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ORIGINAL ARTICLE

Multidimensional improvements induced by an intensive obesity inpatients rehabilitation programme

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Abstract

Purpose To analyse the short-term effectiveness of an intensive multidimensional inpatient programme specifically developed for patients with severe obesity.

Methods A multidisciplinary team managed a 3-week residential programme characterised by the integration of nutritional and physical rehabilitation with psychological and educational intervention. All patients consecutively admitted in 10 months were analysed at admission and discharge for changes in the following domains: anthropometry (weight, body mass index (BMI), waist and neck circumferences), cardiovascular risk factors (glycaemia, HbA1c, lipid profile, blood pressure), quality of life, eating behaviour, and physical performance (VO_{2peak} by incremental cycle ergometer test, 6-min walking test (6MWT), chair stands test).

Results 136 subjects (61% females, median age 52.7 years) with obesity (mean BMI 43.2 kg/m^2) and multiple comorbidities were analysed. A 3.9% BMI reduction and a reduction in waist (-3.8%) and neck (-3.3%) circumferences were observed. Glycaemic control was achieved in 68% of patients with uncontrolled diabetes at admission. Blood pressure control was achieved in all patients with uncontrolled hypertension at admission. Total cholesterol (-16%), LDL-cholesterol (-19%) and triglycerides (-9%) were significantly reduced. Psychometric assessment showed improvements in quality of life perception and binge eating disorder. Finally, a significant improvement in physical performance ($+4.7\%$ improvement in VO_{2peak}, with longer distances in 6MWT and a higher number of standings) was observed.

Conclusions Our preliminary data prove that a 3-week programme determined a clinically significant multi-dimensional improvement in patients with severe obesity. Long-term follow-up data are needed to confirm the efficacy of our rehabilitation setting.

Keywords Obesity · Nutrition · Physical activity · Multi-dimensional management · Rehabilitation

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Introduction

Lifestyle modification is considered the standard of care and the first step in obesity management [1, 2]. Therapeutic lifestyle modification should include an improvement of dietary habits, with reduction of dietary fat, reduced portion size, avoidance of snacking, and increased consumption of fibres-rich foods, coupled with an increase in daily physical activity. The maintenance of these changes over time requires the acquisition by the patients of some cognitive skills that can help them in controlling and improving their behaviours. These skills can be implemented through programmes of personalised or group-based behavioural therapy [1, 2].

The efficacy of outpatients programmes for lifestyle modification and prevention of type 2 diabetes in high-risk patients with obesity has been proved in large seminal randomised control trials [3, 4]. The obtained metabolic benefits were proportional to the number of lifestyle

changes achieved [3] and tend to be maintained years after the termination of the trials, when most of the effects of the intervention programme on body weight and behaviour were no longer evident [5, 6]. However, lifestyle modifications may be difficult to achieve in the outpatient setting, where patients are exposed to the obesogenic environment. In patients with severe obesity, clinical comorbidities and personal physical and psychological problems may further hinder behavioural changes, and the implementation of physical activity in particular. For these reasons, an Italian Expert Consensus Committee on multidimensional treatment of obesity and eating disorders suggested the possibility to use, in selected cases, a residential rehabilitation setting for implementing lifestyle changes and proposed a grid for evaluating appropriateness for this obesity-specific inpatients rehabilitative treatment [7]. These recommendations have been incorporated in current Italian guidelines for clinical management of overweight and obesity [8] and nutritional–psychological–physical inpatients rehabilitation is included in the algorithm for the choice of appropriate management strategy in patients with overweight or obesity recently proposed by the Italian Society for Obesity (Società Italiana dell'Obesità—SIO) [9].

The aim of this study was to analyse the short-term effectiveness of an intensive multidimensional inpatient rehabilitation programme specifically developed for patients with severe obesity. Efficacy was tested in multiple domains, including anthropometry, clinical status, cardiovascular risk, quality of life, eating behaviour, and physical performance. Objective and reproducible testing and examinations were used for each specific domain.

Methods

Description of the rehabilitation programme

The intensive multidimensional inpatient rehabilitation programme analysed in this study was developed and conducted at the "Solatrix" Clinic, Rovereto, Italy. Admission to the programme was consented in accordance to the criteria of appropriateness for inpatients obesity rehabilitation released by Italian Society for Obesity [7] and the costs were covered by the Italian National Health Service. The rehabilitation programme consisted in an integrated multidisciplinary approach (medical, physical, nutritional and psychological) oriented to a healthy weight loss and lifestyle modification. Duration of the programme was 3 weeks. The programme was conducted in groups of 12 patients.

At the beginning of the programme, patients underwent a complete clinical evaluation to identify obesity-related comorbidities, check medical therapy and fix open clinical problems. A complete evaluation of metabolic and cardiovascular risks factors was routinely conducted (see below), but additional testing can be scheduled according to individual patient's clinical evaluation. If necessary, medical therapy was changed or adjusted during the programme.

Baseline nutritional assessment included 24-h dietary recall and diet history. Each patient then received a personalised dietary schedule, realised by the nutritionist and the dietician, designed to provide a caloric deficit of 800–1000 kcal/day from the estimated individual daily total calorie requirements. Daily total calorie requirement was calculated according to basal metabolic rate (BMR) estimated with the Harris-Benedict equation multiplied by a factor corresponding to the individual's physical activity level prior to the admission and the current metabolic status [10]. Therefore, total daily caloric intake prescription ranged from 1200 to 1500 kcal/day for females and from 1200 to 1800 kcal/day for males. Total protein intake was set to 0,8-1 g/kg of ideal weight (calculated as the body weight corresponding to a BMI of 22.5–25.0 kg/m^2) and to 20% of the daily caloric need, with carbohydrates representing 50–55% and fat 25–30% of the daily caloric need [11]. Additionally, daily educational meetings were organised in order to give to the patients the proper information and skills to promote lifestyle modification and restore correct eating habit.

All patients admitted to the obesity rehabilitation programme attended one a week individual interview with an experienced psychologist and two a week group meetings conducted by the same psychologist (the first one concerning mind set and emotions involved on patient's eating behaviours; the second one being a motivational group). Psychological approach was based on cognitive and behavioural therapy of obesity [2, 12] and systemic/strategic approach [13]. Psychological individual interviews initially aimed at a diagnostic evaluation by a psychological assessment and the compilation of weight problem formulation [14]. The subsequent aim was to help patients to achieve more awareness concerning emotional eating [15] and their own mind set (automatic thoughts) concerning eating behaviours [16]. A particular focus was posed on relapse prevention and weight regain. Instruments used during psychological individual interviews included food/emotional diary, weight problem formulation, problem solving, mindful eating [17] and other cognitive behavioural techniques. The motivational group focused on the trans-theoretical model and the wheel of change of Prochaska and Di Clemente [18], while the other group focused on increasing patient's awareness about relationship with food and learning cognitive and behavioural way to individuate and to manage internal and external critical situations. Psychologist leads the meeting by assertive abilities of patients to make them recognise their own food-

related needs, experiences and desires, and making them aware of their own emotionality.

Due to logistic problems and limited space at the gym, patients were divided by physical activity experts in two groups, based on the levels of physical performance assessed during a preliminary medical sportive evaluation and functional testing (see below). Each group performed two sessions, lasting 60 min each, of physical activity per day, divided in aerobic activities in the morning and anaerobic resistance activities in the afternoon. Each physical activity session was organised in 5 min of warm-up, 50 min of main work, and 5 min of cool-down. For aerobic training, treadmill and cyclo-ergometer were used. Aerobic training progression included a gradual increase of exercise duration form 25 min in the first week, to 40 min in the second week, and to 50 min in the third week. Anaerobic activity consisted in resistance with body weight exercises or with additional weight, such as elastic bands and ankle supports. Muscle strengthening involved both upper and lower body. Duration and intensity of the training were adapted day by day in case of pain or fatigue. The overall purpose of the physical rehabilitation programme was to re-educate the patients to an active lifestyle by giving to them the knowledge and the tools to continue activities independently after discharge.

At the beginning and at the end of the rehabilitation programme, all patients underwent a multi-dimensional evaluation in order to obtain objective outcomes for any domain (anthropometry, clinical status, cardiovascular risk, quality of life, eating behaviour, and physical performance).

Anthropometry

Weight was measured to the nearest 0.1 kg using a regularly calibrated electronic calibrate balance, in light clothes and without shoes. Height was measured to the nearest 0.5 cm with the subject standing erect and bare footed using a stadiometer with a movable piece levelled with skull vault. The Body Mass Index (BMI) was calculated as weight in kilograms divided by height in metre squared. Waist circumference was measured to the nearest 0.5 cm on a horizontal plane at the midpoint between the lowest rib and the iliac crest, usually corresponding to level of the umbilicus, at the end of a normal expiration, with the subject standing erect with relaxed abdominal muscles, arms at the side, and feet together [19]. Neck circumference was measured at mid-neck height, between mid-cervical spine and mid-anterior neck, to the nearest 0.5 cm, just below the cricoid cartilage [20].

Clinical status, comorbidities and cardiovascular risk

Metabolic and cardio-vascular risks factors evaluation included the determination of the levels of the following parameters: fasting blood glucose, glycated haemoglobin (HbA1c), total cholesterol, HDL-cholesterol, triglycerides, uric acid. All determinations were performed at the local clinical laboratory of "Solatrix" Clinic, by using standardised automated methodologies. LDL-cholesterol was calculated according to Friedewald's formula in patients with triglycerides levels <400 mg/dl. Systolic and diastolic blood pressure was measured in the sitting position, after a 5-min rest, with an appropriate size cuff.

At baseline, patients were defined as having type 2 diabetes if they had fasting plasma glucose ≥126 mg/dl or HbA1c ≥6.5% or if they used any antidiabetic drug [21]. Hypertension wad defined as blood pressure ≥140/90 mmHg or the use of any antihypertensive drug [22]. Non-alcoholic fatty liver disease (NAFLD) was diagnosed by abdominal ultrasound [23]. Sleep apnoea syndrome was diagnosed according to the results of a nocturnal instrumental registration of the breathing pattern during sleep and standardised diagnostic criteria [24]. Osteoarthritis was defined clinically as the presence of chronic pain in the weight-bearing joints with or without the use of pain suppressant medications. As stated before, the presence of eating behaviour disorders and psychological symptoms were evaluated in all patients during a clinical individual interview performed by an experienced psychologist. Beck Depression Inventory (BDI-II), a well-validated 21-item clinical instrument that measures cognitive, affective, and physiological factors, was administered to all patients and was used for the detection of depression and its severity [25]. Psychiatric consultation was performed routinely.

Quality of life and eating behaviour

Health-related quality of life (HR-QoL) was analysed with the standard (4-week) recall version 2.0 of 36-item Health Survey (SF-36) questionnaire form. The SF-36 measures the following eight subscales: physical functioning, social functioning, role limitations due to a physical problem, role limitations due to an emotional problem, mental health, vitality, bodily pain, and general health perception. The eight subscales form two distinct higher-ordered summary scales: the physical component summary scale (PCS) and the mental summary component scale (MCS) [26]. Binge Eating Disorder (BED) was diagnosed according to DSM-5 criteria during the clinical psychological interview at entry. Binge eating was also tested with the use of the Binge Eating Scale (BES) [27] and a cut-off greater or equal than

27 points was used to identity patients with severe binging [27].

Assessment of physical performance

A graded exercise test was performed for the aerobic assessment in all patients at the beginning and at the end of the rehabilitation programme. All tests were conducted with an electromagnetically braked bicycle ergometer (XScribe2, Mortara Instrument Inc, Milwaukee, WI, USA, coupled with a Bike RHC 400, CLE Elettromedicali, San Bellino, RO, Italy). Before the test, the position on the cycle ergometer was adjusted for each patient. Graded exercise started at a workload of 30 W for 3 min, and the workload was then increased by 15 W every minute until the volitional exhaustion of the subject. The subjects were asked to check their pedalling rate on a pedal-frequency metre and to hop it constant at 60 rounds per minute. Cardio-respiratory measures, such as oxygen consumption (VO_2), carbon dioxide production (VCO_2) and pulmonary ventilation (VE), were collected continuously with breath-by-breath method using an automated open-circuit gas analysis system (K5, Cosmed srl, Rome, Italy). Careful calibration of flow sensors and gas analysis system were performed before each test according to manufacturer's instructions. Gas analysers were calibrated using ambient air (20.93% oxygen and 0.03% carbon dioxide) and a standard gas mixture (16.00% oxygen and 5.02% carbon dioxide). The bidirectional turbine with optoelectronic reader used for the determination of minute ventilation was calibrated with a 3 litres syringe (Cosmed srl, Rome, Italy). The wearable equipment was positioned on the subjects and the bidirectional turbine was attached to a facemask covering both the mouth and the nose (Hans Rudolph Inc, Shawnee, KS, USA). During the test, patients were continuously monitored with a 12-lead electrocardiogramme (XScribe5, Mortara Instrument Inc, Milwaukee, WI, USA) and a pulse oximeter (PalmSAT 2500, Nonin Medical Inc, Plymouth, MN, USA). The following variables were recorded and used for statistical analysis: resting VO_2 (ml/min), defined as mean VO_2 registered at rest, 3 min sitting on bicycle ergometer before starting the test, and peak VO_2 (ml/min) and Peak Power Output (W), registered at the maximal exertion, determined from the average of the last 20 s of the incremental test. Furthermore, the VO_2 (ml/min) and the power output (W) at the first ventilatory threshold (VT_1) were registered. VT_1 was determined by visual inspection using the following detection criteria: (a) the workload level at which the VE starts to exponentially increase (VT_1-VE); (b) the workload corresponding to the first increase in the ventilatory equivalent of O_2 produced in the absence of a concomitant increase in $VE \cdot VCO_2^{-1}$ (VT_1-$VE \cdot VO_2^{-1}$); (c) the workload corresponding to the first increase produced in the end-tidal partial pressure of oxygen (VT_1-$PetO_2$) [28, 29]. All ventilatory parameters were expressed both in absolute terms (ml/min) and after adjustment for body weight (ml/kg/min).

Physical performance was also tested with a Six Minutes Walking Test (6MWT). 6MWT was performed according the standard protocol recommended by the American Thoracic Society [30]. Briefly, the walking test was conducted in a 30 m hallway marked every 5 m with tapes on the floor. Subjects were instructed to walk from end to end covering as much distance as they could during 6 min. When time elapsed, the distance covered was determined and recorded in metres.

Finally, a 30-sec Chair Stands test was administered, using a chair without arms with a seat height of 0.43 m. The chair was placed against a wall for support and safety purposes. The subjects were instructed to stand up and sit back down, with their arm crossed at the chest, as fast as they could for 30 s. The test began with the participant seated in the middle of the chair, back straight, feet placed on the floor approximately shoulder-width apart at an angle slightly back from the knees, with on foot slightly in front of the other in order to help maintain balance when standing [31]. The score was the total number of stands executed correctly within 30 s.

Statistical analysis

Data were shown as means ± standard deviations for quantitative measures, and frequency percentage for categorical variables. The efficacy of the rehabilitation programme was tested by comparing with Student's t test for paired data selected quantitative parameters collected at the beginning and at the end of the programme. Efficacy was also tested for metabolic parameters and weight loss in a categorical way, by analysing the percentage of patients that achieved during the programme the following pre-specified goals: percentage of patients with uncontrolled diabetes at baseline (fasting glucose ≥126 mg/dl) achieving glycaemic control during the programme; percentage of patients with uncontrolled hypertension at baseline (diastolic blood pressure ≥90 mmHg) achieving blood pressure control; percentage of patients with hypercholesterolemia (LDL-cholesterol >140 mg/dl) achieving normal LDL-cholesterol levels; percentage of patients with hypertriglyceridemia (triglycerides >150 mg/dl) achieving normal triglycerides levels; percentage of patients losing >5% of the baseline body weight. The efficacy of the rehabilitation programme was also tested separately in patients with and without severe binging (BES score ≥27) at entry. Relationships between the changes observed in different domains were analysed by simple regression

analysis. All statistical analyses were performed using the IBM SPSS Statistics 21.0 software.

Results

A total of 136 patients (53 men and 83 women) consecutively admitted to the inpatient rehabilitation programme between April, 1st 2015 and January, 10th 2016, were included in the study. Mean age was 52.7 ± 13.2 years (range 19–79 years) and mean BMI was 43.2 ± 7.4 kg/m^2 (range 29.4–60.4 kg/m^2). Only two patients (1.5%) had overweight (BMI 25.0–29.9 kg/m^2), 18 patients (13.2%) had class I obesity (BMI 30.0–34.9 kg/m^2), 28 patients (20.6%) had class II obesity (BMI 35.0–39.9) and 88 patients (64.7%) had class III or morbid obesity (BMI ≥ 40.0 kg/m^2). Forty-four patients (32.4%) previously had unsuccessful bariatric surgery and 37 (27.2%) patients were candidates to bariatric surgery. As expected from admission criteria, the comorbidities burden was high, with 42 patients having type 2 diabetes (30.9%), 72 having hypertension (58.1%), 93 having sleep apnoea syndrome (68.4%), 104 having non-alcoholic fatty liver disease (76.5%), 104 suffering from symptomatic osteoarthritis (76.5%), and 37 having psychiatric diseases (27.2%). No patients fulfilled the diagnostic criteria for BED at the clinical interview. However, 75 patients (51.5%) were found to have severe binging at the BES scale (BES score ≥ 27).

Anthropometric, metabolic and cardiovascular parameters registered at the beginning and at the end of the rehabilitation programme were reported in Table 1. A statistically significant reduction was observed in body weight, BMI, waist circumference, and neck circumference. Fasting blood glucose declined significantly and in patients with type 2 diabetes the HbA1c levels decreased from 53.4 ± 15.0 to 50.1 ± 12.3 mmol/mol ($P < 0.001$). A significant improvement was also observed in total-cholesterol, LDL-cholesterol and triglycerides. On the contrary, HDL-cholesterol declined significantly and uric acid increased significantly. Finally, a statistically significant reduction was found both in systolic and diastolic blood pressure. No significant differences in anthropometric, metabolic and cardiovascular parameters at baseline or in the percent changes of these parameters during the programme were observed between patients with and without severe binging [data not shown]. As for metabolic and cardiovascular predefined outcomes, 14 on 20 patients (70.0%) with uncontrolled diabetes at baseline achieved glycaemic control during the programme, 23 on 26 patients (88.5%) with uncontrolled hypertension achieved blood pressure control, 21 on 27 patients (77.8%) with high LDL-cholesterol achieved normal LDL-cholesterol levels, 21 on

39 patients (53.8%) with hypertriglyceridemia achieved normal triglycerides levels, and 30 on 136 patients (22.0%) had a weight loss >5% of the baseline body weight.

The changes in self-reported health-related quality of life and in binge eating behaviour observed during the programme were reported in Fig. 1. A significant improvement was observed both in the physical component summary scale (PCS) and in the mental summary component scale (MCS) of the SF-36 (PCS: 44.8 ± 20.2 vs 56.5 ± 24.6, $P < 0.001$; MCS: 50.7 ± 18.6 vs 59.6 ± 21.4, $P < 0.001$). No significant differences in health-related quality of live at baseline or in its percent changes during the programme were observed between patients with and without severe binging [data not shown]. The tendency to binge eating was reduced during the programme, as indicated by a significant reduction in the BES score (PCS: 31.2 ± 8.4 vs 28.3 ± 8.1, $P < 0.001$).

Physical activity parameters and performance levels registered at the beginning and at the end of the rehabilitation programme were reported in Table 2. Resting VO$_2$ decreased significantly both in absolute terms and after adjustment for body weight. Peak VO$_2$ did not change significantly in absolute terms, but increased significantly after adjustment for body weight. A significant improvement in Peak Power Output was observed. Data also showed a significant improvement of oxygen consumption, both in absolute terms and after adjustment for body weight, and power output at the first ventilatory threshold (VT$_1$). Physical performance improved significantly, both at the 6MWT and at the 30-sec Chair Stands test. No significant differences in physical activity parameters and performance levels at baseline or in the percent changes in these parameters during the programme were observed between patients with and without severe binging [data not shown].

The interrelationships between the percent changes of the different parameters observed during the rehabilitation programme were investigated by simple correlation analysis in Table 3. The degree of weight loss was significantly related to the reductions in blood glucose and blood pressure, but not to changes in quality of life, eating behaviour or physical performance. The improvement in quality of life was significantly related to the reduction in binge eating behaviour. No significant correlations were found between the changes in physical efficiency or performance and any change in metabolic or cardiovascular parameters.

Discussion

In this study, we analyse by objective and reproducible testing the short-term effectiveness of an intensive 3-week multidimensional inpatient rehabilitation programme

Table 1 Anthropometric, metabolic and cardiovascular parameter registered at the beginning and at the end of the rehabilitation programme in 136 patients (53 men and 83 women) consecutively admitted between April, 1st 2015 and January, 10th 2016

|	Beginning	End	Delta (%)	P
Body weight, kg	120.4 ± 26.0	115.5 ± 24.3	−3.9 ± 1.6	<0.001
BMI, kg/m²	43.2 ± 7.4	41.5 ± 6.9	−3.9 ± 1.6	<0.001
Waist circumference, cm	132.4 ± 18.2	127.2 ± 17.0	−3.8 ± 1.9	<0.001
Neck circumference, cm	45.1 ± 4.9	43.6 ± 4.6	−3.4 ± 2.3	<0.001
Fasting blood glucose, mmol/l	5.74 ± 1.64	5.19 ± 1.00	−7.0 ± 15.1	<0.001
Total cholesterol, mmol/l	4.75 ± 1.06	3.96 ± 0.90	−15.9 ± 12.3	<0.001
LDL-cholesterol, mmol/l	2.85 ± 0.90	2.30 ± 0.80	−19.2 ± 17.7	<0.001
HDL-cholesterol, mmol/l	1.20 ± 0.38	1.10 ± 0.31	−6.5 ± 14.4	<0.001
Triglycerides, mmol/l	1.46 ± 0.72	1.22 ± 0.44	−9.7 ± 24.8	<0.001
Uric acid, μmol/l	455.0 ± 99.2	484.5 ± 123.7	+7.5 ± 21.0	<0.001
Systolic blood pressure, mmHg	139.4 ± 19.3	124.0 ± 12.7	−9.8 ± 12.3	<0.001
Diastolic blood pressure, mmHg	82.6 ± 11.8	73.3 ± 7.7	−9.7 ± 13.8	<0.001
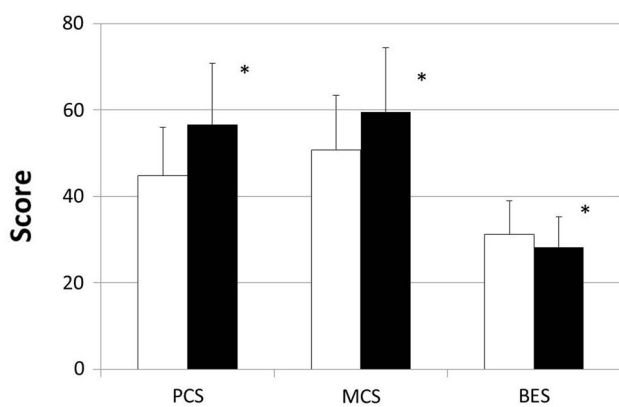
Fig. 1 Health-related quality of life and binge eating registered at the beginning (*white bars*) and at the end (*black bars*) of the rehabilitation programme. *PCS* physical component summary scale of the SF-36, *MCS* mental summary component scale of the SF-36, *BES* binge eating scale score. Student's *t* test for paired data for comparison with baseline data: *$P < 0.001$

specifically developed for patients with severe obesity. The programme comprehends nutritional education and dietary prescription, psychological support for lifestyle and behavioural changes and a personalised guided physical activity training. Clinically significant improvements were observed in multiple domains, including anthropometry, clinical status, cardio-vascular risk, health-related quality of life, eating behaviour, and physical performance.

Lifestyle modifications represent the cornerstone of any programme for obesity management, but they may be difficult to implement in real life, where personal and social factors can hinder patients effort to change. Residential obesity management programmes are widely used in the management of childhood obesity and they proved to be more successful than outpatient programmes, at least in the short term [32]. Application of residential programmes in adulthood received less attention, despite the facts that

Table 2 Physical activity parameters and performance levels registered at the beginning and at the end of the rehabilitation programme in 136 patients (53 men and 83 women) consecutively admitted between April, 1st 2015 and January, 10th 2016

	Beginning	End	Delta (%)	P
VO2$_{REST}$, ml/min	412.3 ± 124.7	369.8 ± 104.4	−7.4 ± 21.4	<0.001
VO2 $_{VT1}$, ml/min	1430.9 ± 403.3	1495.9 ± 365.5	+7.2 ± 20.8	<0.05
VO2$_{peak}$, ml/min	2241.2 ± 670.2	2296.2 ± 637.7	+4.7 ± 19.7	0.153
VO2$_{REST}$, ml/kg/min	3.43 ± 0.73	3.22 ± 0.67	−3.6 ± 22.1	<0.01
VO2 $_{VT1}$, ml/kg/min	11.94 ± 2.61	13.10 ± 2.69	+11.6 ± 21.2	<0.001
VO2$_{peak}$, ml/kg/min	18.92 ± 4.71	20.22 ± 4.78	+9.0 ± 20.3	<0.001
PO$_{VT1}$, W	75.4 ± 23.0	80.9 ± 22.8	+11.0 ± 27.2	<0.01
PO $_{PEAK}$, W	138.1 ± 41.7	146.7 ± 45.3	+7.5 ± 18.5	<0.001
6MWT, m	432.4 ± 113.0	479.0 ± 108.5	+17.1 ± 21.2	<0.001
30-sec Chair Stands, n	12.6 ± 3.8	18.3 ± 9.2	+48.7 ± 71.7	<0.001

VO₂ oxygen consumption during a graded exercise test, *VO₂rest* VO₂ registered at rest, sitting on Bicycle ergometer, *VO₂VT1* VO₂ registered at first ventilatory threshold, *VO₂peak* VO₂ registered at the maximal exertion. Each VO₂ value was expressed both in absolute terms (ml/min) and after adjustment for body weight (ml/kg/min), *PO_VT1* power output registered at first ventilatory threshold, *PO_peak* power output registered at the maximal exertion, *6MWT* Six Minutes Walking Test, *30-sec* Chair Stands: 30-second Chair Stands test

Table 3 Simple linear correlation coefficients between the percent changes observed in selected metabolic, cardiovascular, psychological and physical parameters during the rehabilitation programme

	BW	FBG	LDL	HDL	TG	DBP	QOL	BES	VOR	VOT	VOP	WT	CS
BW	1.00												
FBG	0.230*	1.00											
LDL	0.003	−0.064	1.00										
HDL	−0.027	−0.234*	−0.030	1.00									
TG	0.125	0.088	0.346*	−0.114	1.00								
DBP	0.261*	0.090	−0.014	0.092	−0.019	1.00							
QOL	0.019	0.267*	−0.120	−0.250*	0.085	−0.078	1.00						
BES	0.127	−0.067	0.237*	0.085	0.088	0.048	−0.287*	1.00					
VO2$_{REST}$	0.034	0.068	−0.50	−0.153	−0.054	−0.049	−0.013	0.023	1.00				
VO2$_{VT1}$	−0.160	0.013	0.068	−0.059	0.096	−0.060	−0.039	−0.094	−0.334*	1.00			
VO2$_{peak}$	−0.072	−0.178	0.164	−0.023	−0.059	−0.103	−0.167	0.192	0.302*	0.602*	1.00		
6MWT	0.132	−0.009	−0.039	0.018	−0.076	−0.066	−0.097	−0.062	0.044	−0.005	0.149	1.00	
30-sec CS	0.003	−0.003	0.078	−0.035	0.070	0.085	−0.012	0.030	−0.063	−0.148	−0.042	0.072	1.00

Data are Pearson correlation coefficients: *$P < 0.01$

BW % change in body weight, *FBG* % change in blood glucose, *LDL* % change in LDL-cholesterol, *HDL* %change in HDL-cholesterol, *TG* % change in triglycerides, *DBP* % change in diastolic blood pressure, *QOL* % change in health-related quality of life (SF-36 summary score), *BES* % change in Binge Eating Scale score, *VO$_{2rest}$* % change in resting VO$_2$ adjusted for body weight (ml/kg/min), *VO$_{2VT1}$* % change in VO$_2$ at the first threshold adjusted for body weight (ml/kg/min), *VO$_{2peak}$* % change in peak VO$_2$ adjusted for body weight (ml/kg/min), *6MWT* % change in Six Minutes Walking Test, 30-sec *CS* % change in 30-sec Chair Stands

factors hindering lifestyle modifications are presumably at least equally important in adults as in children or in adolescents. Danielsen et al. reported a substantial weight loss (−17.0 kg) at the end of a 10- to 14-week inpatient lifestyle modification programme, including a minimum of 90 min of physical activity five days/week, in a group of 139 patients with severe obesity (BMI: 42.6 ± 5.2 kg/m^2) [33]. Martins et al. compared the 1-year effectiveness of bariatric surgery, a residential intermittent programme (8–10 weeks in, 8 weeks at home, 4 weeks in, 4–5 months at home, and 2 weeks in), a commercial weight loss 21-week camp and the usual outpatient management [34]. Bariatric surgery led to the largest weight loss (31 ± 9%), but both residential intermittent programme (15 ± 8%) and commercial weight loss camp (13 ± 8%) were more effective than outpatient management (5 ± 8%) [34]. Long or intermittent residential staying may be difficult in adult patients facing work or family duties. Therefore, shorter single staying programmes (usually 3–4 weeks) have been proposed and tested. These shorter programmes are not centred on the degree of weight loss obtained at the end of the residential period, but they are more focused in patients education and in the management and improvement of those clinical, physical or psychologic conditions that may hinder lifestyle changes in each patient [7]. Maffiuletti et al. described the results of a 3-week residential programme combining energy-restricted diet, nutritional education, psychological counselling and moderate physical activity in a group of 64 patients with severe obesity (BMI: 41.3 ± 4.3 kg/m^2) [35]. Weight loss during the programme was moderate (−4.7 ± 1.2% of the baseline body weight), but it was accompanied by significant improvements in physical performance and cardiovascular risk variables. Moreover, the large majority (75%) of these obese individuals at least partially maintained the weight loss for the first year after discharge [35]. In our study, we treated with a 3-week residential multi-dimensional programme a larger group of patients with severe obesity (BMI: 43.2 ± 7.4 kg/m^2) and we obtained similar weight loss levels (−3.9 ± 1.6% of the baseline body weight). Extended follow-up data are clearly needed to confirm the educational strength of our programme and its capability to induce the permanent lifestyle changes able to permit weight maintenance.

One important advantage of obesity management in the residential setting is the possibility to include for all patients a supervised and individualised physical activity programme. Starting physical activity under individualised and controlled conditions may be easier and safer in patients with severe obesity and a high burden of comorbidities, as those for which residential treatment is indicated [7] and/or those included in our study. Reduction of sedentariness and increased physical activity levels are considered important elements for any lifestyle programme

for obesity management, in particular for weight loss maintenance [1, 2]. In addition, physical activity protects against cardiovascular and metabolic diseases [36]. Nevertheless, it seems very difficult to increase physical activity levels in patients with severe obesity [37]. In our programme, every patient performed 2 h of physical activity per day, divided in aerobic activities in the morning and anaerobic resistance activities in the afternoon. The intensity and type of activities were personalised according to the results of a preliminary medical sportive evaluation and a graded exercise test. At the end of the 3-week programme, we observed clinically significant improvements in both physical fitness and performance. In particular, a 17% increase in the metres walked in the Six Minutes Walking Test and a 48% increase in the number of stands executed during the 30-sec Chair Stands test were observed. These changes are larger enough to have an impact on the ability of the patients to perform the activities of their daily livings. It is believed that exercising together with pairs and being introduced to exercise may be of great importance in order to increase long-term compliance in physical activity interventions in patients with severe obesity [38]. We have no data on physical activity maintenance in our patients after discharge. However, Maffiuletti et al. observed physical activity levels still significantly higher than at baseline 1 year after a 3-week residential programme [35] and therefore we are confident that the physical activity improvements obtained during our programme may be at least partially maintained at home. Finally, increased physical activity has been demonstrated to be directly related to the improved quality of life observed after multicomponent lifestyle interventions [39] and we confirmed significant improvements of both physical and mental components of health-related quality of life also in our study.

Despite the shortness of our residential staying, we observed a highly significant improvement in most of the classic cardio-vascular risk factors, including blood glucose, HbA1c levels, total-cholesterol, LDL-cholesterol, triglycerides and systolic and diastolic blood pressure. The only negative findings were a decline in HDL-cholesterol and an increase in uric acid levels, both expected during acute caloric restriction [40, 41]. Weight loss, caloric restriction, better quality of the diet, and physical activity may all participate in metabolic improvement. Reductions in blood glucose and blood pressure seem to be more directly related to the degree of weight loss obtained during the programme, but the interplay of the different factors is so complex that it is difficult to drawn definitive conclusion on the individual role and contribution of each of the single component of our multidimensional programme. The improvement in cardio-vascular risk factors translated to a better control of metabolic comorbidities, with the majority of patients having uncontrolled comorbidities at admission reaching therapeutic targets at the end of the 3-week staying.

Finally, we observed a significant reduction in the BES score, with about a quarter of patients having an improvement of binge eating self-perception during the residential treatment. Reduction in binge eating behaviour was significantly associated to the improvement in self-perceived health-related quality of life in our study, indicating an important role for psychological intervention and empowerment in determining the overall patients satisfaction with the multidimensional programme. Reduction in uncontrolled eating has been previously reported at the end of a residential lifestyle intervention and it was maintained for at least one year after [33]. After one year, the degree of total weight loss was related to the increased cognitive restraint and decreased uncontrolled eating [33], indicating that the behavioural changes induced by our programme may be useful for weigh maintenance during subsequent months.

Our study has several methodological limitations. First, basal metabolic rate (BMR) was estimated by the Harris-Benedict equation and not directly measured by indirect calorimetry, leading to a potential bias in the calculation of the individual daily total calorie requirements. Second, assessment of eating behaviour was limited to the use of the BES scale, whereas the inclusion of other simple but more extensive tests, such as the Eating Disorder Examination Questionnaire (EDE-Q) [42] would give a more complete assessment. Third, no data on body composition at baseline and during the programme were collected. Finally, our study was a limited short-term assessment and the accrual of some follow-up would be strongly needed.

In conclusion, our study indicated that a multidimensional short-term 3-week residential programme induces improvements in multiple domains in patients with severe obesity and a high burden of comorbidities. The global improvement observed at the end of the residential staying may facilitate subsequent further weight loss and maintenance, but more controlled data are clearly needed in order to prove this assumption.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that none of the authors has conflict of interest.

Ethical approval All procedures performed were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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

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