Electrocardiographic Changes during Hemodialysis with the Artificial Kidney

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Rapid alteration of plasma electrolyte concentrations during dialysis with the artificial kidney may be associated with changes in the electrocardiogram and in cardiac function. In this study, the electrocardiographic changes encountered during 33 hemodialyses are described and correlated with abnormal electrolyte patterns and their correction.

EXTENSIVE studies provide the basis for correlating electrocardiograms with specific electrolyte abnormalities in clinical situations. The electrocardiogram has been of considerable value in the diagnosis and management of specific electrolyte imbalance. Hemodialysis with the artificial kidney permits the study of the electrocardiogram during changing electrolyte patterns in the patient with renal disease and the uremic syndrome. The marked alterations in electrolyte concentrations occasionally occurring during dialysis may induce changes in the electrocardiogram and cardiac function which constitute a hazard to the patient.1, 2 At frequent intervals during the course of 33 dialyses in 28 patients, we have had the opportunity to correlate the electrocardiographic changes with the plasma electrolyte concentrations. This report summarizes our experience.

MATERIALS AND METHODS

The dialyses were performed on 12 female and 16 male patients at Bellevue Hospital, The New York Hospital, and the Veterans Administration Hospital, New York City. The patients ranged in age from 10 to 74, with an average of 41 years. The indication for dialysis was acute renal failure in 10 patients and severe symptomatic chronic uremia in 16 patients. One patient with multiple myeloma was treated by dialysis in an attempt to correct hypercalcemia and 1 patient was treated because of symptomatic biliary cirrhosis. Digitalis had been administered to 4 of the patients with acute renal failure, to 7 of the patients with chronic uremia, and to 1 of the other 2 patients.

Hemodialysis was performed with a disposable twin-coil artificial kidney.3,4 In most instances the procedure lasted 6 hours, in several 8 or 10 hours, and in 1 patient 12 hours.

Simultaneous blood specimens were collected from the patient and from the tubing returning blood to the patient from the dialysis unit. Specimens were drawn at 2-hourly intervals or more frequently when indicated by electrocardiographic changes. Plasma was separated at once and frozen for later analysis. The concentrations of sodium, chloride, potassium, carbon dioxide combining power, and osmolality were determined. Blood urea nitrogen values and weights were recorded before and after dialysis in most patients. Calcium and phosphorus determinations were done in selected patients.

Electrocardiograms were recorded by a direct writing portable machine every 2 hours and more frequently when irregularities in rhythm were noted on clinical examination. Laboratory methods for determination of plasma sodium, chloride, potassium, and carbon dioxide combining power have been described previously.5 Osmolality was determined by a Fiske Osmometer.

RESULTS

The values for plasma electrolytes, blood urea nitrogen, serum calcium and phosphorus, and body weights are presented in table 1. In 14 of the 33 studies the plasma potassium concentration was elevated above 5.5 mEq. per L. prior to dialysis. In most patients acidosis, hyponatremia, hypochloremia, and
Table 1.—Values of Plasma Electrolyte, Blood Urea Nitrogen, Serum Calcium and Phosphorus, and Body Weights at the Start and End of Dialysis

<table>
<thead>
<tr>
<th>Patient</th>
<th>START OF DIALYSIS</th>
<th>END OF DIALYSIS</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>mEq/L</td>
<td>mEq/L</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>NA</td>
</tr>
<tr>
<td>1</td>
<td>1.5</td>
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<tr>
<td>2</td>
<td>5.3</td>
<td>140</td>
</tr>
<tr>
<td>3</td>
<td>4.4</td>
<td>132</td>
</tr>
<tr>
<td>4</td>
<td>3.3</td>
<td>124</td>
</tr>
<tr>
<td>5</td>
<td>7.4</td>
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<td>8</td>
<td>7.2</td>
<td>126</td>
</tr>
<tr>
<td>9</td>
<td>4.2</td>
<td>139</td>
</tr>
<tr>
<td>10</td>
<td>4.4</td>
<td>140</td>
</tr>
<tr>
<td>11</td>
<td>7.1</td>
<td>130</td>
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<tr>
<td>12</td>
<td>7.5</td>
<td>109</td>
</tr>
<tr>
<td>13</td>
<td>4.7</td>
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<td>6.5</td>
<td>105</td>
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<tr>
<td>33</td>
<td>4.7</td>
<td>129</td>
</tr>
</tbody>
</table>

Table 2.—Classification of Diagnosis, Digitalis Administration, and Electrocardiographic Changes Associated with Dialysis

<table>
<thead>
<tr>
<th>Diagnosis</th>
<th>Digitalis</th>
<th>EKG at Start of Dialysis</th>
<th>EKG Change During Dialysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>+</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Hypertension</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>T Wave Abnormalities</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ST-T Wave Abnormalities</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
| * Complete EKGs not taken during dialysis. ** EKG prior to dialysis

* Diagnosis: A: Acute Uremia, C: Chronic Uremia, O: Other
hypocalcemia were also present at the start of dialysis.

The electrocardiogram showed normal sinus rhythm in 31 of 33 instances at the start of dialysis. The 2 exceptions were 1 patient with atrial tachycardia and another with atrial arrest with a nodal pacemaker. Table 2 presents data to correlate the diagnosis, digitalis administration, initial electrocardiographic form, and changes during dialysis. The electrocardiographic patterns may be divided into 4 groups.

Group 1. Dialysis was associated with no changes in the form of the electrocardiogram. This occurred in 8 dialyses. Digitalis had been administered to only 2 of these patients. Plasma potassium concentration was elevated in only 2 patients in this group.

Group 2. Dialysis was associated with ST-T wave alterations consistent with regression of hyperpotassemia. This change was noted during the course of 6 dialyses. In 1 patient, J.H. (case 12, fig. 1), the electrocardiogram showed atrial arrest, slight widening of the QRS complex, and peaked T waves. These changes disappeared during dialysis. No patient in this group had received digitalis. In 10 other instances, hyperpotassemia was present without suggestive electrocardiographic changes. The absence of typical

changes of hyperpotassemia may have been due to a basic abnormality in the electrocardiogram, since digitalis had been administered to 8 of these patients. One patient not receiving digitalis had electrocardiographic changes compatible with left ventricular hypertrophy. The remaining patient (case 17) had electrocardiographic changes consistent with hypotension, which persisted throughout the procedure.

Typical changes during regression of hyperpotassemia were seen in case 15.

Case 15. C. P. a 42-year-old white man with carbon tetrachloride intoxication and acute renal failure was subjected to dialysis because of electrocardiographic changes consistent with hyperpotassemia. These regressed during dialysis (fig. 2). It is noteworthy that the initial potassium elevation was slight. The electrocardiographic pattern probably reflected the contribution of other electrolyte abnormalities.

Group 3. Dialysis was associated with ST-T wave alterations suggestive of digitalis effect. ST wave depression occurred in 15 instances. In 13 of these, digitalis had been administered prior to dialysis.

Case 24. P. D. a 42-year-old white man with chronic uremia due to polycystic kidney disease had received digitalis prior to dialysis. During
Figs. 4 and 5. (See legend opposite page.)
ELECTROCARDIOGRAPHIC CHANGES AND HEMODIALYSIS

7:30 pm L2
Na 134, K 7.4, CO2 11.7 mEq/L

9:30 pm L2
Na 138, K 4.1, CO2 17.7 mEq/L

11:10 pm L2

12 midnight L2
Na 138, K 4.1, CO2 21.8 mEq/L

FIG. 6. Note appearance of paroxysmal atrial tachycardia with block (10:50 p.m.) in a digitalized patient with correction of hyperpotassemia and acidosis during dialysis. Thirty grams of potassium chloride were added to the bath immediately and at 11:10 p.m. the rhythm was sinus tachycardia, which gradually slowed.

dialysis, ST-T changes appeared as hypotremia and hypoacalcaemia were corrected (fig. 3).

One patient who had not received digitalis was hypotensive throughout the procedure, an adequate explanation for the S-T depression. This patient died shortly after dialysis. In 1 patient no explanation for the ST-T wave changes is available.

Group 4. Dialysis was associated with an arrhythmia (table 3). Ventricular premature contractions during dialysis occurred in 4 patients. In 3 of these, the arrhythmia could not be related to electrolyte changes or to digitalis toxicity. In the fourth patient, ventricular premature contractions in a quadrigeminy pattern preceded paroxysmal atrial tachycardia with block and was considered to be due to digitalis toxicity.

Case 30. R. F., a 42-year-old white man had severe uremic symptoms secondary to subacute glomerulonephritis. Digitalis had been administered prior to dialysis and the electrocardiogram was consistent with left ventricular hypertrophy. The significant electrolyte alteration during dialysis was a rise in calcium. Ventricular premature

FIG. 4 Top. Note appearance of ventricular premature contractions (12 noon) in a digitalized patient in association with correction of acidosis and lowering of plasma potassium during dialysis. This was followed by the appearance of paroxysmal atrial tachycardia with block (1:00 p.m.), which disappeared (3:15 p.m.) without addition of potassium to the dialyzing bath. Note the rise in serum calcium during the procedure.

FIG. 5 Bottom. Representative leads II during dialysis in which hyperpotassemia and acidosis were corrected. The patient had received digitalis. At 6:00 p.m. wandering of the pacemaker into the A-V node or A-V dissociation appeared. Twenty grams of potassium chloride were added to the bath at 6:45 p.m. and at 8:00 p.m. the electrocardiogram showed normal sinus rhythm.
contractions were noted followed by paroxysmal atrial tachycardia with atrioventricular (A-V) block (fig. 4). This change may have resulted from the acute correction of hypocalcemia. Potassium was not added to the dialysis bath and the changes disappeared.

Nodal rhythm occurred in 5 patients, 4 of whom had received digitalis. In these 4 the rhythm was thought to be secondary to effects of digitalis revealed by correction of electrolyte changes (lowering of potassium and correction of acidosis). Addition of potassium to the dialysis bath effectively restored normal sinus rhythm. In the fifth patient (case 2) nodal rhythm was transient. The rhythm was atrial tachycardia at the start of dialysis and was atrial fibrillation at the end.

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

**Fig. 7.** Note appearance of nodal tachycardia (6:00 p.m.) during dialysis in association with correction of hyperpotassemia and acidosis. The patient had received digitalis. At 6:15 p.m. 30 Gm. of potassium chloride were added to the bath and at 7:15 p.m. the rhythm was normal sinus, initially with first-degree heart block. Note that the plasma potassium at 7:45 p.m. was unchanged from that at 6:00 p.m.

C. O., a 10-year-old white girl was treated by dialysis on 3 occasions because of hyperpotassemia and severe uremia due to acute nephritis. Digitalis had been administered. During the first dialysis (case 26), there was wandering of the pacemaker from the sinus node to the AV node and within the AV node or AV dissociation (fig. 5). During the second dialysis (case 27), the patient developed paroxysmal atrial tachycardia with block (fig. 6). Addition of potassium to the bath reversed the changes on each occasion.

**Case 5.** E. K. a 16-year-old white woman with chronic pyelonephritis was subjected to dialysis because of severe uremic symptoms. She had received digitalis and the initial electrocardiogram revealed T-wave abnormalities. During dialysis nodal rhythm developed. After addition of potassium to the bath normal sinus rhythm returned, initially with first degree heart block (fig. 7).

**DISCUSSION**

Hyperpotassemia classically produces elevation and peaking of the T waves followed by prolongation of the QRS complex and disappearance of the P waves. Such electrocardiographic changes have been shown to correlate only roughly with measured concentrations of plasma potassium, and even this correlation is possible only at extreme concentrations.

The electrocardiogram in hypocalcemia may show QT-interval prolongation due mainly to alterations in the S-T segment and the reverse may be true in hypercalcemia.

Rarely do these abnormalities occur singly. More often complex acid-base and electrolyte abnormalities accompany them and modify or exaggerate the electrocardiographic effects of a specific level of potassium or calcium.
The complex relationships of the electrocardiogram to the measured concentrations of potassium, sodium, calcium, and carbon dioxide combining power (reflecting acidosis) are evident from the data presented. In addition, the effect of potassium appears to be modified if the electrocardiogram is basically abnormal. Moreover, hemodialysis tends to correct many existing electrolyte abnormalities. Equilibrium across the membrane is probably achieved at varying rates, dependent on variations in exchange gradients and available ion stores. Anticipated electrocardiographic patterns are thus often lacking before and during dialysis. Figures 1 to 7 have been chosen to illustrate the complexity of these relationships.

Plasma electrolyte concentration poorly reflects intracellular ion concentration; nor have attempts to correlate the intracellular electrolyte concentration with the electrocardiogram proved more reliable. During dialysis, ion exchange across the cellular membrane can be postulated. In several instances electrocardiographic changes appeared and were reversed by adding potassium to the dialyzing bath without significant change in plasma values. The speed of exchange at the cellular membrane is probably also important. In case 26 (fig. 5) signs of digitalis toxicity appeared when the plasma potassium concentration was 4.0 mEq. per L, and disappeared with the addition of 20.0 Gm. of potassium chloride to the bath. However, at the end of dialysis the plasma potassium concentration was even lower, 3.0 mEq. per L, than that at which digitalis toxicity had been manifest. Addition of potassium to the bath may have slowed or even reversed exchange across the cellular membrane.

The interaction of digitalis and potassium acting on the AV node is demonstrated in figures 6 and 7. In each instance, the addition of potassium to the dialyzing bath reversed signs of digitalis toxicity.

In the patient with heart disease who receives digitalis, electrolyte changes assume particular significance during hemodialysis. The appearance of enhanced digitalis effects and toxicity under these circumstances has been described by several observers. This may result from lowered plasma potassium, correction of acidosis, and elevated calcium level, or all 3. It is not known whether dialysis will decrease total body stores of digitalis.

Because of the occurrence of adverse cardiac effects, particularly in the patient with heart disease, frequent electrocardiographic observations are warranted during the course of hemodialysis.

**SUMMARY**

Extracorporeal hemodialysis employing the disposable coil artificial kidney affords an excellent opportunity for electrocardiographic study during changing electrolyte patterns. Electrolyte data are presented in 28 patients during the course of 33 dialyses and alterations are correlated with the electrocardiogram. The data reemphasize that in most clinical situations electrocardiographic changes are rarely associated with specific electrolyte concentrations and abnormalities.

In the patient who has received digitalis prior to dialysis, frequent electrocardiographic observations during dialysis are necessary to detect and prevent serious digitalis intoxication.

**SOMMARIO IN INTERLINGUA**

Le hemodialyse extracorporee per medio del ren artificial (typo a serpantino non reusabile) offere un excellent opportunitate pro studios electrocardiographic durante cambiante configurationes electrolytic. Es presentate datos relative al electrolytos observate in le curso de 33 dialyses in 28 patientes, e le alterationes es correlacionate con le electrocardiogramma. Le resultatos signala de novo que in le majoritate del situationes clinic, alterationes electrocardiographic es rarmente associate con specific concentrationes del electrolytos o con specific anormalitates in illos.

In patientes qui ha recipite digitalis ante le tempore del dialyse, frequente observationes electrocardiographic es necessari durante le curso del dialyse a fin de deteger e prevenir serie intoxicacion per digitalis.
ACKNOWLEDGMENTS

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REFERENCES

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covers sparse elastic tissue similar to the structure of the normal endocardium. Patients usually have no symptoms before sudden death or may have palpitation due primarily to atrial fibrillation, fits, or blackouts. One of the 8, a woman, had a brother who subsequently died of the same lesion and has a living sister whose symptoms are identical with those of the sister who died.

ERRATUM


On page 229, figure 3 was inadvertently omitted. The arrangement of figures 2 and 3, with legends, should have appeared as shown to the right.

Fig. 2 Top. Note change in peaked T waves with correction of acidosis and slight hyperpotassemia during dialysis.

Fig. 3 Bottom. Note appearance of ST-wave depression as hypocaleemia was corrected during dialysis. The patient had received digitalis. The increase in ventricular rate does not account for the degree of change.