04) I² = 57%
 Test for overall effect: Z = 2.95 (P = 0.003)



Change in functional walking

Study	Sample size		Weight	Standardized difference in change in walking distance Mean (95% CI)
	Exercise	Control		
Coleman 2017 ¹³	21	23	15.6%	4.79 (3.58, 5.99)
Herring 2017 ¹⁶	11	10	16.0%	2.07 (0.96, 3.17)
Hassannejad 2017b ¹⁵	16	15	17.5%	0.61 (-0.11, 1.34)
Hassannejad 2017a ¹⁵	18	15	17.6%	0.44 (-0.26, 1.13)
Castello 2011 ³⁰	11	10	16.9%	0.72 (-0.17, 1.62)
Stegen 2011 ³⁴	8	7	16.3%	0.40 (-0.62, 1.43)
Total	85	80	100%	1.45 (0.32, 2.58)

Heterogeneity: Tau² = 1.75, Chi² = 46.64, df = 5 (P < 0.001) I² = 89%
 Test for overall effect: Z = 2.52 (P = 0.01)

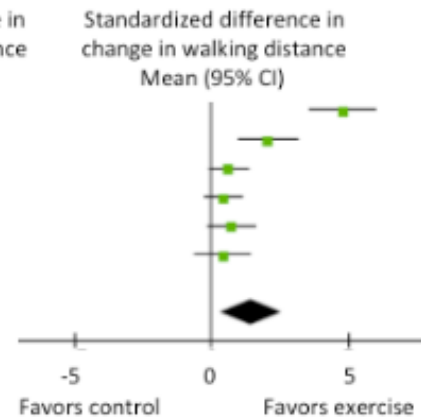


Figure 4