



Changes in Cardiorespiratory Fitness After Gastric Bypass: Relations with Accelerometry-Assessed Physical Activity

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Abstract

Background Exercise training optimizes cardiorespiratory fitness (CRF) after bariatric surgery, but the effect of spontaneous physical activity is not well known. This study aimed to objectively quantify changes in CRF and habitual physical activity 6 months after bariatric surgery and to examine whether change in CRF was related to change in physical activity.

Methods Secondary analyses were performed on data from women who underwent Roux-en-Y gastric bypass (RYGB) between 2010 and 2014. Measurements were performed before and 6 months after RYGB and included $\dot{V}O_{2\text{peak}}$ (graded maximal exercise test on a cycle ergometer), habitual physical activity (Actigraph GT3x accelerometer worn during 7 days), and body composition (DXA absorptiometry). Changes after RYGB were analyzed using Wilcoxon signed-rank test. Relations between change in CRF and change in physical activity were analyzed with Spearman correlations adjusted on age and preoperative BMI.

Results Forty-five women (median [P₂₅–P₇₅] age, 43.0 [38.0–51.0] year; BMI, 42.6 [40.0–45.5] kg/m²) were included. Mean (SD) weight loss 6 months after RYGB was –27.5 (7.9) kg ($P < 0.001$). Absolute $\dot{V}O_{2\text{peak}}$ decreased by 0.35 (0.50) L/min ($P < 0.001$) and relative $\dot{V}O_{2\text{peak}}$ tended to increase by 1.7 (5.3) mL/kg/min ($P = 0.06$), both with large inter-individual variability. Based on objective accelerometry data, daily steps and moderate-to-vigorous physical activity increased by 1275 (3164) steps/day and 7.6 (19.3) min/day, respectively (both $P < 0.05$). Change in absolute $\dot{V}O_{2\text{peak}}$ was positively related to change in moderate-to-vigorous physical activity ($r = 0.35$; $P = 0.03$).

Conclusions The decrease in absolute CRF observed 6 months after RYGB might be prevented by increasing habitual physical activity.

Trial Registration clinicaltrials.gov identifier: NCT01113996

Keywords Physical fitness · $\dot{V}O_{2\text{max}}$ · Physical activity patterns · Accelerometry · Gastric bypass · Obesity

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Introduction

Bariatric surgery induces marked weight loss, reduces mortality, and improves obesity-related comorbidities as well as health-related quality of life [1, 2]. Current guidelines for clinical care in this setting include promotion of physical activity (PA) to maintain or improve overall health and physical fitness [1]. Physical fitness is a major health indicator [3]. The concept of physical fitness includes different dimensions such as cardiorespiratory fitness (CRF), muscular fitness, and flexibility [4]. The gold-standard method for measuring CRF is to perform a graded maximal exercise test with direct measurement of maximal oxygen consumption ($\dot{V}O_{2\max}$) [5], expressed either in absolute values (L/min) or relative to body weight (mL/kg/min). Estimates of CRF can also be calculated from heart rate response or exercise time to exhaustion during maximal or submaximal exercise tests [5]. Low CRF is recognized as a major risk factor for all-cause mortality and cardiovascular events, including in patients with obesity [6, 7]. CRF is also a marker of functional capacity and ability to perform adequately the tasks of daily living [3]. In the bariatric surgery setting, low CRF has been associated with increased short-term postoperative complications [8].

Patients seeking bariatric surgery are characterized by poor physical fitness as measured by low CRF, with mean $\dot{V}O_{2\max}$ values below 20 mL/kg/min [9]. Surgery-induced weight loss has been associated with a significant, although modest, increase in relative $\dot{V}O_{2\max}$ [9–13]. In contrast, absolute $\dot{V}O_{2\max}$ (L/min) has been found either decreased [9, 10, 14] or unchanged [12] after bariatric surgery. However, published studies have not consistently reported changes in both absolute and relative $\dot{V}O_{2\max}$. Therefore, there is a need to better assess the magnitude of change in both absolute and relative CRF values after bariatric surgery.

PA is the main modifiable determinant of CRF, but the response to PA varies greatly between individuals and also depends on genetic factors [15]. We showed in a recent systematic review and meta-analysis that endurance-based exercise training programs performed after bariatric surgery help in improving CRF [16, 17]. Little is known about the role of habitual (i.e., spontaneous) PA in this setting. Change in self-reported PA has been found associated with change in calculated $\dot{V}O_{2\max}$ estimates [18]. However, association between objectively measured PA and directly measured $\dot{V}O_{2\max}$ has not been investigated.

Therefore, the aims of this analysis were to quantify changes in CRF ($\dot{V}O_{2\text{peak}}$ expressed as absolute value or relative to body mass) and in accelerometry-assessed PA patterns 6 months after RYGB and to examine whether change in CRF was related to change in habitual PA, with special attention to moderate-to-vigorous PA which forms the basis of current PA recommendations.

Methods

Study Population

This analysis was conducted on a subgroup of participants from a randomized clinical trial examining the effect of exercise on physical fitness and body composition 6 months after RYGB (clinicaltrials.gov identifier: NCT01113996) [19]. In that trial performed at a single academic center, patients undergoing RYGB and recruited from 2010 to 2014 were randomly assigned to usual care (controls, $N=22$), or usual care and additional oral protein intake ($N=31$), or usual care, additional protein intake, and supervised resistance training ($N=23$). All patients were encouraged to accumulate 150 min/week of moderate-intensity PA, as part of usual care [20]. As reported elsewhere, analyses revealed no differences in changes in CRF and habitual PA between the three groups [19]. Therefore, data from patients included in the control group and protein group were pooled for analyses in the present study. The study protocol was approved by the ethics committee of our institution. All patients signed a written informed consent prior to initiating the study.

Measures

All measurements were performed before and 6 months after RYGB [19]. CRF was measured by indirect calorimetry (Cardiac Assessment System for Exercise (CASE), GE Medical Systems Information Technologies Inc.) during a graded maximal exercise test on a cycle ergometer (GE Healthcare), as previously described [19]. Maximally achieved oxygen consumption ($\dot{V}O_{2\text{peak}}$) was determined as the highest attained $\dot{V}O_2$ during the test and expressed in absolute values (L/min) and relative to body mass (mL/kg/min) and to lean body mass (mL/kg LBM/min).

Habitual PA and sedentary time were measured using the Actigraph GT3x accelerometer (Manufacturing Technology, Inc., FL, USA). Participants were asked to wear the Actigraph at the hip using the provided elastic belt for 7 consecutive days during all waking hours except during water-based activities. Data were considered valid when the accelerometer was worn for at least 4 days during at least 8 h each day [21]. Analyses were restricted to patients who provided valid accelerometry data both before and 6 months after RYGB. Based on previous literature [22], cut-points below 100 cpm, between 100 and 1951 cpm, between 1952 and 5723 cpm, and over 5724 cpm were used to quantify sedentary behavior, light-, moderate-, and vigorous-intensity PA, respectively. Moderate-to-vigorous PA (MVPA) bouts were defined as 10 or more consecutive minutes above the MVPA activity count threshold with allowance of 2 min below this threshold [23]. Daily steps, corresponding to the total steps accumulated during wear time for a day, were calculated. As previously described,

a conservative approach was used to determine step counts: only steps taken at an intensity ≥ 500 cpm were registered [24]. Patients were considered compliant to the 2008 US PA guidelines when MVPA accumulated in ≥ 10 -min bouts was ≥ 150 min/week [4] and compliant to the 2018 US PA guidelines when total MVPA was ≥ 150 min/week [25].

Body composition (fat mass, lean body mass) was measured by DXA scanning (Hologic Discovery W, software v12.9; Hologic, Bedford, MA), as previously described [19]. Weight loss was expressed as change in body weight and in body mass index (BMI). Diabetes was defined according to a fasting blood glucose > 7 or > 11 mM 2 h after a 75-g oral glucose tolerance test, or the use of antidiabetic drugs, insulin, or GLP-1 analogs [19].

Statistical Analyses

Pre- and postoperative values are presented as median values (25th–75th percentile) for continuous data and frequencies and percentages for categorical data. Pre- to postoperative changes are presented as mean (SD). Mean (min–max) values are presented to characterize inter-individual variability in CRF and MVPA changes. Given the non-normality of most variables, non-parametric tests were used. Preoperative and postoperative values were compared with Wilcoxon signed-rank test for continuous variables and with McNemar test for categorical variables (proportion of participants with obesity comorbidities or compliant with PA recommendations). Relations between change in CRF and change in MVPA were analyzed with Spearman correlations adjusted for age and preoperative BMI. The null hypothesis was rejected at $P < 0.05$. Analyses were performed using R version 3.4.3.

Results

Participant Characteristics

From the 53 participants included in the initial trial in the groups without PA intervention, 45 participants provided valid accelerometry data before and after surgery and 41 participants also performed a maximal exercise test at both time points. Participants who did not provide valid accelerometry and $\dot{V}O_{2\text{peak}}$ data ($N = 12$) did not differ significantly from participants who provided valid data (data not shown). Before surgery, 11 (24.4%) patients had type 2 diabetes. Six months after RYGB, a significant weight loss (mean [SD] -27.5 [7.5] kg) and fat mass and lean body mass loss (all $P < 0.001$) were observed (Table 1). The proportion of participants with type 2 diabetes and hypertension tended to decrease ($P = 0.07$ and $P = 0.08$, respectively).

Changes in CRF and in Accelerometry-Assessed Physical Activity

Absolute $\dot{V}O_{2\text{peak}}$ significantly decreased after RYGB by -0.35 (0.50) L/min ($P < 0.001$) (Table 1), with values ranging from -1.30 to $+0.53$ L/min. $\dot{V}O_{2\text{peak}}$ relative to body weight tended to increase by 1.7 (5.3) mL/kg/min ($P = 0.06$), with values ranging from -9.6 to $+10.8$ mL/kg/min. $\dot{V}O_{2\text{peak}}$ relative to lean body mass was not significantly different 6 months after RYGB.

Accelerometer wear time did not differ 6 months after RYGB. A significant increase in daily steps (all $P < 0.05$) was observed. Mean duration of moderate- and vigorous-intensity PA significantly increased ($P < 0.05$), which resulted in a $+39.7$ (84.5) % increase in total MVPA ($P < 0.05$). Change in total MVPA ranged from -23 to $+69$ min/day. The duration of MVPA accumulated in ≥ 10 -min bouts increased on average by more than twofold ($P < 0.05$). The proportion of MVPA accumulated in ≥ 10 -min bouts also increased from 7 to 16% of total MVPA ($P < 0.05$). The number (%) of patients who did not engage in any MVPA bout ≥ 10 min changed from 16 (36%) before RYGB to 8 (18%) after RYGB ($P = 0.08$). However, the proportion of patients compliant to the 2008 and the 2018 US PA guidelines was not significantly different 6 months after RYGB (9 to 20%, $P = 0.07$ and 60 to 67%, $P = 0.60$, respectively). The duration of sedentary time and light-intensity PA was not different after RYGB.

Relations Between Changes in CRF and MVPA

When adjusting for age and preoperative BMI, change in absolute $\dot{V}O_{2\text{peak}}$ after RYGB was positively related to change in total MVPA ($r = 0.35$; $P = 0.03$) (Fig. 1a). Change in relative $\dot{V}O_{2\text{peak}}$ tended to be related to change in total MVPA ($r = 0.30$; $P = 0.07$) (Fig. 1b).

Discussion

In this study, we assessed changes in CRF and in accelerometry-assessed habitual PA after bariatric surgery in women with obesity. Six months after RYGB, we observed a significant decrease in absolute $\dot{V}O_{2\text{peak}}$ and a significant increase in habitual PA, with large inter-individual variability for both outcomes. We also found that change in CRF was positively related to change in MVPA.

Our findings strengthen the notion that absolute CRF decreases in the first months after bariatric surgery [9, 10, 14]. In contrast, because of massive weight loss, relative $\dot{V}O_{2\text{peak}}$ increases after bariatric surgery [9–13]. Relative $\dot{V}O_{2\text{peak}}$ being a strong predictor of both mortality and functional impairment, this is an important benefit of

Table 1 Characteristics of study participants before and after RYGB (N = 45)

	Before RYGB	After RYGB	Change Mean (SD)	P value
Age, years	43.0 (38.0–51.0)	–	–	–
Body composition (N = 45/53)				
Body weight, kg	114.3 (104.2–129.4)	89.3 (77.3–100.2)	–27.5 (7.9)	< 0.001
BMI, kg/m ²	42.6 (40.0–45.5)	32.7 (29.8–36.0)	–10.2 (2.7)	< 0.001
Body fat, %	50.2 (48.0–52.0)	43.1 (40.2–45.8)	–7.2 (3.2)	< 0.001
Fat mass, kg	57.6 (52.7–66.2)	39.7 (33.3–43.5)	–19.8 (4.7)	< 0.001
LBM, kg	56.4 (51.8–61.2)	47.9 (44.1–52.0)	–8.4 (3.0)	< 0.001
Cardiorespiratory fitness (N = 41/53)				
Absolute $\dot{V}O_2$ peak, L/min	2.13 (1.77–2.47)	1.78 (1.38–2.25)	–0.35 (0.50)	< 0.001
$\dot{V}O_2$ peak relative to body mass, mL/kg/min	18.8 (16.2–21.7)	20.2 (16.6–24.3)	1.7 (5.3)	0.059
$\dot{V}O_2$ peak relative to LBM, mL/kg LBM/min	38.8 (32.2–42.6)	35.1 (32.2–45.0)	–1.3 (10.2)	0.509
Physical activity (N = 45/53)				
Number of valid days	7 (6–7)	7 (6–7)	–0.1 (1.3)	0.596
Wear time, h/day	13.3 (12.3–14.1)	12.9 (12.1–14.3)	–0.1 (1.5)	0.778
Counts, counts/min	303 (238–373)	296 (249–406)	29.3 (126.5)	0.337
Daily steps, steps/day	5930 (4964–7726)	7244 (5735–9757)	1275 (3164)	0.024
Sedentary time, min/day	484.9 (423.7–537.0)	501.6 (416.1–531.7)	–1.3 (78.1)	0.612
Light-intensity PA, min/day	265.0 (225.4–344.9)	263.2 (229.1–317.8)	–11.1 (71.2)	0.491
Moderate-intensity PA, min/day	25.0 (16.7–35.9)	30.7 (17.9–45.4)	6.8 (17.9)	0.028
Vigorous-intensity PA, min/day	0 (0–0)	0 (0–0.1)	0.8 (3.0)	0.042
MVPA, min/day	25.0 (16.7–36.0)	31.1 (17.9–45.4)	7.6 (19.3)	0.024
MVPA in ≥ 10-min bouts, min/week	20 (0–92)	45 (20–91)	38.1 (110.2)	0.034
MVPA in ≥ 10-min bouts, % total MVPA	7.1 (0.0–26.4)	15.9 (6.8–30.1)	+ 5.6 (15.0)	0.014

Data are median (25th–75th percentile) unless otherwise stated

P value from Wilcoxon signed-rank test; italicize values indicate significance with P < 0.05

Censored steps were calculated by censoring steps taken at an intensity < 500 cpm [24]

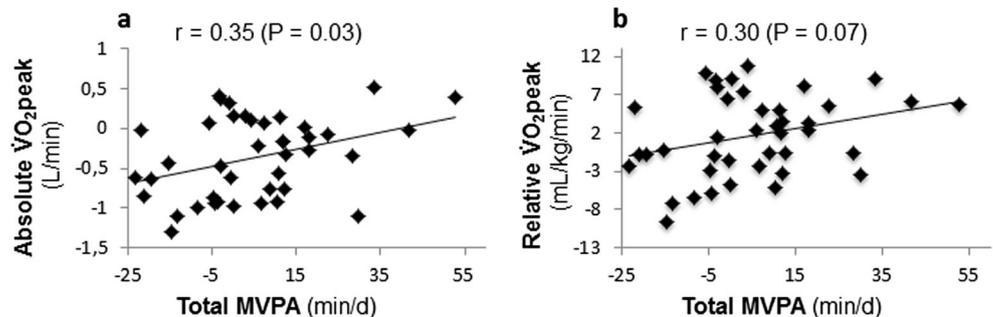
BMI, body mass index; LBM, lean body mass; RYGB, Roux-en-Y gastric bypass; PA, physical activity; MVPA, moderate-to-vigorous physical activity

bariatric surgery. Previous studies had reported mean increases in $\dot{V}O_2$ peak 6 months after bariatric surgery ranging from +1.3 [11] to 5.2 mL/kg/min [10]. The +1.7 mL/kg/min increase in $\dot{V}O_2$ peak observed in our study is therefore consistent with previous results. However, despite such increase, mean $\dot{V}O_2$ peak remains very low after surgery, with mean values around 20 to 25 mL/kg/min, corresponding to that usually observed in older women from the

general population [26]. Further improving CRF in this context is therefore an important objective to optimize the benefits of bariatric surgery on health status and functional capacity.

Our data suggest that increasing habitual MVPA may be an important contributor to maintain CRF in the first months after bariatric surgery. This is in line with controlled trials that reported improvements in CRF after an exercise training

Fig. 1 Correlation between change in absolute $\dot{V}O_2$ peak (a) or relative $\dot{V}O_2$ peak (b) and change in total MVPA 6 months after Roux-en-Y gastric bypass. Pearson correlation (r) adjusted on age and preoperative BMI



program in patients undergoing bariatric surgery [16]. In our study, MVPA increased on average by 8 min/day, with large between-subject variability in both the direction and magnitude of change. Six months after RYGB, two-third of patients were compliant with the latest US PA guidelines [25], and only 20% were compliant with previous recommendations that considered only MVPA accumulated in bouts of 10 min or longer [4]. Some previous studies have shown no significant change in accelerometry-assessed PA in the first months after bariatric surgery [21, 27–30], in contrast with a number of studies that have consistently reported increases in self-reported PA [31]. Objectively measured PA data suggest that weight loss alone might not be sufficient to substantially increase habitual PA. Behavioral interventions targeting daily PA might therefore be needed to help patients undergoing bariatric surgery in reaching the recommended level of PA.

Another important finding of this study was that MVPA accumulated in bouts represented less than 10% of total MVPA before RYGB and less than 20% 6 months after RYGB. Short bouts of MVPA were therefore largely predominant both before and after RYGB. Similar patterns of MVPA have been described in previous studies, with ≥ 10 -min bouts MVPA representing 9 to 22% of total MVPA in patients after bariatric surgery [21, 28, 32, 33]. Prolonged bouts of MVPA appear more prevalent in normal-weight or adults with overweight, in whom MVPA accumulated in ≥ 10 -min bouts has been found to reach up to 40% of total MVPA [34]. Growing evidence suggests that MVPA is associated with health benefits, independently of bout duration: short bouts of MVPA have been associated with a reduction in mortality risk [35], BMI or adiposity, blood pressure, and blood lipids and with improved glycemic control [36]. However, there is no consensus as to whether prolonged bouts of MVPA are more strongly associated with health outcomes than short bouts [36]. Our data suggest that modest improvement in total MVPA might provide additional benefits on CRF after bariatric surgery, even though short bouts of MVPA remain predominant. In these subjects, maintaining long bouts of MVPA might be a particularly challenging task. Therefore, promoting both incidental and prolonged PAs may represent an important and reachable objective in patients with severe obesity undergoing bariatric surgery.

Strengths of the study include the objective measurement of CRF and PA before and after RYGB in a homogeneous group of women who received the same surgical procedure. The use of min-by-min accelerometry data provided new insights about accumulation of PA in these subjects, especially regarding bout analysis. Although the most widely used accelerometers in clinical and population studies, Actigraph accelerometers have not been specifically validated in subjects with severe obesity. Only women were included in the study, and our subjects underwent only one type of bariatric procedure, which prevents us from extrapolating results to all obese

subjects and to those undergoing other types of bariatric surgery. In addition, patients were initially included in a clinical trial although we did not include subjects from the exercise training group in our analyses.

Conclusion

This study shows that CRF relative to body weight tends to increase in the early first months following bariatric surgery, but that absolute CRF decreases significantly. A significant, although modest, increase in habitual PA was also found. Changes in both CRF and PA were characterized by large inter-individual variability in both the direction and magnitude of change. The change in CRF was positively related to the change in PA, suggesting that habitual PA contributes to the improvement in physical fitness after bariatric surgery. These findings highlight the need to identify effective interventions for promoting PA after bariatric surgery that can be incorporated into routine clinical care.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflicts of interest.

Ethical Standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

References

1. Mechanick JI, Youdim A, Jones DB, et al. Clinical practice guidelines for the perioperative nutritional, metabolic, and nonsurgical support of the bariatric surgery patient—2013 update: cosponsored by American Association of Clinical Endocrinologists, The Obesity Society, and American Society for Metabolic & Bariatric Surgery. *Obesity* (Silver Spring). 2013;21(Suppl 1):S1–27.
2. Sjostrom L, Peltonen M, Jacobson P, et al. Bariatric surgery and long-term cardiovascular events. *JAMA*. 2012;307(1):56–65.
3. Ross R, Blair SN, Arena R, et al. Importance of assessing cardiorespiratory fitness in clinical practice: a case for fitness as a clinical vital sign: a scientific statement from the American Heart Association. *Circulation*. 2016;134(24):e653–e99.
4. U.S. Department of Health and Human Services. Physical activity guidelines for Americans. Washington: 2008.

5. ACSM. American College of Sports Medicine's guidelines for exercise testing and prescription. 9th edition. Baltimore: Lippincott; 2014.
6. Kodama S, Saito K, Tanaka S, et al. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. *JAMA*. 2009;301(19):2024–35.
7. Fogelholm M. Physical activity, fitness and fatness: relations to mortality, morbidity and disease risk factors. A systematic review. *Obes Rev*. 2010;11(3):202–21.
8. McCullough PA, Gallagher MJ, Dejong AT, et al. Cardiorespiratory fitness and short-term complications after bariatric surgery. *Chest*. 2006;130(2):517–25.
9. Seres L, Lopez-Ayerbe J, Coll R, et al. Increased exercise capacity after surgically induced weight loss in morbid obesity. *Obesity (Silver Spring)*. 2006;14(2):273–9.
10. Kanoupakis E, Michaloudis D, Fridakis O, et al. Left ventricular function and cardiopulmonary performance following surgical treatment of morbid obesity. *Obes Surg*. 2001;11(5):552–8.
11. de Souza SA, Faintuch J, Sant'anna AF. Effect of weight loss on aerobic capacity in patients with severe obesity before and after bariatric surgery. *Obes Surg*. 2010;20(7):871–5.
12. Wilms B, Ernst B, Thurnheer M, et al. Differential changes in exercise performance after massive weight loss induced by bariatric surgery. *Obes Surg*. 2013;23(3):365–71.
13. Lund MT, Hansen M, Wimmelmann CL, et al. Increased post-operative cardiopulmonary fitness in gastric bypass patients is explained by weight loss. *Scand J Med Sci Sports*. 2016;26(12):1428–34.
14. Neunhaeuserer D, Gasperetti A, Savalla F, et al. Functional evaluation in obese patients before and after sleeve gastrectomy. *Obes Surg*. 2017;27(12):3230–9.
15. Bouchard C, Rankinen T. Individual differences in response to regular physical activity. *Med Sci Sports Exerc*. 2001;33(6 Suppl):S446–51. discussion S52–3
16. Bellicha A, Ciangura C, Poitou C, et al. Effectiveness of exercise training after bariatric surgery—a systematic literature review and meta-analysis. *Obes Rev*. 2018;19(11):1544–56.
17. da Silva ALG, Sardeli AV, Andre LD, et al. Exercise training does improve cardiorespiratory fitness in post-bariatric surgery patients. *Obes Surg*. 2019;1.
18. Tettero OM, Aronson T, Wolf RJ, et al. Increase in physical activity after bariatric surgery demonstrates improvement in weight loss and cardiorespiratory fitness. *Obes Surg*. 2018;28(12):3950–7.
19. Oppert JM, Bellicha A, Roda C, et al. Resistance training and protein supplementation increase strength after bariatric surgery: a randomized controlled trial. *Obesity (Silver Spring)*. 2018;26(11):1709–20.
20. Jensen MD, Ryan DH, Apovian CM, et al. 2013 AHA/ACC/TOS guideline for the management of overweight and obesity in adults: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines and the Obesity Society. *Circulation*. 2014;129(25 Suppl 2):S102–38.
21. Bond DS, Jakicic JM, Unick JL, et al. Pre- to postoperative physical activity changes in bariatric surgery patients: self report vs. objective measures. *Obesity (Silver Spring)*. 2010;18(12):2395–7.
22. Freedson PS, Melanson E, Sirard J. Calibration of the Computer Science and Applications, Inc. accelerometer. *Med Sci Sports Exerc*. 1998;30(5):777–81.
23. Troiano RP, Berrigan D, Dodd KW, et al. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc*. 2008;40(1):181–8.
24. Tudor-Locke C, Brashear MM, Johnson WD, et al. Accelerometer profiles of physical activity and inactivity in normal weight, overweight, and obese U.S. men and women. *Int J Behav Nutr Phys Act*. 2010;7:60.
25. Piercy KL, Troiano RP, Ballard RM, et al. The physical activity guidelines for Americans. *JAMA*. 2018;320(19):2020–8.
26. Kaminsky LA, Imboden MT, Arena R, et al. Reference standards for cardiorespiratory fitness measured with cardiopulmonary exercise testing using cycle ergometry: data from the Fitness Registry and the Importance of Exercise National Database (FRIEND) registry. *Mayo Clin Proc*. 2017;92(2):228–33.
27. Giusti V, Theytaz F, Di Vetta V, et al. Energy and macronutrient intake after gastric bypass for morbid obesity: a 3-y observational study focused on protein consumption. *Am J Clin Nutr*. 2016;103(1):18–24.
28. Berglind D, Willmer M, Eriksson U, et al. Longitudinal assessment of physical activity in women undergoing Roux-en-Y gastric bypass. *Obes Surg*. 2015;25(1):119–25.
29. Afshar S, Seymour K, Kelly SB, et al. Changes in physical activity after bariatric surgery: using objective and self-reported measures. *Surg Obes Relat Dis*. 2016;13(3):474–83.
30. Liu X, Lagoy A, Discenza I, et al. Metabolic and neuroendocrine responses to Roux-en-Y gastric bypass. I: energy balance, metabolic changes, and fat loss. *J Clin Endocrinol Metab*. 2012;97(8):E1440–50.
31. Herring LY, Stevinson C, Davies MJ, et al. Changes in physical activity behaviour and physical function after bariatric surgery: a systematic review and meta-analysis. *Obes Rev*. 2016;17(3):250–61.
32. Bond DS, Jakicic JM, Vithiananthan S, et al. Objective quantification of physical activity in bariatric surgery candidates and normal-weight controls. *Surg Obes Relat Dis*. 2010;6(1):72–8.
33. King WC, Chen JY, Bond DS, et al. Objective assessment of changes in physical activity and sedentary behavior: Pre- through 3 years post-bariatric surgery. *Obesity (Silver Spring)*. 2015;23(6):1143–50.
34. Glazer NL, Lyass A, Eslinger DW, et al. Sustained and shorter bouts of physical activity are related to cardiovascular health. *Med Sci Sports Exerc*. 2013;45(1):109–15.
35. Saint-Maurice PF, Troiano RP, Matthews CE, et al. Moderate-to-vigorous physical activity and all-cause mortality: do bouts matter? *J Am Heart Assoc*. 2018;7(6)
36. PAGAC. Physical Activity Guidelines Advisory Committee Report. Washington, DC: US Department of Health and Human Services; 2018.

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