Obesity and Cardiac Function

ORESTE DE DIVITIIS, M.D., SERAFINO FAZIO, M.D., MAURIZIO PETITTO, M.D.,
GIOVANNI MADDALENA, M.D., FRANCO CONTALDO, M.D., AND MARIO MANCINI, M.D.

SUMMARY
We studied 10 obese volunteers, mean age 36.5 ± 10.3 years, who weighed 123.56 ± 28.7 kg and were 69.96 ± 22.5 kg overweight. The subjects did not have diabetes, arterial hypertension or signs of cardiac and respiratory failure or disease and all underwent right- and left-heart catheterization. Cardiac output and stroke volume were high, according to increased oxygen consumption and to the degree of obesity. Ventricular end-diastolic and atrial pressures ranged from normal to high and correlated with body weight, signs of volume loading and reduced left ventricular (LV) compliance. The mean pulmonary artery pressure was elevated and correlated well with weight, pulmonary resistance being normal; mean aortic pressure did not correlate with weight, and systemic arterial resistance tended to have a negative correlation. The LV function curve showed impaired ventricular function, particularly for the heaviest subjects, in whom V\text{max} and the ratio of the stroke work index to LV end-diastolic pressure were reduced. These indexes correlated well with each other and both correlated negatively with the degree of obesity. In contrast, maximal dP/dt was normal and did not correlate with excess weight. These observations show that depressed LV function is already present in relatively young obese people, even if they are free from signs of cardiopathy and other associate diseases. The degree of impairment of heart function seems to parallel the degree of obesity.

HEART FAILURE occurs frequently in obese patients and appears to be the predominant cause of death in grossly obese subjects. Hemodynamic features contributing to the development of cardiac failure have been identified; particularly in obese people, changes in the factors that determine the preload and afterload stresses of the heart are present before cardiac failure occurs. Few studies on the contractile function of the ventricle have been done. However, many features that depend on conditions that are often associated with contractile function, including arterial hypertension, diabetes, arteriosclerotic changes and respiratory disease, can interfere directly or indirectly with cardiac function, adding their own variations to those deriving from obesity. Therefore, we studied the changes of cardiac function in 10 relatively young volunteers who had varying degrees of obesity and were free from such pathologic conditions.

Methods
The 10 obese subjects (table 1) included seven women and three men who were 20–55 years old (mean 36.5 ± 10.3 years) and weighed 81-183 kg (mean 123.56 ± 28.7 kg). Their overweight ranged from 29-100 kg (mean 69.96 ± 22.5 kg). Ideal weights, corresponding to the longest life expectancy, were established according to the tables developed by life insurance companies and converted to metric units.

We excluded subjects who had diabetes, valvular heart disease, signs of cardiac or respiratory failure, significant ECG changes, x-ray cardiothoracic ratio exceeding 0.55 and stable arterial diastolic hypertension (diastolic arterial pressure > 100 mm Hg). None of the patients had treatment with digitalis or anti-hypertensive or diuretic drugs. These subjects underwent both right- and left-heart catheterization. Ten patients gave informed consent for the procedure. Left-heart catheterization was performed through a brachial arteriotomy. The first derivative of left ventricular pressure was obtained simultaneously with the pressure curve by Millar microtip transducer catheter and was recorded at a paper speed of 500 mm/sec with time lines of 0.01 second. Oxygen consumption (VO\text{a}) was determined by a spirometrix metabolimeter (Helite/CV). Hemoglobin and oxygen saturations were obtained by Hb-Oximeter (Philips XO-1000/00). The cardiac output (CO) was measured by the Fick technique.

From the basic data, the hemodynamic variables were calculated as follows: CO (l/min) = VO\text{a}/A-VO\text{a}; CI (l/min/m\text{2}) = CO/BSA; SV (ml/beat) = CO/HR; SI (ml/beat/m\text{2}) = SV/BSA; LSVW (g-m/beat/m\text{2}) = SV (aortic mean pressure - LVEDP) × 0.0136; LSVWI (g-m/beat/m\text{2}) = SI (aortic mean pressure - LVEDP) × 0.0136; TPR (dyn-sec-cm\text{-4}) = PA mean pressure × 80/CO; APR (dyn-sec-cm\text{-4}) = (PA mean pressure – PA wedge mean pressure) × 80/CO; SVR = (dyn-sec-cm\text{-4}) = (aortic mean pressure – RA mean pressure) × 80/CO. (See legend to table 1 for abbreviations.)

Contractile element velocity (V\text{CE}) was calculated every 10 msec as the ratio of dP/dt to its instantaneous isovolumic total pressure, assuming a fixed series elastic constant of 32.]\text{16} The C constant, or zero intercept, for the series elastic element was considered to be negligible. V\text{CE} at zero load (V\text{max}) was linearly extrapolated by hand from total pressure/V\text{CE} curve. The isovolumic indexes (dP/dt max and V\text{max}) represent the average of five beats. Normal values of the isovolumic indexes were obtained in our laboratory in 10 patients, ages 17-45 years (mean 31 years), with normal body weight (overweight 0–19 kg, mean 10.5
TABLE 1. Clinical and Hemodynamic Data in Obese Subjects

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Overweight</th>
<th>RA</th>
<th>PA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>BSA (m^2)</td>
<td>Mean a-wave RVEDP</td>
<td>Mean</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>F</td>
<td>155</td>
<td>81</td>
<td>29</td>
<td>1.8</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>23</td>
<td>M</td>
<td>170</td>
<td>119</td>
<td>56</td>
<td>2.3</td>
<td>8.5</td>
</tr>
<tr>
<td>3</td>
<td>34</td>
<td>F</td>
<td>161</td>
<td>112</td>
<td>53</td>
<td>2.1</td>
<td>7</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
<td>F</td>
<td>149</td>
<td>150</td>
<td>97</td>
<td>2.3</td>
<td>10</td>
</tr>
<tr>
<td>5</td>
<td>40</td>
<td>M</td>
<td>173</td>
<td>183</td>
<td>100</td>
<td>2.7</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>45</td>
<td>F</td>
<td>153</td>
<td>103</td>
<td>50</td>
<td>1.9</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>41</td>
<td>F</td>
<td>152</td>
<td>113</td>
<td>60</td>
<td>2.0</td>
<td>9</td>
</tr>
<tr>
<td>8</td>
<td>41</td>
<td>F</td>
<td>156</td>
<td>134</td>
<td>78</td>
<td>2.2</td>
<td>13</td>
</tr>
<tr>
<td>9</td>
<td>35</td>
<td>F</td>
<td>156</td>
<td>103.6</td>
<td>49.6</td>
<td>2.0</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>31</td>
<td>M</td>
<td>164</td>
<td>137</td>
<td>77</td>
<td>2.3</td>
<td>8</td>
</tr>
</tbody>
</table>

Abbreviations: HR = heart rate; V0_2 = oxygen consumption; ΔV0_2 = arteriovenous oxygen difference; CO = cardiac output; BSA = body surface area; CI = cardiac index; SV = stroke volume; SI = stroke index; RA = right atrium; RVEDP = right ventricular end-diastolic pressure; PA = pulmonary artery; LVSWI = left ventricular end-diastolic pressure; TPR = total pulmonary resistance; APR = arteriolar pulmonary resistance; SVR = systemic vascular resistance; LSVW = left ventricular stroke work; LVSWI = left ventricular stroke work index; Max dp/dt = peak of the rate of change of pressure with respect to time during early systole; Vmax = maximal velocity of the contractile element V_CE derived by extrapolation of V_CE to zero load from the plot of V_CE and total left ventricular pressure during isovolumic phase.

kg), affected by idiopathic pulmonary dilatation (three), benign murmurs (three), very mild mitral stenosis (two), mild pulmonary stenosis (one), and small atrial septal defect (one). The normal range for dP/dt max is 903–2060 mm Hg/sec (mean 1424 mm Hg/sec) and for Vmax 1.27–1.78 muscle lengths (ML)/sec (mean 1.49 ML/sec). Body surface area was calculated according to the formula of Du Bois and Du Bois.11 The ventricular function curve was obtained by plotting LVSWI against LVEDP.12-14

Variables were correlated with weight and with the amount of overweight, and Vmax was correlated with the LVSWI/LVEDP ratio.

Results

The hemodynamic data are summarized in table 2. VO_2, CO and SV were elevated and positively correlated with weight and with amount of overweight. A-VO_2 was normal, but correlated positively with weight and overweight. Mean and a-wave right atrial, right ventricular end-diastolic and mean pulmonary artery pressures were high and correlated positively with weight and overweight; also mean pulmonary capillary wedge pressures, with evident “a” wave, and LVEDP were generally high and correlated significantly with weight and overweight. Systolic, diastolic and mean aortic pressures were normal and did not correlate significantly with the degree of obesity. Total and arteriolar pulmonary resistances were also normal but did not correlate with weights. Systemic vascular resistance was low to normal and showed a significant negative correlation with weight. Left ventricular stroke work was increased in relation to the degree of obesity. The left ventricular function curve showed that ventricular function was impaired in the eight heaviest subjects. In fact, their points lay below Ross and Braunwald’s range of normal variability of left ventricular function.15 and the curve was shifted to the right (fig. 1). Further, the SWI/LVEDP ratio showed a significant negative correlation with weight and overweight (fig. 2). The peak value of first derivative (dP/dt max) of the left ventricular pressure curve was normal. Vmax was low to normal. Although dP/dt max did not correlate with the degree of obesity, Vmax correlated negatively with weight (fig. 3). An excellent correlation (y = 3.878x + 0.088, r = 0.821, p < 0.01) was found between Vmax and LVSWI/LVEDP (fig. 4).

Discussion

Our results indicate that cardiac performance is reduced in obese subjects despite increased cardiac output. This increased cardiac output depends on VO_2, which was also elevated and correlated with weight and overweight. However, the A-VO_2 was normal in each subject, which confirms the absence of clinically evident cardiac failure. However, the A-VO_2 values correlated significantly with the degree of obesity. This tendency of A-VO_2 to increase with weight could be explained by increased oxygen uptake as a consequence of an inadequate CO, which was found at the highest degree of body weight excess. Alexander and Peterson7 reported that A-VO_2, although normal, tends to decrease with weight loss. Further, the increased CO was in turn produced primarily by the increased SV, which was correlated with CO and with weight and overweight, while heart rate remained normal. Such increases in CO and SV were described by Alexander and co-workers and were attributed to increased preload due to increased blood volume.5-7 Also, the increased right ventricular end-diastolic pressure, LVEDP and the large a-wave in the...
### TABLE 1. (Continued)

<table>
<thead>
<tr>
<th>HR (beats/min)</th>
<th>VO₂ (ml/min)</th>
<th>A-VO₂ (vol%)</th>
<th>CO (l/min)</th>
<th>CI (l/min/m²)</th>
<th>SV (ml/beat)</th>
<th>SI (ml/beat/m²)</th>
<th>LVSWI (g/m²/m²)</th>
<th>LVEDP (mm Hg)</th>
<th>Max dp/dt (mm Hg/sec)</th>
<th>Vₘₐₓ (ml/sec)</th>
<th>TPR (dyn-sec-cm⁻⁵)</th>
<th>APR (dyn-sec-cm⁻⁶)</th>
<th>SVR (dyn-sec-cm⁻⁵)</th>
</tr>
</thead>
<tbody>
<tr>
<td>109</td>
<td>170</td>
<td>3.11</td>
<td>5.46</td>
<td>3.03</td>
<td>50</td>
<td>27.7</td>
<td>39.55</td>
<td>71.4</td>
<td>7.91</td>
<td>2002</td>
<td>1.76</td>
<td>219</td>
<td>73</td>
</tr>
<tr>
<td>72</td>
<td>340</td>
<td>4.54</td>
<td>7.48</td>
<td>3.28</td>
<td>104</td>
<td>45.6</td>
<td>56.43</td>
<td>128.7</td>
<td>4.03</td>
<td>887.5</td>
<td>6.88</td>
<td>235</td>
<td>96</td>
</tr>
<tr>
<td>86</td>
<td>280</td>
<td>3.61</td>
<td>7.75</td>
<td>3.65</td>
<td>90</td>
<td>42.4</td>
<td>53.05</td>
<td>112.6</td>
<td>2.94</td>
<td>1145</td>
<td>0.72</td>
<td>206</td>
<td>21</td>
</tr>
<tr>
<td>66</td>
<td>370</td>
<td>4.71</td>
<td>7.85</td>
<td>3.32</td>
<td>119</td>
<td>50.3</td>
<td>62.93</td>
<td>148.9</td>
<td>3.49</td>
<td>1545</td>
<td>0.88</td>
<td>260</td>
<td>117</td>
</tr>
<tr>
<td>86</td>
<td>425</td>
<td>4.42</td>
<td>9.60</td>
<td>3.55</td>
<td>112</td>
<td>41.3</td>
<td>46.02</td>
<td>124.9</td>
<td>1.64</td>
<td>858.7</td>
<td>0.46</td>
<td>308</td>
<td>75</td>
</tr>
<tr>
<td>72</td>
<td>250</td>
<td>4.22</td>
<td>5.92</td>
<td>3.01</td>
<td>82</td>
<td>41.8</td>
<td>46.02</td>
<td>95.9</td>
<td>3.54</td>
<td>1178</td>
<td>0.66</td>
<td>257</td>
<td>81</td>
</tr>
<tr>
<td>94</td>
<td>270</td>
<td>3.08</td>
<td>8.76</td>
<td>4.29</td>
<td>93</td>
<td>45.6</td>
<td>62.67</td>
<td>127.7</td>
<td>4.47</td>
<td>1229</td>
<td>0.99</td>
<td>201</td>
<td>55</td>
</tr>
<tr>
<td>78</td>
<td>300</td>
<td>4.64</td>
<td>6.46</td>
<td>2.88</td>
<td>82.8</td>
<td>36.9</td>
<td>51.52</td>
<td>115.4</td>
<td>2.28</td>
<td>1423</td>
<td>0.99</td>
<td>396</td>
<td>87</td>
</tr>
<tr>
<td>95</td>
<td>300</td>
<td>3.32</td>
<td>7.65</td>
<td>3.82</td>
<td>80.5</td>
<td>40.2</td>
<td>52.55</td>
<td>105.1</td>
<td>3.75</td>
<td>1818</td>
<td>1.20</td>
<td>178</td>
<td>47</td>
</tr>
<tr>
<td>88</td>
<td>410</td>
<td>4.68</td>
<td>8.76</td>
<td>3.74</td>
<td>99.5</td>
<td>42.5</td>
<td>56.68</td>
<td>132.6</td>
<td>2.83</td>
<td>1165</td>
<td>0.95</td>
<td>228</td>
<td>64</td>
</tr>
</tbody>
</table>

### TABLE 2. Summary of Hemodynamic Data in Obese Subjects

<table>
<thead>
<tr>
<th>Weight</th>
<th>HR (beats/min)</th>
<th>VO₂ (ml/min)</th>
<th>A-VO₂ (vol%)</th>
<th>CO (l/min)</th>
<th>CI (l/min/m²)</th>
<th>SV (ml/beat)</th>
<th>SI (ml/beat/m²)</th>
<th>LVSWI (g/m²/m²)</th>
<th>LVEDP (mm Hg)</th>
<th>Max dp/dt (mm Hg/sec)</th>
<th>Vₘₐₓ (ml/sec)</th>
<th>TPR (dyn-sec-cm⁻⁵)</th>
<th>APR (dyn-sec-cm⁻⁶)</th>
<th>SVR (dyn-sec-cm⁻⁵)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>84.6</td>
<td>77.10</td>
<td>0.014x + 2.32</td>
<td>0.60</td>
<td>0.39</td>
<td>0.71</td>
<td>0.072</td>
<td>0.523</td>
<td>0.064</td>
<td>0.155</td>
<td>0.077</td>
<td>0.061</td>
<td>0.054</td>
<td>0.048</td>
</tr>
<tr>
<td>SD</td>
<td>12.97</td>
<td>7.33</td>
<td>2.82</td>
<td>0.752</td>
<td>0.05</td>
<td>0.710</td>
<td>0.821</td>
<td>0.736</td>
<td>0.05</td>
<td>0.718</td>
<td>0.921</td>
<td>0.127</td>
<td>0.392</td>
<td>0.875</td>
</tr>
</tbody>
</table>

Abbreviations: See legend to table 1.
right atrial and pulmonary wedge pressure curves, which were related to increased weight, are signs of volume overloading of the ventricles resulting from increased blood volume in the presence of reduced ventricular compliance.\textsuperscript{7,16}

The mean pulmonary artery pressure was increased and correlated well with weight and overweight, while mean aortic pressure was normal and did not correlate with the degree of obesity; however, hypertensive subjects were excluded from the study. The different responses of pulmonary and systemic pressures must be ascribed to the different responses of pulmonary and systemic resistances to the increased CO. The in-

**Figure 1.** Left ventricular (LV) function curve. The points of eight of 10 obese subjects lie below the range of normal variability.\textsuperscript{16}

**Figure 2.** The significant negative correlation between the ratio of the stroke work index (SWI) to the left ventricular end-diastolic pressure (LVEDP) and the weights and amounts of overweight shows that the higher the degree of obesity, the greater the impairment of left ventricular function.

**Figure 3.** The significant negative correlation between $V_{\text{max}}$ and body weight shows that the reduction of left ventricular performance is related to the degree of obesity.
crease in CO induced an increase in pulmonary pressure in the presence of normal total and arteriolar pulmonary resistances. An augmented pressure gradient was not present between pulmonary artery and pulmonary capillaries, the values of which increased as a consequence of increased LVEDP. On the other hand, systemic vascular resistance was normal to low and correlated negatively with body weight; as a consequence, the increased CO did not induce elevation of arterial pressure.

The left ventricular function curve shows that ventricular function was impaired in eight of the subjects (fig. 1). To compare our data with those of Ross and Braunwald,18 we had to normalize the stroke work, CO and SV for body surface area. We used the formula of Du Bois and Du Bois to obtain body surface area, although we realize this method could cause some error for subjects who weigh more than 150 kg. In only one of our patients, who weighed 183 kg, was the formula considered unsuitable, but we considered this negligible in view of the advantage of having comparable hemodynamic data. Therefore, despite the increased ventricular filling pressure and volume, the contractile response does not allow adequate systolic work.

Although the increase of CO is related to the degree of obesity, ventricular function remained inadequate. The degree of impairment of ventricular function is in turn related to the degree of obesity. In fact, the subjects whose ventricular function was normal are the least heavy ones. Further, the LVSWI/LVEDP ratio shows a significant negative correlation with weight and excess weight. The impaired ventricular function is confirmed by the behavior of the isovolumic indexes: dP/dt max, which is notoriously affected by factors not related to changes in myocardial contractility, was normal and did not correlate significantly with weight. We believe the increased preload could have masked the effect of reduced contractility.17 Instead, Vmax, which is less influenced by preload, tended to be reduced and negatively correlated to body weight. Thus, a higher degree of reduction of cardiac performance corresponds to a higher degree of obesity. On the other hand, Vmax and the LVSWI/LVEDP ratio both suggested reduced LV performance and were negatively correlated with the degree of obesity.

Our results that show impaired cardiac performance in obese subjects confirm the observations of Alexander et al.,3 who showed, echocardiographically, increased LV wall stress and posterior wall thickness in patients with morbid obesity and reduced ventricular performance. Hypertrophy has been documented by echocardiography and also by postmortem examination in morbid obesity. Increased wall thickness and LV hypertrophy have been shown to be associated with increased LV diastolic stiffness, reduced diastolic compliance and probably, normal end-diastolic muscle fiber length and “stretch.” Such LV wall variations may account for the shift to the right of the ventricular function curve: The hypertrophic ventricle may underutilize Starling’s law.

The reduced ventricular performance we found could also be explained as a consequence of impaired myocardial contractility. The variations of Vmax we obtained could support this thesis, but this index has been judged inadequate in the evaluation of myocardial inotropic state. In addition, the concept that myocardial hypertrophy is associated with decrease in contractility is controversial.

In conclusion, our results show that ventricular function is impaired in asymptomatic obese subjects who have no other clinically appreciable cause of heart disease and that it is related to the degree of obesity.

References

5. Alexander JK: Obesity and circulation. Mod Concepts Car-
15. Ross J Jr, Braunwald E: The study of left ventricular function in man by increasing resistance to ventricular ejection with angiotensin. Circulation 29: 739, 1964
29. Meerson FZ, Kapelko VI: The contractile function of the myocardium in two types of cardiac adaptation to a chronic load. Cardiology 57: 183, 1972
Obesity and cardiac function.
O de Divitiis, S Fazio, M Petitto, G Maddalena, F Contaldo and M Mancini

Circulation. 1981;64:477-482
doi: 10.1161/01.CIR.64.3.477
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1981 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/64/3/477

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/