

# **Physical fitness in morbidly obese patients: effect of gastric bypass surgery and exercise training.**

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## ABSTRACT

### **Background:**

There is a growing consensus that bariatric surgery is currently the most efficacious and long-term treatment for clinically severe obesity. However, it remains to be determined whether poor physical fitness, an important characteristic of these patients, improves as well.

The purpose of this pilot study is to investigate the effect of gastric bypass surgery on physical fitness and to determine if an exercise program in the first four months is beneficial.

### **Methods:**

Fifteen morbidly obese patients (BMI: 43,0 kg/m<sup>2</sup>) were tested before and 4 months after gastric bypass surgery. Eight of them followed a combined endurance and strength training program. Before and 4 months after the operation anthropometrical characteristics were measured and an extensive assessment of physical fitness (strength, aerobic and functional capacity) was performed.

### **Results:**

Large scale weight loss through gastric bypass surgery results in a decrease in dynamic and static muscle strength and no improvement of aerobic capacity. In contrast an intensive exercise program could prevent the decrease and even induced an increase in strength of most muscle groups. Together with an improvement in aerobic capacity, functional capacity increased significantly. Both groups evolved equally with regard to body composition (decrease in fat mass and fat-free mass).

### **Conclusions:**

An exercise training program in the first 4 months after bariatric surgery is effective and should be promoted, considering the fact that physical fitness does not improve by weight loss only.

### **Key words:**

Gastric bypass, bariatric surgery, morbidly obese, exercise, physical fitness, strength, functional capacity, endurance, fat-free mass, weight loss

## INTRODUCTION

The number of bariatric surgery procedures has increased significantly over the past few decades, not only in the United States, but also worldwide [1]. Two major reasons can be defined. First, the prevalence of morbidly obesity increases rapidly, approaching 8% for some populations in the United States [2]. Secondly, there is a growing consensus that bariatric surgery is currently the most efficacious and long-term treatment for clinically severe obesity, accompanied with a low mortality rate [3-5]. Morbid obesity is associated with a number of comorbidities such as hypertension, dyslipidemia, type 2 diabetes or insulin resistance, sleep apnea, etc [6-8]. In addition to fat mass reduction, bariatric surgery has pronounced effects on these co-morbidities [3,9], even before weight loss occurs [10,11].

However, it remains to be determined whether poor physical fitness, a key factor in the vicious circle of obesity and physical inactivity [12] and an important characteristic of morbidly obese patients [13,14], improves as well after bariatric surgery. There are some reasons to assume that this is not self-evident. To answer this question we must keep in mind that physical fitness is a broad concept that covers muscle strength but also functional and aerobic capacity. First of all, we do know that large scale weight loss always results in a decrease in fat-free mass (FFM). Carey et al. [15] reported that FFM loss accounts for 30-35% of the total weight loss over the first six months as a consequence of Roux-en-Y Gastric bypass. We can presume that the high amount of weight loss, the malabsorptive characteristic of the procedure and an inadequate protein intake [16] induces this skeletal muscle atrophy, with a concomitant decrease in muscle strength. Muscle strength is an important aspect of functional capacity, e.g. knee extensor muscle strength has been associated with gait speed, stair climbing, getting up from a seated position, postural stability and even to the occurrence of falls in a number of investigations [17,18]. Maffiuletti et al. [19,20] indicated the importance of a decreased relative knee extensor muscle strength in terms of body weight in obese patients, by contributing to reduced functional capacity during daily living activities. Until today, only 2 articles have been published to evaluate changes in functional capacity following bariatric surgery. A prospective 1-year study by Maniscalco et al. [21] showed an improvement of the distance walked in six minutes (6MWD) from 475.7 to 626.3 meters in 15 female morbidly obese patients 1 year after laparoscopic adjustable gastric banding. Tompkins J et al. [22] confirmed these results and added normative values,

namely presurgical walking distance was 55% of normative values and improved up to 75% six months after the operation. Both studies conclude that functional capacity improves because the six minute walking distance improves. The main reason is that less adipose tissue around the legs is more mechanical efficient, which makes walking less exhausting. Additionally, they suggest that aerobic capacity improves as well. However, we believe that this is partly true. Poor aerobic fitness in morbidly obese subjects is explained by both reduced cardiovascular function [23] as well as a low oxidative capacity of skeletal muscle [24-26]. Indeed, weight loss ameliorates cardiovascular function, but this cannot be adopted for the oxidative capacity of the obese muscle. It is known that weight loss alone, accomplished by low calorie diets, does not improve mitochondrial content and electron chain transport activity in skeletal muscle of sedentary obese subjects [27], it even decreases mitochondrial size. Further, a high proportion of fast glycolytic type II muscle fibers and thus a low portion of oxidative type I muscle fibers is characteristic for the obese muscle [28]. Again, weight loss alone cannot change skeletal muscle fiber type. Therefore, there is no reason to assume that the extreme poor aerobic capacity will improve by gastric bypass surgery alone.

A first goal of the present study is to investigate the effect of gastric bypass surgery on physical fitness with a many-sided physical performance battery (muscle strength, aerobic and functional capacity).

An additional goal of this study is to examine the feasibility and effectiveness of an exercise program in morbidly obese patients after gastric bypass surgery. To our knowledge, no studies have been reported that examine the effect of aerobic and resistance exercise in the period following bariatric surgery. Rice et al. [29] and Janssen et al. [30] reported that a low calorie diet (energy deficit of 1000 kcal/d) combined with either aerobic exercise or resistance exercise results in respectively an increased aerobic capacity (VO<sub>2</sub> max) and muscle strength in lower and upper body. The diet group without exercise had no amelioration in aerobic capacity nor in muscle strength, furthermore a significant loss of FFM was present, while not in the exercise groups. It remains to be determined whether these data on low calorie diets can be extrapolated toward the first post-operative period following gastric bypass surgery. We therefore hypothesize that exercise training during the months following a gastric bypass procedure can improve aerobic capacity and prevent the decline in muscle mass and muscle strength, with implications to functional impairment.

## MATERIALS AND METHODS

### Subjects

Nineteen gastric bypass patients were recruited for the study after checking the exclusion and inclusion criteria. Exclusion criteria were diabetes, severe cardio-vascular diseases and exercise-limiting co-morbidities such as musculoskeletal impairments. To be included, patients must undergo gastric bypass surgery, a mixed restrictive and malabsorptive form of bariatric surgery. Also conversions from a gastric banding to a gastric bypass procedure were allowed. The subjects gave their informed consent, and the study was approved by the local Ethics Committee (Ghent University Hospital, Ghent, Belgium).

All patients were able to make the choice between the intervention group (exercise program after gastric bypass 'GB+E', 'the trained patients') or the control group (only gastric bypass 'GB', 'the untrained patients'). There was a drop-out of four patients (2 of GB and 2 of GB+E), so that *finally fifteen morbidly obese patients* (BMI:  $42,5 \pm 6,6$  kg/m<sup>2</sup>, age:  $40,5 \pm 8,1$  years, 4 men and 11 women) finished the study, of which 7 *patients* in 'GB' and 8 *patients* in 'GB+E'. The characteristics of the groups are shown in table 1.

Reasons of refusal were domicile distance and a demanding job and household. Reasons of drop-out were also a demanding job, household or education.

### Study protocol

Both the patients of 'GB' and 'GB+E' underwent the same measurements before and four months after the operation. Only the patients of 'GB+E' started one month after the operation with an exercise program during 3 months.

### EXERCISE PROGRAM

The patients in group 'GB+E' exercised three times a week during 12 weeks (36 sessions). Each training session lasted 75 minutes and included 10 minutes of cardiovascular warming up, 25 minutes of strength training, 30 minutes of endurance training and a cooling-down period of 10 minutes.

During each session, patients were individually guided and supervised by Masters in Movement and Rehabilitation Sciences.

*Strength exercises* were performed using stack-weight equipment (elbow flexion and extension and knee flexion and extension). Intensity of strength training was calculated from 1 repetition maximum (1RM)-values. The starting level was 60% of 1RM, which increased up to 75% of 1RM. Patients were habituated to the exercises and equipment during the first 3 training sessions. The next 15 sessions, 2 sets of 15 repetitions at 60% of 1 RM was done. In the final 18 sessions, 3 sets of 10 repetitions at 75% was done. Resting periods between repetition sets was approximately 60 seconds.

*Endurance training* consisted of cycling (10 min), walking (10 min) and stepping (10 min). Exercise intensity was initially set at 60% of heart rate reserve (HRR, defined as the difference between resting heart rate and peak heart rate) and was gradually increased up to 75% of HRR at the end of the training period. Stationary bicycles, treadmills and steppers were used in a rehabilitation training room of the University Hospital of Ghent (Belgium). During the training sessions, heart rate was monitored by Polar Heart Watches.

## MEASUREMENTS

### 1. Anthropometric variables and Body composition

Body Mass Index or BMI (weight/ height<sup>2</sup>) and waist circumference (at the level of the biggest circumference, near the umbilicus) were determined using a digital balance scale, a stadiometer and a tape meter. Body composition was assessed by bio-impedance (Bodystat 1500 MDD; Bodystat Ltd, Douglas, Isle of Man, UK). Patients were in supine position for at least 5 minutes. Surface electrodes were attached to the right hand (red lead: behind the knuckle of the middle finger; black lead: on the wrist to the ulnar head) and foot (red lead: behind the 2<sup>nd</sup> toe next to the big toe; black lead: On the ankle at the level of and between the medial and lateral malleoli). Total body water (TBW) was calculated from the measured impedance using the following gender specific formula: females:  $TBW=0.382x(\text{height}^2/\text{impedance})+0.105x\text{bodyweight}+8.315$  and men:

$TBW=0.396*(\text{height}^2/\text{impedance})+0.143*\text{bodyweight}+8.399$  [31]. Fat-free mass (FFM) was then calculated from the TBW by assuming 73.2% hydration of FFM:  $FFM=TBW/0.732$  [32]. Body fat mass (FM) was calculated using a two compartment model:  $\text{body weight}=FFM + FM$ .

## 2. Physical fitness test battery

### a. Dynamic muscle strength:

One Repetition Maximum (1RM) was determined unilaterally with the indirect Holten-method using commercially available stack weight and fitness equipment for *biceps*, *triceps*, *quadriceps* and *hamstrings*. For each patient a test weight was defined so that patients would be able to achieve maximal 6 to 12 repetitions. From this number of repetitions the 1RM was calculated using the Holten diagram. The Holten diagram relates the number of repetitions to the percentage of maximum strength. The global score (kg) for the biceps, triceps, quadriceps and hamstrings exercise was calculated by taking the sum of the right and left arm or leg.

### b. Static muscle strength

Static muscle strength was evaluated by measuring the handgrip strength with a handgrip dynamometer (JAMAR). Subjects were standing in the anatomical position, with the arm flexed at 90°, without touching the body. The participant was asked to squeeze as hard as possible. Three trials were made with a pause of about 10-20 seconds between each trial to avoid the effects of muscle fatigue. Left and right hand were alternated. The best score (in kg) was registered.

### c. Muscle fatigue

The participant was in the same position as described in 'b. static muscle strength'. He/she had to squeeze the dynamometer with the strongest hand (determined in b.) with as much force as possible and as long as possible. The test was finished when grip strength dropped to 50% of its maximum during sustained contraction. The seconds were registered.

#### d. Functional capacity

- Sit-to-stand test

This test measured the maximum number of times that a patient could rise to a full stand from a seated position within 30 seconds, without pushing off with the arms. The number of completed stands (up-down) was considered the patient's score. This assessment has high test-retest reliability.

- Six-minute walk distance (6MWD)

All patients performed a standardized, self-paced 6 MWT in a 20-meter long corridor. They were instructed to cover as much distance as possible within 6 minutes without running. Patients were allowed to stop at every moment of the test, but were encouraged to restart as soon as possible. During the test, patients were instructed as described by Enright et al. [33]. Covered distance after 6 minutes was measured to the nearest meter. Heart rates were monitored during the test by Polar Heart Watches.

#### e. Maximal cardiopulmonary exercise test

Patients performed a maximal cardiopulmonary bicycle test on a cyclo-ergometer (Gymna). A gradual protocol was used, starting at 30 watt with gradual increase of 15 watts every minute, with the subjects cycling at 60-70 rotations per minute. Patients continued cycling until self-determined limits of their functional capacities or until the physician stopped the test because of potentially threatening symptoms. After the patients reached their maximum, subjects cycled during 3 minutes for active recovery at 1/3 of their maximal work load. Heart rates were continuously determined by electrocardiogram, whereas blood pressure was measured with a manual sphygmomanometer every two minutes. During the test, gas exchange was measured continuously using a portable mixing chamber system (MetaLyzer II, Cortex, Leipzig, Germany). The oxygen consumption ( $\text{VO}_2$ ), carbon dioxide production ( $\text{VCO}_2$ ), minute ventilation (VE) and respiratory exchange ratio (RER) were registered every 30 seconds. Peak  $\text{VO}_2$  is determined as the highest attained  $\text{VO}_2$  over 30 seconds during the



test and expressed in both absolute values (peak  $\text{VO}_2$ , ml/min), relative to body weight (peak  $\text{VO}_2/\text{kgBW}$ , ml/kg/min) and relative to fat-free mass (peak  $\text{VO}_2/\text{kgFFM}$ , ml/kg/min). The ventilatory equivalent method was used to determine the ventilatory anaerobic threshold (VAT), described by Wasserman K. [34]. This is based on the principle that ventilation increases promptly at the anaerobic threshold in proportion to the increase in  $\text{CO}_2$  produced from  $\text{HCO}_3^-$  buffering of lactic acid. This results in an increase in the ventilatory equivalent for  $\text{O}_2$  ( $\text{VE}/\text{VO}_2$ ) without an increase in the ventilatory equivalent for  $\text{CO}_2$  ( $\text{VE}/\text{VCO}_2$ ). The time of occurrence (seconds) of VAT, together with the workload (power output) and oxygen uptake at that moment are registered.

### Statistical analyses

Interaction and time effects were evaluated using a repeated-measures analysis of variance (ANOVA). To evaluate time effects within groups, paired t-tests were performed. Data are expressed as mean ( $\pm$  standard deviation) and are analyzed with a commercially available statistical software program (SPSS 16.0, SPSS Inc, Chicago, Illinois, USA). Data are significant when  $p < 0,05$ .

## RESULTS

### Anthropometric variables and body composition pre- and 4 months postoperative (Table 2).

The trained patients (GB+E) as well as the untrained patients (GB) had the same decrease in weight (GB:  $-26,6 \pm 14,6$  kg; GB+E:  $-22,7 \pm 5,7$  kg), BMI (GB:  $-8,3 \pm 4,1$  kg/m<sup>2</sup>; GB:  $-8,1 \pm 2,5$  kg/m<sup>2</sup>) and waist circumference (GB:  $-20,3 \pm 11,6$  cm; GB+E:  $-17,2 \pm 8,1$  cm). Weight loss resulted largely from significant decrease in fat mass (GB:  $-19,0 \pm 10,2$  kg; GB+E:  $-17,3 \pm 4,6$  kg), but also fat free mass (GB:  $-7,6 \pm 4,7$  kg; GB+E:  $5,4 \pm 2,6$  kg) decreased significantly four months after the gastric bypass operation. No interaction effects were found.

### Results of the physical fitness test battery (table 3)

#### MUSCLE STRENGTH

The untrained patients (GB) had a pronounced decrease in *Dynamic Muscle strength* four months after the operation. They lost 16% of their quadriceps strength, 36% of their biceps strength and 39% of their triceps strength. By contrast, an exercise program (strength + endurance) could prevent this decrease concerning biceps strength (Pre:  $21,8 \pm 8,0$  kg; Post:  $25,9 \pm 13,0$  kg) and triceps strength ( $24,3 \pm 10,1$  kg; Post:  $30,7 \pm 23,0$  kg) and even increased quadriceps strength with 72% and hamstrings strength with 27%.

*Static muscle strength*, measured as handgrip strength, decreased in both GB and GB+E four months after gastric bypass surgery, respectively with 18% and 7%. No interaction effects could be reported.

*Muscle fatigue*, also measured with the handgrip dynamometer, was not influenced by gastric bypass surgery, nor by an additional exercise program.

#### FUNCTIONAL CAPACITY

Patients were also subjected to two tests that evaluated functional capacity. There was a tendency for an interaction effect concerning the *sit-to-stand test* ( $p=0,08$ ). The trained patients (GB+E) improved their number of times to rise to a full stand from a seated position within 30 seconds (Pre:  $13 \pm 3$  times to Post:  $16 \pm 4$  times;  $p=0,045$ ), whereas the untrained patients (GB) did not (Pre:  $15 \pm 4$  times to Post:

15 ± 3 times; p=0,862). The *six minute walk distance*, another important test that evaluates functional capacity, improved for both groups together. Further analyzes showed us that the increase in the 6MWD is mainly attributed to the increase in the training intervention group, namely GB+E: + 52 ± 30m and GB: + 30 ± 68m. The heart frequency on the end of the 6MWD declined significantly for both groups.

#### (MAXIMAL) AEROBIC CAPACITY

In the maximal bicycle ergometer test, before the operation both groups reached their *ventilatory anaerobic threshold (VAT)* at the power (GB: 93 ± 24 watt; GB+E: 90 ± 24 watt) with an equal time of occurrence (GB: 270 ± 107 sec; GB+E: 266 ± 133 sec). Gastric bypass surgery, with a weight loss of average 25 kg after 4 months, did not improve time of occurrence of VAT and power at VAT.

However, when patients followed an exercise program (GB+E) they could delay the time of occurrence of VAT (time of occurrence of VAT: 349 ± 149 sec) (figure 1). To conclude, %VO<sub>2</sub> at VAT/VO<sub>2</sub>peak (the percentage oxygen uptake at VAT relative to the oxygen uptake at peak, also a measurement to define aerobic capacity in relation to total exercise capacity) revealed an interaction effect, meaning that both groups evolved differently considering exercise versus no exercise (table 4). Also *peak exercise capacity parameters* were recorded. Pre-operatively, the morbidly obese subjects reached a peak oxygen uptake of 17,4 ± 4,9 ml/kg/min (GB) and 17,6 ± 3,2 ml/kg/min (GB+E), which can be defined as an extreme poor physical fitness (< 23 ml/kg/min). Surprisingly, absolute peak oxygen uptake (ml/min) and power (watt) were not improved 4 months after an intensive training program, nor by bariatric surgery. When expressed relative to body weight, peak oxygen uptake and peak power increased in both groups, however peak oxygen uptake relative to fat-free mass remained unchanged (table 5).

## DISCUSSION

### MUSCLE STRENGTH AND MUSCLE MASS

The present study indicates that gastric bypass surgery results in a considerable decrease in dynamic muscle strength four months after the operation (-16% of quadriceps strength, -36% of biceps strength, -39% of triceps strength). The most plausible explanation can be found in the decrease in muscle mass. The untrained patients (GB) lost 7.6 kg muscle mass, which is 29.7% of total body weight loss (- 26.6 kg). Two extensive reviews have been published by Stiegler et al. [35] and Chaston TB et al. [36] that confirm the positive relationship between weight loss and fat-free mass loss (FFML). Moreover, very low caloric diets result in greater FFML compared to low caloric diets and bariatric surgery results in greater FFML than very low caloric diets. Webster et al. [37] was the first to demonstrate that loss in fat-free mass (FFM) should not be more than 22% of total weight loss because of its function in resting metabolic rate, maintenance of functional capacity as the body ages, thermoregulation, oxidative capacity of the body and weight management.

Exercise training can attenuate muscle atrophy or can even maintain FFM during weight loss in diet studies [35,36], but the value of a standardized exercise program after bariatric surgery or more specific, after gastric bypass surgery, has not been investigated. We now show that a 3x/week combined aerobic and resistance exercise program could not prevent the loss in FFM, with no significant differences compared to the untrained patients. However, the decline in FFM seemed less severe (absolute: - 5.4kg; relative: 22.4% of total weight loss) and was brought within the acceptable limits as determined by Webster et al.[37]. Interestingly, although exercise training (GB+E) could not prevent FFML, it completely prevented strength loss and even induced a significant increase in dynamic strength of most muscle groups (+ 72% quadriceps strength, + 27% hamstrings strength and a tendency of + 12% biceps strength) (table 3). The apparent discrepancy between a decline in FFM and an increase in strength in the GB+E group can mainly be attributed to the accepted feature that during the early stages of a training program neurological factors have the greatest contribution in the increase in muscle strength [38].

Besides dynamic muscle strength we also measured peripheral static muscle strength by a handgrip strength test (HGS). Surprisingly, peripheral static muscle strength evolved differently compared to

dynamic muscle strength. There was an overall time effect in the decrease of HGS, meaning that the untrained (GB) as well as the trained patients (GB+E) lost HGS four months after gastric bypass surgery (GB: -18%, GB+E: -7%). Probably, training specificity can give an explanation. In our study no static muscle strength exercises were included in the training program and it is known that the exercise must be specific to the type of strength required [38].

In general we can debate about the question 'is a decrease in muscle strength a problem for morbidly obese patients after weight loss?'. It is known that obese patients have higher absolute muscle strength compared to lean subjects, but they have lower relative muscle strength (in terms of total body weight) [19,39-41]. The latter gives the patients an impaired functional capacity, meaning that more strength is necessary to handle their heavier body. Although morbidly obese patients lose weight after bariatric surgery, they often remain, relatively speaking, less strong. Therefore it seems important to prevent a decrease in muscle strength after bariatric surgery.

## FUNCTIONAL CAPACITY

Muscle strength and muscle mass are important in functional capacity. In our study, we subjected the patients to two functional exercises. With regard to our first test, the sit-to-stand (STS) test, the trained patients (GB+E) improved their number of times to rise to a full stand from a seated position within 30 seconds, whereas the untrained patients (GB) did not. According to literature quadriceps strength and % body fat mainly determines the sit-to-stand test [42,43]. This is in line with our results, where 'GB+E' has 72% increase in quadriceps muscle strength, where 'GB' has a decrease of 16%.

Percentage body fat could not further explain the difference in STS between the two groups, because both groups lost the same amount of body fat.

The six-minute walking distance (6MWD) is the only test where both the trained and the untrained patients improved. However, further analyzes showed us that the increase is mainly attributed to the increase in 'GB+E'. It is known that walking distance is reduced in obese patients compared to lean subjects [44]. According to Tompkins J et al. [22], bariatric surgery leads to an improvement up to 75% of normative values six months after the operation. Indeed, weight loss (especially % body fat) makes walking less exhausting, which can be noticed in our results by a decreased rating of perceived exertion and heart frequency at the end of the test. Not only percentage body fat, but maximal oxygen

uptake ( $\text{VO}_2\text{max}$ ) and quadriceps muscle strength are important predictors as well in the 6MWD [44-46]. As the first two parameters evolved equally in both groups, quadriceps muscle strength is likely responsible for the more pronounced increase in 6MWD for the trained patients.

## EXERCISE CAPACITY AND OXIDATIVE CAPACITY

Aerobic capacity can be evaluated by a maximal incremental bicycle ergometer test, where the anaerobic threshold (AT) reflects true aerobic capacity and where maximal oxygen uptake ( $\text{VO}_2$  peak) reflects exercise capacity (maximal aerobic capacity).

$\text{VO}_2$  peak (ml/min), as well as other peak exercise capacity parameters (peak work, peak heart rate and peak RER) did not change four months after the operation and there were no differences between the untrained and trained patients. To interpret these results, we must know that literature about the effect of weight loss on peak exercise capacity parameters in obese patients is equivocal. Depending on the presence of obesity related disorders, peak exercise capacity will evolve differently. Healthy obese subjects undergoing weight loss will likely experience a decrease in  $\text{VO}_2\text{max}$  and peak work output, because of a decreased muscle mass [47] and because the daily elevated cardiac stress, which is a training for the heart, fades away [48]. In contrast, many obese patients struggle with obesity related disorders such as, impaired cardiac function (impaired left ventricular function and diastolic indices) [49,50], inefficient ventilatory work (added mass on the chest wall and increased pressure in the abdomen) [51] and decreased intramyocellular lipid oxidation [25,52], which are associated with reduced exercise capacity. During weight loss, cardiac and pulmonary systems will restore and will probably overwhelm the negative effect of a decreased muscle mass. This balance can result in a stabilization or even an improvement in maximal oxygen uptake [50].

To neutralize the effect of body weight and fat-free mass,  $\text{VO}_2$  divided by respectively body weight and FFM, is frequently used. Peak  $\text{VO}_2/\text{kg BW}$  improved in both trained and untrained patients and can be explained by an improved body composition (decreased %FM and increased %FFM).

Surprisingly, peak  $\text{VO}_2/\text{kg FFM}$  did not change, meaning that neither weight loss, nor added exercise training could improve the ability of fat-free mass to take up oxygen 4 months after surgery.

With regard to peak power output, the trained patients (GB+E) could produce more work relative to body weight, whereas the control group (GB) remained unchanged. We assume that 'GB+E' could

clear the effect of a decreased muscle mass by a more efficient energy expenditure during cycling and a better use of cardiac reserve [48].

While maximal oxygen uptake is equally determined by the oxygen transport system (pulmonary, cardiac and vascular system) and the oxidative capacity of the skeletal muscle (O<sub>2</sub> use in the mitochondria), the anaerobic threshold (AT) is mostly determined by the latter (if no severe complications of the first are detected). In our study several measurements at VAT indicate that aerobic capacity does not improve 4 months after bariatric surgery. However, it is possible to elicit training effects during large scale weight loss. Power and time of occurrence at VAT evolved positive in 'GB+E' and remained the same for 'GB' (figure 1 and table 3). Further the percentage oxygen uptake at VAT relative to the oxygen uptake at peak ( $\% \text{VO}_2 \text{ at VAT} / \text{VO}_2 \text{ peak}$ ) showed an interaction effect between the intervention group and the control group (table 3). It has been reported that weight loss alone can improve metabolic flexibility (increased insulin sensitivity and reduced IMTG accumulation) [52], but recent diet studies showed that only weight loss combined with exercise can improve aerobic capacity, mitochondrial content and electron chain transport activity in skeletal muscle of sedentary obese subjects [27].

## Conclusion

To summarize, we could demonstrate that large scale weight loss through gastric bypass surgery results in a decrease in dynamic and peripheral static muscle strength and no improvement in aerobic capacity. As a consequence, most components of functional capacity did not improve. In contrast a 3x/week endurance and resistance exercise program could prevent the decrease and even induce an increase in strength in most muscle groups. Together with an improvement in submaximal aerobic capacity (ventilatory threshold), functional capacity increased significantly. Implementation of an exercise training program in the first 4 months after bariatric surgery is effective and should be promoted.

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TABLES

**Table 1:** Pre-operative **characteristics** of the study groups (GB and GB + E).

	Gastric bypass without exercise (GB)	Gastric Bypass with exercise (GB + E)
Number (n)	7	8
Age (years)	43,1 ( $\pm$ 5,6)	39,9 ( $\pm$ 9,9)
Gender male/female (n)	3/4	1/7
BMI (kg/m <sup>2</sup> )	40,4 ( $\pm$ 8,1)	45,3 ( $\pm$ 2,7)
Operation	7 gastric bypass (of which 2 conversions)	8 gastric bypass (of which 2 conversions)

Data are presented as n or means  $\pm$  SD.

**Table 2:** Absolute and relative changes in **anthropometrical characteristics** and **body composition** 4 months after gastric bypass. Comparison GB and GB+E.

		PRE-operative values	Absolute decrease	Relative decrease (%)	Time (p-value)	Interaction (p-value)
<u>Weight</u> (kg)	GB	126,5 (± 24,7)	-26,6 (± 14,6)	-20,1 (± 8,7)	p<0,001	0,511
	GB+E	130,8 (± 17,8)	-22,7 (± 5,7)	-17,9 (± 5,8)		
<u>BMI</u> (kg/m <sup>2</sup> )	GB	40,4 (± 8,1)	-8,3 (± 4,1)	-20,1 (± 8,7)	p<0,001	0,889
	GB+E	45,3 (± 2,7)	-8,1 (± 2,5)	-17,9 (± 5,8)		
<u>Waist</u> (cm)	GB	129,7 (± 20,1)	-20,3 (± 11,6)	-15,3 (± 8,3)	p<0,001	0,555
	GB+E	139,4 (± 11,8)	-17,2 (± 8,1)	-12,3 (± 5,7)		
<u>FFM</u> (kg)	GB	69,0 (± 13,5)	-7,6 (± 4,7)	-10,5 (± 4,6)	p<0,001	0,299
	GB+E	63,9 (± 14,2)	-5,4 (± 2,6)	-8,5 (± 4,3)		
<u>FM</u> (kg)	GB	57,5 (± 14,0)	-19,0 (± 10,2)	-32,1 (± 15,1)	p<0,001	0,689
	GB+E	66,7 (± 9,0)	-17,3 (± 4,6)	-26,8 (± 9,8)		
<u>% FFML</u>	GB	/	/	-29,7 (± 8,2)	<u>Indep. T-test (p-value)</u> 0,166	
	GB+E	/	/	-22,4 (± 10,1)		

Abbreviations: (GB) group with only Gastric Bypass surgery, (GB+E) Gastric Bypass surgery and exercise program, (BMI) Body Mass Index, (FM) Fat Mass,

(FFM) Fat Free Mass and (%FFML) %fat-free mass loss of total weight loss.

P-values for overall intervention (exercise program) and time effects are given (p< 0,05 level of significance). Data are presented as means ± SD.



**Table 3:** Parameters of **physical fitness** pre-operative and 4 months post-operative. Comparison GB and GB+E.

		GB	GB+E	p-value (interaction)	p-value (time)
<b>Dynamic muscle strength</b>					
<u>Quadriceps (kg)</u>	Pre	57,3 (± 28,2)	35,5 (± 11,4)	0,002*	0,244
	Post	45,9 (± 25,1) p=0,022*	58,0 (± 25,6) p=0,023*		
<u>Hamstrings (kg)</u>	Pre	39,0 (± 35,0)	30,5 (± 13,3)	0,094	0,296
	Post	35,3 (± 27,8) p=0,667	45,4 (± 17,3) p=0,055		
<u>Biceps (kg)</u>	Pre	27,3 (± 9,6)	21,8 (± 8,0)	0,001*	0,333
	post	20,8 (± 8,8) p=0,001*	25,9 (± 13,0) p=0,093		
<u>Triceps (sec)</u>	Pre	30,1 (± 10,5)	24,3 (± 10,1)	0,038*	0,799
	Post	22,0 (± 6,6) p=0,023*	30,7 (± 23,0) p=0,269		
<b>Static muscle strength</b>					
<u>HGS (kg)</u>	Pre	95,9 (± 24,9)	76,5 (± 30,3)	0,340	0,008*
	post	78,7 (± 22,2) p=0,043*	67,6 (± 20,2) p=0,131		
<b>Muscle fatigue</b>					
<u>MF (sec)</u>	Pre	33,8 (± 17,8)	35,8 (± 15,5)	0,199	0,562
	Post	30,9 (± 16,9) p=0,421	43,4 (± 7,9) p=0,289		
<b>Functional capacity</b>					
<u>STS (n)</u>	Pre	15 (± 4)	13 (± 3)	0,081	0,117
	Post	15 (± 3) p=0,862	16 (± 4) p=0,045*		
<u>6MWD (m)</u>	Pre	475,2 (± 58,8)	485,9 (± 28,8)	0,430	0,010*
	Post	505,2 (± 86,8) p=0,330	537,9 (± 40,6) p=0,002*		
<u>HF 6MWD (bpm)</u>	Pre	132 (± 21)	146 (± 19)	0,123	0,001*
	Post	113 (± 23) p=0,009*	137 (± 15) p=0,056		
<u>RPE 6MWD</u>	Pre	5 (±2,6)	5 (±2,3)	0,261	0,027*
	Post	3 (±0,4) p=0,109	4 (±1,1) p=0,262		

Abbreviations: (GB) group with only Gastric Bypass surgery, (GB+E) Gastric Bypass surgery and exercise program, (HGS) Handgrip strength, (MF) Muscle fatigue, (STS) Sit-to-stand, (6MWD) Six minute walk distance, (HF\_6MWD) heart frequency on the end of the 6 MWD, (RPE\_6MWD) rating perceived exertion on the end of the 6 MWD.

P-values for overall intervention (exercise program) and time effects are given. Also the significance of the evolution within each group is recorded (p< 0,05 level of significance). Data are presented as means ± SD.

**Table 4: Power and oxygen uptake at ventilatory anaerobic threshold** derived from the maximal bicycle ergometer test.

Parameters at Anaerobic threshold		GB	GB+E	P-value (Time)	P-value (interaction)
Power at VAT (Wattage)	Pre	93 ( $\pm$ 24)	90 ( $\pm$ 24)	0,03	0,074
	Post	95 ( $\pm$ 32) 0,695	111 ( $\pm$ 40) 0,025		
% VO <sub>2</sub> at VAT/VO <sub>2</sub> peak	Pre	69 ( $\pm$ 11)	59 ( $\pm$ 9)	0,566	0,049
	Post	65 ( $\pm$ 8) 0,305	65 ( $\pm$ 5) 0,191		

Abbreviations: (GB) group with only Gastric Bypass surgery, (GB+E) Gastric Bypass surgery and exercise program, (VAT) ventilatory anaerobic threshold, (% VO<sub>2</sub> at VAT/VO<sub>2</sub>peak) percentage oxygen uptake at the ventilatory anaerobic threshold, relative to the oxygen uptake at peak. P-values for overall intervention (exercise program) and time effects are given. Also the significance of the evolution within each group is recorded ( $p < 0,05$  level of significance). Data are presented as means  $\pm$  SD.

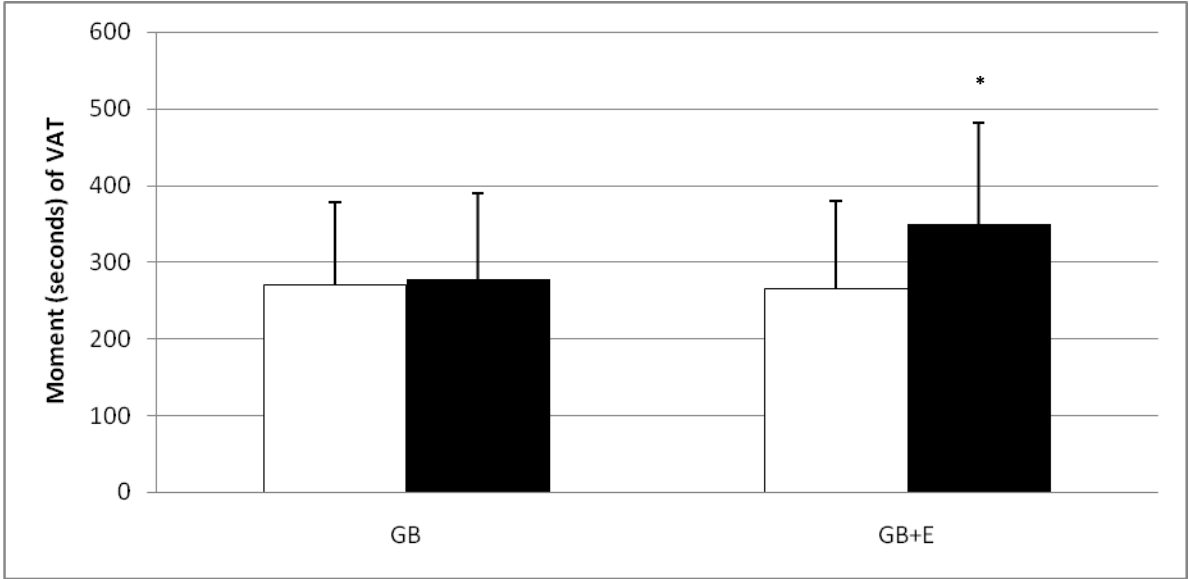
**Table 5: Peak exercise capacity parameters** of the maximal bicycle ergometer test. Comparison between GB and GB+E.

Peak exercise capacity parameters		GB	GB+E	P-value (Time)
Peak VO <sub>2</sub> (ml/min)	Pre	2253 (± 981)	2278 (± 599)	0,729
	Post	2148 (± 688) 0,634	2294 (± 777) 0,915	
Peak VO <sub>2</sub> /kg BW (ml/kg/min)	Pre	17,4 (± 4,9)	17,6 (± 3,2)	0,001
	Post	21,8 (± 6,3) 0,023	22,1 (± 5,1) 0,024	
Peak VO <sub>2</sub> /kg FFM (ml/kg/min)	Pre	31,5 (± 7,8)	36,4 (± 7,2)	0,09
	Post	34,6 (± 7,9) 0,316	41,1 (± 10,9) 0,180	
Power(W)	Pre	150 (± 53)	158 (± 46)	0,605
	Post	147 (± 44) 0,809	168 (± 63) 0,338	
Power/kg BW (W/kg BW)	Pre	1,26 (± 0,51)	1,20 (± 0,25)	0,002
	Post	1,48 (± 0,51) 0,143	1,54 (± 0,37) 0,002	
Heart rate (beats/min)	Pre	146 (± 30)	164 (± 17)	0,742
	Post	156 (± 17) 0,441	157 (± 14) 0,037	
RER	Pre	1,13 (± 0,14)	1,11 (± 0,12)	0,342
	Post	1,14 (± 0,06) 0,364	1,10 (± 0,07) 0,832	

Abbreviations: (GB) group with only Gastric Bypass surgery, (GB+E) Gastric Bypass surgery and exercise program, (Peak VO<sub>2</sub>) peak oxygen uptake, (Peak VO<sub>2</sub>/kg BW) peak oxygen uptake relative to body weight, (Peak VO<sub>2</sub>/kg FFM) peak oxygen uptake relative to fat-free mass, (Power/kg BW) Power output relative to body weight, RER (respiratory exchange ratio).

No interaction effects were recorded. P-values for overall time effects are given. Also the significance of the evolution within each group is recorded (p < 0,05 level of significance). Data are presented as means ± SD.

**Figure 1:** Time of occurrence (seconds) of **Ventilatory Anaerobic Threshold (VAT)** during the maximal bicycle ergometer test. Comparison between GB and GB+E.



Abbreviations: (GB) group with only Gastric Bypass surgery, (GB+E) Gastric Bypass surgery and exercise program. □ pre-operative, ■ post-operative. \*  $p < 0,05$  versus pre-operatively.