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ORIGINAL CONTRIBUTIONS

Physical Fitness and Body Composition Two Years after Roux-En-Y Gastric Bypass in Adolescents

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Abstract
Background We have previously shown promising results 2 years after Roux-en-Y gastric bypass surgery, within the Adolescence Morbid Obesity Surgery study (AMOS). The aim of the current study was to describe the 2-year outcome in cardiorespiratory fitness, body composition, and functional capacity in the Stockholm subset of the AMOS study.
Methods Forty-one adolescents (10 male, 31 female, age 14–18 years, body mass index 35–69 kg·m^{-2}) were included. In addition to anthropometric measurements, participants performed a submaximal bicycle test, 6-min walk test, dual-energy X-ray absorptiometry, and a short interview at baseline, 1 and 2 years after surgery.
Results Relative improvements in maximal oxygen consumption (VO_2max) per kilogram body mass (+62 %) and per kilogram fat-free mass (+21 %), as well as walking distance (+13 %) were observed after 1 year, and persisted 2 years after surgery. Despite a reduction of fat-free mass (−15 %), absolute VO_2max was maintained across the full group (+8 %, p = ns) and significantly increased in non-smokers. Body mass and fat mass were significantly decreased (−45.4 and −33.3 kg, respectively). Self-reported physical activity was significantly increased, and pain associated with movement was reduced.
Conclusions In adolescents with obesity, Roux-en-Y gastric bypass improved VO_2max more than could be explained by fat mass loss alone. In combination with improved functional capacity and body composition, these results suggest that surgery in adolescence might add specific benefits of importance for future health.

Keywords Bariatric surgery · Cardiorespiratory fitness · Functional capacity · Children

Introduction

Obesity is a global health concern, pervading all nations and all age groups. Childhood obesity most often transcends into adulthood and children of today might be the first generation with a shorter lifespan than their parents [1]. Adolescents with obesity are seemingly the most difficult to treat with conventional behavioral treatment [2], which relies on changes to diet and physical activity (PA) behaviors. In recent decades, the number of bariatric surgical interventions has markedly increased in adults suffering from severe obesity, and positive results have been shown across outcomes including long-term weight control, quality of life, morbidity, and mortality [3–5]. Roux-en-Y gastric bypass (RYGB) is associated with superior long-term weight control and improved control of type 2 diabetes (T2D) in comparison to banding techniques in most studies [5].

It is well established that low PA and low cardiorespiratory fitness are important risk factors for cardiovascular disease in the general population [6]. In patients with obesity, a low cardiorespiratory fitness is independently associated with increased mortality [7–9].

Studies investigating the effect of gastric bypass on cardiorespiratory fitness in adults show improved maximal oxygen

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consumption (VO_2max) relative to body mass in the short term [10–13]. However, results are scarce, even among adult populations and, to our knowledge, there are no long-term follow-up studies in adults nor any studies at all of cardiorespiratory fitness in adolescents after bariatric surgery.

Among adolescents with severe obesity, bariatric surgery is only recommended for carefully selected individuals [14], owing to a paucity of long-term safety and effectiveness studies. However, results so far are promising [15–18], and a recent study with 3-year follow-up has indicated that remission of type 2 diabetes after bariatric surgery is better in adolescents than in adults [19].

The Adolescent Morbid Obesity Surgery study (AMOS) is a prospective Swedish national multicentre intervention study investigating the outcome of RYGB in adolescents with severe obesity AMOS started in 2006, and 2-year follow-up results on weight, quality of life, and metabolic risk markers, as well as co-morbidities, have been published previously [16].

In the present study, we describe cardiorespiratory fitness, functional capacity, body composition outcomes, and self-reported PA in adolescents undergoing RYGB in the Stockholm subset of patients from the AMOS study.

Methods

Participants

A total of 81 adolescents were enrolled into the AMOS study and underwent RYGB between 2006 and 2009. Inclusion criteria and methods are described elsewhere [16].

Results in the present study relate to the subset of 41 patients recruited at the National Childhood Obesity Center in Stockholm; 37 having been included in the AMOS cohort and four additional subjects, who met the inclusion criteria and underwent RYGB under the same treatment protocol as the AMOS cohort, after recruitment to AMOS had closed. The Stockholm patients were comparable with the non-Stockholm patients included in AMOS (from Gothenburg and Malmö), with regard to weight, age, and gender. All patients were operated at the same center (Gothenburg) and treated similarly both before and after surgery. The Stockholm subset also underwent additional tests including a submaximal ergometry bicycle test, a 6-minute walk test (6MWT), and a semi-structured interview regarding PA.

Participants were predominantly female (n = 31, 75.6 %), age 14–18 years old at the time of surgery, with a body mass index (BMI) at inclusion of 46.0 ± 6.6 kg m^{-2}. Baseline characteristics are shown in Table 1.

Measurements

Anthropometry

Participants' body mass (BM) was measured in light clothing to the closest 0.1 kg using a digital scale (Vetek TI-1200S OIML, Vetek, Sweden) and height was measured, without shoes, to the closest 0.1 cm using a stadiometer (Ulmer stadiometer, Busse Design + Engineering, Switzerland). BMI was calculated by dividing weight/height^2.

To measure participants' total body composition, a dual-energy X-ray absorptiometry (DXA) scan was performed (Lunar DPX-L, version 1.5E; Lunar Corp, Madison, WI USA or Lunar Prodigy X-R. model 6830, Madison, WI, USA) with the participant in a supine position. Fat-free mass (FFM) was calculated by subtracting fat mass (FM) from total body mass.

Cardiorespiratory Fitness

Participants performed a submaximal ergometry bicycle test, developed by Åstrand and Ryhming [20]. All tests were carried out using the same bicycle (Monark, 864, Varberg, Sweden). Pulse rate was monitored using a Polar watch (Polar, Polar Oy, Kempele, Finland). Absolute VO_2max was calculated from measured work, pulse, and workload using a nomogram provided by Åstrand and Ryhming [20] and expressed in L/min. Relative BM VO_2max was calculated from absolute VO_2max and measured body weight. Relative FFM VO_2max was calculated from absolute VO_2max and fat-free mass according to the DXA scan.

Functional Capacity

Walking distance from the 6MWT was used as a measurement of functional capacity. The 6MWT was performed in a 70-m indoor corridor [21]. Heart rate was monitored by a Polar watch (Polar, Polar Oy, and Kempele, Finland). Participants were told not to run and to take resting periods, or even to abort the test, if they felt it necessary. The participants were also asked whether they experienced pain during the test.

Interview

A semi-structured interview regarding participants' exercise and PA habits, movement-related pain, and smoking status was conducted at baseline and at each follow-up contact. From the answers given, time spent participating in PA was summarized to determine whether or not each individual reached an equivalent of the recommended level of 150 min of moderate to vigorous PA per week [22]. Participants who reached this recommendation were categorized as physically "active"; those who did not were categorized as "inactive."

Table 1 Changes in anthropometric data, body mass index (BMI), body composition, absolute VO_2max, relative body mass (BM) VO_2max, relative fat-free mass (FFM) VO_2max, walking distance mean (sd) and participation in physical activity, smoking and pain associated with movement

	n	Baseline	*n*	Year one	*n*	Year two
Weight (kg)	41	133.74 (22.89)	41	90.35 (17.49)	41	88.34 (20.54)
Height (cm)	41	170.64 (8.39)	41	171.19 (8.64)	41	171.48 (8.66)
BMI	41	46.03 (6.64)	41	30.50 (5.29)	41	29.91 (5.78)
Fat (%)	33	52.25 (3.59)	39	39.55 (8.08)	35	37.83 (9.68)
Fat mass (kg)	33	66.95 (11.46)	39	36.21 (11.80)	35	34.81 (14.56)
Fat-free mass (kg)	33	60.91 (8.73)	39	54.30 (10.87)	35	54.99 (11.24)
Absolut Vo2 max (L/m)	25	2.80 (0.59)	30	3.05 (0.79)	35	2.98 (0.82)
Relative BM Vo2 max (ml/kg/min)	25	22.75 (6.40)	30	34.30 (9.68)	35	34.07 (9.30)
Relative FFM Vo2max (ml/FFM/min)	23	47.93 (10.44)	28	56.35 (14.74)	34	54.64 (14.16)
6-min walk test (m)	23	540.30 (65.60)	31	616.81 (64.69)	32	603.47 (58.92)
Physically active	32	3 (9.4 %)	37	15 (40.5 %)	36	19 (52.8 %)
Smoking	23	11 (47.8 %)	29	17 (58.6 %)	32	17 (53.1 %)
Pain associated with movement	28	20 (71.4 %)	34	15 (44.1 %)	33	18 (54.5 %)

Movement-related pain and smoking status were similarly categorized as "yes, experiencing pain associated with movement" or "no, not experiencing pain associated with movement" and "yes currently a smoker" or "no, not currently a smoker."

Incomplete Cases

Follow-up for weight and height was 100 % at 1 and 2 years after surgery. However, for other variables, such as the submaximal ergometry bicycle test, 6MWT, and DXA scan, there was a number of missing observations. These missing data resulted from logistic problems leading to absent baseline recordings, testing failures or participants being unable to perform physical tests due to pain, dumping syndrome and illness, and subjects refusing to participate. As described previously [17], this is a group of patients with a high prevalence of psychosocial problems, which to some extent may explain the incomplete data. Participants with missing baseline data from the ergometry bicycle test or the 6MWT did not differ from those with recorded baseline data with regard to BMI or body composition or following results from the ergometry bicycle test or the 6MWT. As a large number of participants missed one or more tests during the course of this study, a linear mixed model was used in order to make use of all available data.

Statistical Analysis

The statistical software used was SPSS for Windows, version 22 (SPSS, Chicago, IL, USA). Descriptive statistics are presented as mean and standard deviation or as proportions (%). Linear mixed models with compound symmetry for repeated measures were used to fit the data, fixed factors were included in further analysis, and interactions are reported. If the change over time was found to be significant, mean comparison with Bonferroni adjustment followed. Results from the linear mixed model are presented as mean with 95 % confidence intervals. The Cochrane Q test was used to analyze change over time for nominal data. Pearson correlation and Cramer's V were used to test associations. A repeated measurement ANOVA model was also used. There were no differences in terms of significant findings between repeated measured ANOVA and linear mixed models, and the results presented are all from the linear mixed model.

Results

Anthropometry

Mean weight change during the first year was −43.4 kg (95 % CI −49.1, −37.7) and during the second year −2.0 kg (95 % CI 3.7, −7.7). Total weight change during 2 years post-surgery was −45.5 kg (95 % CI −51.2, −39.6). The mean change in BMI was −15.5 $kg{\cdot}m^{-2}$ (95 % CI −17.4, −13.6) from baseline to 1-year follow-up. During the second year after surgery, the mean BMI change was −0.6 $kg{\cdot}m^{-2}$ (95 % CI −1.3, 2.5). Total BMI change was −16.1 $kg{\cdot}m^{-2}$ (95 % CI −18.0, −14.2).

Changes in body composition are shown in Fig. 1. Body composition in terms of FM and FFM decreased significantly across the study period. Mean changes of −31.7 kg (95 % CI −35.9, −27.9) in FM and −8.8 kg in FFM (95 % CI −10.8, −6.8) were observed during the first year. During the second year, the mean FM change was −1.5 kg (95 % CI −2.4, 5.3) and the mean FFM change was −0.9 kg (95 % CI −1.1, 2.8).

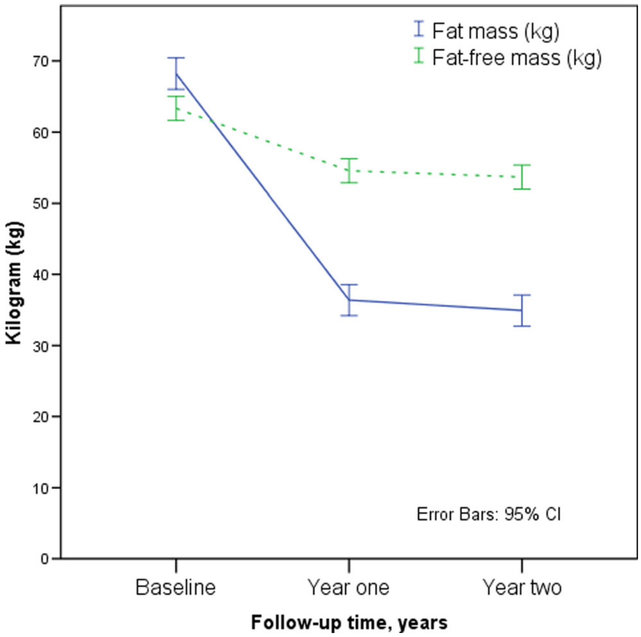


Fig. 1 Changes in body composition from baseline across 2 years

Cardiorespiratory Fitness

At baseline, all but three participants were classified as "Very poor," according to the ACSM classification of maximal aerobic fitness [23], and three females were classified as "Poor." At the 2-year follow-up, 14 participants were classified as "Very poor," seven as "Poor," while 13 were classified as "Fair." Relative BM VO_2max increased significantly (+66 %) during the first year after surgery and remained unchanged during year two Table 2. Relative FFM VO_2max also increased significantly (+25 %) during the first year and remained unchanged during year two Table 2. The absolute VO_2max did not increase significantly (+8 %) Table 2. Absolute VO_2max, when adjusted for smoking status, was significantly associated with fat-free mass at the 2-year follow-up, but not at baseline or 1-year follow-up (r = 0.377 p = 0.044). Non-smokers' absolute VO_2max increased significantly from baseline to 2-year follow-up (p = 0.005), while no change was observed among smokers (p = 0.182) (Fig. 2a). Smoking status showed similar interaction effects in both relative BM VO_2max (p = 0.003) (Fig. 2b) and relative FFM VO_2max during the second year after surgery (p = 0.002) (Fig. 2c). There was no association between the proportion of FM lost and change in cardiorespiratory fitness between baseline and 2-year follow-up.

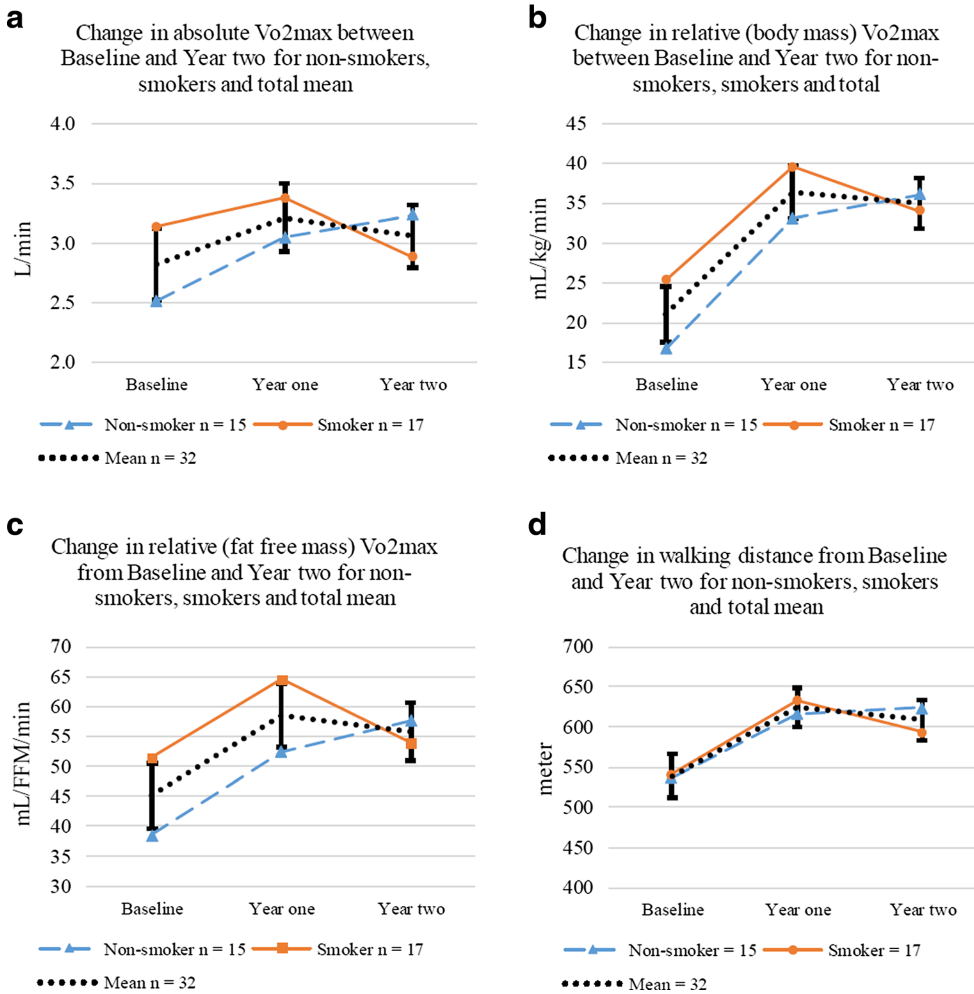
Functional Capacity

Walking distance increased significantly (+15 %) from baseline to year one and remained unchanged during year two Table 2. Walking distance was, independently of smoking status, significantly correlated to FM but not FFM at year one and year two follow-up but not at baseline (r = −0.513, p = 0.007 and r = −0.423, p = 0.031, respectively). There was

Table 2 Predicted values in anthropometric data, body mass index (BMI), body composition, absolute VO_2max, relative body mass (BM) VO_2max, relative fat-free mass (FFM) VO_2max, walking distance mean, and 95 % confidence interval, from the linear mixed model

	Subjects n	Total observations n	Baseline mean (95 % CI)	Year one mean (95 % CI)	Year two mean (95 % CI)	*P baseline* vs *year one*	*P year one* vs *year two*	*P baseline* vs *year two*
Weight (kg)	41	123	133.74 (127.44–140.05)	90.35 (84.05–96.65)	88.34 (82.04–94.64)	<0.001	1	<0.001
Height (cm)	41	123	170.64 (167.97–173.30)	171.19 (168.52–173.86)	171.48 (168.81–174.14)	<0.004	0.264	<0.001
BMI	41	123	46.03 (44.20–47.86)	30.50 (28.67–32.33)	29.91 (28.09–31.74)	<0.001	1	<0.001
Fat (%)	41	107	52.21 (49.67–54.76)	39.42 (36.97–41.88)	38.31 (35.79–40.82)	<0.001	0.754	<0.001
Fat mass (kg)	41	107	68.22 (64.05–72.40)	36.36 (32.32–40.40)	34.91 (30.78–39.04)	<0.001	1	<0.001
Fat-free mass (kg)	41	107	63.35 (59.89–66.81)	54.56 (51.14–57.98)	53.67 (50.22–57.12)	<0.001	0.808	<0.001
Absolute Vo2 max (L/m)	39	90	2.76 (2.47–3.04)	3.07 (2.81–3.34)	2.97 (2.72–3.21)	0.191	1	0.604
Relative BM Vo2 max (mL/kg/min)	39	90	21.09 (17.83–24.36)	34.92 (31.87–37.97)	34.26 (31.37–37.14)	<0.001	1	<0.001
Relative FFM Vo2max (mL/FFM/min)	38	85	45.36 (40.11–50.61)	56.79 (51.94–61.64)	54.76 (50.27–59.25)	0.001	1	0.006
6-minwalk test (m)	39	86	536.84 (512.19–561.49)	619.57 (597.35–641.78)	608.09 (586.13–630.05)	<0.001	1	<0.001

Fig. 2 Change in cardiorespiratory fitness from baseline across 2 years expressed in: **a** Absolute VO_2max. **b** Relative (body weight) VO2max. **c** Relative (fat-free mass) VO_2max. **d** Functional capacity in the form of walking distance



no significant difference in walking distance between smokers and non-smokers (Fig. 2d).

Physical Activity

Self-reported PA increased from baseline and was significantly higher, both at 1 and 2 years, after RYGB. Those categorized as physically active had a higher absolute VO_2max and relative BM VO_2max after 2 years, compared to those categorized as inactive. However, the difference was not significant after adjusting for smoking status (data not presented).

Movement-Related Pain

Self-reported prevalence of pain associated with movement was highest before surgery and declined during the first year, before rising slightly during the second year Table 1. The Cochrane Q test revealed a significant (p = 0.028) reduction in pain prevalence in repeated measure analysis (n = 25). Data on movement-related pain were available for 33 participants at year two. Of these, ten participants (30.3 %) reported no improvement in pain from baseline to year one and 15 (45.5 %) were either pain free or their pain improved from baseline or year one to year two. Eight participants (24.2 %) reported debut or recurrence of pain at 2 years.

There was a strong negative association between self-reported pain and self-reported PA (r = 0.516, p = 0.012), with pain associated with inactivity.

Discussion

This is, to our knowledge, the first long-term study of cardiorespiratory fitness and functional capacity outcomes 2 years after RYGB surgery. Adolescents demonstrated improvement in relative BM VO_2max, FFM VO_2max, and functional capacity, during the first year, and sustained these improvements during the second post-operative year.

These findings are most likely primarily due to a consistent decrease in fat mass and are in agreement with previous short-term findings in adults [10–13]. The magnitude of the relative change, i.e., a 62 % increase in relative BM VO_2max, appeared to be greater in adolescents than previously reported in adults 4–12 months after surgery [10–13]. A significant increase of 21 % in VO_2max per kilogram FFM was observed, which is two to three times higher than that reported for adults, despite one of the adult studies including a physical training intervention [10, 13].

A trend toward an increase in absolute VO_2max for the whole group and a significant improvement for non-smokers were apparent. Functional capacity increased by 13 %, a figure comparable to the 10–32 % increases in walking distance reported in adults after surgery [24–26]. It has previously been shown that VO_2max for adolescent normal-weight females is decreasing [27]. However, the positive change in cardiorespiratory fitness was not significantly affected by the age at surgery. This may be due to that our cohort was homogeneous with respect to physical maturation as one of the inclusion criteria was that the adolescents should have passed peak height growth velocity and be of at least Tanner pubertal stage III. This strengthens that the apparent positive increase in cardiorespiratory fitness is dependent of the surgical intervention.

As previously demonstrated in adults [28], the reduction in body weight during the first year consisted of both fat and lean body mass. Cardiorespiratory fitness is dependent on muscle mass [29], and this was apparent in the present study. Absolute VO_2max was maintained across the cohort and increased in non-smokers, despite a mean net loss of approximately 10-kg FFM during the two post-operative years. In addition, an increase in relative VO_2max per kilogram FFM was apparent. Both of these factors suggest an improvement in physical fitness, which is independent of fat mass loss per se. The superior improvement in cardiorespiratory fitness following surgery, observed in adolescents compared with adults, suggests that surgery may be more beneficial at a younger age.

VO_2max is itself a direct reflection of the integrated cardiorespiratory system. A number of additional factors, indirectly related to the loss of fat mass, may contribute to the improvement in physical fitness observed, including reduced systemic inflammation [16], improved cardiovascular function [30] and mitochondrial function [31], as well as improved lung function [32]. Regardless of the relative contribution of each of these factors, the present results indicate that—already in adolescents—obesity negatively affects the cardiorespiratory capacity more than could be expected by the increased fat mass only.

Physical activity is also important for cardiorespiratory fitness [33]. A significant increase in self-reported PA from baseline was apparent in the present cohort, in line with previous studies in adults [34]. However, it remains to be shown whether this reflects a genuine increase in PA, or an overestimation of post-surgery activity by participants, which has been seen in comparisons between objectively measured and self-reported PA [35–37]. Indeed, no differences were apparent between those who were “active” and “inactive” in any of our objectively measured variables linked to physical capacity when adjusted for smoking.

There was a reduction in the prevalence of pain among the participants in the present study. However, improvements were not superior to those observed in adults [38]. Participants with no improvement in movement-related pain had significantly lower relative BM VO_2max at 2 years compared with those whose pain improved following weight loss. This association may be bidirectional, since joint pain may negatively effect individuals’ ability and motivation to engage in PA and PA can also reduce joint pain [39]. Specific PA support for bariatric surgery patients with joint pain may, therefore, be beneficial.

This study has a number of strengths, foremost the follow-up duration of 2 years. During the second year, the body composition is more stable and, therefore, the results better reflect the persisting effects of surgery. The use of a submaximal, rather than maximal, test is less dependent on motivation and experience of exercise, which may better suit subjects with obesity. Important limitations of the study include its relatively small number of subjects and a considerable number of missing tests, primarily due to the heavy psychosocial burden in this group of patients [17]. The number of males in the group was low, which makes comparisons between genders difficult to interpret. However, the proportion of males and females in this study reflects the ratio among bariatric surgery patients in general. As mentioned, self-reported measured PA is unreliable. Movement-related pain represents a crude outcome measure. Further research into movement-related pain after bariatric surgery is required, since it was associated with inactivity.

Conclusion

Gastric bypass surgery in adolescents was associated with improvements in both cardiorespiratory fitness and functional capacity over 2 years. The relative VO_2max increased, not solely as a result of reduced fat mass, but also because of improved cardiorespiratory and/or metabolic function. Since poor cardiorespiratory fitness is an independent risk factor for premature death, our results adds to reasons why undergoing bariatric surgery in adolescents may offer superior health benefits compared with surgery in adulthood.

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Compliance with Ethical Standards The AMOS study was ethically approved by the regional ethical review board in Gothenburg (523–04) and conducted in accordance with the Declaration of Helsinki.

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Conflict of Interest Authors declare no conflict of interest to the submitted work. Dr. Olbers reports personal fees and non-financial support from Johnson & Johnson, grants from Johnson & Johnson, outside the submitted work.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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