

A Weight Reduction Program Preserves Fat-Free Mass but Not Metabolic Rate in Obese Adolescents

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Abstract

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Objective: To determine the effects of a multidisciplinary weight reduction program on body composition and energy expenditure (EE) in severely obese adolescents.

Research Methods and Procedures: Twenty-six severely obese adolescents, 12 to 16 years old [mean BMI: 33.9 kg/m²; 41.5% fat mass (FM)] followed a 9-month weight reduction program including moderate energy restriction and progressive endurance and resistance training. Body composition was assessed by DXA, basal metabolic rate by indirect calorimetry, and EE by whole-body indirect calorimetry with the same activity program over 36-hour periods before starting and 9 months after the weight reduction period.

Results: Adolescents gained (least-square mean \pm SE) 2.9 \pm 0.2 cm in height, lost 16.9 \pm 1.3 kg body weight (BW), 15.2 \pm 0.9 kg FM, and 1.8 \pm 0.5 kg fat-free mass (FFM) ($p < 0.001$). Basal metabolic rate, sleeping, sedentary, and daily EE were 8% to 14% lower 9 months after starting ($p < 0.001$) and still 6% to 12% lower after adjustment for FFM ($p < 0.05$). Energy cost of walking decreased

by 22% ($p < 0.001$). The reduction in heart rate during sleep and sedentary activities (-10 to -13 beats/min), and walking (-20 to -25 beats/min) ($p < 0.001$) resulted from both the decrease in BW and physical training.

Discussion: A weight reduction program combining moderate energy restriction and physical training in severely obese adolescents resulted in great BW and FM losses and improvement of cardiovascular fitness but did not prevent the decline in EE even after adjustment for FFM.

Key words: energy expenditure, body composition, indirect calorimetry, physical activity, diet

Introduction

The prevalence and severity of childhood overweight and obesity and their comorbidities are increasing in industrialized countries (1,2). Therefore, overweight must be contended with as early as possible. However, body weight (BW)¹ loss is usually associated with significant declines in fat mass (FM) and fat-free mass (FFM). Several studies in children have shown that hypocaloric diets alone induce FM and FFM reductions, which could explain the observed decreases in basal metabolic rate (BMR) and thermic effect of food during the weight reduction program (3–5). In contrast, with a weight reduction program including hypocaloric diet, exercise, and behavior modification, significant decreases in BW and FM without significant reductions of FFM and BMR have been reported (6,7).

Preservation of FFM is desirable for maintenance of energy expenditure (EE) and, thus, prevention of BW regain, improvement of physical capacities of postobese children and adolescents, and also to allow them to perform

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¹ Nonstandard abbreviations: BW, body weight; FM, fat mass; FFM, fat-free mass; EE, energy expenditure; BMR, basal metabolic rate; M 0, 15 days before the beginning of the weight reduction program; M 9, 9 months after the beginning of the weight reduction program; HR, heart rate; DEE, daily energy expenditure; bpm, beats per minute; RMR, resting metabolic rate; MR, metabolic rate; LSMean, least-square mean.

normal physical activities and to have better interaction with their peers. The main objective of the present study was to assess the impact of a long-term multidisciplinary weight reduction program including moderate energy restriction, progressive training, and regular physical activity on body composition and EEs corresponding to various activities in obese adolescents.

Research Methods and Procedures

Study Design

Twenty-six (12 boys and 14 girls) severely obese adolescents (8, 12 to 16 years old, participated in this study. The adolescents were recruited from the Pediatrics Department of the Clermont-Ferrand Hospital, where they had a medical and dietetic follow-up. The inclusion criteria were: age between 12 and 16 years and a BMI above the 97th percentile for gender and chronological age (8). The exclusion criteria were: not in good health and use of any medication known to influence energy metabolism. The experimental protocol was approved by the University Ethical Committee on Human Research for Medical Sciences in the Auvergne Region (AU no. 361). The purpose and objectives of the study were carefully explained to each subject and his or her parents. Written informed consent was obtained from all adolescents and their parents before beginning the study.

The adolescents spent 10 months, 5 days per week, in a specialized institution, and weekend, Christmas, and Easter holidays at home. Full testing sessions were conducted 15 days before the beginning (M 0) and 9 months later (M 9) before completion of the BW reduction program. Meanwhile, subjects followed a 9-month personalized weight reduction program consisting of lifestyle education, physical activity, and dietary and psychological follow-up. Anthropometric characteristics and physical capacities were controlled monthly to adjust the weight reduction program individually.

Diet and Nutritional Education

Personalized diets were developed on the basis of the results obtained during the initial BMR test. Energy supply was adjusted to be close to 1.3 times BMR, that is ~15% to 20% less than the estimated EE, and diet composition was formulated according to the French-recommended dietary allowances (9). Once a week, adolescents had a dietetics lesson including choice and cooking of foods. In addition, energy supply was adjusted 2 months before M 9 to stabilize BW and allow the volunteers to maintain BW after the end of the weight reduction program.

Physical Activity

During the 9-month weight reduction period, adolescents followed a personalized progressive physical training program including two 40-minute sessions (preceded and fol-

lowed by 5 to 7 minutes of stretching) per week under medical supervision. Each program of exercises was developed according to the results of an initial maximal oxygen uptake test for aerobic exercises (cycle-ergometer, treadmill, stationary rowing, and stepper) and of the initial strength test for anaerobic exercises (leg press, bench press, leg extension, lat-pull, leg curl, seated row, triceps extension, and biceps curl). During the aerobic training sessions, adolescents were under heart rate (HR) monitoring (Polar Electro KY, Kempele, Finland). The intensity was set at HRs corresponding to 55% to 60% of initial maximal oxygen uptake test. At the end of each month, aerobic and anaerobic tests were performed to assess physical capacities and to adjust physical training intensity individually. In addition, the physical activity program included 2 hours of physical education lesson per week at school and 2 hours per week of aerobic activities at the institution. The adolescents and their parents were also advised to practice leisure physical activities during the weekend.

Physical Characteristics and Body Composition

BW was measured to the nearest 0.1 kg using a calibrated manual weighing scale (Seca 709; Seca, Hamburg, Germany). Height was measured to the nearest 0.5 cm on a standardized wall-mounted height board. Circumferences at the waist and hip were measured in triplicate to the nearest 0.1 cm using a steel tape according to the atlas of Sempé et al. (10).

Body composition was assessed by DXA using Hologic QDR-4500 equipment and version 9.10 of total body scans software (Hologic Inc., Bedford, MA). The total body scan provided values for bone mineral content, non-bone lean tissue, and FM in total body and in arms, legs, trunk, and head separately. FFM was defined as the sum of non-bone lean tissue and bone mineral content. Hydration of the FFM was assumed to be constant (73.2%). The scanner was calibrated daily against the standard calibration block supplied by the manufacturer to control for possible baseline drift.

EE

BMR was determined by means of open-circuit, indirect computerized calorimetry (Deltatrac calorimeter; Instrumentarium Oy, Datex Division, Helsinki, Finland) with a rigid, transparent, ventilated canopy after a 13-hour fast. After achieving steady state, the BMR was measured for 45 minutes. Before each test, the gas analyzers were calibrated with a reference gas mixture. Oxygen consumption and carbon dioxide production, standardized for temperature, barometric pressure, and humidity, were measured continuously and averaged at 1-minute intervals, then over the whole measurement period.

In standardized conditions, EE was measured continuously by indirect calorimetry using two comfortable open-

circuit whole-body calorimeters (11). The validity of gas exchange measurements was checked gravimetrically. EE was calculated using the equation of Brouwer (12) from the minute-to-minute measurement of gas exchanges. HR was measured by telemetry (Life scope 6, Nikon Kohden, Tokyo, Japan) and recorded continuously during the stay in the calorimeters.

The adolescents spent 36 hours in the whole-body calorimeters, one evening and one night for adaptation, and 24 hours for measurement in M 0 and M 9. During this period, they followed the same standardized activity program simulating usual activities. The program was composed of five main periods: sleeping (8.5 hours), sedentary activities (watching television, video games, listening to music, board games, homework, 10.5 hours), miscellaneous activities (washing and dressing, making the bed, and tidying the room, 1 hour), meals (breakfast, lunch, snack, and dinner, 2 hours), and six 20-minute exercises of walking at six different speeds (2 hours). In M 0, subjects walked at their own speed on the treadmill, and the slope was altered to obtain the six appropriate equivalent horizontal speeds (13). The same exercises were performed in M 9.

Food Intake

Food, including snacks, was offered ad libitum before the beginning of the weight reduction program to simulate nutrition in free-living conditions but according to individual rations at the end of the weight reduction program. The quantities of each food offered and not eaten were determined using an accurate balance (0.1 g) during 7 consecutive days in free-living conditions in the institution and 1 day in the calorimeters. The nutrients and energy intakes (EIs) were assessed using GENI software version 4.0 (MICRO 6, Villers les Nancy, France) based on the nutritive value of foods (14).

Statistical Analyses

Step-wise linear multiple regressions were used to determine the significant predictors of BMR and EE of sleeping, sedentary, and physical activities using PROC REG of SAS software (version 6.12, 1996; SAS Institute Inc., Cary, NC). The effects of gender as main factor, period (before or after the weight reduction program) as repeated measures factor, and interaction (gender \times period) on physical characteristics, body composition, energy cost of the various activities, and HR of adolescents were tested using PROC MIXED of SAS software (version 6.12, 1996). The same model with FFM as covariate was used to study the effects of gender, period, and interaction on BMR and energy costs of sleep and sedentary activities. The effects of gender, period, BW, and speed and interactions on walking EE were tested using the same model with BW and speed as covariates. The least-square means (LSMeans) were computed and compared using the pdiff option. Significance was set at $p < 0.05$. The data are presented as LSMean and SEM.

Results

Subjects' Characteristics

The BMI z score of subjects averaged 4.0 (SD = 0.64), and the BMI for gender and chronological age was above the 99th percentile (8). The percentage of FM averaged $41.5 \pm 1.8\%$ (LSMean \pm SE; Table 1). Age and pubertal stage (15) were significantly higher in girls than in boys. During the 9-month weight reduction program, the pubertal stage increased significantly in boys (Table 1). BW was stabilized before M 0 and M 9. The mean BW variations were 0.1 ± 1.7 and -1.4 ± 1.5 kg, respectively, during the last 2 preceding months. BW decreased by 16.9 ± 1.2 kg, whereas height increased by 4.5 ± 0.2 and 1.4 ± 0.2 cm ($p < 0.001$), and BMI was reduced by 8.1 ± 0.4 and 6.3 ± 0.4 kg/m² ($p < 0.001$) in boys and girls, respectively. Arm, waist, and hip circumferences decreased significantly by 4.1 ± 0.6 , 16.9 ± 1.3 , and 11.8 ± 0.9 cm, respectively ($p < 0.001$). Body FM decreased more in boys than in girls (18.0 vs. 12.5 kg; $p < 0.005$), whereas FFM did not vary significantly in boys but decreased by 3.3 kg in girls ($p < 0.001$) (Table 1). The variations were similar in the various body segments (data not shown). Finally, total-body bone mineral density and bone mineral content increased significantly ($p < 0.001$), and the differences were higher in boys than in girls ($p < 0.01$) (Table 1).

EE

FFM was a significant determinant of EE for all types of activities and explained from 52% to 66% of the variance. FM was a significant determinant of EE only during sleep ($p < 0.01$) and explained 4.3% of the variance. BMR, sleeping EE, and sedentary EE were significantly lower in M 9 than in M 0, both in absolute values (-8.3 , -14.0 , and -14.0% , respectively; $p < 0.001$) and after adjustment for FFM (-6.3 , -12.6 , and -11.7% , respectively; $p < 0.001$) (Tables 2 and 3). EE during sleep was 6.3% lower after adjustment for FFM and FM ($p < 0.05$).

Speed, BW, and gender were significant determinants of walking EE and explained 45.9% ($p < 0.001$), 25.2% ($p < 0.001$), and 4.0% ($p < 0.001$), respectively, of the variance; the interaction between BW and gender was significant ($p = 0.014$) (Table 2). The energy cost of walking at the same speeds also decreased significantly (-24% and -22% in boys and girls, respectively), even after adjustment for BW (-17.6% in boys; $p = 0.004$) (Table 3). As a consequence, with the same activity program, daily energy expenditure (DEE) was significantly lower (11.67 vs. 13.96 MJ/d; $p < 0.001$) after the weight reduction period, even after adjustment for FFM (11.84 vs. 13.76 MJ/d; $p < 0.001$).

HR

For the same activity program, HR was significantly lower in M 9 than in M 0 by 10, 11, and 13 beats/min (bpm)

Table 1. Physical characteristics and body composition of adolescents before (M 0) and after (M 9) the weight reduction program

	Boys		Girls		SE	Significance (<i>p</i>)		
	M 0	M 9	M 0	M 9		P	G	P × G
Age (years)	13.5	14.2	14.7	15.5	0.56	0.001	0.037	0.953
Pubertal stage	2.5	3.5	4.1	4.4	0.49	0.001	0.021	0.013
Weight (kg)	89.8	71.4	94.2	78.6	6.10	0.001	0.354	0.289
Height (cm)	163.9	168.4	164.5	165.9	4.27	0.001	0.835	0.001
BMI (kg/m ²)	33.1	25.0	34.7	28.5	1.53	0.001	0.001	0.026
FFM (kg)	54.2	53.8	53.7	50.5	4.36	0.001	0.663	0.008
FM (kg)	35.6	17.6	40.6	28.1	2.54	0.001	0.006	0.012
FM (%)	40.0	25.1	42.9	35.3	1.82	0.001	0.001	0.001
Bone mineral content (g)	2044	2244	2284	2406	184.5	0.001	0.290	0.010
Bone mineral density (g/cm ³)	0.987	1.061	1.088	1.134	0.042	0.001	0.051	0.010
Waist circumference (cm)	109.6	89.9	109.8	95.8	4.12	0.001	0.467	0.045
Hip circumference (cm)	104.4	91.2	113.4	103.1	3.28	0.001	0.003	0.129
Waist-to-hip ratio	1.05	0.99	0.97	0.93	0.018	0.001	0.001	0.195

LSMeans and SE. Significance by ANOVA of the main effects of period (P) and gender (G); period × gender interaction (P × G).

for deep sleep, sleep, and sedentary activities, respectively ($p < 0.001$). In addition, the reduction of HR was greater during walking ($p < 0.001$), and the difference increased from 20 to 25 bpm with speed and slope. Furthermore, the decrease was greater in boys than in girls (25 vs. 20 bpm; $p < 0.001$) (Table 4). The weight reduction program resulted in a shift of the HR/EE relationship (Figure 1). After adjustment for EE, HR was 13.6 and 10.3 bpm lower in boys and girls, respectively ($p < 0.001$), which suggested an improvement of cardiovascular fitness.

Discussion

The objective of the present study was to assess changes in body composition and EE in severely obese adolescents after a weight reduction program. The results showed that a 9-month multidisciplinary program including lifestyle education, balanced diets with a moderate energy restriction, endurance and resistance training, and regular physical activity resulted in: great decreases in BW and FM, with FFM decreases in girls only and without affecting statural growth; improvement of cardiovascular fitness; and signif-

Table 2. EE, energy intake, and MR of adolescents before (M 0) and after (M 9) the weight reduction program

	Boys		Girls		SE	Significance (<i>p</i>)		
	M 0	M 9	M 0	M 9		P	G	P × G
DEE (MJ)	14.68	12.42	13.23	10.92	0.911	0.001	0.120	0.932
Energy intake (MJ)	17.49	12.32	17.35	9.79	1.475	0.001	0.376	0.383
BMR (kJ/min)	6.00	5.56	5.47	4.96	0.326	0.001	0.095	0.758
Sleeping MR (kJ/min)	5.70	4.98	5.23	4.33	0.346	0.001	0.119	0.446
Sedentary act. MR (kJ/min)	9.25	8.21	8.59	7.17	0.546	0.001	0.168	0.521
Miscellaneous act. MR (kJ/min)	9.11	7.91	9.32	7.70	0.541	0.001	0.998	0.509
Walking MR (kJ/min)	35.12	26.70	30.36	24.27	3.400	0.001	0.012	0.014

LSMeans and SE. Significance by ANOVA of the main effects of period (P) and gender (G); period × gender interaction (P × G).

Table 3. DEE and MR for various activities of adolescents before (M 0) and after (M 9) the weight reduction program

	Boys		Girls		SE	Significance (<i>p</i>)		
	M 0	M 9	M 0	M 9		P	G	P × G
DEE (MJ)*	14.43	12.26	13.09	11.41	0.156	0.001	0.003	0.415
BMR (kJ/min)*	5.92	5.50	5.42	5.13	0.048	0.001	0.004	0.491
Sleeping MR (kJ/min)*	5.61	4.92	5.18	4.51	0.060	0.001	0.078	0.932
Sedentary act. MR (kJ/min)*	9.12	8.13	8.51	7.43	0.132	0.001	0.056	0.616
Miscellaneous act. MR (kJ/min)†	9.00	7.85	9.19	7.93	0.132	0.001	0.637	0.862
Walking MR (kJ/min)†	32.37	26.66	27.82	26.00	0.220	0.072	0.360	0.276

LSMeans and SE. Significance by ANOVA of the main effects of period (P) and gender (G); period × gender interaction (P × G).

* Values adjusted for FFM.

† Values adjusted for body weight.

icant reductions of BMR and energy costs of sleep, sedentary and physical activities, and DEE, even after adjustment for FFM or BW.

Several studies carried out in obese adults showed that a severe energy restriction associated or not with physical training resulted in significant FFM loss (16). In addition, a protein intake of 1.5 g/d per kilogram ideal BW was required to maintain FFM in adult females (17). Similarly, in adolescents, a severe energy restriction without physical training for 3 or 6 weeks or several months resulted in significant decreases in FFM (3,5). On the contrary, physical training associated or not with energy restriction favored FM loss and preserved FFM (6,7,18).

Few studies have investigated the effects of a long-term multidisciplinary weight reduction program on body composition and physical fitness (18). In the present study, during the weight reduction program, EI averaged 10 to 11 MJ/d (a value close to EI of nonobese adolescents) (19), and protein intake averaged 1.8 g/d per kilogram ideal BW, that

is, per kilogram BW of nonobese adolescents of same gender, age, and height. These favorable nutritional conditions associated with physical training may have limited FFM loss, in agreement with results of previous studies corresponding to much lower FM losses (6,7,18). However, although FFM did not vary significantly in boys, it decreased significantly by 3.1 kg in girls. This gender effect could be explained by the fact that boys were 1.2 year younger and at a lower pubertal stage than girls. They grew 4.6 cm compared with 1.4 cm in girls during the 9-month weight reduction period. It is noticeable that statural growth was not affected by the moderate energy restriction. A multiple regression analysis showed that the changes in height and BW accounted for 98% of the variance of FFM, and that the intercept was not significant. The results suggest that if boys and girls had no growth during the weight reduction period, they would have lost ~3.6 and 4.3 kg FFM, respectively. In addition, according to the variations in body composition in nonobese adolescents, height and

Table 4. Heart rate (beats per minute) of adolescents before (M 0) and after (M 9) the weight reduction program

	Boys		Girls		SE	Significance (<i>p</i>)		
	M 0	M 9	M 0	M 9		P	G	P × G
Daily	103	85	100	87	2.8	0.001	0.767	0.133
Sleep	72	62	71	59	2.7	0.001	0.592	0.483
Sedentary activities	94	78	92	79	2.9	0.001	0.818	0.420
Miscellaneous activities	90	77	91	83	2.9	0.001	0.278	0.137
Walking	138	113	137	117	4.9	0.001	0.441	0.001

LSMeans and SE. Significance by ANOVA of the main effects of period (P) and gender (G); period × gender interaction (P × G).

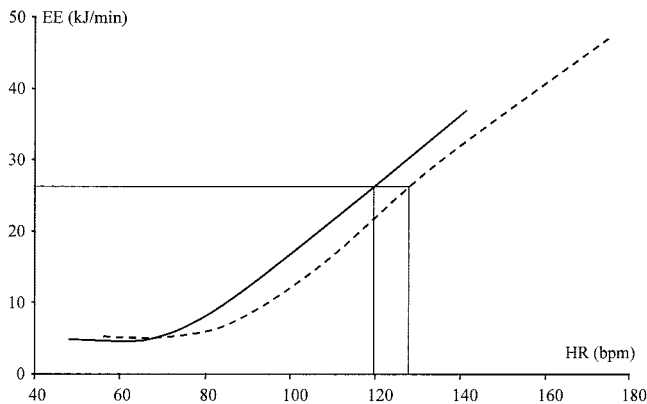


Figure 1: Relationship between HR and EE as measured by whole-body calorimetry before (---) and after (—) the weight reduction program (mean values of all subjects).

FFM increased by 15 cm and 12.4 kg, respectively, in boys between 13 and 15 years of age and by 2 cm and 2.4 kg, respectively, in girls between 14 and 16 years of age (20). The expected FFM gains of our subjects during the weight reduction period would be ~ 3.7 and 1.7 kg in boys and girls, respectively. Thus, it can be estimated that the weight reduction program prevented additional predicted gains of 3.7 and 4.8 kg FFM in boys and girls, respectively, in agreement with the estimates from the regression analysis.

Bone mineral density and total-body bone mineral content were higher in girls than in boys, but the increases were lower in girls than in boys during the weight reduction period because bone mass gain and density peak earlier in girls than in boys (21), and girls were 1.2 years older and at the higher pubertal stage than boys. The increases in bone mineral density (4.3% to 7.5%) and bone mineral content agreed with previous results of the above authors.

The improvement of cardiovascular fitness was observed during sleep, sedentary activities, and walking at different speeds and slopes. It did not result only from weight loss because for the same EE, walking HR was significantly lower after the weight reduction period. Fitness increased continuously during the weight reduction program, as shown by the results of the aerobic and anaerobic tests performed monthly (22). The improvement of fitness illustrates the beneficial effects of physical training in agreement with the results obtained in obese adolescents assigned to a moderate or a high-intensity physical training program without weight loss (18). This cardiovascular improvement is of major interest to reduce the global risk in the obese population because it has been evaluated recently at the vascular level in obese children (23).

The second main objective of the present study was to examine the effect of a multidisciplinary weight reduction program on the various components of EE. The latter was determined during stable BW periods before and at the end

of the weight reduction period. BMR, sleeping, and sedentary EEs were significantly reduced, in agreement with the results of previous studies (3,5), but in contrast with other findings (7). This reduction cannot be explained only by the decrease in FFM and FM because BMR, sleeping, and sedentary EEs were still 6% to 12% lower after adjustment for FFM, and sleeping EE was 6.3% lower after adjustment for FFM and FM. Moreover, the 7.1% and 10.6% reductions in BMR and sleeping EE in boys were not associated with any changes in FFM, suggesting that other factors controlling EE were involved.

Recent studies (24) showed that BMR estimated from tissues/organ masses and their corresponding metabolic rates (MRs) were not significantly different from BMR measured by indirect calorimetry. These studies show strong association between BMR and organ weights because of their high MR (25). Several studies in growing pigs, lambs, or adult sheep showed that reduction of feed intake resulted in decreases in mass and EE of organs (stomach, intestines, pancreas, liver, and kidneys) and decreased animal fasting heat production (26,27). Furthermore, reduction of feed intake caused significant decrease of *in vitro* metabolic rate (MR) (total O_2 consumption and Na^+ , K^+ ATPase-dependent O_2 consumption, O_2 per hour per milligram dry weight) of intestinal epithelium and liver (28). The reduction in EE of portal-drained viscera and liver occurred within 1 week (27), which could explain that reductions in BMR have been observed in obese subjects after 2 or 3 weeks of energy restriction (3,16). In addition, protein turnover in the body is an energy costly biochemical process. During food restriction, protein turnover slows down to adapt to new nutritional conditions (29). Thus, it is likely that protein turnover was reduced after energy restriction, resulting in a decreased EE.

EI was significantly higher in M 0 than in M 9, which could affect the thermic effect of food and DEE. It averaged 11.11 and 9.29 MJ/d (SE = 0.53) in the institution and 17.42 and 10.95 MJ/d (SE = 1.47) in the calorimeters in M 0 and M 9, respectively. The great difference in EI observed in M 0 could be explained by the fact that some volunteers reduced food intake when they arrived at the institution and/or did not report all the snacks. In contrast, some subjects (hearty eaters) ate more (especially snacks) than usual in the calorimeters, perhaps because they were alone and did not feel under dietitian supervision. However, sleeping EE and respiratory quotient were not significantly different between the first and the second night spent in the calorimeters both in M 0 and M 9 (data not shown). Energy balance was positive in M 0 (+3.51 MJ/d). Assuming a 90% efficiency of energy use for body energy gain (30,31), EE associated with energy storage would be 0.35 MJ/d. As a consequence, the estimated DEE for zero energy balance would be $\sim 13.90 - 0.35 = 13.55$ MJ/d on average in M 0 and would remain significantly lower in M 9 than in M 0,

both in absolute value (11.61 vs. 13.55 MJ/d, $p < 0.001$) and after adjustment for FFM (11.83 vs. 13.42 MJ/d, $p < 0.001$).

The reduction in BMR and sleeping and sedentary EEs between M 0 and M 9 may also result from an increase in muscle oxidative capacity (32) and modifications in substrate use by muscles for ATP production, as shown by the decrease in respiratory quotient (22), due to both BW loss and physical training. In other respects, the decrease in energy cost of walking associated with weight loss, even after adjustment for BW, agrees with the results obtained in ambulatory weight-reduced subjects when the weight loss was replaced by exogenous weights (33). This might result from improved muscle work efficiency, as shown in adult subjects after a 10% weight reduction, as assessed by cycle ergometry and magnetic resonance spectroscopy (34).

Interestingly, sleeping and sedentary EEs of obese subjects after the weight reduction period were not significantly different from those of aged matched nonobese adolescents obtained in our laboratory with the same activity program (35), despite great differences in BW (75.0 vs. 49.3 kg) and FFM (52.1 vs. 39.2 kg), in agreement with previous results (5). Furthermore, after adjustment for FFM, sleeping and sedentary EEs were 22.1% and 15.7% lower in the post-obese than in the nonobese adolescents ($p < 0.001$). These decreases in EE despite unchanged FFM may have deleterious consequences in postobese adolescents by their contribution to weight regain. As a consequence, the postobese adolescents ought to maintain a reduced EI, and regular and sustained physical activity to keep the benefit of the weight reduction program or to continue to lose weight.

Association of a moderate energy restriction, progressive endurance and resistance physical training, and regular physical activity in severely obese adolescents resulted in great BW and FM losses, reduction in FFM only in girls, and improvement of cardiovascular fitness. These improvements should favor spontaneous physical activity, leisure sport activities, and social interaction of the postobese adolescents with their peers. However, BMR, sleeping, sedentary activity, and daily EEs decreased significantly, even after adjustment for FFM, probably due to reductions of organ mass and MR. In addition, the energy costs of physical activities decreased. These changes in energy metabolism after a weight reduction period may explain the frequent weight regain of postobese subjects.

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