CIRCULATORY STATE OF PATIENTS ON CHRONIC HEMODIALYSIS

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In 16 patients on chronic hemodialysis, the cardiac catheterization was performed. They had received the hemodialytic treatment for 41 months in the average. All but two cases had cardiothoracic ratio above 50%. It was 58 ± 7% in all. The laboratory data, body weight, or the interdialytic body weight change was comparable with those of other patients with normal heart size. Pericardial effusion was denied by echocardiographic study.

Cardiac index and the left ventricular stroke work index were higher than normal; 4.7 L/min/m² and 85 ± 31 g·m/m² respectively. Cardiac index was higher than 3.9 L/min/m² in 11 patients and left ventricular stroke work index was above 68 g·m/m² (= mean value of control). The pulmonary artery wedge pressure was 16 ± 6 mmHg and abnormally high in six patients (> 15 mmHg). The pulmonary artery wedge pressure was found to be correlated with the cardiac work (r = 0.53, p < 0.02), and with the cardiothoracic ratio (r = 0.64, p < 0.02). The present study revealed a circulatory abnormality of pulmonary congestion which may be brought by an excessive load upon the heart in the renal failure patients. A further increase in the cardiac work by aggravation of anemia, retention of body fluid, or the elevation of blood pressure may easily result in an acute pulmonary edema. The reduction of the load by vasodilator may be useful for the relief of the acute rise of the pulmonary artery wedge pressure as suggested in the study of a small group in the present paper.

THE long-term prognosis of renal failure patients seems to be curtailed by cardiovascular complications. An accelerated atherosclerosis was suggested in the renal failure patients! Overhydration, anemia and shunt-flow as well as hypertension will bring excess load upon heart. The cardiac function in the patients on long-term hemodialysis has not been fully studied because of afraid of a susceptibility to infection or complications accompanying the invasive technique. An invasive data of circulatory function in nine patients on chronic hemodialysis was recently reported by Capelli and his coworkers. Since four of six deaths were attributed to myocardial infarction in their study, they stressed again the importance of the cardiovascular complication.

This paper concerns the study of the circulatory state in renal failure patients on stable regular hemodialytic treatment. The majority of them had a large heart in the chest X-ray.

Key Words:
Long-term hemodialysis
Pulmonary congestion
Cardiac work

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### TABLE I LABORATORY DATA

<table>
<thead>
<tr>
<th>Age  (years)</th>
<th>HD  (months)</th>
<th>Creat. (mg/dl)</th>
<th>Na  (mEq/L)</th>
<th>K  (mEq/L)</th>
<th>Cl  (mEq/L)</th>
<th>Ca  (mg/dl)</th>
<th>Ht  (%)</th>
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<td>58 ± 7</td>
<td>41 ± 39</td>
<td>11 ± 3</td>
<td>139 ± 2</td>
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<td>105 ± 2</td>
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### TABLE II RESULTS OF RIGHT HEART CATHETERIZATION

<table>
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<th>Case</th>
<th>MBP (mmHg)</th>
<th>HR (beats/min)</th>
<th>CI (L/min/m²)</th>
<th>PA (mmHg)</th>
<th>RA (mmHg)</th>
<th>PAWP (mmHg)</th>
<th>LVSWI (g·m/m²)</th>
<th>CTR (%)</th>
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<td>83</td>
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*Mean ± SD* 104 ± 19 67 ± 9 4.7 ± 1.3 35 ± 6 6 ± 2 16 ± 6 85 ± 31 58 ± 7

### SUBJECTS AND METHODS

The present study was primed to study the circulatory state of 16 patients on chronic hemodialysis with a large heart. All but two cases had cardiothoracic ratio above 50%. An accumulation of pericardial effusion was denied by echocardiographic study and it could not be responsible for the large heart of these patients. Six had systolic hypertension (above 145 mmHg) but below 170 mmHg at the study and their blood pressure was well controlled; normal to border line level in the ordinary state. Five received hypotensive drugs; alpha-methyl dopa (750 mg/day), reserpine (0.3 mg/day) or hydralazine (30 mg/day). The diastolic pressure was below 100 mmHg in all cases. No case with previous myocardial infarction or valvular heart disease was involved in the present study. The renal failure was due to chronic glomerulonephritis in 14, and hypertension in two. They were dialyzed three times a week by several dialyzers using the usual acetate containing dialysate. The laboratory data prior to each hemodialysis were summarized in Table I. These data were comparable with those observed in other patients who had normal heart size at our clinic. The pre-dialytic body weight change was accidentally identical with that predicted from the body length by Broca's modified equation; 48 ± 7 Kg. The interdialytic body weight change was 2.2 ± 0.7 Kg. This value was within the standard ranges at our clinic.

Right heart catheterization was performed.
on the next day of each hemodialysis. Pulmonary artery wedge pressure (PAWP), pulmonary artery, right ventricular, and right atrial pressures were obtained with Statham P23Db transducer. Cardiac output was measured by the thermodilution method using a Swan-Ganz catheter. Three to five successive measurements were averaged and used. Left ventricular stroke work index (LVSWI) was calculated as follows;

$$LVSWI = (MBP - PAWP) \times SI \times 0.0136 \text{ (g} \cdot \text{m}^2)$$

where MBP is the mean systemic blood pressure (= (2 x diastolic pressure + systolic pressure)/3) and PAWP is the mean pulmonary artery wedge pressure (= left ventricular filling pressure). SI is the stroke index. The systemic blood pressure was used to determine LVSWI as previously reported by some investigators. LVSWI obtained by this method was assured to be highly correlated with that obtained by the left ventricular pressure curve in the catheterization data (r = 0.98, p < 0.001) (unpublished data).

The data were compared with the normal values. LVSWI was then compared with the pulmonary artery wedge pressure or cardiothoracic ratio. In five patients with an abnormally high PAWP, a vasodilator was given to see its acute hemodynamic effect. Nitroprusside in 70 to 100 $\mu$g/min was administered by drip intravenous infusion. In this small group, the blood pressure, cardiac index, LVSWI and PAWP were compared before and after the administration.

The results were presented as the mean ± SD. Statistical analysis was performed by Student's t-test.

RESULT

Hemodynamic data. These were summarized in Table II. Mean systemic blood pressure was 104 ± 19 mmHg. Systolic pressure was higher than 145 mmHg in six patients. Diastolic pressure was below 100 mmHg in each patient. Heart rate was 67 ± 9 beats/min. Cardiac index was 4.7 ± 1.3 L/min/m² (control = 3.0 ± 0.6 L/min/m²). It was higher than 3.9 L/min/m² in 11 patients. LVSWI was 85 ± 31 g·m² and it was above 68 g·m² (= mean value of our control) in 10 patients. Pulmonary artery wedge pressure (PAWP) was 16 ± 6 mmHg and abnormally high in 6 patients (> 15 mmHg). Systolic and diastolic pulmonary artery pressures were 35 ± 10 mmHg, and 15 ± 6 mmHg respectively. Right atrial pressure was 6 ± 2 mmHg. The cardiothoracic ratio was 58 ± 7%.

Relation between the pulmonary artery wedge pressure and LVSWI or cardiothoracic ratio

As shown in Figure 1 (Left), LVSWI was weakly but significantly correlated with PAWP (r = 0.53, p < 0.02). Since the cardiac work is higher in these patients, an excessive work demand may be responsible for a rise of PAWP. The reduction of LVSWI resulted in a fall in PAWP as shown later.

A fair correlation was observed between the cardiothoracic ratio and PAWP (r = 0.64, p < 0.02) (Right of Fig. 1).

Acute hemodynamic effects of a vasodilator

The effects of nitroprusside was summarized in
Table III. Following the intravenous administration of nitroprusside in 70 to 100 μg/min, mean blood pressure fell from 116 ± 9 mmHg to 94 ± 12 mmHg in all patients (p < 0.01). Cardiac index or heart rate remained unchanged. LVSWI was decreased from 100 ± 11 g·m/m² to 78 ± 10 g·m/m² (p < 0.05). A significant fall in PAWP was observed following the administration of nitroprusside; from 20 ± 9 mmHg to 14 ± 6 mmHg (p < 0.01).

DISCUSSION

The stresses to be sustained by the cardiovascular system seem to be multiple in the renal failure patients. Hypertension or volume overload from anemia, and shunt-flow may promote a myocardial hypertrophy. The lowered oxygen carrying capacity due to uremic anemia may compromise the oxygen supply for myocardium and result in a heart failure. The earlier workers revealed a high output state in the renal failure patients which was supposed to be mainly due to uremic anemia. However, these authors did not discuss other parameters of cardiac function. An invasive study of cardiac hemodynamics has been infrequently performed to avoid the catheterization-related complications. Scheer and his coworkers performed left heart catheterization in 4 uremic patients. They regarded the hemodynamic data as an evidence of uremic cardiomyopathy which were compatible with that found in the other forms of cardiomyopathy except for the high cardiac output. Drüke and his coworkers obtained a similar conclusion. Five patients on chronic hemodialytic treatment for 7 to 62 months, had the cardiothoracic ratio over 60%. In two of them, an excessive cardiac work seem to be responsible for heart failure. A recent study by Capelli and his coworkers showed a significant increase in the cardiac output, stroke index, or cardiac work.

TABLE III  HEMODYNAMIC CHANGES FOLLOWING NITROPRUSSIDE ADMINISTRATION  (mean ± SD)

<table>
<thead>
<tr>
<th></th>
<th>MBP (mmHg)</th>
<th>CI (L/min/m²)</th>
<th>LVSWI (g·m/m²)</th>
<th>PAWP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>116 ± 9</td>
<td>4.6 ± 0.5</td>
<td>100 ± 11</td>
<td>20 ± 9</td>
</tr>
<tr>
<td>A</td>
<td>94 ± 12*</td>
<td>4.7 ± 0.4</td>
<td>78 ± 10**</td>
<td>14 ± 6*</td>
</tr>
</tbody>
</table>

* or ** denotes a significant change; p < 0.01 or < 0.05 respectively

Left ventricular enddiastolic pressure was markedly high in five of nine patients (above 22 mmHg). Four deaths were related to myocardial failure. An increase in cardiac work in the study of Capelli et al. was directly associated with hypertension since seven of nine patients had marked (the diastolic pressure above 110 mmHg) or severe (the diastolic pressure above 120 mmHg) hypertension.

The present study confirmed an increased cardiac output and cardiac work (Table II). Anemia, or A-V shunt flow will be factors for the increased output or cardiac work, but these factors seem comparable with those of other patients with normal heart size. They had no overt sign of heart failure except for a cardiomegaly. No rales, neck vein distension, nor pitting edema was observed. Body weight was well controlled and an excess accumulation of body fluid seems unlikely as might be expected in the patients with terminal renal failure. More rigid control of body fluid by restriction of intake or by removal of body fluid at dialysis resulted in only a hypotension or lethargy to fail the correction of heart size. The rise of pulmonary artery wedge pressure was associated with increased cardiac work (Left of Fig. 1). A reduction of cardiac work by a vasodilator decreased PAWP toward normal levels, suggesting a reversibility of abnormal circulatory state (Table III). A direct evidence of specific uremic cardiomyopathy is not obvious in these patients with pulmonary congestion.

Another important implication of the abnormal rise of PAWP is a danger of development of acute pulmonary edema. A progression of anemia, poor control of body fluid, or an elevation of blood pressure may trigger the attack of life-threatening acute pulmonary edema. Blood pressure may be easily elevated because of dysregulation of blood pressure control system. In such emergent situation, the correction of cardiac work (unloading) will be required by hemodialysis, or by a vasodilator administration, as shown to be effective in our preliminary study.

Some patients on chronic hemodialysis may have a large heart which is associated with increased cardiac work, and an abnormal elevation of PAWP though they are asymptomatic. A reversal of abnormal PAWP by a reduction of cardiac work suggests an inappropriate work demand upon the heart in these patients.
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