Changes in motor control and muscle performance after a short-term body mass reduction program in obese subjects[1]

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ABSTRACT. Two hundred and thirty obese subjects (age: 18-77 yr, BMI: 31.1-65.8 kg/m^2) were studied before and after a 3-week body mass reduction (BMR) program, coupling restricted energy diet (1200-1500 kcal/day) with low intensity exercise prescription. It involved 5 days per week (consisting of one-hour dynamic aerobic standing and floor exercise plus 30 min of cycloergometer exercise at 60 W or, alternatively, 4 km outdoor leisure walking on flat terrain) and psychological counseling. One-leg standing balance test (OLSB) and stair climbing test (SCT) were employed to assess motor control and maximal lower limb muscle power, respectively. The BMR program induced a significant weight loss (4.1%; $p<0.001$), a higher reduction of body mass index (BMI) being observed in males than in females ($p<0.001$). OLSB performance time increased by 20.5% ($p<0.001$) after treatment, the improvement being evident in both genders. A 20.8% reduction in SCT time ($p<0.05$) was also observed and corresponded to a 13.2% increase ($p<0.001$) in average absolute muscle power and 15.0% increase ($p<0.001$) in specific muscle power (*i.e.* the power output per kg of body mass), with no differences between genders. In conclusion, in spite of the moderate reduction of body mass after restricted energy diet and low intensity physical conditioning, significant improvements in motor control and performance, likely to ameliorate the execution of simple daily activities, were observed in obese subjects.
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INTRODUCTION

Although several studies have explored the impact of physical conditioning of various intensities on the reduction of weight and body fat (1-3), to date fewer data are available on the influence of restricted energy diet and physical activity on muscle function in obese patients (4). In fact, while it is well established that diet plus physical activity affects body composition and weight favourably, by provoking fat loss, less is known about how this approach may influence muscle function and the ability to perform muscular work over a set period of time, that is the ability to deliver muscular power.

One of the most plausible explanations for the lack of data concerning the combined effect of diet plus physical activity on muscle performance is probably the difficulty in finding easy, economic and reliable tests to be used in severe obese patients on a large scale.

Therefore, the aim of the present study was to investigate the effects of a short-term body mass reduction (BMR) program (consisting of energy-restricted diet, low intensity exercise prescription and psychological counseling) on motor control and muscle performance employing two simple tests (one-leg standing balance, OLSB; stair climbing test, SCT) for the evaluation of motor fitness and lower limb muscle power on a large group of obese patients of different age and gender.

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Key words: Muscle performance, obesity, physical activity, weight loss.

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SUBJECTS AND METHODS

Subjects

Two hundred and thirty obese patients (43 male and 187 female, age range: 18-77 yr, mean± SE: 49.9±0.9 yr, BMI range: 31.1-65.8 kg/m^2, mean±SE: 41.4±0.4 kg/m^2) were admitted to the study after giving informed consent. No one dropped out during the study.

Patients with liver, heart, lung or kidney failure or diabetes were excluded. All subjects were in-patients of the 3rd Division of Metabolic Diseases (Italian Institute for Auxology, Piancavallo, Italy) and were evaluated before and after a 3-week BMR program, consisting of restricted energy diet (1200-1500 kcal/day), low intensity exercise prescription and psychological counseling.

BMR program

The diet contained 21% protein, 53% carbohydrate and 26% lipid. Estimated water content of food was 1000 ml water, 1560 mg Na, 3600 mg K and 900 mg Ca. Fluid intake of at least 2000 ml/day was encouraged. All subjects underwent low intensity exercise activity supervised by a physiotherapist, according to a daily program performed throughout 5 days/week and consisting of: i) one-hour dynamic aerobic standing and floor exercise performed with arms and legs at moderate intensity under the guide of a therapist, and ii) 30 min of cycloergometer exercise at 60 W or, alternatively, according to individual capabilities and clinical status, 4 km outdoor leisure walking on flat terrain.

Functional tests

The following functional tests were performed in a random order upon subject admittance and repeated at the completion of the BMR program (*i.e.* after 21 days):

i) One-leg standing balance (OLSB). The subjects were invited to stand on one leg with the other flexed for as long as possible, looking straight ahead. The test was considered to terminate with the ground contact of the flexed leg or with an overt loss of equilibrium, although compensatory movements of arms and lifted leg were allowed. An operator noted the value in seconds with a digital stopwatch and ranked the subject's performance according to a three-level qualitative scale, as described by Vellas *et al.* (5). According to this ranking, subjects not able to stand were coded as abnormal (AB); if they were able to stand unsupported on one leg without any difficulty they were coded as normal (N); and if they were able to stand unsupported on one leg but had some apparent difficulty in maintaining the balance they were coded as adaptive (AD);

ii) Stair climbing test (SCT). The subjects were invited to climb up ordinary stairs at the highest possible speed, according to the subject's capabilities. The stairs consisted of 13 steps of 15.3 cm each, thus covering a total vertical distance of 1.99 m. An operator measured the time employed to cover the test with a digital stopwatch. The test was considered to start at the moment when the first foot was lifted and to terminate with the contact of the same foot on the last step. The operator also ranked the subject's test performance according to a three-level qualitative scale, similarly to the previous test. If subjects were not able to complete the stair climbing, that is they failed in reaching the final step or did not complete the test within 60 s, they were coded as abnormal (AB). If they were able to complete the test without any difficulty they were coded as normal (N), and if they completed the test but had some apparent difficulty as stopping and restarting or searching for handrail support they were coded as adaptive (AD). The vertical component of the speed was calculated from the vertical and horizontal dimensions of the steps. In these conditions the specific mechanical power (*i.e.* the power per unit body mass) is directly proportional to the vertical component of the speed, since, whatever the speed, the subject raises every unit of his body mass by a height (in m) equivalent to his vertical speed (in $m \cdot s^{-1}$).

At the moment of the first execution of both tests upon admittance, 2-3 practice trials were allowed so that the subjects gained a good control of the performing technique. No further repetition was tried until the completion of the BMR program.

Statistical analysis

All the values are given as means±SE. The mean values of the investigated variables before and after BMR program were compared using Student's paired-sample *t* test, while differences between gender and age groups in the response to BMR program were tested with a two-factor analysis of variance (ANOVA) for repeated measurements. *p* values less than 0.05 were considered statistically significant.

RESULTS

Weight loss

The 21-day BMR program induced a significant weight loss in both gender (from 106.9±1.2 kg to 102.7±1.1 kg, $p<0.001$, corresponding to a – 4.1% change), a significantly higher reduction of BMI being observed in males than in females ($F=14.47$, $p<0.001$).

Figure 1 shows the effects of treatment on BMI values in the study group, subdivided for age ranges.

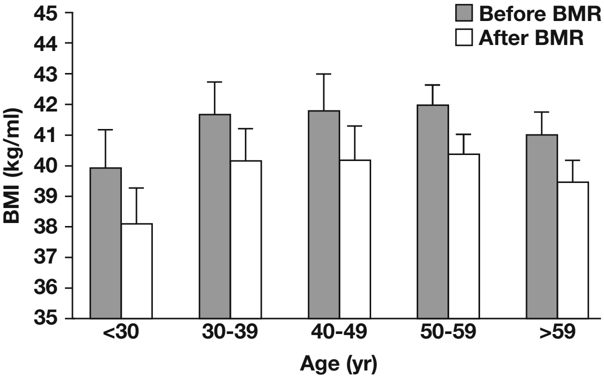

Fig. 1 - *Age class distribution of the body mass index (BMI) in 230 obese patients before and after a short-term body mass reduction (BMR) program. Changes due to the treatment were statistically significant in all classes of age, as assessed with ANOVA (F=1290,* p*<0.001).*

It is clearly evident that, in spite of different baseline and final BMI values (higher in the middle ages), the effects of BMR program were similar in all subgroups (delta BMI range: 1.54-1.85 kg/m^2).

OLSB

Before starting the BMR program, the standing time during the OLSB test was 37.4±3.5 s in males and 25.0±1.5 s in females (49.6% difference, p<0.001). This tendency for a better OLSB performance in male than in female patients was observed in all age groups.

After the BMR program, OLSB performance time increased significantly by an average of 20.5% in all subjects (from 27.3±1.4 s to 32.9±0.5 s, p<0.001). The improvement was evident in both sexes (males: from 37.4±3.5 s to 43.5±3.4 s, p<0.05; females: from 25.0±1.5 s to 30.5±1.6 s, p<0.001), and there was no significant difference between genders in the response to BMR program (F=0.04, p>0.05).

The general picture of the results obtained in the OLSB test in relation with age is shown in Figure 2. A significant decrease in OLSB time as a function of age can also be appreciated, either before and after BMR (F=14.7 and 20.3, respectively, p<0.001); a marked effect is apparent in all age subgroups.

Upon admission, 177 patients were classified as N, 25 patients as AB and 28 patients as AD. After BMR period, the ranks N, AB and AD included 193, 19 and 18 patients, respectively.

SCT

Before starting the BMR program, males performed SCT better than females, the SCT time before the treatment being significantly (p<0.01) lower in males (4.5±0.4 s *vs* 7.8±0.6 s), in all age groups.

In all subjects, SCT time significantly decreased by 20.8% (from 7.2±0.5 s to 5.7±0.4 s, p<0.05) after the BMR program. The decrease was evident in both gender (males: from 4.5±0.4 s to 4.1±0.4 s, p<0.05; females: from 7.8±0.6 s to 6.1±0.5 s, p<0.005), the change in SCT time for effect of BMR program being not influenced by gender (F=1.49, p>0.05).

Figure 3 shows the results of SCT in relation with age. It appears that SCT times significantly increased with age either before and after BMR (F=8.35 and 4.09, respectively; p<0.001 and p<0.01). After treatment,

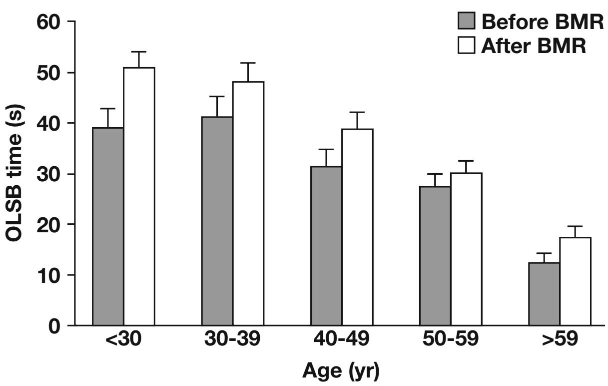

Fig. 2 - *Standing time during the one-leg standing balance test (OLSB time) observed in 230 obese patients of different classes of age, before and after a short-term body mass reduction (BMR) program. ANOVA showed significant effects of BMR program in all classes of age (F= 31.1,* p*<0.001).*

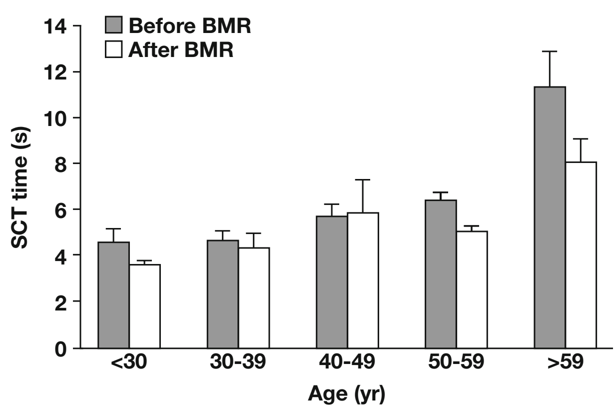

Fig. 3 - *Time of execution of the stair climbing test (SCT time) in 230 obese patients of different classes of age, before and after a short-term body mass reduction (BMR) program. The program significantly affected the performance for age groups higher than 50 yr.*

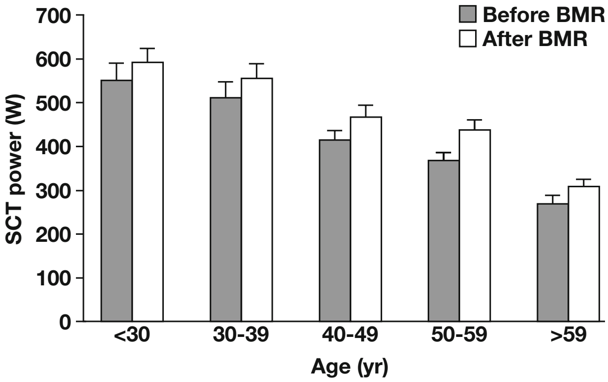

Fig. 4 - *Average muscular power developed during the execution of the stair climbing test (SCT power) in 230 obese patients of different age, before and after a short-term body mass reduction (BMR) program. Performance significantly declines with age (F=6.42,* p*<0.001) and BMR program had statistically significant effects in all age groups (F=60.6,* p*<0.001).*

the most relevant improvement in SCT time was observed in older patients (>50 yr).

Upon admission, 208 patients were classified as N, 15 as AB and 7 as AD. After the BMR period, SCT rank was N, AB and AD in 219, 6 and 5 subjects, respectively.

SCT power output

Male obese patients developed a significantly higher average absolute muscle power than females during SCT, both before (571.5±29.6 W *vs* 345.5±10.8 W, $p<0.001$) and after BMR program (599.9±28.5 W *vs* 402.1±12.2 W, $p<0.001$).

In all subjects, the treatment induced a 13.2% increase in average absolute muscle power (from 387.7±11.9 W to 439.1±12.3 W, $p<0.001$), which was evident in both gender.

Figure 4 shows how the average absolute muscle power significantly declines with age (F=6.42, $p<0.001$), both before and after BMR, the positive effect of treatment being evident in young as well as in older patients.

In terms of specific power (*i.e.* the power output per kg of body mass), BMR program determined a 15.0% increase in all subjects (from 3.48±1.45 W kg^{-1} to 4.09±1.50 W kg^{-1}, $p<0.001$), without differences between the two sexes.

In order to investigate the impact of body weight loss alone on the observed muscle functional improvements, a correlation analysis between weight loss and the improvements in both OLSB and SCT was carried out. No significant correlation resulted ($p>0.05$, assessed with Fisher's z test)

DISCUSSION

The present study reveals that a short-term period of restricted energy diet associated with low intensity exercise in obese patients, beside a moderate but significant reduction in body weight and BMI, entails an improvement in motor control and maximal lower limb power, as assessed by the functional tests performed.

In this respect, OLSB is a simple and commonly employed test found to be a reliable indicator of health related motor fitness in populations with different levels of physical activity patterns and age (6-9). This test correlates with leg muscular force, training degree (9, 10), as well as with the level of sensory-motor co-ordination in health, disease, and aging (5, 11).

Moreover SCT, first introduced by the present study as a modification of the Margaria test (12), is a simple but reliable method for the measurement of lower limb mechanical power, often used in many athletic activities as routine assessment for optimizing performance (13).

This test is generally well accepted by the subjects, being easy to perform and not exhaustive, economical and well suitable for large population surveys.

In spite of these advantages, these tests have never been employed, to our knowledge, for the study of motor fitness and maximal power output in large obese populations, before and after BMR.

Performances in the tests investigated in the present study were gender-dependent. In fact obese females, presumably due to a lower muscular mass, maintain a shorter OLSB time and display a significantly lower average muscular power during the execution of SCT than obese males. Similar differences between males and females were reported in non-obese subjects with the standard balance test (6, 14) and the original and modified Margaria test (12, 15).

The present data also show a progressive age-dependent decline in motor fitness and maximal lower limb power, which appears in line with the results obtained in non-obese subjects in both tests (11, 12, 14, 16).

To our knowledge, the only comparable study evaluating SCT power in obese subjects is the report by Kitagawa *et al.* (17), who however examined a selected group of young, mildly obese patients. These authors found significantly higher power output in obese than in lean subjects of the same age, the results being attributed to the training effect of inert mass of fat.

Although in the present study we have not actually selected an age-matched control group of nor-

mal weight subjects, preliminary data from our laboratory seem to suggest that severe obese patients have reduced SCT power, both in terms of absolute (-19%) and specific values(-38%), in comparison with non-obese subjects.
The discrepancy between the two studies might be explained both by the different age ranges (previous study: 18-22 yr *vs* present study: 18-77 yr) and, particularly, by the different BMI (26 *vs* 41 kg/m^2) of the study groups.
As far as the effects of BMR program are concerned, significant improvements in OLSB and SCT performances were observed in these obese patients, without significant differences between males and females. On the contrary, some differences were detected in the effects of BMR on SCT between the different classes of age, being more marked over 50 years. Although body weight loss is one of the factors responsible for the functional improvements observed in OLSB and SCT, it does not appear to be alone a direct determinant of muscle functional improvement, at least within the statistical confidence of this sample, as indicated by the correlation analysis performed between weight loss and both tests. Yet, several mechanisms may be at the basis of the observed performance improvement in the tests proposed in the present investigation.
Physical conditioning *per se* might play a substantial role by increasing the absolute active muscle mass of obese patients, although we have actually no direct measurements of this parameter. On the other hand, the improvement of SCT power per unit body mass might be attributed to the simple reduction of body weight. However, since the 4% reduction of body mass is associated with a 15% increase of specific power, it seems plausible that a combination of these factors may have a role in determining the results we observed after the BMR program.
Moreover, a change in muscle operational condition (*i.e.* a shift along the force-velocity diagram) for effect of the BMR program can not be ruled out. In fact muscle power, that is the rate of performing mechanical work, can be derived from the force-velocity relationship of the muscle, as traditionally described by Hill (18). Normal muscle power (Fig. 5) is optimally developed under a well-determined combination of muscle force and velocity of shortening (at approximately 1/3 of maximum shortening velocity). As far as obese subjects are concerned, it can be hypothesized that in order to perform the same movement of a non-obese individual, the muscles of these patients may have to use a higher force but a lower velocity (because of the added, inert fat mass), thus operating in a sub-optimal region of the power-velocity curve. Under this perspective BMR, by decreasing the load, might shift the operational condition of muscles toward the optimal setting point (that is the optimum velocity at which peak power is attained) of normal subjects.

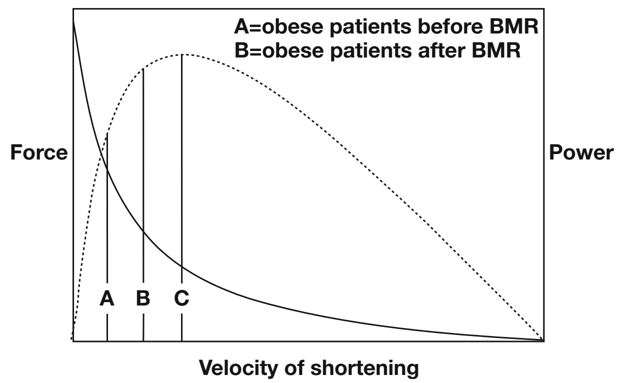

Fig. 5 - *Schematic representation of the force-velocity (solid line) and its derivative power-velocity (broken line) relationship of skeletal muscle. The hypothetical position of operational setting point along these functions is also shown for three different conditions. Due to fat mass overload, muscles of obese patients (A) perform at lower shortening velocity and higher force to attain a given motor task, possibly operating in a suboptimal range of power-velocity curve as compared with normal subjects (C). BMR program (B), by decreasing body mass and permitting higher velocity of contraction, may contribute to shift setting point toward normality.*

In conclusion, a short-term BMR program (restricted energy diet associated with low intensity exercise) produces significant improvements both in motor control and muscle performance, likely to improve the execution of simple daily activities of obese patients.
The finding of favorable effects of BMR program in older obese subjects is of relevant interest, since these results are obtained throughout a simple, well-tolerated and suitable protocol.

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