Cardiopulmonary Function and Exercise Capacity in Patients With Morbid Obesity

Luis Serés, Jordi López-Ayerbe, Ramón Coll, Oriol Rodríguez, José M. Manresa, Jaume Marrugat, Antonio Alastrue, Xavier Formiguera and Vicente Valle

Introduction and objectives. The effect of obesity on cardiac function is still under discussion. The objective of this study was to assess cardiopulmonary capacity in morbidly obese patients.

Patients and method. A symptom-limited cardiopulmonary exercise stress test was carried out in 31 morbidly obese patients (BMI 50 ± 9 kg/m²) and 30 normal controls (BMI 24 ± 2 kg/m²). Cardiovascular function was evaluated using the oxygen pulse (oxygen uptake/heart rate).

Results. There were no differences in age, sex and height between both groups. During the effort the obese subjects presented greater oxygen uptake, heart rate, systolic arterial pressure and minute ventilation and shorter test duration than control group (14 ± 3 vs 27 ± 4 min; p < 0.001). Oxygen pulse values were higher in obese patients. However, after oxygen uptake indexation by fat free mass, these differences disappeared, suggesting a similar cardiovascular function. At the end of the exercise, the control group reached 96% of their age-predicted maximal heart rate and their respiratory exchange ratio was 1 ± 0.2. Obese patients only reached 86% and 0.87 ± 0.2, respectively.

Conclusions. Due to their need of more energy output to move total body mass morbidly obese patients have a reduced exercise capacity. They finish the test having done a submaximal exercise. However, during this effort they show a normal cardiopulmonary capacity.

Key words: Obesity. Exercise. Cardiopulmonary capacity.

Full English text available at: www.revespcardiol.org

Este estudio forma parte de un proyecto de investigación aprobado por el FIS (expediente 99/1021), con el título: Alteraciones de la anatomía y función cardiaca en pacientes con obesidad mórbida. Modificaciones tras la pérdida ponderal secundaria a cirugía bariátrica.

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and with high cardiovascular morbidity and mortality. Its effects on cardiac function, however, are still controversial. While some authors describe alterations of systolic or diastolic function, others indicate cardiac function to be normal. The cardiopulmonary exercise test offers objective measurements of functional capacity and cardiac reserve. Several studies have evaluated the exercise capacity of obese patients, but results have been contradictory. Some authors believe obese people to have a cardiopulmonary response within normal limits, but that their exercise capacity is compromised by the large body mass they have to carry. Others indicate that they have reduced aerobic capacity compared to people of normal weight, their fat mass interfering with cardiac and pulmonary function and limiting their aerobic response to exercise. Some of the discrepancies in the results of these studies might be due to the different methodologies employed, and because they examined different populations with different ages and degrees of obesity. Using treadmill exercise test and gas analysis, the present cross-sectional study prospectively analyzed cardiopulmonary functional capacity in a group of patients with morbid obesity (MO), and in a group of healthy, volunteer controls of normal body weight.

**PATIENTS AND METHODS**

**Study group**

The study subjects were 55 patients of both sexes, all of whom suffered OM. All were receiving treatment at the Nutritional Disorder Unit of our hospital and were included in a bariatric surgery program. MO was defined as having a body mass index (BMI) equal to or greater than 40 kg/m². All patients had suffered obesity for more than 15 years. In nine patients, exercise tests could not be performed because of the physical difficulty experienced in walking. The BMI of these latter patients was significantly greater than those who were able to undergo exercise tests (BMI 57.7 ± 10 compared to 50 ± 10 kg/m²; P<0.001). Of those who did undergo this testing, 15 were excluded because of high blood pressure (their results were, however, reserved for future studies). This was to try to control for the potential negative influence that this variable might have on cardiac function. Thirty one MO patients with normal blood pressure therefore made up the final sample (56% of the initial population).

The control group was made up of 30 healthy, normotensive volunteers of normal body weight (BMI<27 kg/m²). These were recruited from the patients’ families and from among healthcare personnel via advertisement of the study. Pairing with the OM group was performed on the basis of age (± 5 years) and height (± 5 cm). Before starting, all participants underwent physical examination and a normal 12 lead electrocardiogram. None of the participants practiced sport regularly nor did they take any type of medication that might interfere with the exercise test results.

The study protocol was assessed and accepted by the Clinical Trials and Research Committee of our hospital. All participants received detailed information about the aim of the study and the methods to be used. They all provided written consent to participate.

**Cardiopulmonary exercise test**

A symptom-limited cardiopulmonary exercise test (Enraf Nonius Holland ergometer) with analysis of respiratory gases was performed at least 3 h after breakfast. After trying several different tests with a patient weighing 244 kg, an appropriate experimental protocol (a modification of Balkes protocol) was designed. The belt speed and the gradient settings were: stage 1–2.5 km/h, 0%; stage 2–2.5 km/h, 2%; stage 3–2.5 km/h, 4%; stage 4–2.5 km/h, 6%; stage 5–2.5 km/h, 8%; stage 6-3 km/h, 10%; stage 7-3 km/h, 12%; stage 8–3 km/h, 14%; stage 9–3 km/h, 16%; stage 10–3 km/h, 18%; stage 11–3.5 km/h, 20%; stage 12–3.5 km/h, 22%; stage 13–3.5 km/h, 24%; stage 14–3.5 km/h, 25%. From this point on, both belt speed and gradient were held constant. Each stage lasted 2 min. The patients were asked to keep going until they could continue no longer.

Cardiac frequency (CF) was monitored by continuous electrocardiographic recording. Blood pressure was monitored at the beginning of the test and every 2 minutes thereafter, during both exercise and recovery, using a sphygmomanometer attached to the arm. An ergospirometer (Minijarth 4, Holland) with a Hans Rudolf one-way mask was used for the analysis of gases expired during rest and exercise. Tidal volume (TV, in mL), breathing frequency (BF, in breaths per min), ventilation per minute (VE, in L/min), oxygen con-
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RESULTS

Baseline characteristics

No differences were seen between the groups with respect to age, sex or height. Patients with MO had significantly greater weight, BMI, and lean and fat masses (Table 1). Table 2 shows the results for the parameters recorded at rest and during maximum effort. When baseline and maximum values are taken into account, ventilation patterns (BF, TV and VE) were no different between groups. Although under baseline conditions the SBP was significantly higher in the patients, the maximum SBP reached by both groups was similar.

The duration of exercise endured by the patients was shorter than that endured by the controls (14 ± 3 compared to 27 ± 4 min; P<.001). The distance patients traveled was therefore much shorter (661 ± 175 m compared to 1.363 ± 290 m; P<.001) (Table 2).

Variables during exercise

Important differences were seen in the behavior of the CF, SBP, VO₂ and VE curves (Figure 1). From the beginning, and throughout exercise, the patients showed marked increases in the values of these variables. Compared to the control group, this determined an upward shift of their curves steeper slopes. This reflects the patients’ greater energy consumption. After 4 min of exercise walking at 2.5 km/h on a 2% gradient (Table 3), the patients reached 75% of their maximum CF, 86% of their maximum blood pressure and 58% of their peak VO₂ whereas control subjects had only reached 57, 75 and 34% respectively. After 14 min of exercise, when the patients had all ended the test through exhaustion, they were consuming 2.17 L/min of O₂, almost double that seen in the controls (1.12 L/min) (Table 3). Since the abscissa represents time, the graphs for all these variables were shorter in patients, corresponding to the shorter duration of their tests (Figure 1).

Baseline and final VO₂ were higher in the patients (Figure 1 and Table 2). In both situations, if VO₂ is corrected for body weight, the relationship inverts and

<table>
<thead>
<tr>
<th>TABLE 1. Characteristics of participants</th>
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<tbody>
<tr>
<td></td>
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<tr>
<td><strong>Obese</strong> (n=31)</td>
</tr>
<tr>
<td>Age, years</td>
</tr>
<tr>
<td>Women</td>
</tr>
<tr>
<td>Height, cm</td>
</tr>
<tr>
<td>Weight, kg</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
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<tr>
<td>Lean mass, kg</td>
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<tr>
<td>Fat mass, kg</td>
</tr>
</tbody>
</table>

BMI indicates body mass index; NS: nonsignificant.

The maximum theoretical cardiac frequency (MTCF) is calculated using the algorithm

\[ \text{MTCF} = 220 - \text{age in years} \]

MTCF and RQ were used to determine the effort made. 22

Body densitometry

Total body mass, fat mass and lean mass were measured by dual densitometry with an X-ray source using a Lunar Prodigy densitometer (Lunar Corp., Madison, WI, USA). Precision controls were performed daily using an external calibrator. The margin of error for total body mass was 1%.

Statistical analysis

Categorical variables were expressed as percentages. Quantitative values were expressed as mean ± SD. The Student t test was used to compare means, and Persons χ² test to assess gender proportions. The influence of obesity was studied by repeated measures analysis of variance (RM ANOVA). To compare the O₂ pulse between the groups, the 25th, 50th and 75th percentiles were calculated for each subject, as well as baseline and maximum values. RM ANOVA was used to test the hypothesis that VO₂, VE, CF and systolic blood pressure (SBP) vary differently throughout the exercise test in patients and in controls. Significance was set at P<.05. All analyses were performed using SPSS statistical software (version 10.0.6) for Windows.

assumption O₂ (VO₂, in mL/min), carbon dioxide production (VCO₂, in mL/min) and respiratory quotient (RQ = VCO₂/VO₂) were measured every 30 s. Before each session, the system was calibrated using standard gases with known O₂ and CO₂ concentrations. The metabolic equivalent (ME) is a unit of oxygen consumption at rest with the subject sitting 20 (3.5 mL of O₂ per kg of body weight per min [mL/kg/min]).

The efficiency of the cardiovascular system during exercise was evaluated by the O₂ pulse (the amount of O₂ consumed during a complete cardiac cycle; calculated by dividing O₂ consumption by the cardiac frequency[VO₂/CF]). If an individual’s VO₂ is expressed according to the principle of Fick: 21

\[ \text{VO₂} = \text{cardiac usage} \times \text{arterio-venous difference in O₂} \]

If cardiac usage is equal to the stroke volume multiplied by the CF, then O₂ pulse equals the stroke volume multiplied by the arterio-venous difference in O₂. Given that during exercise this difference has a physiological limit 20 of 15-17 vol/%, if a large physical effort is made then the O₂ pulse allows the behavior of the stroke volume to be evaluated.

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TABLE 2. Resting and maximum effort of patients and controls

<table>
<thead>
<tr>
<th></th>
<th>Obese (n=31)</th>
<th>Control (n=30)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resting</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BR, breaths/min</td>
<td>15 ± 3</td>
<td>14 ± 2</td>
<td>NS</td>
</tr>
<tr>
<td>TV, L/min</td>
<td>0.74 ± 0.2</td>
<td>0.71 ± 0.2</td>
<td>NS</td>
</tr>
<tr>
<td>V, L/min</td>
<td>11 ± 3</td>
<td>10 ± 2</td>
<td>NS</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>131 ± 15</td>
<td>118 ± 15</td>
<td>&lt;.002</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>84 ± 10</td>
<td>78 ± 9</td>
<td>&lt;.03</td>
</tr>
<tr>
<td>CF, beats/min</td>
<td>90 ± 12</td>
<td>85 ± 13</td>
<td>NS</td>
</tr>
<tr>
<td>VO(_2), L/min</td>
<td>0.40 ± 0.1</td>
<td>0.29 ± 0.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>VO(_2), ml/min/kg</td>
<td>2.9 ± 0.9</td>
<td>4.5 ± 1.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>VO(_2), ml/min/kg lean mass</td>
<td>6.8 ± 2</td>
<td>6.7 ± 2</td>
<td>NS</td>
</tr>
<tr>
<td>O(_2) pulse, mL/beat</td>
<td>4.3 ± 1.3</td>
<td>3.4 ± .9</td>
<td>&lt;.02</td>
</tr>
<tr>
<td>O(_2) pulse, mL/kg lean mass</td>
<td>7.4 ± 2.3</td>
<td>8.2 ± 2</td>
<td>NS</td>
</tr>
<tr>
<td>mass/beat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RQ</td>
<td>0.71 ± 0.2</td>
<td>0.81 ± 0.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td><strong>Maximum effort</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BF, breaths/min</td>
<td>32 ± 4</td>
<td>32 ± 5</td>
<td>NS</td>
</tr>
<tr>
<td>TV, L/min</td>
<td>1.9 ± .5</td>
<td>1.9 ± .4</td>
<td>NS</td>
</tr>
<tr>
<td>V, L/min</td>
<td>59 ± 17</td>
<td>60 ± 14</td>
<td>NS</td>
</tr>
<tr>
<td>SBP, mm Hg</td>
<td>184 ± 30</td>
<td>180 ± 17</td>
<td>NS</td>
</tr>
<tr>
<td>DBP, mm Hg</td>
<td>95 ± 14</td>
<td>88 ± 9</td>
<td>&lt;.02</td>
</tr>
<tr>
<td>CF, beats/min</td>
<td>156 ± 16</td>
<td>173 ± 15</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>VO(_2), L/min</td>
<td>2.37 ± 5</td>
<td>2 ± 0.5</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>VO(_2), ml/min/kg</td>
<td>17 ± 3.4</td>
<td>32 ± 4</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>VO(_2), ml/min/kg lean mass</td>
<td>42 ± 8</td>
<td>47 ± 6</td>
<td>&lt;.02</td>
</tr>
<tr>
<td>O(_2) pulse, mL/beat</td>
<td>15 ± 3</td>
<td>12 ± 2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>O(_2) pulse, mL/kg lean mass</td>
<td>0.28 ± 0.05</td>
<td>0.27 ± 0.04</td>
<td>NS</td>
</tr>
<tr>
<td>mass/beat</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RQ</td>
<td>0.87 ± 0.2</td>
<td>1 ± 0.2</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Duration, min</td>
<td>14 ± 3</td>
<td>27 ± 4</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Distance, m</td>
<td>661 ± 175</td>
<td>1.369 ± 290</td>
<td>&lt;.001</td>
</tr>
</tbody>
</table>

RQ indicates respiratory quotient; CF, cardiac frequency; BF, breathing frequency; DBP, diastolic blood pressure; SBP, systolic blood pressure; TV, tidal volume; VE, ventilation per minute; VO\(_2\), oxygen consumption; O\(_2\) pulse (ml/kg mm/beat); O\(_2\) pulse having corrected VO\(_2\) for kg lean body mass; NS: nonsignificant.

VO\(_2\) becomes much greater for the control group (Table 2). However, VO\(_2\) per kg of lean mass was the same in baseline conditions in both groups and, although the maximum was slightly lower in the patients, no significant differences were seen between the two groups during exercise.

The baseline, maximum (Table 2) and in-exercise O\(_2\) pulse values of patients were significantly greater than those of the controls. This variable was always higher in the patients whether comparisons were made for the 25th, 50th or 75th percentiles, at rest, or at the point of maximum effort (P<.001) (Figure 2). However, when O\(_2\) pulse was calculated after correcting for VO\(_2\) for lean body mass, the differences between the groups disappeared (Figure 2).

When exercise was finished, the controls had reached 95% of their MTCF, and their RQ was 1 (Table 2); therefore the effort made by these subjects was practically their maximum. When the patients reached the end of exercise, however, they had only reached 86% of their MTCF and their RQ was 0.87 (Table 2); therefore, they had not reached the limit of their cardiopulmonary capacity and their effort was sub-maximum. The gradients of the patients’ VO\(_2\) and CVO\(_2\) curves during exercise were almost parallel (Figure 3); the expected increase in CO\(_2\) production with increased O\(_2\) consumption—seen in the control group—did not occur (Figure 3).

**DISCUSSION**

The patients endured the exercise test for much shorter times than the controls—the former therefore covered only half the distance achieved by the latter. As soon as effort began, the patients had higher CF, SBP, VO\(_2\) and VE levels (Figure 1), showing them to consume more energy from the beginning of exercise. This might be needed to move their much heavier bodies. When walking at 2.5 km/h and with only a very slight gradient, the patients had already reached 58% of their maximum VO\(_2\). In contrast, the controls had only reached 34%. These results agree with those reported by other authors. For these patients, a simple walk therefore exacted a metabolic output much greater than that required of the normal weight controls. After 14 minutes of exercise, when the patients could no longer continue the test (and their effort ended), the controls had consumed only 5 ME, i.e., the VO\(_2\) needed to perform the basic activities of daily life.

Although the majority of authors agree on the limitation of effort by obese people, controversy remains with respect to their cardiopulmonary capacity. Some authors consider it to be normal.
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![Graphs showing exercise variables: CF, VO_2, VE, SBP](https://www.revespcardiol.org/)

Fig. 1. Behavior of the different variables during exercise. From the outset, the patients showed higher values in general than those of controls. CF indicates cardiac frequency; SBP, systolic blood pressure; VE, ventilation per minute; VO_2, oxygen consumption; beats/min, beats per minute. Points are means, bars are standard errors.

while others believe it to be affected. The patients in the present study showed higher O_2 pulse rates during exercise. Bearing in mind that O_2 pulse depends on stroke volume and the arterio-venous difference in O_2, and given that during maximum exercise the latter is similar in obese and normal weight people, the higher O_2 pulse values of the patients must correspond to a greater stroke volume. This response has also been described in people who practice top level sport. For this reason, it is indicated by some that obese people are physically more able because of the training that carrying their excess weight provides. On the contrary, when the stroke volume is incapable of increasing in response to exercise, the O_2 pulse is low.

The controversy surrounding cardiopulmonary response to exercise in obese people stems from the lack of agreement on how to compare populations with different body sizes. When the absolute VO_2 of different populations with different weights is compared, there is wide consensus that the heaviest individuals will have the greatest O_2 consumption. But if VO_2 is corrected for body weight, those who are obese show much lower values. This criterion has been used to argue that their cardiopulmonary functional capacity is deficient. However, the normalization of variables by weight for obese people has been criticized by several authors for not taking into account the different metabolic needs of the various body tissues. Recently, it has been suggested that lean body mass might be a better variable to use since it is metabolically very active and correlates strongly with VO_2. In the present study, when the O_2 pulse of the two groups is compared after correcting VO_2 for lean mass (Figure 2), the differences between the groups disappear. This supports the idea that cardiopulmonary capacity is similar in both groups, and, therefore, normal. The small capacity the patients showed for exercise is due to the high metabolic cost of their daily life activities. Their greater O_2 consumption is insufficient to compensate for the overload of their fat mass, as
shown by their low VO\textsubscript{2} per kg body weight figures (Table 2).

RQ is equivalent to the carbon dioxide produced divided by the oxygen consumed. At high levels of exercise, the production of CO\textsubscript{2} is greater than VO\textsubscript{2} and, therefore, the RQ is greater than 1. This is one of the parameters used to determine the level of effort.\textsuperscript{20} Reaching the MTCF is another indicator of having reached the limit of cardiovascular capacity. In the patients, the production of CO\textsubscript{2} throughout the test was always lower than O\textsubscript{2} intake, and their RQ at the end of exercise was below 0.9 (Figure 3). Further, only 86\% of MTCF was reached. Therefore, the patients finished their effort without having reached the maximum limit of their cardiopulmonary capacity. The present study does not allow us to determine whether this is due to a subjective sensation of poor tolerance to effort,\textsuperscript{34} the incapacity to perform functions in anaerobiosis,\textsuperscript{35} or an alteration in pulmonary function.\textsuperscript{36,37} Hulens\textsuperscript{18} obtained the same results—in that particular study, only 18\% of patients ended their effort due to skeletomuscular discomfort.

**Limitations of the study**

Since only 56\% of the original obese population was studied, it could be argued that the present results are biased since the least affected subjects were those chosen. However, those who were analyzed were a wide selection and showed an acute degree of obesity.

Since the patients did not reach their maximum cardiopulmonary capacity and only managed a sub-maximum effort, this study does compare two groups with different effort levels. In any event, the patients showed normal cardiopulmonary capacity for the effort they made.

**CONCLUSIONS**

The patients finished the test only having made a sub-
maximum effort. Despite this, they showed cardiopulmonary capacity within the normal limits for the effort made. After correcting VO\textsubscript{2} for lean body mass, the O\textsubscript{2} pulse of the patients was no different from that of the normal weight controls. However, as soon as exercise began, the patients showed high energy consumption—necessary to move their large mass. This metabolic cost determines the reduced exercise capacity they suffer, as reflected in the short duration of their tests.

REFERENCES