Obesity Preserves Myocardial Function During Blockade of the Glycolytic Pathway

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Abstract

Background: Obesity is defined by excessive accumulation of body fat relative to lean tissue. Studies during the last few years indicate that cardiac function in obese animals may be preserved, increased or diminished.

Objective: Study the energy balance of the myocardium with the hypothesis that the increase in fatty acid oxidation and reduced glucose leads to cardiac dysfunction in obesity.

Methods: 30-day-old male Wistar rats were fed standard and hypercaloric diet for 30 weeks. Cardiac function and morphology were assessed. In this paper was viewed the general characteristics and comorbidities associated to obesity. The structure cardiac was determined by weights of the heart and left ventricle (LV). Myocardial function was evaluated by studying isolated papillary muscles from the LV, under the baseline condition and after inotropic and lusitropic maneuvers: myocardial stiffness; postrest contraction; increase in extracellular Ca2+ concentration; change in heart rate and inhibitor of glycolytic pathway.

Results: Compared with control group, the obese rats had increased body fat and co-morbidities associated with obesity. Functional assessment after blocking iodoacetate shows no difference in the linear regression of DT, however, the RT showed a statistically significant difference in behavior between the control and the obese group, most notable being the slope in group C.

Conclusion: The energy imbalance on obesity did not cause cardiac dysfunction. On the contrary, the prioritization of fatty acids utilization provides protection to cardiac muscle during the inhibition of glycolysis, suggesting that this pathway is fewer used by obese cardiac muscle. (Arq Bras Cardiol. 2014; [online].ahead print, PP.0-0)

Keywords: Obesity; Rats; Myocardial; Metabolism; Fatty Acid.

Introduction

Obesity is a chronic metabolic disease defined by an excessive accumulation of body fat compared to lean tissue. According to estimates by the World Health Organization, in 2015, about 2.3 billion adults are overweight and of these, at least 700 million are considered obese (body mass index [BMI]> 30 g/m²). The increased availability and consumption of energy and highly palatable diets has led to increased body weight in the population. For this reason, experimental studies, diet-induced obesity is the most appropriate model to study the consequences of this disease.

Obesity is associated with increased risk of mortality and reduced life expectancy and cardiovascular disease. Clinical studies or experimental show that obesity can lead to depression of cardiac function, the pathophysiological mechanisms responsible for this change are not entirely clear. In normal aerobic conditions, approximately 70% of myocardial energy production derived from fatty acid metabolism, glycolytic contribution being about 30%. In obesity, the increased uptake and oxidation of fatty acids is associated with decreased myocardial glucose utilization. These changes in energy substrates can be held responsible for cardiac dysfunction observed in obese animals. In mice db/db obese and diabetic patients, normalization of energy metabolism, increased utilization of glucose, reversed the contractile dysfunction in these animals. This finding concurs with studies...
suggested that ATP generated by the oxidation of glucose is used preferentially by the calcium pump (Ca$$^{2+}$$) from the sarcoplasmic reticulum (SERCA2)$$^{12,13,22-24}$$, the protein responsible for reuptake of cytosolic calcium. The objective of this study was to test the hypothesis that the myocardial energy balance, increased fatty acid oxidation and decreased glucose in obese animals leads to cardiac dysfunction resulting ATP deficit for SERCA2. In order to test this premise, the glycolytic pathway was inhibited by myocardial administration of iodoacetate (IAA), a drug that blocks the activity of the enzyme glyceraldehyde 3-phosphate dehydrogenase$$^{25}$$, The inhibition of glycolysis enhance cardiac dysfunction in obese mice.

Methods

Animal Model and Experimental Protocol

Thirty-day-old male Wistar rats were randomly assigned to one of two groups: control (C, n=12) and obese (Ob, n=12). The control group was fed a standard rat chow containing 11.2% fat, 55.5% carbohydrate, and 33.3% protein; whereas the obese animals received a high-fat diet containing 45.2% kcal fat, 28.6% carbohydrate, and 26.2% protein. Each group was fed the diet for 30 consecutive weeks. High fat diet was designed in our laboratory and contained powdered commercial Agroceres rat chow (Agroceres$$^\text{®}$, Rio Claro, SP, Brazil), industrialized feed, protein supplement, vitamins and minerals. The high-fat diet was calorically rich (high-fat diet = 3.65 kcal/g versus standard diet = 2.95 kcal/g) due to the higher fat composition, made with saturated (20.2%) and unsaturated fatty acid (79.8%). All rats were housed in individual cages in an environmentally-controlled clean-air room at 23 ± 3°C with a 12 h light/dark cycle and 60 ± 5% relative humidity. Food consumption was measured daily and water ad libitum. Initial and final body weights (IBW and FBW, respectively) were recorded. Weekly caloric intake was calculated as the average weekly food consumption x caloric value of each diet. Feed efficiency, the ability to translate calories consumed into body weight, was also evaluated.

All experiments and procedures were performed in accordance with the Guide for the Care and Use of Laboratory Animals, published by the U.S. National Institutes of Health$$^{26}$, and were approved by the Botucatu Medical School Ethics Committee (UNESP, Botucatu, SP, Brazil).

Composition of Experimental Diets

The experimental diets provided sufficient amounts of protein, vitamins, and minerals according to the Nutrient Requirements of Laboratory Animals (1995). The standard and the four high-fat diets used in the study were formulated by Agroceres (Rio Claro, SP, Brazil). The ingredients were first ground and then mixed with vitamins and minerals. The mixture was made into pellets, dried in a ventilated drying oven at 55 ± 5°C, and stored at -20°C. The standard diet (RC Focus 1765) contained soybean oil, whole corn, wheat bran, soybean bran, dicalcium phosphate, sodium chloride, fish and meat flour, antioxidant additive, and a vitamins and minerals mixture. Meanwhile, the dietary ingredients used to prepare the high-fat diets were sodium chloride, casein, powdered milk, soybean protein concentrate, whole corn, cracker flour, dicalcium phosphate, Ca2+ carbonate, additives emulsifier, antioxidants and flavoring (cheese, vanilla, chocolate, and bacon), and a vitamins and minerals mixture. The composition of the high-fat diet consisted of saturated and unsaturated fatty acids, which provided 20% and 80% of the fat-derived calories, respectively$$^{26}$$.

Determination of Obesity

A criterion based on the adiposity index was used to determine obesity according to several authors$$^{9,26-28}$$, After animals had been anesthetized (sodium pentobarbital 50 mg/kg intraperitoneal [i.p.]), decapitated, and thoracotomized, the fat pads of adipose tissue were dissected and weighed. The adiposity index was calculated by the following formula: adiposity index = (total body fat (BF)/final body weight) × 100. BF was measured from the sum of the individual fat pad weights as follows: BF = epididymal fat + retroperitoneal fat + visceral fat$$^{9,26}$.

Comorbidities Associated with Obesity

As the rat models of diet-induced obesity may develop some of the characteristics of human obesity, such as hypertension, glucose intolerance, insulin resistance, dyslipidemia, hyperinsulinemia, and hyperleptinemia, the following evaluations were performed in all groups. For biochemical analysis, ten animals of each group were used.

Systolic Blood Pressure

At the conclusion of the experiment, the systolic blood pressure was assessed by using the non-invasive tail-cuff method$$^{27}$ with a Narco BioSystems$$^\text{®}$ Electro-Sphygmomanometer (International Biomedical, Austin, TX, USA). The average of two pressure readings was recorded for each animal.

Oral Glucose Tolerance Test

At the end of the 30-week feeding period, an oral glucose tolerance test was performed. Rats fasted overnight (12-15 h) and blood samples were drawn from the tip of the tail. Blood glucose was collected under basal conditions and after intraperitoneal [i.p.] administration of 2 g/kg glucose load$^9$. Blood samples were collected at 0, 15, 30, 60, 90 and 120 minutes, and analyzed using a glucometer (Accu-Check Go Kit; Roche Diagnostic Brasil Ltda, SP, Brazil).

Plasma Analysis of Hormones

At the end of treatment, animals were subjected to 12-15 h fast, anaesthetized with sodium pentobarbital (50 mg/kg intraperitoneal) and euthanized by decapitation. Blood was collected in heparinized tubes, centrifuged at 3000 × g for 15 minutes at 4°C, and then stored at -80°C. Plasma leptin and insulin concentrations were determined by ELISA$$^9$ using specific commercial kits (Linco Research Inc., St. Louis, MO, USA).
Cholesterol, Triacylglycerol, non-esterified Tatty Acid, Insulin, and Leptin

At the end of the experimental period, animals were submitted to 12–15 h of fasting, anesthetized with sodium pentobarbital (50 mg/kg i.p.), and euthanized by decapitation. Blood samples were collected in heparinized tubes, and the serum was separated by centrifugation at 3000 × g for 15 minutes at 4°C and stored at -80°C until further analysis. Serum was analyzed for levels of GL, triglycerides (TG), total cholesterol (T-Chol), non-esterified fatty acid (NEFA), and hormones (insulin and leptin). Serum concentrations of GL, TG, and T-Chol were measured with an automatic enzymatic analyzer system (Technicon, RA-XTMM System, Global Medical Instrumentation, Minnesota, USA). NEFA levels were determined by method of Johnson and Peters (1993) by using colorimetric kits (WAKO NEFA-C, Wako Pure Chemical Industries, Osaka, Japan). Leptin and insulin levels were determined by ELISA using specific commercial kits (Linco Research Inc., St. Louis, MO, USA).

Body Fat Analysis

After animals had been anesthetized (sodium pentobarbital 50 mg/kg i.p.), decapitated and thoracotomized, the fat pads of adipose tissue were dissected and weighed. The total body fat was measured from the sum of the individual fat pad weights: epididymal fat + retroperitoneal fat + visceral fat. The adiposity index was calculated from: (body total fat/final body weight)*100.

Cardiac Structure and Function

The heart and left ventricle (LV) weights were determined as indices of cardiac structure in absolute values and after normalization with the length of the shin-bone (SB).

Myocardial function was evaluated by studying isolated papillary muscles from the LV. This procedure has been utilized by various authors. This preparation allows us to measure the capacity of cardiac muscle to shorten and develop force by various authors. This preparation allows us to measure the capacity of cardiac muscle to shorten and develop force independently of influences that can modify in vivo mechanical performance of the myocardium, such as heart rate, preload, and afterload. Briefly, at the time of investigation, rats were anesthetized with sodium pentobarbital (50 mg/kg IP) and sacrificed by decapitation. The hearts were quickly removed anesthetized with sodium pentobarbital (50 mg/kg i.p.), decapitated and thoracotomized, the fat pads of adipose tissue were dissected and weighed. The total body fat was measured from the sum of the individual fat pad weights: epididymal fat + retroperitoneal fat + visceral fat. The adiposity index was calculated from: (body total fat/final body weight)*100.

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samples. The glucose profile of the groups was compared by ANOVA for repeated measures. When significant differences were found (p < 0.05), the Bonferroni test post hoc for multiple comparisons was carried out. The regression curves of the blockade of the glycolytic pathway and myocardial stiffness were compared by the angular coefficient test and linear regression. The program used for statistical analysis was the Sigma Plot 3.5 for Windows (Systat Software Inc., San Jose, CA, USA). The normality of variables was analyzed by the Kolmogorov-Smirnov test. The level of significance considered was 5%.

### Results

**General characteristics and comorbidities associated to obesity**

The general characteristics and comorbidities associated to obesity are shown in Table 1. The final body weight, total body fat, adiposity index and glucose, leptin and insulin levels were higher in Ob than in C. There was no significant difference between groups in protein and lipids levels. The test results of glucose tolerance are shown in Figure 1. Glucose levels were similar at baseline between groups. After intraperitoneal

### Table 1 – General characteristics and comorbidities associated to obesity

<table>
<thead>
<tr>
<th>Variables</th>
<th>C (n = 12)</th>
<th>Ob (n = 12)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBW (g)</td>
<td>498 ± 25</td>
<td>562 ± 36*</td>
<td>0.03467</td>
</tr>
<tr>
<td>Adiposity index (%)</td>
<td>4.28 ± 1.65</td>
<td>5.96 ± 1.54*</td>
<td>0.02872</td>
</tr>
<tr>
<td>Glucose (mg/dL)</td>
<td>107 ± 22</td>
<td>126 ± 19*</td>
<td>0.00548</td>
</tr>
<tr>
<td>Triglicerides (mg/dL)</td>
<td>6.0 ± 15.2</td>
<td>66.1 ± 24.4</td>
<td>0.30161</td>
</tr>
<tr>
<td>Colesterol (mg/dL)</td>
<td>58.3 ± 10.5</td>
<td>59.0 ± 8.1</td>
<td>0.78859</td>
</tr>
<tr>
<td>HDL (mg/dL)</td>
<td>24.8 ± 4.3</td>
<td>27.1 ± 4.9</td>
<td>0.10570</td>
</tr>
<tr>
<td>LDL (mg/dL)</td>
<td>14.0 ± 3.3</td>
<td>12.2 ± 2.8</td>
<td>0.13769</td>
</tr>
<tr>
<td>NEFA (mmol/L)</td>
<td>0.27 ± 0.05</td>
<td>0.28 ± 0.06</td>
<td>0.66658</td>
</tr>
<tr>
<td>Leptin (ng/dL)</td>
<td>2.40 ± 0.36</td>
<td>7.60 ± 0.81*</td>
<td>0.00005</td>
</tr>
<tr>
<td>Insulin (ng/dL)</td>
<td>0.23 ± 0.08</td>
<td>0.54 ± 0.07*</td>
<td>0.00067</td>
</tr>
<tr>
<td>SBP (mmHg)</td>
<td>127 ± 12</td>
<td>129 ± 13</td>
<td>0.87912</td>
</tr>
</tbody>
</table>

Values expressed as mean ± standard deviation. C: control; Ob: obese; FBW: final body weight; HDL: lipoprotein of high density; LDL: lipoprotein of low density; NEFA: non-esterified fatty acids; SBP: systolic blood pressure. Student’s t-test for independent samples.

![Figure 1](image-url) – Oral glucose tolerance test in control animals (C, n = 12) and obese (Ob, n = 12). Values expressed as mean ± standard deviation. ANOVA and Bonferroni test. * p < 0.05 vs C.
administration of glucose, blood glucose was higher in Ob group at all times evaluated.

Cardiac structure and function

The macroscopic cardiac structure is presented in Table 2; there was no significant difference between the two groups. Basal papillary myocardial function is presented in the Table 3; there were no significant differences in mechanical data. Moreover both groups, control and obese, presented same behavior with inotropic stimulations. The influence of variation of muscle length on the resting tension of the papillary muscle is shown in Figure 2; there were no significant differences between the two groups. This result shows that obesity did not increase the stiffness of the myocardium. Functional evaluation after blockade by iodoacetate is shown in Figure 3A and 3B; while there was no difference between linear regression of DT (Figure 3A), the RT showed a statistically significant difference in behavior between control and obese group, being the slope of the more remarkable in group C (Figure 3B).

Discussion

In the study period the diet was able to develop obesity because the adiposity index was 39.2% higher than the control. Data from this study are consistent with work done in our laboratory using the same methodology 9,17,26. In this paper was viewed some comorbidities associated with obesity experimental as glucose intolerance, hyperinsulinemia and hyperleptinemia. These results reveal that our model promotes changes in metabolic and hormonal parameters and are in agreement with the findings of several researches 9,30,31.

Obesity did not cause structural remodeling in heart rate and systolic blood pressure. The data differ from studies that showed that obesity induced by high-fat diet promoted cardiac hypertrophy 9,32,33 and increased blood pressure 34. The change in these variables do not suggest that obesity did not cause significant change neuro hormone capable of producing cell proliferation, vasoconstriction, and hydro-saline retention. In this study, myocardial function was assessed in vitro using isolated LV papillary muscles. Papillary muscle preparations permit the measurement of cardiac muscle force ability to develop and to shorten, independent of changes in cardiac load and heart rate that might modify mechanical performance of the myocardium in vivo. Inotropic stimulation allows the identification of alterations in contraction and relaxation phases observed that can not be read help under basal conditions and in the understanding of the mechanisms involved alterations in myocardial function. The animals used in both groups had similar cross-sectional area and this allows to avoid the homogenizing influence of cross-sectional area on the results 35. The results show that obesity did not cause deterioration of cardiac function and myocardial stiffness in basal and with inotropic stimulation. This behavior is similar to that obtained by other authors, who used isolated hearts of obese rabbits by 12 weeks 36 and isolated myocytes of obese mice for 14 weeks 37. However, researchers differ from that observed depression of mechanical function in isolated myocytes of obese mice for 12 weeks 38 and the authors found that elevation of basal contractile performance of papillary

Table 2 – Macroscopic cardiac structure

<table>
<thead>
<tr>
<th>Variables</th>
<th>Groups</th>
<th>p-value</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>C (n = 12)</td>
<td>Ob (n = 12)</td>
</tr>
<tr>
<td>LV (g)</td>
<td>0.18 ± 0.02</td>
<td>0.20 ± 0.02</td>
</tr>
<tr>
<td>Heart (g)</td>
<td>0.055 ± 0.01</td>
<td>0.060 ± 0.01</td>
</tr>
<tr>
<td>LV/SB (g/mm)</td>
<td>0.021 ± 0.003</td>
<td>0.023 ± 0.002</td>
</tr>
<tr>
<td>Heart/SB (g/mm)</td>
<td>0.29 ± 0.02</td>
<td>0.32 ± 0.02</td>
</tr>
</tbody>
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Values expressed as mean ± standard deviation. C: control; Ob: obese; LV: left ventricle; SB: shin-bone. Student’s t-test for independent samples.

Table 3 – Basal isometric contraction

<table>
<thead>
<tr>
<th>Variables</th>
<th>Groups</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C (n = 12)</td>
<td>Ob (n = 12)</td>
</tr>
<tr>
<td>DT (g/mm²)</td>
<td>7.14 ± 1.77</td>
<td>6.89 ± 1.54</td>
</tr>
<tr>
<td>RT (g/mm²)</td>
<td>0.68 ± 0.24</td>
<td>0.67 ± 0.20</td>
</tr>
<tr>
<td>+dT/dt (g/mm²/s)</td>
<td>69.4 ± 18.1</td>
<td>62.9 ± 14.6</td>
</tr>
<tr>
<td>-dT/dt (g/mm²/s)</td>
<td>22.1 ± 5.9</td>
<td>21.6 ± 4.9</td>
</tr>
<tr>
<td>CSA (mm²)</td>
<td>0.97 ± 0.24</td>
<td>0.98 ± 0.27</td>
</tr>
</tbody>
</table>

Values expressed as mean ± standard deviation. C: control; Ob: obese; DT: peak developed tension; RT: resting tension; +dT/dt: maximum rate of tension development; -dT/dt: maximum rate of tension decline; CSA: cross sectional area. Student’s t-test for independent samples.
muscle in obese mice by 7 weeks. Leopoldo et al. did not observe change in basal myocardial function in obeses rats by 15 weeks; however, these authors found differences between obese and control groups after L-type Ca2+ channel and SERCA2 blockers.

The blockade of the glycolytic pathway with iodoacetate on myocardial function showed that the slope of developed tension in obese animals was similar to control group; however, this slope of the RT in obese rats was significantly lower than controls. This finding suggests, contrary to expectations, that the control rats showed myocardial stiffness higher than the obese. This behavior could be related to the highest elevation of cytosolic calcium, possibly resulting from a lower recapture by SERCA2 and/or greater affinity between calcium and troponin C. The smallest contracture observed in obese rats suggests that prioritization of fatty acids in the myocardium at the expense of glucose increased energy availability for SERCA2 provided by fatty acids led to myocardial protection during the blockade of the glycolytic pathway. This suggests that in situations that occur in increased concentrations of fatty acids, the SERCA2 also uses energy from the beta-oxidation. Therefore, in this experiment, obesity promoted metabolic changes that resulted in myocardial protection.

The difference in behavior between the TR and TD, the TD being equal between the groups could be related to the ratio between the amount of calcium that diffuses and is removed from the cytosol during a cardiac cycle. The reason, according to Katz, approximately 150 shows that the amount of calcium that is removed is less than the spread to the interior of the cell. Since SERCA2, largely responsible for the reuptake of

Figure 2 – The influence of variation of muscle length on the resting tension in control animals (C, n = 12) and obese (Ob, n = 12). Linear regression.

Figure 3 – Effects of blockade of glyceroldehyde 3-phosphate dehydrogenase with iodoacetate in the myocardium of rats by linear regression model in control animals (C, n = 12) and obese (Ob, n = 12). A: DT: peak developed tension. B: RT: resting tension. Linear regression. * p < 0.05 vs Ob.
calcium ions in rodents\(^{40}\), uses ATP to its basic function, an energy deficit for this organelle would have severe deleterious consequences for diastole than in systole\(^{40}\).

**Conclusion**

In conclusion, the energy imbalance in obesity does not cause cardiac dysfunction. Rather, the prioritization of the use of fatty acids provides protection to the heart muscle during the blockade of glycolysis, suggesting that this pathway is lesser utilized by myocyte in obese animals.

The results of this study suggest that the use of fatty acids by the myocardium, in certain situations, may have beneficial effects; thus, could do his job in models of cardiac remodeling as a therapy of low cost and easy implementation.

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**Author contributions**

Conception and design of the research: Campos DHS; Nascimento AF; Cicogna AC. Acquisition of data: Campos DHS; Leopoldo AS; Lima-Leopoldo AP; Nascimento AF; Oliveira-Júnior AS; SILVA DCT. Analysis and interpretation of the data: Campos DHS; Leopoldo AS; Lima-Leopoldo AP; Oliveira-Júnior AS; SUGIZAKI MM; Cicogna AC. Statistical analysis: Campos DHS; Leopoldo AS; Padovani CR. Obtaining funding: Campos DHS; Cicogna AC. Writing of the manuscript: Campos DHS; Cicogna AC. Critical revision of the manuscript for intelectual contente: Campos DHS; Sugizaki MM; Cicogna AC.

**Potential Conflict of Interest**

No potential conflict of interest relevant to this article was reported.

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**Study Association**

This article is part of the thesis of master submitted by Dijon Henrique Salomé de Campos, from Faculdade de Medicina de Botucatu – UNESP.

**References**


