Circulatory Changes in Acute Glomerulonephritis

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Conflicting opinions have been expressed as to the mechanism of pulmonary and peripheral congestion frequently observed in the oliguric stage of acute glomerulonephritis. Hemodynamic studies in 7 patients studied during the oliguric edematous phase of the disease demonstrated that these patients have high ventricular filling pressures associated with an increase in cardiac output and are, therefore, examples of a high output congestive state.

Dyspnea, orthopnea, pulmonary rales, cardiac enlargement, gallop rhythm, and elevated venous pressures are frequently observed in acute glomerulonephritis. The symptoms of circulatory congestion in this condition are considered expressive of heart failure by the majority of authors, who consider that heart failure is a frequent complication of acute glomerulonephritis and the most frequent cause of death in the initial stage of this disease.1-7

Conflicting opinions have been expressed by the different investigators as to mechanism producing circulatory congestion in acute glomerulonephritis. Various explanations have been advanced, but the factors that have received major consideration as responsible for the circulatory complications are hypertension, myocardial damage, and hypervolemia.

An elevation of both systolic and diastolic blood pressure is usually present in acute glomerulonephritis, although it is frequently of moderate degree. It is generally believed to be due to an increase in total peripheral vascular resistance, but the evidence in favor of this explanation is not definite. Hypertension has been considered as the cause of "heart failure" in acute glomerulonephritis.8-10 However, some studies have shown a poor correlation between high blood pressure and signs of circulatory congestion.6,11,14

Moreover, cases of acute glomerulonephritis with cardiac enlargement without hypertension have been reported.1,13 Thus, the results of previous investigation indicate that hypertension may contribute to the production of circulatory congestion in acute glomerulonephritis, but that it is not the sole, and probably not the major factor.

Histologic changes in the myocardium of patients dying of acute glomerulonephritis have been observed,1,15,16 whereas, others have found no significant lesions.6,17 According to the majority of the investigators it would be difficult to explain the circulatory derangement observed in acute glomerulonephritis solely on the basis of the reported pathologic changes in the myocardium.18,19

It has been suggested that water retention, which is known to occur in acute glomerulonephritis, is the main factor producing circulatory congestion in this disease. Lyons, Jacobson, and Avery20 showed that the administration of salt and water to normal subjects led to increase in weight, increased blood volume and elevation of the venous
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pressure. It is also known that desoxycorticosterone acetate (DOCA) may produce cardiac enlargement, pulmonary congestion, increased venous pressure, and edema, and, more recently, the same effects have been observed as a result of the sodium retention induced by cortisone.21

On the basis of these observations and because in 5 patients both cardiac output and arm-to-tongue circulation time were found to be normal, Davies11 suggested that what has been called “heart failure” in acute glomerulonephritis is, in reality, a state of circulatory congestion due to hydremia. Also, Eichna and his associates22 expressed the view that the syndrome suggesting heart failure seen in acute glomerulonephritis is not a true heart failure, but an “extracardiac circulatory congestion due to water and salt retention.”

An increase of the blood volume with decreased hematocrit value has been shown to occur in acute glomerulonephritis by Cardozo23 and by Roscoe.14 More recently, Eisenberg24 in 8 patients with acute glomerulonephritis, edema, venous hypertension, and cardiac enlargement has found a mean increase of the blood volume of 29 per cent with selective increase in plasma volume.

It is apparent that any attempt to evaluate the mechanism responsible for the circulatory congestion in acute glomerulonephritis requires a knowledge of the actual hemodynamic changes in these patients. Hemodynamic data in 5 patients with acute glomerulonephritis have been reported by Eichna and Farber,25 and Davies11 has reported hemodynamic studies in 5 patients, 4 of whom were normotensive at the time of the study. Both groups reported normal cardiac output and stroke volume. Data were not given relating left ventricular filling pressures, nor to pressures in the pulmonary circulation. It was considered, therefore, that a more detailed hemodynamic study of a group of patients in the early phase of acute glomerulonephritis would provide additional information pertaining to the actual changes of the various circulatory parameters in this disease.

Patient Material

Hemodynamic studies were carried out in 7 patients with typical clinical and laboratory findings of acute glomerulonephritis. The patient material was obtained with as little selection as possible, i.e., attempts were made to study all patients with acute glomerulonephritis admitted in the oliguric phase of the disease. Patients below the age of 10 years, however, and occasional adults who were too severely ill to cooperate were not studied. Also excluded, were those patients in whom the diagnosis was made after the diuresis had started.

The main clinical and laboratory findings of the 7 patients studied are shown in tables 1 and 2. There were 6 males and 1 female, ranging in age from 11 to 36 years; only 1 patient was under the age of 20.

Six of the 7 patients had edema, and, during the later course of their hospitalization, showed a loss of body weight, ranging from 19 to 36 pounds, as a result of diuresis. All patients were moderately to severely hypertensive. Three subjects had dyspnea, pulmonary basal rales, slight to moderate cardiac enlargement on x-ray, and increased venous pressures; 2 of these also had orthopnea and an apical protodiastolic gallop. A fourth patient had slight cardiac enlargement, apical gallop rhythm, and increased venous pressure, but no pulmonary rales, nor did he complain of dyspnea.

All patients had urinary findings of proteinuria, hematuria, and cylindruria. The serum antistreptolysin titer was greater than 240 Todd units in 5 subjects. The blood urea nitrogen was slightly to moderately elevated in 3, the highest level being 55 mg. per 100 ml. in patient B.L. The total serum proteins were normal in all patients and the albumin ranged from 3.5 to 4.8 Gm. per cent. Plasma sodium was within normal limits in the 6 individuals in whom it was determined, plasma potassium being slightly elevated in 2.

Four of the patients had a history of “cold” or “sore throat” 2 to 3 weeks prior to admission to the hospital. In all subjects, the signs and symptoms of acute glomerulonephritis were of less than 2 weeks’ duration, and they were all afebrile at the time of study.

Methods

The hemodynamic studies were carried out in the postabsorptive state. In order to decrease the apprehension and obtain a reasonably basal state, all patients were sedated with pentobarbital (Nembutal), 100 mg., or meperidine (Demerol), 50 to 100 mg., administered ½ hour before beginning the procedure.

Cardiac catheterization was carried out in the usual manner, with a double-lumen cardiac cathe-
ter. The distal lumen of the catheter was wedged into a branch of the pulmonary artery to record the pulmonary "capillary" pressure.26 The proximal lumen was in the pulmonary artery. An indwelling Cournand needle was placed in the brachial artery. The cardiac output was measured by the Fick principle. Expired air was collected in a Tissot spirometer for 3 minutes, blood samples being drawn simultaneously and at a constant rate from the pulmonary artery and the brachial artery during the second minute of air collection. In 1 case, the hemodynamic response to exercise was also studied. The patient was required to pedal a bicycle ergometer in the recumbent position at the rate of 50 to 60 revolutions per minute for 4 minutes. Expired air was collected between the third and fourth minute of exercise, blood samples being drawn simultaneously and at a constant rate from the pulmonary and the brachial artery over the entire minute. Pulmonary "capillary," pulmonary artery and brachial artery pressures were measured at rest and at each minute over the 4 minutes of exercise.

Sanborn electromanometers were used for recording pressures, the zero level being 10 cm. anterior to the back. Mean pressures were obtained by electrical integration. Oxygen consumption was determined by analysis of expired air and room air for oxygen on a Pauling oxygen analyzer. A correction factor of 1.007 was used for the conversion of expired into inspired air volume.27 Blood samples were analyzed in duplicate for oxygen content by the method of Van Slyke and Neill,28 duplicates being required to check within 0.1 volumes per cent. The following calculations were made:

Total peripheral resistance in dynes sec. cm.−5 =
$$\frac{BAm \times 1332}{CO}$$

Pulmonary arteriolar resistance in dynes sec. cm.−5 =
$$\frac{(PAm - "PC"m) \times 1332}{CO}$$

Left ventricular work index in Kg. M. min./M.2 BSA =
$$\frac{CI \times 1.055 \times (BAm - "PC"m) \times 13.6}{1000}$$

Table 1.—Clinical Findings*

<table>
<thead>
<tr>
<th>Patient, sex, age (yr.)</th>
<th>Drypow</th>
<th>Orthopen</th>
<th>Rasa</th>
<th>Edema</th>
<th>Weight in pounds</th>
<th>Heart enlargement</th>
<th>Murmur</th>
<th>Gallop rhythm</th>
<th>Blood pressure (mm. Hg)</th>
<th>Venous pressure (cm. Hg)</th>
<th>Circulation time (sec.)</th>
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<tbody>
<tr>
<td>A.B., male, 11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>122</td>
<td>Doubtful</td>
<td>Gr. I syst.</td>
<td>No</td>
<td>150/101</td>
<td>140</td>
<td>8</td>
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<tr>
<td>I.P., male, 23</td>
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<td>0</td>
<td>0</td>
<td>++</td>
<td>205</td>
<td></td>
<td>Gr. I syst.</td>
<td>Yes</td>
<td>237/158</td>
<td>180</td>
<td>15</td>
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<tr>
<td>R.T., male, 36</td>
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<td>0</td>
<td>+</td>
<td>+++</td>
<td>195</td>
<td></td>
<td>+  0</td>
<td>No</td>
<td>182/142</td>
<td>220</td>
<td>15</td>
</tr>
<tr>
<td>A.W., female, 26</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>++</td>
<td>139</td>
<td></td>
<td>0</td>
<td>No</td>
<td>177/113</td>
<td>102</td>
<td>9</td>
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<tr>
<td>R.L., male, 20</td>
<td>+++</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>240</td>
<td></td>
<td>++  0</td>
<td>Yes</td>
<td>176/126</td>
<td>120</td>
<td>13</td>
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<tr>
<td>W.H., male, 31</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>145</td>
<td></td>
<td>0</td>
<td>0</td>
<td>228/128</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>G.J., male, 29</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
<td>++++</td>
<td>164</td>
<td></td>
<td>++</td>
<td>Gr. II syst.</td>
<td>Yes</td>
<td>190/120</td>
<td>140</td>
</tr>
</tbody>
</table>

*Most of the clinical findings are graded on a scale of + to ++.
†Weight change during period of hospitalization.
‡In all cases, clinical evaluation of the heart size has been confirmed by x-ray.
TABLE 2.—Laboratory Findings

<table>
<thead>
<tr>
<th>Patient</th>
<th>Protein</th>
<th>Red blood cells</th>
<th>Casts</th>
<th>Blood urea nitrogen (mg/100 ml)</th>
<th>Serum proteins (Gm./100 ml)</th>
<th>Plasma sodium (mEq./L)</th>
<th>Plasma potassium (mEq./L)</th>
<th>Serum creatinine (mg/100 ml)</th>
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</thead>
<tbody>
<tr>
<td>A.B.</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>38</td>
<td>8.3</td>
<td>3.8</td>
<td>4.5</td>
<td>137</td>
</tr>
<tr>
<td>I.P.</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>17</td>
<td>8.4</td>
<td>4.3</td>
<td>4.1</td>
<td>140</td>
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<tr>
<td>R.T.</td>
<td>+++</td>
<td>+++</td>
<td>+++</td>
<td>17</td>
<td>7.0</td>
<td>3.5</td>
<td>3.5</td>
<td>140</td>
</tr>
<tr>
<td>A.W.</td>
<td>++++</td>
<td>+++</td>
<td>++</td>
<td>19</td>
<td>7.5</td>
<td>4.8</td>
<td>2.7</td>
<td>149</td>
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<tr>
<td>B.L.</td>
<td>+++</td>
<td>+++</td>
<td>+</td>
<td>55</td>
<td>8.2</td>
<td>4.8</td>
<td>3.4</td>
<td>150</td>
</tr>
<tr>
<td>W.H.</td>
<td>+++</td>
<td>+</td>
<td>0</td>
<td>11</td>
<td>7.6</td>
<td>4.3</td>
<td>3.3</td>
<td>&gt;625</td>
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<tr>
<td>G.J.</td>
<td>++++</td>
<td>+++</td>
<td>+++</td>
<td>36</td>
<td>7.4</td>
<td>3.9</td>
<td>3.5</td>
<td>149</td>
</tr>
</tbody>
</table>

Left ventricular stroke work index in Gm. M./beat/M.² BSA =

\[
\text{Left ventricular stroke work index} = \frac{\text{Left ventricular work index}}{\text{heart rate}} \times 1000
\]

Right ventricular work index in Kg. M./min./M.² BSA =

\[
CI \times 1.055 \times (PAm - RAm) \times 13.6
\]

Right ventricular stroke work index in Gm. M./beat/M.² BSA =

\[
\text{Right ventricular work index} = \frac{\text{Right ventricular stroke work index}}{\text{heart rate}} \times 1000
\]

Where: \( BAm \) = mean brachial artery pressure in mm. Hg; \( PAm \) = mean pulmonary artery pressure in mm. Hg; \( "PC"m \) = mean pulmonary "capillary" pressure in mm. Hg; \( RAm \) = mean right atrial pressure in mm. Hg; \( CO \) = cardiac output in ml. per second; \( CI \) = cardiac index in L. per minute per M.² of body surface area; \( BSA \) = body surface area; \( 1332 \) = factor to convert mm. Hg to dynes per cm.²; \( 1.055 \) = specific gravity of blood; \( 13.6 \) = specific gravity of Hg.

For statistical evaluation, the data obtained in this group of patients have been compared with those obtained in normal subjects studied in our laboratory. The normal mean values for oxygen consumption, arteriovenous oxygen difference, cardiac output and index, brachial artery pressure and total peripheral resistance have been calculated from the findings in a group of 19 normal controls. The remaining normal mean values have been obtained in a group of 6 normal subjects. For each hemodynamic parameter, the significance of the difference between the normal mean and the mean obtained in the patients with glomerulonephritis, has been evaluated by the t test.

RESULTS

The main hemodynamic data, together with their mean values, standard deviations and standard errors are shown in table 3. The same table shows the mean normal figures and the \( p \) values of the differences between the means.

The oxygen consumption was higher than normal in 3 patients, being within normal limits in the remaining 4 cases. The slight to moderate increase observed in the 3 patients could have been due to apprehension, or the increased work of breathing incident to pulmonary congestion. The mean oxygen consumption for the group of patients was 176.4 ±17.4 ml. per minute per M.² BSA, as compared to the normal mean of 139 ± 6.9. The difference between the 2 means is of questionable significance, the \( p \) value being greater than 0.05 but smaller than 0.1.

The arteriovenous oxygen difference ranged from 25.7 to 45.8 ml. per L., with a mean of 33.7 ± 2.7, as compared to the normal mean of 39.8 ± 1.86. The difference between these 2 means is of questionable significance (\( p > 0.05 \)).

The cardiac output was significantly increased in all patients, as shown by a cardiac index ranging from 4.43 to 7.08 L. per minute per M.² BSA. The mean for the group was 5.3 ± 0.36, which, compared with the normal
### Table 3. Hemodynamic Data

<table>
<thead>
<tr>
<th>Patient, sex, age (yr)</th>
<th>Body surface area (M²)</th>
<th>Oxygen consumption (ml/min./M², BSA)</th>
<th>Oxygen A-V difference (mm Hg)</th>
<th>Cardiac index (L/min./M², BSA)</th>
<th>Heart rate (mm Hg)</th>
<th>Stroke volume index (ml/bib/ M², BSA)</th>
<th>Arterial oxygen saturation (%)</th>
<th>Brachial artery mean arterial pressure (mm Hg)</th>
<th>Pulmonary capillary wedge pressure (mm Hg)</th>
<th>Right atrium (cm Hg)</th>
<th>Total peripheral resistance (Orms sec. cm⁻²)</th>
<th>Pulmonary arteriolar resistance (Orms sec. cm⁻²)</th>
<th>Left ventricular stroke work index (Kg M⁻²/min./M⁻²)</th>
<th>Right ventricular stroke work index (Kg M⁻²/min./M⁻²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A.B., male, 11</td>
<td>1.45</td>
<td>176</td>
<td>25.7</td>
<td>10.27</td>
<td>10.8</td>
<td>165</td>
<td>67.4</td>
<td>91</td>
<td>136</td>
<td>15</td>
<td>22</td>
<td>7</td>
<td>1116</td>
<td>171</td>
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<td>159</td>
<td>31.7</td>
<td>10.66</td>
<td>5.00</td>
<td>70</td>
<td>71.5</td>
<td>92</td>
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<td>24</td>
<td>27</td>
<td>11</td>
<td>1370</td>
<td>23</td>
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<td>2.02</td>
<td>140</td>
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<td>8.96</td>
<td>4.43</td>
<td>65</td>
<td>68.2</td>
<td>93</td>
<td>142</td>
<td>24</td>
<td>32</td>
<td>11</td>
<td>1261</td>
<td>71</td>
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<td>73</td>
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<td>23</td>
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<td>14</td>
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<td>9.85</td>
<td>4.56</td>
<td>56</td>
<td>81.4</td>
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<td>88</td>
<td>58.2</td>
<td>94</td>
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<td>14</td>
<td>21</td>
<td>5</td>
<td>1470</td>
<td>63</td>
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<tr>
<td>G.J., male, 29</td>
<td>1.83</td>
<td>272</td>
<td>45.0</td>
<td>10.00</td>
<td>5.46</td>
<td>83</td>
<td>65.8</td>
<td>96</td>
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<td>30</td>
<td>47</td>
<td>12</td>
<td>1330</td>
<td>136</td>
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<tr>
<td>Mean</td>
<td>176.4</td>
<td>33.7</td>
<td>5.30</td>
<td>77</td>
<td>68.4</td>
<td>153</td>
<td>32.7</td>
<td>10.3</td>
<td>1308</td>
<td>90.1</td>
<td>45</td>
<td>47.0</td>
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<tr>
<td>Standard deviation</td>
<td>46.1</td>
<td>7.2</td>
<td>0.94</td>
<td>7.6</td>
<td>21</td>
<td>8.6</td>
<td>11.3</td>
<td>3.6</td>
<td>45</td>
<td>47.0</td>
<td>19.3</td>
<td>47.0</td>
<td>18.7</td>
<td>0.61</td>
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<tr>
<td>Standard error</td>
<td>17.4</td>
<td>2.7</td>
<td>+0.38</td>
<td>2.8</td>
<td>7.9</td>
<td>3.3</td>
<td>4.3</td>
<td>1.4</td>
<td>17.3</td>
<td>0.78</td>
<td>7.3</td>
<td>0.23</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Normal mean ± S.E.</td>
<td>139 ± 6.9</td>
<td>39.8 ± 1.9</td>
<td>3.55</td>
<td>42.5</td>
<td>91.9 ± 2.6</td>
<td>6 ± 0.3</td>
<td>14 ± 1.5</td>
<td>5 ± 0.8</td>
<td>1305 ± 29.1</td>
<td>114 ± 25</td>
<td>4.03</td>
<td>50 ± 4.8</td>
<td>0.40 ± 0.45</td>
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</tr>
<tr>
<td>p</td>
<td>&lt;0.1</td>
<td>&lt;0.1</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001 ± 0.05</td>
<td>&gt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.01 ± 0.05</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.001 ± 0.05</td>
<td>&lt;0.01 ± 0.05</td>
</tr>
</tbody>
</table>
ACUTE GLOMERULONEPHRITIS

mean of 3.55 ± 0.17, appears markedly elevated. The difference is significant at a level of less than 1 per cent (fig. 1). Although cardiac output tended to be higher in those patients with an elevated oxygen consumption, there was no significant correlation between these 2 parameters.

The heart rate was within normal limits in 6 of the 7 patients, being 105 in patient A.B. The stroke volume was significantly greater than normal in all patients, the mean stroke volume index for the group being 68.4 ± 2.8 ml. per beat per M.² BSA, as compared to the normal of 42.5 ± 3.8.

The arterial oxygen saturation was within limits normal for our laboratory in 6 patients. One patient (B.L.) had an arterial oxygen saturation of 87 per cent. This patient had marked pulmonary congestion with dyspnea, orthopnea, and pulmonary rales. Both pulmonary congestion and alveolar transudation can explain the low oxygen saturation of the arterial blood observed in this patient.

The hemoglobin values ranged from 9.8 to 13.1 Gm. per 100 ml. These levels are probably falsely low as a consequence of hemodilution due to the water retention that is observed in acute glomerulonephritis. These hemoglobin values, however, are all within a range that is usually not accompanied by any significant hemodynamic change.

The pulmonary "capillary" pressure was significantly elevated in all patients, ranging from 14 to 39 mm. Hg with a mean of 24.0 ± 3.3, as compared to the normal mean of 6 ± 0.3. The difference is significant at the level of less than 1 per cent. This marked increase in pulmonary "capillary" pressure, in the absence of mitral disease or pulmonary vein obstruction, indicates an elevated left ventricular filling pressure (fig. 2).

A satisfactory right ventricular pressure curve was obtained in 4 of the 7 patients. In these 4 cases, the right ventricular end-diastolic pressures were very close to the mean right atrial pressure, the differences being not greater than 1 mm. Hg. It was decided, therefore, to use the mean right atrial pressures, which were obtained in all 7 patients, as an index of the right ventricular filling pressures. Some objections have been raised to the use of the mean right atrial pressure as reflecting the right ventricular end-diastolic pressure. However, Sarnoff observed in the experimental animal that the correlation between these two pressures is satisfactory in the low and medium ranges. For this and other technical reasons, Sarnoff preferred to use mean atrial pressures instead of directly recorded ventricular end-diastolic pressures. In our study, the mean right atrial pressure was elevated in 4 of the 7 patients, ranging from 5 to 15 mm. Hg, with a mean of 10.3 ± 1.4, as compared to the normal of 5.0 ± 0.8.
tricuspid valvular disease was absent in these patients, the elevation of the mean right atrial pressure was considered to be an indication of elevated right ventricular filling pressure.

A marked elevation of both systolic and diastolic pressures in the systemic circulation was present in all patients. The brachial artery mean pressure ranged from 136 to 182 mm. Hg with a mean of 153 ± 7.9. The calculated total peripheral resistance was within normal limits in all cases, however, ranging from 1,116 to 1,502 dynes sec. cm.⁻⁵, with a mean of 1,308 ± 17.3, as compared to the normal mean of 1,305 ± 29.1 (fig. 3).

The mean pulmonary artery pressures ranged from 21 to 50 mm. Hg, with a mean of 32 ± 4.3, which is significantly higher than the normal mean of 14 ± 1.5. The pulmonary arteriolar resistance was within normal limits in all patients (fig. 2).

Both left and right ventricular total and stroke work against pressure were markedly increased, the difference from the normal values being statistically significant at the level of 0.001 for the left ventricle and of 0.01 for the right ventricle (fig. 4).

**DISCUSSION**

The 7 patients with acute glomerulonephritis were characterized from a hemodynamic standpoint by a high cardiac output and stroke volume, a normal to low arteriovenous oxygen difference, an elevated left ventricular filling pressure, a normal total peripheral resistance, an elevated pulmonary artery pressure, and a normal pulmonary arteriolar resistance. In 5 of these subjects, an increase of the right ventricular filling pressure was also present. Both total and stroke work of the right and left ventricles were markedly elevated in all patients.

The high cardiac output places these patients in the group of the high output states, such as is seen in normal subjects during exercise or under emotional stress, and in patients with such conditions as marked anemia, hypoxemia, hyperthyroidism, arteriovenous fistula, and beri-beri. None of these disease entities associated with high output was present in these patients. The slight increase in the mean oxygen consumption for the group was of questionable statistical significance and does not explain the moderate to marked increase in cardiac output. In fact, an elevation of the cardiac output was also present in the 4 subjects in whom the oxygen consumption was within normal limits. In none of the patients was the hemoglobin low enough to increase the cardiac output significantly. Only 1 patient had a slight decrease of the arterial oxygen saturation, thus the increase in output cannot be explained on the basis of hypoxemia.

Hypertension and myocardial damage, both of which have been suggested as possible causes of the circulatory changes in acute glomerulonephritis, do not produce, per se, an increase of the minute volume output of the heart. On the other hand, hypervolemia could explain the high cardiac output observed in this group of patients. Hypervolemia in the oliguric phase of acute glomerulonephritis has been reported. More extensive studies are necessary, however, to determine whether a significant correlation exists between hypervolemia and minute volume output of the heart.

The left ventricular filling pressure was elevated in all 7 patients, with consequent increase in pulmonary venous and capillary pressures, which, in some of the patients, reached levels sufficiently high to produce symptoms and signs of pulmonary congestion. This elevation of the left ventricular filling pressures might be interpreted as evidence that the patients were in left ventricular
failure. The same applies to the right ventricle in the 5 cases that showed an increase in the filling pressure of this chamber. However, the concept that an elevation of the ventricular end-diastolic pressure always indicates heart failure is open to question.

Patterson and Starling,31 in the heart-lung preparation, observed that increments in ventricular filling pressure, within certain limits, were accompanied by a greater energy of contraction with an increase in cardiac output and stroke work. A better correlation existed between length of the myocardial fibers and force of contraction. Thus, what is now known as the Starling law of the heart relates stroke work to diastolic volume and not to diastolic pressure.

Because of the difficulty in measuring end-diastolic volume, Sarnoff and his associates30 tried to correlate ventricular filling pressure and stroke work in the experimental animal, both with the open and the closed chest. They found a good correlation between these 2 parameters, but for each heart, instead of 1 curve, they found a family of pressure-work curves. A shift from one curve to another was produced by a "modification of factors which govern the response of the myocardium" or "the vascular resistance."

Although the Starling mechanism is not the sole factor regulating the heart's performance in the intact animal, from the above-mentioned observations it appears likely that a normal heart may respond to an increase in inflow volume with an increase in end-diastolic pressure. In the light of this concept, the increased ventricular filling pressures in our patients would not necessarily indicate heart failure. A state of failure would have been demonstrated if, on exercise, a subnormal response in cardiac output and work had occurred. Because of the clinical condition of the patients, only one was studied during exercise. In this patient the total circulatory response to exercise could not be considered abnormal. In the absence of exercise studies in the remaining 6 patients, it would be difficult to determine whether some, or all, of them were in heart failure.

![Graph](http://circ.ahajournals.org/)

**Fig. 4.** Right and left ventricular work parameters in acute glomerulonephritis compared to normal subjects. Symbols as in figure 1.

The presence of a normal calculated peripheral resistance distinguishes these patients with acute glomerulonephritis from other high output states in which decrease in peripheral resistance is usually observed and the high cardiac output is not associated with an increase in arterial blood pressure. This difference would indicate that the compensatory vasodilatation, which is ordinarily present in other high output states, is absent in patients with acute glomerulonephritis. In these patients, the combination of a greater inflow volume with an elevated arterial blood pressure, produces an elevation of the left ventricular work load far above that present in comparable high output states in which the mean arterial blood pressure is normal. According to the Starling concept, one could postulate that this marked increase in work load requires a greater diastolic volume and, in turn, a significant elevation of the filling pressure.

**Summary**

Hemodynamic studies employing the technic of cardiac catheterization have been carried out in 7 patients with typical clinical and laboratory findings of acute glomerulonephritis in the oliguric phase. All patients were hypertensive, 6 were edematous; 3 had car-
diac enlargement, gallop rhythm, and signs of pulmonary congestion. The arm-to-tongue circulation time was measured in 6 patients and was normal.

The main hemodynamic findings observed in all patients were as follows: high cardiac output and stroke volume, normal to low arteriovenous oxygen difference, elevated left ventricular filling pressure, normal total peripheral arteriolar resistance, elevated pulmonary artery pressure, and normal pulmonary arteriolar resistance. An increase of the right ventricular filling pressure was present in 5 patients. Both total and stroke work of the right and left ventricles were markedly elevated in all patients.

The high cardiac output observed in this group of patients could not be explained on the basis of anemia, hypoxemia, or increased oxygen consumption. Water retention and the consequent hypervolemia known to occur in acute glomerulonephritis could explain the elevation of the cardiac output.

The finding of a normal total peripheral resistance would indicate absence of the vasodilatation that usually accompanies other high output states.

The elevation of the ventricular filling pressures might be interpreted as evidence that all patients were in heart failure. According to the Starling concept, however, an elevated ventricular filling pressure is not necessarily indicative of heart failure. The combination of hypertension with increased inflow volume in this group of patients produced an elevation of the left ventricular work load far above that present in other high output states of comparable degree, in which the mean arterial pressure is not increased. It is suggested that the resulting increase in work load was of such a magnitude as to require a greater diastolic volume and, in turn, a significant elevation of the filling pressure.

The circulatory response to exercise would show whether the heart in some of the patients with acute glomerulonephritis is in failure. In the only patient studied during exercise, the circulatory response could not be considered abnormal. Further studies in this line are needed.

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Summario in Interlingua

Studios hemodynamic per medio del tecnica de catheterisation cardiae esseva effectuate in 7 patientes con typic constatationes clinic e laboratorial de glomerulonephritis acute in le phase oliguric. Omne le patientes esseva hypertensive, 6 esseva edematose, e 3 habeva allargamento cardiae, rhythmo de galope, e signos de congestion pulmonar. In 6 patientes, le tempore del circulation inter bracio e lingua esseva measurate e trovate normal.

Le sequentes es le major constatationes hemodynamic facite in omne le patientes. Alte valores pro rendimento cardiae e volumine per pulso, normal o basse valores in le differentia arterio-venose de oxygeno, elevate valores del pression de replenation sinistro-ventricular, normal resistentia peripheric total, elevation del tension pulmono-arterial, e normal resistentia pulmono-arteriolar. Un augmento del pression de replenamento dexter-ventricular esseva presente in 5 patientes. In omne patientes, le travaliol total e etiam le travaliol per pulso in le ventriculos dexter e sinistre esseva marcamente elevate.

Le alte rendimento cardiae observate in iste patientes non poteva esser explicate per anemia, hypoxemia, o augmento del consumption de oxygeno. Le retention de aqua e le consequente hypervolemia, que occurre cognoscite in glomerulonephritis acute, provida possibilemente un effiplication pro le elevation del rendimento cardiae.

Le constatation de un normal resistentia peripheric total pare indicar le absentia del vasodilatation que es usualmente un tracto de altere statos con augmento del rendimento cardiae.
ACUTE GLOMERULONEPHRITIS

Le elevation del pressiones de replenation ventricular es possibilmente interpretabile como prova que omne le patientes se trovava in disfallimento cardiac. Tamen, secundo le conception de Starling, un elevate pression de replenation ventricular non indica necessariemente le presentia de disfallimento cardiac. Le combination de hypertension con augmento del volumine de influxo produceva in iste gruppo de patientes un elevation del carga de labor sinistro-ventricular mucho plus markate que lo que se incontra in altere statos a augmentante rendimento de grado comparabile in le quales le tension arterial medie non se acercese. Es presentate le theses que le resultante augmento del carga de labor esseva de un tal magnitude que illo necessitava un plus grande volumine diastolic e, per conseguente, un elevation significative del pression de replenation.

Le responsa del circulation a exercitios physic poterea monstrar si o non le corde in certe patientes con glomerulonephritis acute se trovava in stato de disfallimento. Un sol patiente esseva studiata durante exercitio. In ille, le responsa circulatori non poteva esser designate comme anormal, sed studios additional in iste respecto es necessari.

REFERENCES

Medical Eponyms

Bence Jones Protein. A paper "On a new substance occurring in the Urine of a patient with Mollities Ossium" was read before the Royal Society April 22, 1847, by Henry Bence Jones (1813-1873), Physician to St. George's Hospital. This appears in the Philosophical Transactions of the Royal Society of London for the year 1848, part I, pp. 55-62 (vol. 138).

"On the 1st of November 1845 I received from Dr. Watson the following note, with a test tube containing a thick, yellow, semi-solid substance:—The tube contains urine of very high specific gravity; when boiled it becomes highly opake; on the addition of nitric acid it effervesces, assumes a reddish hue, becomes quite clear, but, as it cools, assumes the consistence and appearance which you see: heat reliquifies it. What is it?"

"A few hours afterward a specimen of the same urine, passed by a grocer forty-seven years of age, who had been out of health for thirteen months, was sent to me by Dr. MacIntyre. He being in attendance on the case with Dr. Watson had two days previously first observed the peculiar reactions of the urine.

"The specimen of urine was slightly acid; specific gravity 1034.2; it contained a sediment consisting of crystalline phosphate of lime, oxalate of lime, and cylinders of fibrin. The urine became thick with heat from a deposit of phosphates, but cleared with a drop of acid. It gave no precipitate with an excess of nitric acid, unless left to stand, or unless heated and left to cool, when it became solid. This solid redissolved by heat, and again formed on cooling. Continued boiling with strong nitric acid evolved but little gas, and did not quickly hinder this reaction. Hydrochloric acid gave the same solid precipitate, soluble by heat. Strong acetic acid gave only a slight precipitate, which redissolved by heat. Caustic potash and sulphate of copper gave a splendid bright blue, clear liquid, passing over when heated to claret colour."

"January 2nd. The patient died. The following day I saw that the bony structure of the ribs was cut with the greatest ease, and the bodies of the vertebrae were capable of being sliced off with the knife. For an account of the structure of the bone, see a paper by Mr. Dalrymple in the third number of the Dublin Journal, August 1846."

"The ultimate analysis of this substance may be represented by C₄₈, H₃₈, N₉, O₁₈, or by C₄₀, H₃₁, N₅, O₁₅; according as protein is=C₄₈, H₃₇, N₆, O₁₅, or C₄₀, H₃₀, N₅, O₁₂. Hence it is an oxide of albumen, and from ultimate analysis, it is the hydrated deutoxide of albumen."

"The peculiar characteristic of this hydrated deutoxide of albumen was its solubility in boiling water, and the precipitate with nitric acid being dissolved by heat and reformed when cold."

"This substance must again be looked for in acute cases of mollities ossium. The reddening of the urine on the addition of nitric acid might perhaps lead to the rediscovery of it."
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VALENTINO DEFAZIO, RAYMOND C. CHRISTENSEN, TIMOTHY J. REGAN, LESEM J. BAER, YOSHIKAZU MORITA and HARPER K. HELLEMS

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