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CLINICAL RESEARCH

Differential Changes in Exercise Performance After Massive Weight Loss Induced by Bariatric Surgery

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Abstract
Background Exercise performance and pulmonary function are often impaired in severely obese subjects. Bariatric surgery represents the most effective therapy for severe obesity, but data on changes in exercise performance after massive weight loss induced by bariatric surgery have rarely been assessed so far.
Methods Exercise performance was obtained by bicycle spiroergometry in 18 severely obese patients before and at least 1 year after bariatric surgery. Additionally, pulmonary function was assessed by spirometry.
Results BMI was reduced from 46.3±1.6 to 33.5±1.4 kg/m^2 after surgery. Pulmonary function (forced expiratory volume within 1 s; inspiratory vital capacity) improved after weight loss (both $p \leq 0.01$). At peak exercise, heart rate (HR) peak, absolute oxygen uptake (VO_2) peak, and load peak did not differ between both assessments (all $p > 0.25$). However, relative (related to actual body weight) VO_2 peak and workload peak were higher after than before surgery (both $p \leq 0.005$), while gross efficiency peak and ventilatory equivalent peak remained unchanged (both $p > 0.30$). At anaerobic threshold (AT), patients showed lower HR AT and absolute VO_2 AT after than before surgery (both $p < 0.05$), while absolute workload AT did not differ ($p = 0.58$). In turn, relative VO_2 AT did not change ($p = 0.30$), whereas relative workload AT was higher after surgery ($p = 0.04$). Also, ventilatory efficiency AT and gross efficiency AT tended to be improved (both $p = 0.08$). Before surgery, the patients performed 27.0 % of VO_2 peak above their AT, while this fraction increased to 35.3 % ($p = 0.006$).
Conclusions Results indicated differential changes in exercise performance, with the relative but not the absolute peak performance being improved after massive weight loss. Interestingly, anaerobic exercise tolerance was markedly improved after surgery.

Keywords Exercise performance · Pulmonary function · Bariatric surgery · Weight loss · Obesity

Introduction

The prevalence of obesity has reached epidemic proportions worldwide and the most severe forms of obesity appear to show the steepest rise in particular [1, 2]. Obesity is associated with an increased risk for many diseases such type 2 diabetes, hypertension, cardiovascular events, and even different kinds of cancer [3–5]. Furthermore, severely obese subjects often show reduced cardiorespiratory fitness and pulmonary function, both of which represent additional independent risk factors for premature death [6–12]. Even more important, poor cardiorespiratory function can profoundly affect severely obese subjects' lives as they often become easily short of breath during everyday activities like going up the stairs or even walking around a block.

During the last decade, bariatric surgery has been proven to be the most effective therapy for severe obesity and thus is performed in a continuously increasing number of severely obese subjects worldwide [13]. Besides reducing body weight and obesity-associated comorbidities and mortality [14–16], bariatric surgery has been shown to increase the subjects' physical activity and thus contributes to the establishment of a healthier lifestyle [17]. However, little is known on the effects of bariatric surgery and the associated weight loss on cardiorespiratory fitness and exercise

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performance. One study [18] that repeatedly tested exercise performance in 65 severely obese subjects by treadmill ergospirometry found an increase, as compared with the pre-operative state, in peak oxygen uptake (VO_2) related to the actual body weight, i.e., relative VO_2 peak, at 12 months after bariatric surgery. Another study [19] that also assessed exercise performance by treadmill ergospirometry likewise found an increased relative but not absolute peak VO_2 at 1 year after bariatric surgery in 31 severely obese subjects. However, both of these studies did not provide detailed information on distinct exercise performance parameters such as oxygen uptake at the anaerobic threshold or gross efficiency so that the physiological mechanisms underlying the post-operative improvement remain obscure [20]. Also, the use of treadmill exercise test protocols in foregoing studies may have been strongly biased results since they largely depend on body weight which is markedly reduced after bariatric surgery. To overcome previous limitations, we assessed changes in exercise performance by a more weight-neutral bicycle exercise test protocol as well as pulmonary function after bariatric surgery. We hypothesized that relative exercise performance, e.g., related to the actual body weight, is increased after bariatric surgery and that exercise economy is improved. Furthermore, we expected pulmonary function to be improved after surgery.

Materials and Methods

Patients

We tested 18 severely obese patients (11 women) before and at least 1 year after bariatric surgery. Sixteen patients (11 women) had undergone a Roux-en-Y gastric bypass procedure and two patients (one woman) had undergone a sleeve gastrectomy. All patients had a pre-operative body mass index (kilograms per meter squared) higher than 35.0 kg/m^2 and thus qualified according to the European guidelines for bariatric surgery [21]. All patients gave written informed consent and the study was approved by the local ethical committee of St. Gallen.

Testing Procedures and Calculations

Measurements of pulmonary function (forced expiratory volume within 1 s, FEV1; inspiratory vital capacity, IVC; ratio of FEV1 to IVC in %) were obtained by standard spirometry (CARDIO-VIT CS-200, Schiller AG, Baar, Switzerland). The spirometer was calibrated before each test using a 3-l syringe. The tests were conducted by specially trained technicians and each participant completed the test while standing. In order to compare measured with predicted pulmonary function variables, individual reference FEV1 and IVC values were calculated upon the formula according to the guidelines of the Austrian Society for Pneumology [22].

Exercise performance was assessed by bicycle ergospirometry. Gas exchange was analyzed breath by breath every 20 s using a computer-based system (CARDIO-VIT CS-200, Schiller AG, Baar, Switzerland). The system was calibrated before each test using standard gases of known oxygen and carbon dioxide concentration (6.0098 % CO_2; 15.0184 % O_2; rest N_2) and a 3-l syringe. A 12-lead electrocardiogram was recorded continuously during the test and the subsequent 5-min recovery period. Systolic and diastolic blood pressure was measured every 2 min. The test protocol was characterized by starting at a workload (W) of 25 to 75 W depending on the presumed patient's fitness and increased by 25 W every 2 min until volitional exhaustion. During exercise against the resistance of a cycle ergometer, the external workload is calculated as the product of the distance traveled by a point on the circumference of the wheel, the rotational frequency of the flywheel, and the restraining force [23]. The post-operative test protocols were matched to the individual's pre-operative protocol.

Maximally achieved O_2 uptake (VO_2 peak), heart rate (HR peak), and respiratory exchange ratio (RER peak) as well as external workload (W peak) were recorded. The RER represents the ratio of exhaled carbon dioxide (VCO_2) to simultaneously measured O_2 uptake (VO_2). The anaerobic threshold (AT) was identified by the V-slope method [23] and corresponding VO_2, HR, and workload (VO_2 AT; HR AT, and W AT, respectively) values were recorded. In order to account for the massively reduced body weight after the surgery, VO_2 as well as workload values were related to actual body weight. Oxygen pulse (VO_2-puls), i.e., the ratio of VO_2 to simultaneously recorded HR, is an indicator of oxygen consumption per heart beat and was also calculated at peak exercise (VO_2-puls peak). Age-related maximum HR (HR max) as well as the RER peak was used to characterize the degree of exhaustion at the end of the exercise. The age-related HR max was calculated by the following formula [23]: HR max=220−age.

The ventilatory equivalent for oxygen was calculated as the ratio of the volume of gas expired per minute (ventilation, VE) to the volume of oxygen taken up (VO_2) per minute at peak effort (VE/VO_2 peak) and at anaerobic threshold (VE/VO_2 AT). The VE/VO_2 ratio represents the amount of ventilation required for the uptake of 1 l of oxygen and, therefore, reflects ventilatory efficiency. VE/VO_2 peak can also be used to characterize the degree of exhaustion.

Gross efficiency (GE), another important indicator of performance, was calculated as the ratio between workload, as measured in watt (i.e., Joule per second), and metabolic power input (PI). PI was calculated upon VO_2 and RER [20] by using the following formula [24]:

$$PI = \frac{VO2}{60} * (RER * 4940 + 16040)$$

Gross efficiency was calculated at anaerobic threshold (GE AT) as well as at peak exercise (GE peak).

Statistical Analysis

Statistical analyses were performed by using SPSS for Windows (Version 12, SPSS, Chicago, IL, USA). All data are presented as mean±SEM. Student's *t*-tests for paired samples (ratio data) or McNemar test (categorical data) was used to test for differences before and after bariatric surgery. Relationships between exercise performance parameters assessed before and after weight loss were analyzed by Pearson correlation analysis. Individual variability of changes in exercise performance after surgery was assessed by calculating the intra-individual coefficient of variation (CV). A *p*-value of less than 0.05 was considered as significant.

Results

The clinical characteristics of the patients before and after the surgery are summarized in Table 1.

The average time that had been elapsed since surgery until the post-operative reassessment was 27.7±2.5 month (range, 15–45 months). As expected, body weight was markedly reduced after surgery by, on average, 27±2 % of the pre-operative weight, and preoperatively existing comorbidities like diabetes and hypertension were markedly improved or even resolved in the majority of patients.

Results on pulmonary function variables are provided in Table 2. IVC and FEV1 significantly improved after weight loss (both $p \leq 0.001$) with a somewhat more pronounced increase in IVC, leading to a slight decrease of the FEV1/IVC ratio ($p=0.049$).

Results on ergospirometric variables are provided in Table 3. At the end of the exercise tests, HR peak as well as absolute VO_2 peak and workload peak values did not significantly differ between the pre- and post-operative assessment (all $p>0.25$). Accordingly, peak VO_2-puls values were also found to be unchanged after the surgically induced weight loss ($p=0.94$). Also, neither gross efficiency nor ventilatory equivalent at peak exercise was different between both assessments ($p>0.30$). However, when VO_2 peak and workload peak values were related to the actual body weight, the respective values turned out to be significantly higher after than before surgery (both $p \leq 0.005$).

Correlation analyses revealed that absolute peak VO_2 and absolute peak workload before and after the surgery were significantly associated ($r=0.56$, $p<0.016$ and $r=0.76$, $p<0.001$, respectively). Intra-individual CVs were 13.5±2.1 % for peak VO_2 and 7.3±2.7 % for peak workload.

AT could be automatically detected with V-slope method by the internal software algorithm and was visually verified in 16 patients before and in 17 after surgery, respectively, with 15 patients having a detectable AT at both assessments. At the AT, the patients showed significantly lower HR AT and lower absolute VO_2 AT values after than before weight loss (both $p<0.05$), while the absolute workload AT did not differ between the two assessments ($p=0.58$). In turn, when VO_2 AT was related to the patient's actual body weight, i.e., VO_2 AT/BW, the respective values did not significantly differ between the pre- and post-surgical state ($p=0.30$), whereas workload AT/BW was significantly higher after surgery ($p=0.04$). In contrast to peak exercise values, there was no significant relationship between absolute VO_2 uptake at AT before and after surgery ($r=0.27$; $p=0.33$), while the respective absolute workload AT values tended to be correlated ($r=0.50$; $p=0.06$).

Ventilatory efficiency at the AT, i.e., VE/VO_2 AT, tended to be improved after weight loss as reflected by lower values ($p=0.078$). Accordingly, gross efficiency at AT also tended to be higher after than before the surgically induced weight loss ($p=0.078$). The relationship between VO_2 AT and workload AT is shown in Fig. 1, illustrating the change in exercise economy at

Table 1 Characteristics of the study population ($n=18$) before and after bariatric surgery

	Before surgery	After surgery	*p*
Age (years)	42.5±2.5	45.0±2.3	<0.001
Body weight (kg)	123.8±6.1	89.3±4.5	<0.001
BMI (kg/m^2)	46.3±1.6	33.5±1.4	<0.001
Type 2 diabetes (*n*)	7	0	0.016
Hypertension (*n*)	10	3	0.016
Dyslipidemia (*n*)	4	1	0.25
Sleep apnea syndrome (*i*)	4	2	0.50

All values are mean±SEM or absolute values. *P* values derived from paired Student's *t* tests or McNemar test

BMI body mass index

Table 2 Pulmonary function of the study population before and after marked weight loss induced by bariatric surgery

	Before surgery	After surgery	p
IVC (l)[a]	3.4±0.2	3.7±0.2	<0.001
IVC (% of predicted)	87.4±2.9	98.3±3.3	<0.001
FEV1 (l)[b]	2.6±0.2	2.9±0.2	0.010
FEV1 (% of predicted)	80.6±3.7	88.7±3.8	0.003
FEV1/IVC ratio[c]	82.2±1.3	79.4±1.6	0.049

All values are mean±SEM. *P* values derived from paired Student's *t* tests

IVC inspiratory vital capacity, *FEV1* forced expiratory volume in 1 s

[a] Analyzed in 17 patients

[b] Analyzed in 17 patients

[c] Calculated in 16 patients

the anaerobic threshold as characterized by the parallel upward shift of the regression line after surgery.

Intriguingly, before surgery, the tested patients performed only 27.0 % of the peak exercise above their individual AT, while this fraction increased to 35.3 % after surgery ($p=0.006$; Fig. 2). Correspondingly, the average RER peak achieved by the patients was significantly higher after than before the surgically induced weight loss ($p=0.03$). However, there were no differences in the percentage of patients reaching the age-predicted maximal HR as well as in ventilatory efficiency (VE/VO_2 peak) before and after surgery (both $p>0.3$).

Discussion

In the present study, we assessed pulmonary function and exercise performance in severely obese subjects before and after they had undergone bariatric surgery associated with a consecutive massive weight loss. Pulmonary function was found to be markedly improved after weight loss with a most prominent increase in IVC, which is likely explained by the putatively reduced intra-abdominal fat mass and pressure [25]. Absolute peak exercise performance remained unchanged after massive weight loss, but relative peak performance, i.e., performance related to actual body weight, showed a clear-cut improvement. Intriguingly, after the surgically induced weight loss, the tested patients performed a much greater fraction of their peak performance under anaerobic conditions, pointing to a strikingly enhanced anaerobic tolerance.

The pattern of ergospirometric results found in our studies needs to be discussed in detail. Although our study does not provide any data on body composition, it should be noted that previous studies have indicated that marked weight loss induced by bariatric surgery is not only associated with a reduction of fat but also,

Table 3 Exercise performance parameters at peak effort and at the anaerobic threshold before and after marked weight loss induced by bariatric surgery

	Before surgery	After surgery	p
Peak effort ($n=18$)			
HR peak (beats/min)	154±4.5	148±4.9	0.29
Workload peak (W)	136±10.2	144±11.4	0.27
Workload peak/BW (W/kg)	1.13±0.09	1.65±0.12	<0.001
VO_2 peak (l/min)	1.93±0.14	1.91±0.18	0.91
VO_2 peak/BW (ml/kgmin^{-1})	15.9±1.2	21.5±1.7	0.005
RER peak	1.11±0.02	1.18±0.01	0.03
VO_2 puls peak (ml/beat)	12.9±0.9	12.8±1.0	0.94
VE/VO_2 peak	32.2±1.9	31.1±1.3	0.52
GE peak (%)	19.9±1.0	21.4±0.9	0.31
Test duration (sec)	518±30	549±39	0.30
Anaerobic threshold ($n=15$)			
HR AT (beats/min)	130±3.5	120±5.0	0.008
Workload AT (W)	98±9.6	93±7.9	0.58
Workload AT/BW (W/kg)	0.86±0.09	1.11±0.10	0.037
VO_2 AT (l/min)	1.39±0.08	1.16±0.10	0.041
VO_2 AT/BW (ml/kgmin^{-1})	12.0±0.8	13.5±1.1	0.30
RER AT	0.96±0.003	0.96±0.003	0.39
VE/VO_2 AT	28.1±1.9	24.8±0.7	0.078
VO_2 above AT (%)	27.0±1.9	35.3±3.1	0.006
GE AT (%)	20.3±1.7	24.0±1.5	0.078

All values are mean±SEM. *P* values were derive from paired Student's *t*-tests

HR heart rate, *BW* body weight, *VO_2* oxygen uptake, *RER* respiratory exchange ratio, *VE* ventilation, *GE* gross efficiency, *AT* anaerobic threshold

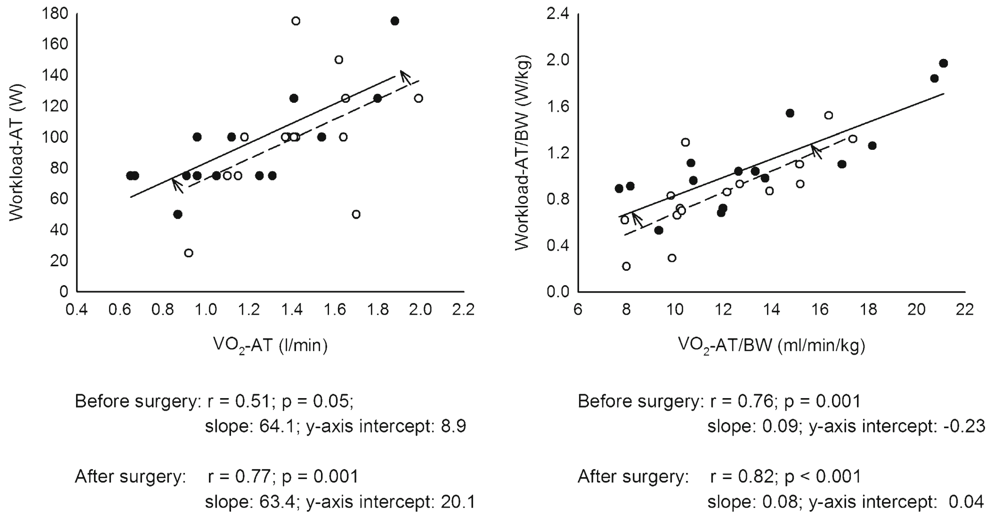

Fig. 1 Relationship between absolute (*left*) as well as relative (*right*) workload and oxygen uptake at anaerobic threshold before (*white circles*, *dashed regression line*) and after (*black circles*, *solid regression line*) the surgically induced weight loss

albeit to a lesser extent, of muscle mass [26–29]. On this background, one may assume that total muscle mitochondrial capacity is also reduced after bariatric surgery. This is important since the extent muscles' mitochondria determine the oxidative capacity and thus maximal performance [30]. Assuming that total muscle mass was reduced after the surgically induced weight loss in our patients, one may have expected the absolute peak performance to be reduced after surgery. As this was obviously not the case, it can be speculated that a post-operative increase in mitochondria density or mitochondrial function may have compensated for the lower muscle mass so that absolute peak performance remained essentially unchanged. Obesity has been shown to be associated with a reduction in skeletal muscle mitochondrial content and oxidative capacity in obesity. While some studies have shown reduced mitochondrial content in obese patients [31, 32], other studies have shown perturbations in mitochondrial structure and function [33]. Exercise training has been demonstrated to enhance mitochondrial content in obese patients with [34] and without [35] diabetes, pointing to the dynamic nature of the muscle's mitochondrial capacity. The observed increase in relative performance, i.e., peak VO_2 and workload related to body weight, may provide further support for this notion.

Our findings regarding the anaerobic threshold clearly point to profound changes in the metabolic sources of energy required to perform the exercise after weight loss. The anaerobic threshold was detected at distinctly lower VO_2 values after than before surgery, implying that the capacity of the muscles to generate energy under aerobic conditions was reduced. While a reduction of the muscles' glycogen content may play a role in this context [36], again the putative reduction of absolute muscle mass associated with weight loss most likely explains this finding. Further support for this assumption derives from the unchanged relative VO_2 uptake, i.e., VO_2 related to body weight, at the AT since the body weight can be assumed to correlate with body muscle mass.

Of note, the relative workload at the AT, in contrast to the relative VO_2 AT, was increased after surgery and the absolute workload at the AT was unchanged despite lower VO_2 AT. Accordingly, gross efficiency and also the ventilatory equivalent at the AT tended to be improved. Taken together, this pattern of results points to an improved exercise economy after the surgically induced weight loss, which certainly is of great relevance for everyday activities. In this context, it is

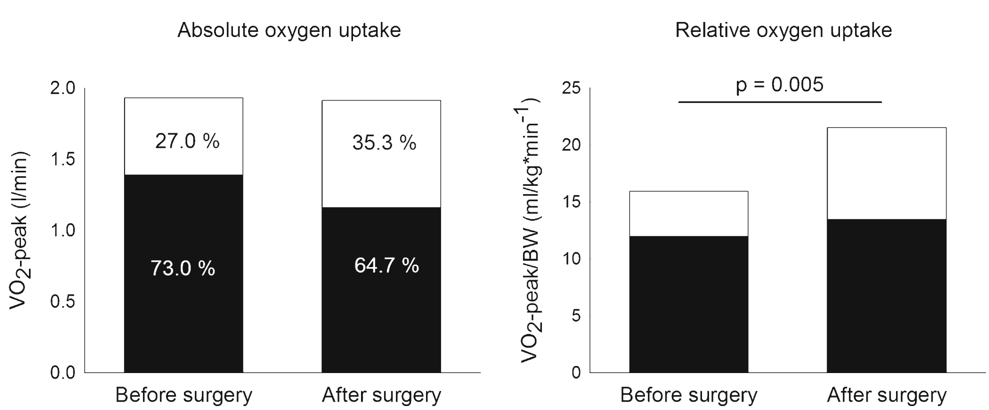

Fig. 2 Absolute (*left*) and relative oxygen uptake (*right*) below (*black columns*) and above (*open columns*) the anaerobic threshold before and after marked weight loss induced by bariatric surgery. *Numbers* in the *left graph* indicate the percentage of relative oxygen uptake below and above the anaerobic threshold

noteworthy that several foregoing studies have revealed an increased energy cost of different exercises in obese patients [6, 37, 38]. Regarding cycling in particular, decreased exercise economy in obese patients can be attributed to the higher energy involved in moving the heavier legs and to stabilize the trunk [6, 38]. Thus, it appears reasonable to assume the exercise economy to have been improved after marked weight loss as suggested by the results of the present study.

A most prominent finding in our study was that the patients showed greatly enhanced anaerobic tolerance and performance capacity after weight loss. The mechanism underlying this improvement cannot be determined upon our data. Psychological factors such as motivation or pain tolerance may play a prominent role in this context. Unfortunately, we didn't quantify subjective exhaustion at peak performance, e.g., by applying the Borg scale, so that it remains unknown whether the perceived exhaustion and effort of the patients changed after weight loss. However, whatever the underlying mechanisms are, the enhanced anaerobic tolerance clearly helped the patients to maintain their absolute peak performance at the level as it was before the surgery despite a putatively reduced muscle mass.

Several limitations of our study need be pointed out. First, we have not assessed body composition in our patients, which precludes any conclusion on changes in fat and lean body mass or even muscle mass after surgery. Second, habitual physical activity and exercise performed before and particularly after surgery were not assessed. In this context, it should be noted that a recent study investigating the effects of a supervised exercise training program during the first 4 months after bariatric surgery demonstrated a profound improving influence on post-operative changes in exercise performance [39]. Furthermore, biopsy studies have shown that exercise modulates the changes in mitochondrial content and function, as measured by skeletal muscle mitochondrial electron transport chain activity, during a diet-induced weight loss [40, 41]. On this background, it may well be that inter-individual differences in habitual physical activity and exercise have influenced the variability of changes in exercise performance in our study. However, it appears unlikely that they have systematically biased our results.

In conclusion, our results indicated differential changes in exercise performance after massive weight loss induced by bariatric surgery. While absolute performance did not change, relative performance, which is more relevant for everyday life, was found to be markedly improved. However, it should also be noted that exercise performance after surgery was still much lower than published weight-dependent reference values [42]. This indicates that our patients still displayed an impaired exercise performance after the marked weight loss. Thus, further insights on the physiology of reduced exercise performance in obesity and respective changes after weight loss are clearly needed as they may provide the basis for the development of new intervention strategies.

Conflict of Interest No conflicts of interest were declared by any of the authors (BWI, BE, MT, BWE, and BS).

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