The Cardiac Output in Chronic Cor Pulmonale

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A comparative study was made of the resting cardiac index in 12 cases of chronic cor pulmonale, in 14 normal subjects, and in 10 patients suffering from heart failure due to vascular or valvular disease. The mean cardiac index in the subjects with chronic cor pulmonale was significantly higher than in the group with other types of heart disease and was significantly lower than in the normal individuals. An explanation for the failure to observe elevation of cardiac output in some of these cases of chronic cor pulmonale is offered.

INCE the publication of McMichael and Sharpey-Schafer, cor pulmonale has been generally grouped with thyrotoxicosis, beriberi, systemic arteriovenous fistula, anemia and Paget’s disease of the bone as a type of heart disease associated with a high cardiac output. During the past two years we have had the opportunity to study the hemodynamics of 15 cases of chronic cor pulmonale, and five other cases of chronic lung disease. Since we were impressed by the infrequency of high cardiac output in these 20 subjects, it was believed that a report of their findings would be of interest.

MATERIAL

The patients studied were from the medical wards of the Cincinnati General Hospital and from the Veterans Administration Hospital, Dayton, Ohio. The diagnosis of chronic cor pulmonale was made on the basis of a history of chronic lung disease, x-ray evidence of chronic lung disease (usually emphysema), and the presence of either x-ray or electrocardiographic evidence of right ventricular hypertrophy in the absence of valvular or congenital heart disease (table 1). Eight of the 15 subjects with chronic cor pulmonale had evidence of retention of carbon dioxide in the blood; all save one had resting arterial oxygen saturations below 92 per cent of capacity. Eleven of the 15 having cor pulmonale had congestive heart failure; in two the failure was irreversible. For comparative purposes, 25 patients having normal hearts and 13 patients having heart failure or a history of heart failure associated with valvular disease or vascular disease were studied.

METHOD

Patients were studied in the fasting state, unsedated or having received 0.1 Gm. of Seconal. Cardiac venous catheterization was done as described by Cournand and Ranges. Cardiac outputs were determined by the direct Fick principle. During the collection of expired air, mixed venous samples were obtained over a 45 second period from the proximal portion of the pulmonary artery or from the right ventricle simultaneously with blood samples from a peripheral artery. Blood was collected under oil and stored in ice water over mercury. Duplicate samples were analyzed in the Van Slyke manometric apparatus and were required to check within 0.2 volumes per cent. Two minute samples of expired air were collected in Douglas bags, measured in a Tissot spirometer and analyzed in the Haldane apparatus. Duplicate samples were required to check within 0.03 per cent. Pulmonary “capillary” pressures were measured according to the method of Hellems and co-workers. Pressures were recorded by means of a five channel optical oscillograph (Hathaway).

RESULTS

These are summarized in tables 1 and 2. Cardiac output values were considered acceptable only if the oxygen consumption fell within the range given by Dexter, allowing an occasional decrease up to 8 per cent because of the age of the patient or the effect of sedation. Using this criterion, satisfactory outputs were obtained in 12 of 15 cases of chronic cor pulmonale, in 14 of 25 normals, and in 10 of 13 cases with other types of heart failure (table 1). In the normal group, the mean cardiac index was 3.3 liters per minute, with a range from 2.5 to 4.2. In the group with chronic cor pulmonale,
the mean cardiac index was 2.7 liters per minute, with a range between 1.7 and 3.8. The difference was significant at the \( p < 0.02 \) level (table 2). The mean cardiac index in 10 cases with other types of heart disease was 1.8 liters per minute, with a range from 1.2 to 2.9. The cardiac output in this group was significantly lower than in the normal group \( (p < 0.001) \) and than in the group with chronic cor pulmonale \( (p < 0.01) \) (table 2). If the index of only the group of nine patients having cor pulmonale with failure is compared with that of the group of 10 with “low output failure” the difference is less striking but is significant at the \( p < 0.02 \) level (table 2), the group with cor pulmonale and failure having a mean cardiac index of 2.6 liters. A comparison of arteriovenous oxygen differences (table 2) reveals significant differences between the group with heart failure due to hypertension or valvular disease and the normal group, \( p < 0.001 \), on the one hand and the group with chronic cor pulmonale on the other \( (p < 0.01) \). The arteriovenous oxygen differences were not significantly different in the group with chronic cor pulmonale and in the normal group.

A significant association between the cardiac index and the resting arterial oxygen saturation was found in the 12 patients with chronic cor pulmonale \( (b = 0.359; p = < 0.01) \) (table 2).

The pulmonary artery pressure was recorded in 11 of the 12 patients having chronic cor pulmonale; in the other one right ventricular pressure was recorded. There was evidence of hypertension in the lesser circuit (the mean pulmonary artery pressure was above 17 mm. Hg, or right ventricular systolic pressure above 30 mm. Hg) in all cases. Satisfactory record of the pulmonary “capillary” pressure was observed in 5 of the 12 cor pulmonale patients and in five others having chronic lung disease. The pulmonary “capillary” pressure was normal, that is, below 12 mm. Hg, in all save one. In this subject, G. An. (table 1) there was generalized irreversible heart failure. A significant negative regression was found of cardiac index on pulmonary artery mean pressure in 11 patients (table 2) having chronic cor pulmonale, but was not marked enough to be significant. Right atrial mean pressure was measured in all 12 subjects. The pressure was elevated (above 5 mm. Hg) in seven, all of whom had congestive heart failure clinically.

Five of the 15 subjects with cor pulmonale had evidence of polycythemia. All of these had congestive failure.

**DISCUSSION**

The finding of high cardiac output in cor pulmonale was described by McMichael,\(^1\) by Richards,\(^2\) and by Harvey and co-workers.\(^3\) Harvey and co-workers postulated that the cardiac output is high in cor pulmonale due to pulmonary emphysema because of hypoxia, and that the cardiac output falls with the advent of congestive heart failure, still remaining above the normal until failure is irreversible. In their cases of cor pulmonale due to silicosis without marked hypoxia, the cardiac output was not elevated. However in diffusion fibrosis of the lung, they found elevation of the cardiac output even in the absence of hypoxia. This is unexplained, but may be due to the activity of the underlying disease.

Dexter\(^4\) has found the cardiac output to be normal or low in a number of cases of cor pulmonale. He has found a significant negative correlation between cardiac index and pulmonary arteriolar resistance in cor pulmonale. Dexter\(^5\) found that the cardiac output in cor pulmonale was no longer elevated when pulmonary “arteriolar” resistance rose above approximately four times normal.

In our group of 12 patients with chronic cor pulmonale, all of whom had arterial hypoxia, none had outputs above our normal range; eight had normal outputs; four had outputs below the normal. Two patients with cor pulmonale and irreversible failure had cardiac indices below 2 liters per minute.

We were unable to find evidence of negative association between cardiac index and arterial oxygen saturation; in fact a positive association was found, suggesting that the cardiac output becomes lower as the heart becomes damaged and the pulmonary artery pressure elevated by increasing hypoxia. The general finding of normal pulmonary “capillary” pressure in chronic cor pulmonale and in chronic lung disease with pulmonary hypertension is of interest. This
### Table I.—Hemodynamic Data of 18 Cases of Chronic Cor Pulmonale

<table>
<thead>
<tr>
<th>Case</th>
<th>X-Ray</th>
<th>ECG</th>
<th>Arterial O₂ Content vol. %</th>
<th>Arterial O₂ Saturation % of cap.</th>
<th>Mean RA Pressure mm. Hg</th>
<th>R V Pressure mm. Hg</th>
<th>P A Pressure mm. Hg Syst./Diast. Mean</th>
<th>P C Mean Pressure mm. Hg</th>
<th>Cardiac Index L./min.</th>
<th>A V O₂ Difference cc/100 cc</th>
<th>Pulmonary Resistance dynes Sec. cm⁻²</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. D. H. 61, W. M.</td>
<td>Pulmonary fibrosis. Emphysema. Cor pulmonale. Angiography: Right ventricular hypertrophy</td>
<td>Right ventricular hypertrophy</td>
<td>60.1</td>
<td>72.3</td>
<td>12</td>
<td>—</td>
<td>85/40</td>
<td>57</td>
<td>—</td>
<td>2.6</td>
<td>5.1</td>
<td>— Reversible heart failure MBC—29%† VC—43%‡ Polycythemia</td>
</tr>
<tr>
<td>2. J. S. 54, W. M.</td>
<td>Pulmonary emphysema. Large pulmonary arteries. Cor pulmonale</td>
<td>Right ventricular hypertrophy</td>
<td>52.1</td>
<td>81.3</td>
<td>4</td>
<td>53/6</td>
<td>56/34</td>
<td>40</td>
<td>—</td>
<td>3.0</td>
<td>5.1</td>
<td>— No heart failure No polycythemia</td>
</tr>
<tr>
<td>3. C. B. 57, W. M.</td>
<td>Pulmonary emphysema. Large right ventricle. Cor pulmonale</td>
<td>Right ventricular hypertrophy</td>
<td>65.7</td>
<td>51.3</td>
<td>17</td>
<td>81/16</td>
<td>92/50</td>
<td>59</td>
<td>—</td>
<td>2.1</td>
<td>5.4</td>
<td>— Reversible heart failure Polycythemia</td>
</tr>
<tr>
<td>4. G. A. 60, C. M.</td>
<td>Pulmonary emphysema. Cor pulmonale</td>
<td>Right ventricular hypertrophy</td>
<td>40.3</td>
<td>55.2</td>
<td>20</td>
<td>—</td>
<td>119/54</td>
<td>74</td>
<td>19</td>
<td>1.8</td>
<td>6.3</td>
<td>1,331 Heart failure, irreversible Autopsy—emphysema and cor pulmonale. VC 29% No polycythemia</td>
</tr>
<tr>
<td>5. M. T. 45, W. M.</td>
<td>Pulmonary emphysema and fibrosis. Large pulmonary artery compatible with cor pulmonale</td>
<td>Right ventricular hypertrophy</td>
<td>46.8</td>
<td>85.2</td>
<td>10</td>
<td>56/12</td>
<td>47/28</td>
<td>38</td>
<td>—</td>
<td>2.5</td>
<td>5.3</td>
<td>— Heart failure partly reversible Polycythemia VC—48% MBC—35%</td>
</tr>
<tr>
<td>6. R. W. 56, W. M.</td>
<td>Pulmonary emphysema. Right ventricle enlarged. Left ventricle normal</td>
<td>Right ventricular hypertrophy</td>
<td>50.7</td>
<td>88.4</td>
<td>5</td>
<td>53/5</td>
<td>—</td>
<td>—</td>
<td>3.8</td>
<td>3.7</td>
<td>—</td>
<td>Heart failure reversible No polycythemia</td>
</tr>
<tr>
<td>7. J. B. 53, C. M.</td>
<td>Pulmonary emphysema and fibrosis. Large pulmonary artery compatible with cor pulmonale</td>
<td>Digitalis effect</td>
<td>60.8</td>
<td>78.1</td>
<td>4</td>
<td>57/7</td>
<td>55/20</td>
<td>11</td>
<td>3.2</td>
<td>3.8</td>
<td>381</td>
<td>Heart failure reversible No polycythemia VC—30%</td>
</tr>
<tr>
<td>No.</td>
<td>Name</td>
<td>Diagnosis</td>
<td>Findings</td>
<td>Albumin</td>
<td>Creatinine</td>
<td>Albumin/Creatinine</td>
<td>Erythrocytes</td>
<td>Hemoglobin</td>
<td>Hemoglobin/Creatinine</td>
<td>Platelets</td>
<td>Platelets/creatinine</td>
<td>Remarks</td>
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</tr>
<tr>
<td>8. M. L.</td>
<td>52, W. F.</td>
<td>Pulmonary emphysema. Prominent pulmonary arteries consistent with cor pulmonale</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No heart failure VC—63% No polycythemia</td>
</tr>
<tr>
<td>9. D. M.</td>
<td>46, W. M.</td>
<td>Cardiac enlargement. Prominent pulmonary artery. Miliary infiltrate. Cor pulmonale</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lung biopsy—chronic interstitial pneumonitis Nodular fibrosis Early right heart failure No polycythemia VC—100% MBC—129%</td>
</tr>
<tr>
<td>10. G. A.</td>
<td>59, W. M.</td>
<td>Congenital diaphragmatic hernia. Cardiac silhouette not well visualized</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Heart failure reversible VC—32% MBC—28% Spirogram: No emphysema Polycythemia</td>
</tr>
<tr>
<td>11. L. N.</td>
<td>52, W. M.</td>
<td>Pulmonary emphysema. Cor pulmonale</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>No heart failure VC—54% MBC—27% No polycythemia</td>
</tr>
<tr>
<td>12. H. S.</td>
<td>59, C. M.</td>
<td>Pulmonary emphysema. Prominent outflow tract, right ventricle. Cor pulmonale</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Partly reversible Heart failure VC—60% MBC—39%; Velocity index .65 No polycythemia</td>
</tr>
</tbody>
</table>

* Upper limit of normal—54 volumes per cent.  
†% of the predicted normal.  
MBC = Maximum breathing capacity.  
VC = Vital capacity.  
RV = Right ventricle.  
RA = Right atrium.  
PA = Pulmonary artery.  
PC = Pulmonary “capillary.”
has been observed by Dexter\textsuperscript{7} and by Blount.\textsuperscript{8} We have found this measurement occasionally helpful in excluding left ventricular failure. Pulmonary "arteriolar" resistance was elevated in 10 cases of chronic lung disease and chronic cor pulmonale where it was determined. Polycythemia was found in five subjects, all of whom had cor pulmonale with congestive failure. This is consistent with the observations of Baldwin and co-workers.\textsuperscript{9}

### Table 2.—Statistical Analysis of Hemodynamic Data in Normal Subjects, in Patients with Chronic Cor Pulmonale, and in Patients with Heart Failure due to Valvular or Vascular Disease

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Mean Cardiac Index L./Min</th>
<th>t value</th>
<th>p value</th>
<th>Mean A-V O\textsubscript{2} Diff.</th>
<th>t value</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. 14 normal subjects..........................</td>
<td>3.3</td>
<td>2.67</td>
<td>&lt;0.02</td>
<td>4.3</td>
<td>1.907</td>
<td>&lt;0.1</td>
</tr>
<tr>
<td>12 subjects having chronic cor pulmonale......</td>
<td>2.7</td>
<td></td>
<td></td>
<td>4.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. 14 normal subjects..........................</td>
<td>3.3</td>
<td>7.38</td>
<td>&lt;0.001</td>
<td>4.3</td>
<td>4.997</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>10 subjects having heart failure due to valvular or vascular disease</td>
<td>1.8</td>
<td></td>
<td></td>
<td>8.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. 12 subjects having chronic cor pulmonale....</td>
<td>2.7</td>
<td>3.40</td>
<td>&lt;0.01</td>
<td>4.9</td>
<td>3.675</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>10 subjects having heart failure due to valvular or vascular disease</td>
<td>1.8</td>
<td></td>
<td></td>
<td>8.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. 9 subjects having chronic cor pulmonale with failure</td>
<td>2.6</td>
<td>2.86</td>
<td>&lt;0.02</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 subjects having heart failure due to valvular or vascular disease</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Regression of cardiac index on arterial O\textsubscript{2} saturation in 12 cases chronic cor pulmonale...</td>
<td>0.359</td>
<td>3.26</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Regression of cardiac index on mean pulmonary artery pressure</td>
<td>-0.15</td>
<td>5.2</td>
<td>&lt;0.01</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Our findings are very similar to those of Blount.\textsuperscript{8} He, too, found elevation of the cardiac output in only an occasional case of cor pulmonale and very poor correlation between degree of hypoxia and cardiac output. Borden,\textsuperscript{10} in his study of emphysema, did not measure cardiac output but did find no decrease in the arteriovenous oxygen difference and concluded that the cardiac output was probably not consistently elevated in emphysema.

It is not our contention that hypoxia plays no role in the genesis of chronic cor pulmonale, nor that the cardiac output is never elevated in this state, but that the cardiac output may be normal or even low. The discrepancy between our findings and those of Blount\textsuperscript{8} on the one hand, and those of Richards\textsuperscript{8} and McMichael\textsuperscript{11} on the other, is puzzling. In some cases, at least, our failure to find elevation of the cardiac output in cor pulmonale can be explained on the basis of the nearly terminal condition of the patient. Others can be explained on the basis of extremely high pulmonary arteriolar resistance, as hypothesized by Dexter.\textsuperscript{7} Still others may have normal or low outputs associated with fibrosis in the lung without marked hypoxia. Even when these three groups are excluded, one still finds a few patients (for example, J. B., G. A., table 1) whose hypoxia is associated with normal cardiac output and no exceptional increase in pulmonary "arteriolar" resistance.

### Summary

Measurements of the pulmonary circulation were made in 12 patients suffering from chronic cor pulmonale.

The resting cardiac index was not elevated above normal limits in these patients. The mean resting cardiac index in chronic cor pul-
monale was significantly higher than in heart failure due to hypertension or valvular disease, and was significantly lower than in a normal group.

Pulmonary "capillary" mean pressure was normal in 9 of 10 cases of chronic lung disease with increased pulmonary arteriolar resistance and may be of aid in the diagnosis of cor pulmonale. Pulmonary arteriolar resistance was elevated in all 10 cases of chronic lung disease where the measurement was made.

A significant association between resting cardiac index and arterial oxygen saturation was found. A significant negative association was observed between cardiac output and pulmonary artery mean pressure.

CONCLUSION

It is concluded that low or normal resting cardiac index may frequently be found in chronic lung disease and cor pulmonale for one of the following reasons: absence of hypoxia; high pulmonary vascular resistance; terminal condition of the patient; or some as yet unexplained factor. The mean cardiac index in chronic lung disease and cor pulmonale was higher than in a group with heart failure or a history of heart failure due to hypertension or valvular disease. The mean cardiac index in 12 cases of chronic cor pulmonale was not higher than in normal controls, and, in fact, was significantly lower than normal.

REFERENCES

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