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5 (8) **Abbreviations:** PA, physical activity; PF, physical function; BMI, body mass index; SD,
6 standard deviation; SE, standard error; CI, confidence interval; SPPB, short physical
7 performance battery; SF-36, short form health survey; SMD, standardised mean difference.

8
9
10 **Abstract**

11 Although physical activity performed after bariatric surgery is associated with enhanced
12 weight loss outcomes, there is limited information on patients' physical activity behaviour in
13 this context. This systematic review and meta-analysis assessed pre to post-operative changes
14 in physical activity and physical function outcomes among obese adults undergoing bariatric
15 surgery. A total of 48 studies met inclusion criteria with 25 papers reporting data for meta-
16 analysis. Increases in both objectively recorded and self-reported physical activity at 12
17 months were demonstrated. Studies indicated that there was a shift towards a greater amount
18 of active time, but of a lower intensity within the first 6 months of bariatric surgery,
19 suggested by a reduction in moderate to vigorous physical activity but an increase in step
20 count. A standardised mean difference (SMD) of 1.53 (95% CI: 1.02 to 2.04) based on nine
21 studies indicated improved walking performance at 12 months. Similarly analysis of five
22 studies demonstrated increased musculoskeletal function at 3-6 months (SMD: 1.51; 95% CI:
23 0.60 to 2.42). No relationship was identified between changes in weight and walking
24 performance post-surgery. More studies assessing physical activity, physical function, and
25 weight loss would help understand the role of physical activity in optimising post-operative
26 weight and functional outcomes.

1 **Introduction**

2 Bariatric surgery is an effective weight-loss intervention for morbidly obese patients, and also
3 a successful treatment for comorbidities such as type 2 diabetes mellitus¹. A higher level of
4 physical activity after surgery has been associated with additional weight loss²⁻⁴. There is
5 currently limited information on patterns of physical activity in bariatric surgery patients.
6 One review suggested that physical activity tended to increase after surgery, although
7 considerable variation in results was observed⁴. This was partly attributed to the
8 heterogeneity in measurement tools across the studies included, most of which relied on self-
9 reported methods for assessing physical activity. It is notable that more recent studies⁵⁻⁷ have
10 included objective methods which may provide more accurate estimates of changes in
11 physical activity.

12 In addition to weight loss, several studies have reported positive changes in physical function
13 outcomes after surgery, such as cardiovascular endurance and muscular fitness^{5, 8-10}.

14 These functional abilities are important for enabling individuals to carry out activities of daily
15 living such as housework, childcare, lifting and carrying heavy objects, walking up hills or
16 stairs. A recent narrative review suggested that physical function improves after bariatric
17 surgery¹¹, but it remains unclear whether the improvements are a direct consequence of
18 weight loss, or whether physical activity leads to superior outcomes, over and above the
19 weight loss associated with surgery.

20 Given the rapidly-growing literature in physical activity for bariatric surgery patients, a
21 comprehensive and up-to-date review of the evidence is due. This review, therefore, aims to
22 assess pre to post-operative changes in physical activity behaviour and physical function
23 outcomes among obese adults receiving bariatric surgery.

24

25

1 **Methods**

2 *Eligibility criteria*

3 Studies were included if they involved at least 10 adults (aged ≥ 18 years) undergoing weight-
4 loss surgery, reported prospective assessments of physical activity or physical function pre-
5 surgery and at three or more months post-surgery. Published and unpublished studies were
6 searched and no language restrictions were imposed. Physical activity measures included
7 self-reported and objective methods (e.g. accelerometer, pedometer). Measures of physical
8 function included tests of cardiovascular endurance (e.g. treadmill/cycle ergometer stress
9 tests, timed walking tests), musculoskeletal fitness (e.g. timed up-and go, 1-rep repetition
10 maximum tests) and self-report (e.g. physical functioning scale of the Short-Form Health
11 Survey; SF-36). Studies were excluded if they only reported measurements at one time point
12 (i.e. only pre-surgery or only post-surgery), or only assessed anthropometric outcomes, gait
13 biomechanics, cardiac or respiratory muscle function.

14 *Search methods*

15 The search strategy was developed for Medline with advice from an information specialist.
16 The following electronic databases were searched from their respective inceptions: Medline,
17 SPORTDiscus, Cinahl, EMBASE, Cochrane Library, SCIRUS and OpenGrey (an
18 unpublished literature source). Search terms included MeSH headings and key words based
19 on bariatric surgery (e.g. bariatric surgery, gastric bypass, gastric band), physical activity/
20 physical function (e.g. exercise, physical activity, physical fitness, muscle strength) and were
21 modified for each individual database. In addition to searching databases, the reference lists
22 of all included papers and relevant review articles were scanned for further eligible studies¹².
23 The citation tracking service within Web of Science was also used for all papers meeting the
24 review criteria in order to identify papers published subsequently that may be eligible for

1 inclusion. Finally, five experts in the field of exercise and obesity were contacted to ask for
2 any further published or unpublished studies. Studies were included up until July 2015.

3 ***Study selection***

4 The titles and abstracts of all items identified through the electronic searches were screened
5 for potential eligibility by the primary author (LH) and a random 25% of items were screened
6 independently by a second reviewer (CS) to check for consistency. A kappa score of 0.93
7 was achieved. Full versions were read by two reviewers (100% by the primary author [LH]
8 and 50% each by two further reviewers [CS, PC]) who independently applied the selection
9 criteria and recorded the decisions on a standardised form. The three reviewers met to discuss
10 any disagreements to reach a consensus.

11 ***Data extraction***

12 A data extraction form was developed and piloted. Details on study design, participants,
13 outcome measures, and results were recorded. The primary researcher (LH) reviewed and
14 extracted 100% of the data and two reviewers independently reviewed and extracted 50%
15 each (CS, PC). Any disagreements regarding data extraction were discussed until consensus
16 reached. In eight cases study authors were contacted in an attempt to obtain any missing
17 information.

18 ***Data analysis***

19 All included studies were summarised descriptively in tables. Meta-analyses were conducted
20 using Review Manager version 5.3 for Windows, for outcomes where mean and standard
21 deviation (SD) data were available, or could be obtained, from at least four studies. Post-
22 surgery assessments mostly aligned with one of two time points: 3-6 months, and 12 months.
23 To allow for the use of different measures across studies for some outcomes, pre-post
24 changes were calculated as a standardised mean difference (SMD) using Hedges' (adjusted) g,

1 which includes a correction for sample size bias. Studies were combined using a random-
2 effects model. Statistical heterogeneity was assessed by the I^2 test¹³.

3 **Results**

4 ***Study characteristics***

5 After removing duplicates, 990 articles had been identified by the search; 50 studies met the
6 inclusion criteria for the review and 26 papers reported data to be included in the meta-
7 analysis (Figure 1). The majority of studies were performed in the United States^{5, 7, 14-32}, with
8 five conducted in the Netherlands³³⁻³⁷ and four in Brazil³⁸⁻⁴¹. The types of bariatric surgery
9 received by participants varied between studies, but the two main surgery types were Roux-
10 en-y gastric bypass (30 studies)^{14, 16-25, 27, 29-32, 34, 38-49} and gastric banding (8 studies)^{33, 35-37, 50-}
11 ⁵³. Fourteen studies reported a physical activity outcome^{7, 14, 15, 17, 23, 25, 35-37, 42, 43, 47, 54, 55}, 30
12 reported a physical function outcome^{8, 18-21, 24, 26-34, 38-41, 44, 45, 49, 51-53, 56-60} and six reported both
13 physical function and physical activity data^{5, 16, 22, 46, 48, 50}. Included studies are described in
14 Tables 1 (physical activity outcomes) and 2 (physical function outcomes).

15 ***Physical activity outcomes***

16 Seventeen studies employed self-reported measures of physical activity, with seven reporting
17 increased activity at 3-6 months, and 11 at 12 months (Table 1). All but one study¹⁷ reported
18 improvements in activity 12 months post-surgery. Two studies reported leisure time physical
19 activity at both time points. Sjostrom *et al*⁵⁵ reported from a study of 1845 participants that
20 the proportion of individuals classified as active increased by 37.3% at 3-6 months, which
21 was maintained at 12 months. Vatieer *et al*⁴⁷ reported an improvement in leisure time physical
22 activity of 10 minutes per week at 3-6 months, and a further improvement of eight minutes
23 per week at 12 months. Seven studies used objective measures of physical activity (five used
24 accelerometers and two used pedometers). Step count data indicated an average increase of

1 between 1225-2749 daily steps^{5, 22, 50}, but accelerometer results suggested little change at
2 either 3-6 months or 12 months^{7, 15, 23, 42}.

3 *Physical function outcomes*

4 All studies assessing cardiovascular endurance outcomes reported improvements post-surgery
5 (Table 2). These included 19 tests of walking performance (treadmill exercise test, fastest
6 possible walking speed, walking speed, walking minutes per week, 6 minute walk test (6
7 MWT), 4-metre walk time, walking energy expenditure)^{22, 24, 26-31, 34, 38-41, 46, 51, 52, 58, 59} and two
8 of cycle ergometer endurance^{56, 60}. Meta-analysis based on 11 studies showed an increase in
9 walking performance at 3-6 months (SMD: 0.82; 95% CI: 0.57 to 1.06), with a heterogeneity
10 score of $I^2=43\%$ (Figure 2). At 12 months, analysis of nine studies also indicated increased
11 performance (SMD: 1.53; 95% CI: 1.02 to 2.04; $I^2=83\%$) (Figure 3).

12 Sub-sample analyses were carried out on the 6 MWT, a test indicative of functional exercise
13 capacity. At 3-6 months, based on five studies, an increase of 74.55 metres (95% CI: 46.9 to
14 102.2) was shown, with a heterogeneity score of 59%. From the three studies reporting 12
15 month data the increase was 184.36 metres (95% CI: 1.35 to 2.30). There was no clear
16 association between percentage weight change and percentage change in walking
17 performance pre to 12 months post bariatric surgery (Figure 4).

18 Measures of musculoskeletal function were used in 10 studies. Table 2 displays the specific
19 tests and indicates the direction of results. Meta-analysis demonstrated improvements 3-6
20 months post-surgery with a SMD of 1.51 (95% CI: 0.60 to 2.42; $I^2=81\%$). Only two studies
21 examined musculoskeletal outcomes at 12 months with both showing improved outcomes^{21, 24}.
22 Measures of absolute muscle strength/force/torque were reported in five studies with post-
23 surgery assessment ranging from 3 to 12 months. All studies reported a reduction in absolute

1 strength post-surgery, with pooled data indicating a SMD of -1.04 (95% CI: -1.76 to -0.33),
2 and heterogeneity score of $I^2=77\%$.

3 Eighteen studies included self-reported physical function, 17 of which used the SF-36^{5, 16, 18-}
4^{22, 32, 33, 44-46, 50, 53, 59} for assessing physical function. All studies reported an increase in the
5 physical function or physical component score post-surgery (Table 2). Mean SF-36 scores are
6 recorded out of a maximum of 100. Meta-analysis of eight studies indicated a mean SF-36
7 score difference of 22.57 (95% CI: 14.92 to 30.21) and heterogeneity score of $I^2=91\%$ at 3-6
8 months. At 12 months, the mean SF-36 score difference from eight studies was 22.35 (95%
9 CI: 16.6 to 28.10, $I^2=95\%$).

10

11 **Discussion**

12 This review indicates that physical activity is increased after bariatric surgery, as assessed by self-
13 reported and objective measures. All cardiovascular and musculoskeletal measurements of physical
14 function improved from pre to post surgery, while absolute muscle strength measurements decreased.
15 Meta-analyses of physical function suggest that self-reported physical function (SF-36), objective
16 musculoskeletal, and walking function improved within 6 months of bariatric surgery and improved
17 further by 12 months post-surgery.

18 *Physical Activity*

19 Self-reported outcome measures consistently indicated increased physical activity post-surgery.
20 However, the heterogeneity of measurement tools makes comparisons between studies difficult. The
21 Leisure Time Physical Activity Questionnaire⁶¹ was used in 3 studies, but a further 12 other tools
22 were reported across the remaining 14 studies. These provide a range of outcome data based on
23 minutes of activity^{15-17, 22, 43, 47, 48}, energy expenditure¹⁴, points on a scale^{35, 36, 46}, questionnaire specific
24 scoring^{37, 50} or percentage of active participants^{25, 54, 55}. Consistent use of a validated assessment tool
25 across studies would allow meaningful comparisons of physical activity behaviour in this population.

1 When examined by length of follow up, self-reported physical activity increased after surgery in all
2 studies at 3-6 months, and in all except one study at 12 months. However, whether self-reported
3 measures of physical activity concur with objectively measured physical activity in this population
4 has been questioned¹⁵.

5 In the current review, accelerometers and pedometers were utilised to obtain objective measurements
6 in seven studies. Only one of three studies demonstrated an increase in physical activity based on step
7 count from pre to 3-6 month follow up²², whereas all four studies showed increases at 12 months. The
8 two studies indicating a decrease in physical activity at 3-6 months post-surgery were based on
9 accelerometer data collected at exactly 6 months^{15, 23}. However the type of physical activity differed
10 (total physical activity²³ versus moderate to vigorous physical activity (MVPA)¹⁵). This reduction in
11 physical activity could be a result of the post-surgical metabolic changes induced by calorific
12 restriction²³. The study reporting increased physical activity 3-6 months post-surgery found an
13 increase of 2749 steps per day²². Step count does not provide an indication of the intensity of the
14 activity undertaken; however, when taking in to consideration the reduction of MVPA and total
15 physical activity, an increase in step count would suggest a shift in the intensity of physical activity
16 being undertaken 3-6 months post operatively. Participants may therefore undertake more light
17 activity at earlier post-operative time points.

18 The improvement in self-reported physical activity from pre to 3-6 months, and the general reduction
19 in objectively measured physical activity using accelerometers at the same post-operative time point is
20 of interest. Results support previous research which has also demonstrated over-reporting of post-
21 operative physical activity¹⁵. Over-reporting may represent a change in perceptions in the ease of
22 performing activities, due to improved physical function resulting from weight loss. Further research
23 is therefore needed to determine the reason for over-reporting post-operative physical activity in this
24 population. This over-reporting of physical activity, if unintentional, could have a detrimental
25 outcome on long-term weight maintenance. This review does, none the less, indicate that from pre to
26 12 months post-bariatric surgery both objective and self-reported physical activity increases.

1 Only two studies measured physical activity at both 3-6 months and 12 months post-surgery, both of
2 which used self-reported tools^{47, 55}. Sjoström *et al*⁵⁵ reported that the proportion of individuals that
3 were self-categorised as active increased by 37% at 3-6 months and was maintained at 12 months
4 after surgery, although we cannot tell their volume of physical activity. Vazier *et al*⁴⁷ reported an
5 improvement in leisure time physical activity at both post-operative time points. Physical activity
6 increased more in the first 3-6 months after bariatric surgery and then continued to improve at 12
7 months but at a slower rate, reflecting weight loss patterns observed in previous research⁵⁵. Weight
8 loss after bariatric surgery occurs rapidly in the first 6 months and slows towards 12 months with
9 weight regain indicated at the 12 to 24 month time point⁵⁵.

10 The most recent study included in this review focused on objective MVPA assessed by accelerometry
11 in a large sample. It suggested that 89.4% of post-surgery patients were still not sufficiently active by
12 12 months post-surgery⁵, that is they were not meeting the guidelines of ≥ 150 minutes of moderate
13 intensity physical activity weekly as recommended for the general adult population⁶². Step count data
14 indicated that participants were classified as ‘somewhat active’; that is, likely to be undertaking some
15 volitional activities and/or occupational activity 12 months post-surgery⁶³. Self-reported physical
16 activity questionnaires predominantly focus on leisure time physical activity, making it difficult to
17 determine intensity and enable comparisons to current physical activity guidelines. A large study by
18 Colles *et al*⁵⁰ did however differentiate between physical activity domains showing leisure time and
19 sport physical activity increased whereas work physical activity remained the same 12 months post-
20 operatively. The variability of self-reported and objectively measured physical activity tools used in
21 the different studies within this review makes it difficult to definitively state that physical activity
22 guidelines are not met 12 months post-surgery. More research is therefore needed to determine if the
23 increase in physical activity is sufficient. If not, interventions for increasing physical activity to
24 recommended levels post-surgery should be explored.

25 *Objective Physical Function*

1 Extreme obesity drastically inhibits physical function, physical performance and increases disability²⁴.
2 The current meta-analyses displayed large improvements in walking outcomes at 3-6 months and even
3 greater improvements at 12 months through bariatric surgery. As previously reported, walking speed
4 slows as a result of obesity⁴⁶. Therefore any post-operative improvements in walking speed would be
5 likely attributed to weight loss which would mean the greatest improvements occurring within 6
6 months of surgery. Walking distance improvement appeared to be similar between post-surgery
7 segments (pre to 3-6 months, 3-6 to 12 months) and functional walking distance patterns increased
8 consistently to 12 months at a greater rate than either physical activity or weight loss. This suggests
9 that walking improves as a result of weight loss, although it seems likely that physical activity is
10 required for improvement to be maintained once the rate of weight loss plateaus. However, the 12
11 month pooled result should be interpreted with caution due to high heterogeneity.

12 Objective evaluation of fitness and functional exercise capacity in this population is regularly assessed
13 by the 6 minute walk test³⁹. The mean improvements in all the studies which reported the 6 minute
14 walk tests distance from pre to 3-6 months and pre to 12 months post-surgery were 75 metres and 184
15 metres respectively. A minimal clinically importance difference (MCID) for the 6 minute walk test in
16 bariatric surgery patients has not been established. However, for patients with chronic obstructive
17 pulmonary disease, a change in the range of 54 to 80 metres has been estimated as clinically
18 meaningful⁶⁴. Based on these data, the improvement of 184 metres observed at 12 months in this
19 analysis, is likely to be of sufficient magnitude to be clinically useful in this population.

20 Large increases in musculoskeletal function were recorded at 3-6 months, which can translate into
21 mobility and strength improvements that facilitate activities of daily living. These might include
22 housework, stair climbing, hill walking, lifting and carrying heavy objects^{11, 24, 48}. Previous research
23 has also found that obesity affects musculoskeletal function and movements of daily living such as
24 transitioning from sitting to standing^{24,46}. The small number of studies reporting 12 month outcomes
25 meant meta-analysis was not possible. The two studies which did report 12 month data also reported
26 3-6 month data helping the understanding of post-surgery musculoskeletal function patterns. One
27 study reported the timed 'get up and go' test which improved by 2.3 seconds by 3-6 months, and a

1 further 0.7 seconds at 12 months²¹. This improvement is more than double the minimal detectable
2 change of 1.14 seconds reported in the literature⁶⁵. The second study reported the short physical
3 performance battery score improvement of 1.2 points at 3-6 months and a further 0.8 points at 12
4 months²⁴; this is double the score of 1.0 which represents a substantial meaningful change⁶⁶. Both
5 studies show the majority of improvement occurs by 3-6 months concurring with previous research²¹.
6 The current review does show that musculoskeletal function continues to improve at least up until 12
7 months post bariatric surgery.

8 With rapid weight loss, drastic fat free mass loss also occurs, typically between 33% and 50%
9 ^{48,67}. This supports the large reduction in absolute muscle strength indicated by the meta-analysis
10 (SMD of -1.04). Muscle torque was the only absolute value reported at both post-operative time
11 points showing a decrease of 15 newton metres by 3-6 months, and a twofold decrease by 12 months.
12 Fat-free mass loss negatively affects resting metabolic rate, with this metabolic response occurring
13 naturally to counter weight loss⁶⁸. Exercise training post bariatric surgery would be a useful
14 intervention to optimise post-surgical weight loss and body composition outcomes^{11, 69}.

15 *Self-reported Physical Function*

16 All included studies reported improvements in self-reported physical function regardless of post-
17 operative follow up time frame. This suggests patients perceive an improvement in their day to day
18 lifestyle activities and mobility after bariatric surgery. Studies reporting data from both post-operative
19 time points reveal greater improvements in self-reported physical function by 3-6 months after
20 surgery, with smaller improvements or maintenance from 3-6 to 12 months^{18, 21, 59}. This suggests that
21 the weight loss is directly responsible for functional improvements. However, it also reflects the
22 patterns observed of post-operative physical activity although data assessing both post-operative time
23 points is currently limited⁴⁷. Minimal clinically important points scores (MCIPS) for the SF-36 have
24 been identified between 10 (small) and 30 (large) in patients with chronic obstructive pulmonary
25 disease⁷⁰. The improvement of 18 points demonstrated at 12 months in the current analysis could
26 therefore be tentatively interpreted as moderately important changes in perceived function.

1 *Objective vs Self-reported Physical Function*

2 Objective and self-reported physical function measurements are not easily comparable because they
3 do not assess the same outcome. Nevertheless when examining the post-operative improvements,
4 physical function as assessed by the SF-36 as a component of health-related quality of life showed a
5 similar mean improvement at both 3-6 and 12 months, whereas the objective measurement of the
6 6MWT more than doubled in improvement from 3-6 to 12 months. Objective musculoskeletal results
7 also display larger improvements by 3-6 months with continued improvement by 12 months, albeit at
8 a slower rate. Absolute muscle torque was the only absolute value reported at both post-operative time
9 frames showing absolute muscle torque decreased consistently to 12 months. No obvious pattern was
10 shown between objective and subjective methods. This may suggest that self-reported assessments of
11 physical function may over estimate improvements 3-6 months post-surgery, or under estimate
12 improvements 12 months post-surgery, indicating the importance of objective measurement of
13 physical function.

14 *Physical function and weight loss*

15 Positive changes in physical function outcomes and weight loss alone have been reported following
16 bariatric surgery^{5, 8-10}. We therefore plotted the results of eight studies that provided data on the 6MWT
17 and weight (Figure 4), concluding that the relationship between weight loss and walking performance
18 is still unclear. Research also suggests that physical activity is associated with greater weight loss
19 leading to improved physical function¹¹, however self-reported improvements in physical function
20 from pre to post surgery as a result of weight loss alone have also been reported⁷¹. A clear relationship
21 between physical activity, physical function and weight loss is yet to be identified, since patterns have
22 not been directly investigated. Objective physical activity, self-reported physical function and weight
23 have been investigated in two studies^{5, 50}. Similarly only two studies report objective physical function,
24 self-reported physical activity and weight^{46, 48} and only one study reports weight with both objective
25 activity and function²². This makes it difficult to draw conclusions about the relationship between
26 post-operative outcomes, and more studies are needed that assess physical activity, physical function

1 and weight loss so that post-operative activity guidelines can be developed to optimise individuals'
2 outcomes.

3 One way to examine the importance of physical activity after surgery for optimising physical function
4 and weight outcomes is through exercise interventions. Although few such clinical trials exist, there
5 are encouraging findings in respect of the benefits of post-surgical exercise. Results of three
6 randomised trials indicate that an additional aerobic exercise programme after gastric banding surgery
7 led to superior improvements in functional capacity over surgery alone^{6, 72, 73} (as assessed by the
8 6MWT). A further trial investigated the effects of resistance training on fitness and functional strength
9 after bariatric surgery, and reported improvements in the sit-to-stand test, $\dot{V}O_2$ max and functional
10 strength compared to non-exercising counterparts⁷⁴. This research therefore suggests the importance
11 of exercise training post bariatric surgery to optimise physical activity, physical function, fat mass
12 loss and preserve fat free mass.

13 In conclusion, a systematic review of the evidence demonstrates that objective and self-reported
14 physical activity improves by 12 months after bariatric surgery. A decrease in objectively measured
15 MVPA and an increase in step count at 3-6 months, indicates a shift towards a greater amount of
16 lower intensity physical activity within the first 6 months after surgery. Walking, musculoskeletal and
17 self-reported physical function all improved by 12 months. No relationship was identified between
18 changes in weight and physical function. However, based on promising results from pilot studies,
19 larger trials are necessary to further understand the effects of physical activity on post-surgical
20 outcomes.

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- 1 Figure 1: The systematic review search process.
- 2 Table 1: Characteristics of all included studies with pre and post-operative measures of
- 3 physical activity.
- 4 Table 2: Characteristics of all included studies with pre and post-operative measures of
- 5 physical function.
- 6 Figure 2: Meta-analyses of pre to post-operative walking ability at 3-6 months. Forest plots of
- 7 random-effects meta-analyses of pre to post-operative objective functional walking ability.
- 8 Figure 3: Meta-analyses of pre to post-operative walking ability at 12 months. Forest plots of
- 9 random-effects meta-analyses of pre to post-operative objective functional walking ability.
- 10 Figure 4: Percentage improvement in pre to 12 months post-operative walking verses weight.
- 11

Table 1: Characteristics of all included studies with pre and post-operative measures of physical activity

Author, publication date (Reference)	Sample size	BMI	Surgery Type	Measure of physical activity	Measurement units	Physical activity level Pre-surgery	Physical activity level 3-6 month post-surgery	Physical activity level 12 month post-surgery	Improved outcome when compared to baseline
Self-Reported Physical Activity									
Boan <i>et al.</i> , 2004 ¹⁴	40	52.9	RYGB	Baseline questionnaire of activity	Kcal/week	239.8 ± 266	1230.3 ± 1092	N/A	Yes (990.5 Kcal/week)
Bond <i>et al.</i> , 2008 ¹⁶	119	49.9	RYGB	International PA questionnaire – short form	min/week	170.2 ± 325.2	N/A	385.9 ± 458	Yes (215.7 min/week)
Bond <i>et al.</i> , 2010 ¹⁵	20	50.1	RYGB, GB	Paffenbarger PA questionnaire	min/week	44.6 ± 80.8	212.3 ± 212.4	N/A	Yes (167.7 min/week)
Carrasco <i>et al.</i> , 2007 ⁴³	31	44	RYGB	Leisure time PA questionnaire	min/week	600 ± 878.4	1410 ± 1374	N/A	Yes (810 min/week)
Colles <i>et al.</i> , 2008 ⁵⁰	129	44.3	GB	Baecke PA questionnaire	Baecke total score	6.3 ± 1.17	N/A	7.32 ± 1.27	Yes (1.02Baecke total score)
Das <i>et al.</i> , 2003 ¹⁷	30	50.1	RYGB	Minnesota leisure time PA questionnaire	min/week	2205 ± 1540	N/A	1869 ± 91.7	No (336 min/week)
Josbeno <i>et al.</i> , 2013 ²²	18	46.9	RYGB	7 day PA recall	min/week	191.1 ± 228.23	231.7 ± 239.04	N/A	Yes (40.6 min/week)
King <i>et al.</i> , 2012 ⁵	276	47	All	7 day PA diary (≥150 min/week)	Number of people	82 ± 29.7	N/A	127 ± 46	Yes (45 people)
Lyytinen <i>et al.</i> , 2013 ⁴⁶	16	45.1	RYGB	Leisure time PA scale	Point scale (1[low]-3 [high])	1.81 ± 0.66	2.0 ± 0.57	N/A	Yes (0.19 point scale)
Mathus-Vliegen <i>et al.</i> , 2007 ³⁶	44	50.7	GB	PA duration per week	Point scale (1[low]-5 [high] min categories)	2.2 ± 1.0	N/A	2.8 ± 1.0	Yes (0.6 point scale)
Mathus-Vliegen <i>et al.</i> , 2004 ³⁵	49	50.0	GB	PA scale Score	Point scale	5.5 ± 1.4	N/A	7.2 ± 2.3	Yes (1.7 point scale)
Rosenberger <i>et al.</i> , 2010 ²⁵	131	51.8	RYGB	Proportion of people reporting no PA	%	37.4	N/A	7.6	Yes (29.8%)
Ruiz-Tovar <i>et al.</i> , 2013 ⁵⁴	50	50.4	SG	Modifiable PA questionnaire	% of sample (sedentary, moderate & active)	45 (90%) sedentary; 4 (8%) moderate; 1 (2%) active	N/A	20 (40%) sedentary; 25 (50%) moderate; 5 (10%) active	Yes (42% moderately active, 8% active)
Sjostrom <i>et al.</i> , 2004 ⁵⁵	1845	41.9	GB, RYGB, VBG	Proportion active during leisure time	%	54.7 (95% CI)	92.0 (95% CI)	92.0 (95% CI)	Yes (37.3%); Yes (37.3%)
Vatier <i>et al.</i> , 2012 ⁴⁷	86	48.1	RYGB	Leisure time PA questionnaire	min/week	80.0 ± 80.0	90 ± 80	108 ± 84	Yes (10); Yes (18 min/week)
Wouters <i>et al.</i> , 2010 ³⁷	42	47.0	GB	Baecke PA questionnaire	Sport index score	2.0 ± 0.6	N/A	2.5 ± 0.7	Yes (0.5 sport index score)
Wiklund <i>et al.</i> , 2014 ⁴⁸	29	42.0	RYGB	International PA questionnaire – short form	MET min/week	1231 ± 2001	N/A	2428 ± 2979	Yes (1197 MET min/week)
Objective Physical Activity									
Berglind <i>et al.</i> , 2014 ⁴²	56	39.1	RYGB	Accelerometer	MVPA min/day	30.9 ± 17.7	N/A	32.1 ± 24	Yes (1.2 min/day)
Bond <i>et al.</i> , 2010 ¹⁵	20	50.1	RYGB, GB	Accelerometer	MVPA min/week	41.3 ± 109.3	39.8 ± 71.3	N/A	No (1.5 min/week)
Colles <i>et al.</i> , 2008 ⁵⁰	129	44.3	GB	Pedometer	steps/day	6061.0 ± 2740.0	N/A	8716.0 ± 5348.0	Yes (2655 steps/day)
Josbeno <i>et al.</i> , 2010 ²²	11	46.9	RYGB	Pedometer	steps/day	4621.0 ± 3701.2	7370.0 ± 4240.0	N/A	Yes (2749 steps/day)
King <i>et al.</i> , 2012 ⁵	310	47.0	All	StepWatch 3	steps/day	7563 (median)	N/A	8788 (median)	Yes (1225 steps/day)
King <i>et al.</i> , 2015 ⁷	473	45.4	All	StepWatch 3	MVPA min/week	77.3 (median) (70.9-84.2)	N/A	106.0 (median) (97.8-116.4)	Yes (28.7 min/week)
Liu <i>et al.</i> , 2012 ²³	18	44.6	RYGB	Accelerometer	All PA hours/day	11.1 ± 4.2	10.6 ± 2.5	N/A	No (0.5 hours/day)

KEY: *RYGB: Roux-en Y gastric bypass; GB: gastric banding; VBG: vertical banded gastrectomy; PA: physical activity; min: minutes; Kcal: kilocalories; N/A - not applicable; CI: confidence interval.

Table 2: Characteristics of all included studies with pre and post-operative measures of physical function

Author, publication date (Reference)	Sample size	BMI	Surgery Type	Measure of physical function	Measurement units	Physical function level Pre-surgery	Physical function level 3-6 month post-surgery	Physical function level 12 months post-surgery	Improved outcome when compared to baseline
Self-Reported Physical Function									
Bond <i>et al.</i> , 2008 ¹⁶	119	49.9	RYGB	SF – 36	Physical function score	35.2 ± 10.6	N/A	51.9 ± 8.4	Yes (16.7 score)
Colles <i>et al.</i> , 2008 ⁵⁰	129	44.3	GB	SF – 36	Physical component score	37.2 ± 10.0	Not stated	49.2 ± 9.8	Yes (12 score)
Frezza <i>et al.</i> , 2007 ¹⁸	40	46.55 (median)	RYGB	SF – 36	Physical function score	17 (range, 10-38)	26.5 (range 11-30)	26.5 (range 11-30)	Yes (9.5 score)
Gorin <i>et al.</i> , 2009 ¹⁹	196	47.2	RYGB	SF - 36	Physical function score	46.5	79.5	N/A	Yes (33.2 score)
Hooper <i>et al.</i> , 2007 ²⁰	48	51.0	RYGB	SF - 36	Physical function score	38 ± 19	N/A	74.0 ± 21.4	Yes (36 score)
Horchner <i>et al.</i> , 1999 ³³	39	40.9	GB	SF - 36	Physical function score	72.7 ± 23.2	N/A	90 ± 14.3	Yes (17.3 score)
Huang <i>et al.</i> , 2011 ⁴⁴	40	43.6	RYGB	SF – 36	Physical function score	57.3 ± 25.9	73.8 ± 22.6	N/A	Yes (16.5 score)
Iossi <i>et al.</i> , 2013 ²¹	39	49.0	RYGB	SF – 36	Physical component score	30.1 ± 9.1	40.9 ± 9.5	45.9 ± 11.4	Yes (10.8); Yes (15.8 score)
Julia <i>et al.</i> , 2013 ⁴⁵	71	47.6	RYGB	SF-36	Physical function score	38.9	49.9(mean change)	52.6 (mean change)	Yes (49.9); Yes (52.6 score)
Josbeno <i>et al.</i> , 2010 ²²	17	46.9	RYGB	Medical outcomes SF-36	Physical function score	38.2 ± 23.6	89.7 ± 15.5	N/A	Yes (51.5 score)
King <i>et al.</i> , 2012 ⁵	310	47.0	All	SF – 36	Physical function score	37.6 ± 10.7	N/A	50.7 ± 8.3	Yes (13.1 score)
Lyytinen <i>et al.</i> , 2013 ⁴⁶	16	44.0	RYGB	RAND – 36	Physical function score	58.5 ± 18	81.5 ± 25.6	N/A	Yes (23.0 score)
Nickel <i>et al.</i> , 2005 ⁵³	21	47.4	GB	SF – 36	Physical function score	37.8 ± 13.1	N/A	61.3 ± 17.2 (3 years)	Yes (23.5 score)
Ohrstrom <i>et al.</i> , 2001 ⁵⁹	11	41	VBG	SF – 36	Physical function score	46 ± 24	78 ± 23	88±17	Yes (32); Yes (42 score)
Sarwer <i>et al.</i> , 2010 ³²	200 (198, 147)	N/A	RYGB	SF - 36	Physical function score	34.2 ± 25.5	67.5 ± 23.9	74.0 ± 21.8	Yes (33.3); Yes (39.8 score)
Tompkins <i>et al.</i> , 2013 ²⁷	25	45.5	RYGB	SF – 36	Physical function score	34.43 ± 9.63	52.14 ± 8.64	N/A	Yes (11.5 score)
Vincent <i>et al.</i> , 2012 ²⁸	25	47.0	RYGB, GB	SF – 36	Physical function score	32.1 ± 11.9	43.6 ± 11.2	N/A	Yes (17.17 score)
Wiklund <i>et al.</i> , 2015 ⁴⁹	70	44.7	RYGB	Disability rating index	Total score	30.4	N/A	14.2 (18 months)	Yes (16.2 DRI score)
Objective Physical Function									
Ben-Dov <i>et al.</i> , 2000 ⁵⁶	19	43.3	VBG	Incremental maximal cycle test	watts	124.0 ± 30.5	N/A	127.0 ± 39.2	Yes (3.0 watts)
Bond <i>et al.</i> , 2008 ¹⁶	119	49.9	RYGB	Walking	min/week	170.2 ± 325	N/A	385.9 ± 458	Yes (215.7 min/week)
Da Silva <i>et al.</i> , 2013 ³⁸	17	46.0	RYGB	6 MWT	m	489.0 ± 14.0	536.0 ± 14.0	N/A	Yes (47 metres)
Da Silva <i>et al.</i> , 2013 ³⁸	17	46.0	RYGB	30% handgrip force	kgf	10 ± 0.7	9 ± 0.7	N/A	No (1kgf)
De Souza <i>et al.</i> , 2010 ⁴⁰	61	49.4	RYGB	Treadmill exercise test	m	401.8 ± 139.0	513.4 ± 159.9	690.5 ± 76.2	Yes (111.6); Yes (288.7 metres)
De Souza <i>et al.</i> , 2009 ³⁹	49	51.1	RYGB	6 MWT	m	381.9 ± 49.3	N/A	467.0 ± 40.3	Yes (85.1 metres)
Handrigan <i>et al.</i> , 2010 ⁸	10	49.1	DS	Lower limb maximal force	kg	74.4 ± 15.1	58.9 ± 11.8	50.4 ± 8.6	No (15.5kg); No (24.0kg)
Hortobagyi <i>et al.</i> , 2010 ³⁴	10	43.2	RYGB	Walking speed	step/min	121.0 ± 7.5	117.0 ± 8.2	119.0 ± 8.6	Yes (4.0); Yes (2.0 step/min)
Hue <i>et al.</i> , 2010 ⁵⁷	10	50.2	DS	Lower limb maximal force	N	742.8 ± 131.3	N/A	493.9 ± 84.3	No (248.9 N)
Iossi <i>et al.</i> , 2013 ²¹	39	49.0	RYGB	Timed get up and go	sec	12.6 ± 3.1	10.3 ± 2.4	9.6 ± 2.7	Yes (2.3); Yes (3.0 s)

Josbeno <i>et al.</i> , 2010 ²²	17	46.9	RYGB	6 MWT	m	393 ± 62.1	446 ± 41.4	N/A	Yes (53 metres)
Josbeno <i>et al.</i> , 2010 ²²	18	46.9	RYGB	Short physical performance battery	SPPB score	11.2 ± 1.2	11.7 ± 0.6	N/A	Yes (0.5 SPPB score)
Kanopakis <i>et al.</i> , 2001 ⁵⁸	16	49.0	VBG	Treadmill exercise test	s	675.0 ± 226.0	1007.0 ± 389.0	N/A	Yes (332 s)
Lyytinen <i>et al.</i> , 2013 ⁴⁶	16	44.0	RYGB	6 MWT	m	500.7 ± 56.8	561.4 ± 50.6	N/A	Yes (60.7 metres)
Lyytinen <i>et al.</i> , 2013 ⁴⁶	16	44.0	RYGB	Timed up and go	s	7.4 ± 1.7	6.35 ± 0.9	N/A	Yes (1.05 s)
Maniscalco <i>et al.</i> , 2006 ⁵²	15	42.1	GB	6 MWT	m	475.7	N/A	626.3	Yes (150.6 metres)
Maniscalco <i>et al.</i> , 2007 ⁵¹	12	43.2	GB	6 MWT	m	416.5 ± 67.1	N/A	615.2 ± 104.0	Yes (198.7 metres)
Miller <i>et al.</i> , 2009 ²⁴	18	53.0	RYGB	4 meter walk time	s	5.4 ± 3.3	4.2 ± 2.4	3.9 ± 1.4	Yes (1.2); Yes (2.5 s)
Miller <i>et al.</i> , 2009 ²⁴	18	53.0	RYGB	Short physical performance battery score	SPPB score	9.1 ± 1.7	10.3 ± 2.1	11.1 ± 1.3	Yes (1.2); Yes (2.0 SPPB score)
Miller <i>et al.</i> , 2009 ²⁴	16	53.0	RYGB	Maximal torque	Nm	126.3 ± 7.2	111.7 ± 36.8	97.7 ± 31.6	No (14.6); No (28.6 Nm)
Ohrstrom <i>et al.</i> , 2001 ⁵⁹	11	41	VBG	Walking energy expenditure	KJ.min ⁻¹	27.4 ± 4.9	19.3 ± 3.3	19.1 ± 3.0	Yes (8.1); Yes (8.3 KJ.min ⁻¹)
Seres <i>et al.</i> , 2006 ²⁶	31	51.0	Not stated	Treadmill exercise test	min	13.8 ± 3.9	N/A	21.6 ± 4.3	Yes (7.8 minutes)
Tompkins <i>et al.</i> , 2008 ²⁷	25	45.5	RYGB	6 MWT	m	414.1 ± 104.0	551.5 ± 101.2	N/A	Yes (137.4 metres)
Valezi <i>et al.</i> , 2011 ³¹	31	35.9	RYGB	Treadmill exercise test	m	378.9 ± 126.5	N/A	595 ± 140.4	Yes (216.1 metres)
Vargas <i>et al.</i> , 2013 ⁴¹	67	50.5	RYGB	6 MWT	m	405.3 ± 92.3	500.1 ± 111.6	N/A	Yes (94.8 metres)
Vargas <i>et al.</i> , 2013 ⁴¹	67	50.5	RYGB	Timed up and go	sec	10.0 ± 2.5	7.5 ± 1.4	N/A	Yes (2.5 s)
Vincent <i>et al.</i> , 2012 ²⁸	25	47.0	RYGB, GB	Fastest possible walking speed	cm/ s	155.0 ± 26.0	162.0 ± 27.0	N/A	Yes (7 cm/ s)
Wasmund <i>et al.</i> , 2011 ²⁹	153	47.0	RYGB	Treadmill exercise test	s	917.0 ± 358.0	N/A	1362 ± 322 (2 years)	Yes (445 s)
Wiklund <i>et al.</i> , 2014 ⁴⁸	37	42	RYGB	Peak grip force (Right & Left)	N	298 ± 102 (R) 295 ± 92 (L)	N/A	287 ± 62 (R) 276 ± 60 (L)	No (11 N) No (19 N)
Wiklund <i>et al.</i> , 2014 ⁴⁸	37	42	RYGB	6 MWD	m	532 ± 81.0	N/A	599 ± 70.5	Yes (67 metres)
Wilms <i>et al.</i> , 2012 ⁶⁰	18	46.3	RYGB, Sleeve	Cycle exercise test	s	518.0 ± 127.3	N/A	549 ± 165.5 (27.7 months)	Yes (31 s)
Zavala <i>et al.</i> , 1984 ³⁰	13	Not stated	RYGB	Treadmill exercise test	METs	4.6	3.8	N/A	Yes (0.8 METs)

KEY: *RYGB: Roux-en Y gastric bypass; GB: gastric banding; VBG: vertical banded gastrectomy; DS: duodenal switch; PF: physical function; 6MWT: 6 minute walk test; MET: metabolic equivalent; KJ: Kilojoule; Nm: Newton metre; SPPB: short physical performance battery; kgf: kilogram force; m: metre; min: minute; s: second; cm: centimetre; N/A: Not applicable.

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