Severe Acidosis and Hyperpotassemia Treated with Sodium Bicarbonate Infusion

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Four uremic patients with severe acidosis, hyperpotassemia, and electrocardiographic signs of toxicity were treated with intravenous sodium bicarbonate. Serial determinations showed a fall in plasma potassium, a rise in blood pH, and regression of the electrocardiogram toward normal. The mechanisms responsible for these changes are discussed.

Hyperpotassemia is a serious and often fatal complication of advanced renal insufficiency. Its principal lethal action is its depressant effect on the myocardium.\(^1\)\(^2\)

In uremia, hyperpotassemia is frequently accompanied by acidosis, hypernatremia, hypocalcemia, alterations in body water, and changes in cellular metabolism.\(^3\) Correction of these associated electrolyte abnormalities is often accompanied by improvement in the electrocardiographic manifestations of hyperpotassemia. In the correction of hyperpotassemia and acidosis with alkali salts, therapeutic success has been achieved with both sodium bicarbonate and sodium lactate. Recently, the latter agent has been the more popular. This report outlines our experience with 4 uremic patients with severe acidosis, hyperpotassemia, and electrocardiographic evidence of advanced cardiac effects. Treatment consisted of the rapid infusion of 5 per cent sodium bicarbonate and, in each case, correction of the acidosis was accompanied by lowering of plasma potassium and reversal of the electrocardiographic signs.

Methods

Plasma sodium and potassium were determined on a Perkin-Elmer, Model 52-A flame photometer, with use of a lithium internal standard. Plasma chlorides were determined by the method of Schales and Schales, as modified by Summerson. Venous blood pH was determined on a Cambridge Research pH meter with use of a constant-temperature water bath to maintain at 37 C. Plasma volume was measured by the dye-dilution technic with T 1821.

Case Reports

Case 1. B. R., a 46-year-old woman with polycystic kidney disease, was admitted to another hospital with symptoms of uremia. On admission, physical examination revealed masses in both flanks. The blood urea nitrogen was 90 mg. per cent. The plasma sodium was 134 mEq./L., plasma potassium 4.8 mEq./L., and plasma chloride 108 mEq./L. Carbon dioxide combining power was not determined. An electrocardiogram was within normal limits. Five days after admission the patient became disoriented, and deep respirations were noted. She was transferred to Bellevue Hospital for possible dialysis with the artificial kidney.

Plasma electrolyte values on admission were potassium 5.9 mEq./L., chloride 89 mEq./L., carbon dioxide combining power 1.3 mEq./L., and blood pH 7.18. The blood urea nitrogen was 100 mg./cent. Plasma volume was markedly reduced. The electrocardiogram revealed peaked T waves (fig. 1, 10:05 p.m.). Because of the severe symptomatic acidosis, an intravenous infusion of 5 per cent sodium bicarbonate was begun. After administration of 408 mEq. (34 Gm.) of sodium bicarbonate in 4 hours, the patient’s respirations became normal and her sensorium cleared. An electrocardiogram at this time had changed and now suggested hyperpotassemia. The duration of the QRS complex was now normal (fig. 1, 2:00 a.m.). The plasma electrolyte values were sodium 144 mEq./L., potassium 3.0 mEq. L., chloride 89 mEq./L., and carbon dioxide combining power 6.2 mEq./L. The blood pH was 7.29. During this interval urinary output was 200 ml. with electrolyte concentrations of sodium 87.0 mEq./L., potassium 31.0 mEq./L., and chloride 38.0 mEq./L.

Subsequently the patient was maintained on 5 to 10 Gm. of sodium bicarbonate a day during

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hospitalization. This amount of sodium bicarbonate was found necessary to maintain the carbon dioxide combining power between 15 and 20 nM/L. She was accordingly discharged on maintenance bicarbonate therapy.

**Case 2.** H. M., a 28-year-old white woman, was admitted to a local hospital with acute renal failure associated with a *Bacillus Welchii* infection following an induced abortion. She was oliguric for 8 days and was transferred to Bellevue Hospital for dialysis with the artificial kidney. On admission, the blood pressure was 90/60 and the respirations were deep. Chvostek and Trousseau signs were present. The electrocardiogram showed prolongation of the QRS complex and atrial arrest (fig. 2, 5:00 p.m.). Plasma electrolyte values were sodium 131 mEq./L., potassium 8.6 mEq./L., chloride 90 mEq./L., carbon dioxide combining power 1.3 mM/L., and calcium 5.4 mg. per cent. Blood pH was 7.10 and urea nitrogen was 210 mg. per cent. Plasma volume was within normal limits.

While preparations for dialysis were being made, 144 mM (12 Gm.) of sodium bicarbonate and 2 Gm. of calcium gluconate were administered intravenously in 2 hours and 15 minutes and, at the start of dialysis, the electrocardiogram revealed normal sinus rhythm with normal intraventricular conduction (fig. 2, 7:15 p.m.). At this time, plasma sodium was 136 mEq./L., potassium 6.5 mEq./L., carbon dioxide combining power 4.0 mM/L., the blood pH was 7.32. Urinary output was negligible. The patient did not improve and died 24 hours after dialysis.

**Case 3.** P. V., an 89-year-old white woman, was admitted to the urologic service because of 2 weeks of dysuria. Two days prior to admission she developed hematuria, suprapubic pain, and malaise. On admission, she appeared cachectic and dehy-
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drated. Blood pressure was 170/60 and respirations were deep and regular at a rate of 24 per minute.

Initially the patient was oliguric, with a urinary output of less than 10 ml per hour, and urinalysis revealed a specific gravity of 1.020, 2 plus albumin, a trace of acetone, and many red blood cells. The hematocrit level was 27 per cent. The plasma electrolyte values were sodium 137 mEq./L., potassium 8.3 mEq./L., chloride 112 mEq./L., and carbon dioxide combining power 6.3 mM/L. The blood urea nitrogen was 164 mg. per cent.

Because of the dehydration and oliguria she was given 3,000 ml. of 5 per cent dextrose in water in the first 12 hours, during which time she remained oliguric. Her neck veins became distended and a venous pressure was 180 mm. of saline, at which time she was seen by a medical consultant. Plasma volume was expanded by approximately one liter over the mean predicted value. The red cell mass was decreased, and the hematocrit level was 18 per cent. Electrocardiogram showed peaking of the T waves, prolongation of the QRS complex, and atrial arrest (fig. 3, 4:00 p.m.). The plasma electrolyte values were sodium 132 mEq./L., potassium 7.9 mEq./L., and carbon dioxide combining power 4.9 mM/L. At this time the blood pressure became unobtainable.

In view of the abnormal electrocardiogram, the appearance of shock, and the persistent, severe, symptomatic acidosis, an intravenous infusion of 5 per cent sodium bicarbonate was begun. After administration of 180 mM (15 Gm.) of sodium bicarbonate in 4 hours followed by 1 unit of whole blood, the electrocardiogram revealed normal sinus rhythm, lowering of the T waves, and normal intraventricular conduction (fig. 3, 8:00 p.m.). The plasma electrolytes were sodium 134 mEq./L., potassium 4.9 mEq./L., chloride 111 mEq./L., and carbon dioxide combining power 4.0 mM/L. During this interval, respirations became normal, the arm venous pressure fell to 110 mm. saline and the blood pressure rose to 110/70. Throughout the succeeding 24 hours she received an additional 150 mEq. (12.5 Gm.) of sodium bicarbonate and the plasma carbon dioxide combining power rose to 10.8 mM/L. Oliguria persisted, and cystoscopy revealed severe, generalized, pseudomembranous cystitis obscuring both ureteral orifices. Culture of the urine showed Bacillus proteus, and the patient was treated with tetracycline. During this period urinary volumes increased to 1,000 ml. daily. Subsequently, the patient developed high, spiking fever and hypotension and died on the eighth hospital day. Postmortem examination revealed chronic pyelonephritis with contracted kidney, severe hemorrhagic cystitis, partial ureteral obstruction bilaterally, and hydrenephrosis.

Case 4. G. C., a 19-year-old white girl with chronic glomerulonephritis, was admitted to the hospital because of oliguria. She was comatose and respirations were deep and labored. Electrocardiogram revealed normal sinus rhythm and suggested peaking of the T waves (fig. 4, 4:00 p.m.). Plasma electrolyte values were sodium 134 mEq./L., potassium 6.6 mEq./L., chloride 109 mEq./L., carbon dioxide combining power 7.3 mM/L; the blood pH was 7.18. The blood urea nitrogen was 102 mg. per cent. Plasma volume was normal.

An intravenous infusion of 5 per cent sodium bicarbonate was begun. After 150 mM (12.5 Gm.) had been administered in 3 1/2 hours, the electrocardiogram showed slight decrease in the height of the T waves (fig. 4, 7:30 p.m.). Plasma electrolyte values were sodium 143 mEq./L., potassium 4.3 mEq./L., chloride 105 mEq./L., carbon dioxide combining power 7.7 mM/L, and blood pH 7.38. Respirations became normal but there was no other change in clinical status. The following day, after an additional 108 mM (9.0 Gm.) of sodium bicarbonate intravenously, the plasma carbon dioxide combining power rose to 11.2 mM/L. Subsequently, urinary volumes increased to between 700 and 1,000 ml. daily, and the patient improved markedly over a 2-week period.

DISCUSSION

The serial electrocardiographic changes in potassium intoxication are well known. The relatively poor correlation of these changes with the plasma level of potassium probably reflects the role of ions other than potassium as well as the complex shifts in intracellular-extracellular ion concentrations that occur in the presence of altered states of hydration, acid-base balance, and cellular metabolism.

In uremia only a few of the factors contributing to potassium metabolism and cardiac toxicity can be defined. These include metabolic acidosis, hyponatremia, hypocalcemia, dehydration, and increased catabolism.

Animal experiments have shown an inverse relationship between blood pH and plasma potassium concentration. It has been demonstrated in dogs that perfusion with acidic solutions produces electrocardiographic changes analogous to those produced during infusion with potassium. Rise in plasma potassium was demonstrated uniformly throughout the induction of acidosis, but cardiac toxicity was manifest at lower levels of
hyperpotassemia. This potentiation of potassium toxicity by acidosis has also been suggested by studies in patients with diabetic acidosis.\textsuperscript{12}

Hyponatremia may augment the changes produced by an increase in plasma potassium.\textsuperscript{13} Metabolic acidosis is often associated with increased renal sodium excretion. In addition, increased quantities of sodium may enter the cell to buffer the fall in intracellular pH. Together, these may lead to a fall in plasma sodium concentration. Finally, studies on isolated cardiac muscle as well as in intact animals and human subjects have shown that hypocalcemia, also, potentiates the effect of hyperpotassemia.\textsuperscript{14–16}

Dehydration, increased catabolism, and hypotension, all of which may accompany uremia, cannot be so clearly related to cardiac toxicity. With sustained increased catabolism, as in fever with infections, hyperpotassemia may occur. Hypotension frequently leads to myocardial ischemia; increased sensitivity to potassium has been demonstrated in hypoxic states.\textsuperscript{17}

Hyperpotassemia constitutes a serious medical emergency. Its management includes hemodialysis, cation exchange resins, intravenous infusion of hypertonic glucose and insulin, hypertonic saline, calcium salts and, most recently, molar sodium lactate.\textsuperscript{18, 19}

These agents fall into 2 major groups. The first, which includes dialysis, resins, and glucose infusions, acts through the direct removal of potassium from the extracellular fluid. The second group, comprising hypertonic saline and calcium infusions, may also encourage intracellular transfer of potassium, but produces an additional effect through replacement of ions, deficiency of which potentiates hyperpotassemia.

Recent reports have appeared on the use of molar sodium lactate in the treatment of advanced cardiac toxicity due to hyperpotassemia, with prompt reversal of electrocardiographic changes and rapid clinical improvement.\textsuperscript{18, 19} The authors suggest the possibility of a specific action of lactate ion in addition to the effect of this therapy on acidosis, extracellular fluid volume, and intracellular potassium shifts.

Our observations indicate that correction of the bicarbonate deficit with sodium bicarbonate lowers plasma potassium directly, apparently through intracellular transfer of potassium ions. We were led to employ 5 per cent sodium bicarbonate because of the severe clinical acidosis that the 4 patients presented in addition to the electrocardiographic signs of hyperpotassemia. Treatment of acidosis in this manner reversed the electrocardiographic signs. These effects were identical to those reported by Bellet\textsuperscript{18, 19} with the use of sodium lactate.

In each instance, plasma potassium was lowered. Since urinary potassium excretion was negligible during the period of infusion, it may be assumed that this was accomplished in large measure through intracellular transfer, although expansion of normal extracellular volume may have played a small role. In addition, blood pH rose in the 3 instances in which values were obtained. The plasma carbon dioxide combining power changed only slightly immediately following the bicarbonate infusion. The administration of additional sodium was probably not important, since initial plasma values were only slightly reduced. The results of treatment were similar whether or not there was a significant alteration in plasma sodium. The effect of bicarbonate infusion appears to be independent of correction of dehydration, since the initial plasma volume was not reduced in 3 of the 4 patients.

The mechanism by which sodium bicarbonate acts in this instance seems to depend, therefore, upon its effectiveness in reducing the plasma concentration of potassium ions, and possibly hydrogen ions. The latter is accomplished directly by means of repletion of buffer alkali, and is best demonstrated by serial pH determinations. Moreover, correction of extracellular alkali deficit is accompanied by restoration of intracellular bicarbonate as well. Since potassium is the major intracellular cation, correction of intracellular acidosis is associated with a shift of po-
tassium as well as bicarbonate into the cell, and hence a reduction in plasma potassium concentration.

**Summary**

In 4 uremic patients with severe clinical acidosis associated with electrocardiographic evidence of hyperpotassemia, intravenous administration of 5 per cent sodium bicarbonate resulted in correction of the acidosis, fall in plasma potassium, and reversal of electrocardiographic signs. The effect of this treatment did not depend on changes in plasma sodium, renal excretion of potassium, or on correction of dehydration.

In the treatment of severe acidosis, reversal of electrocardiographic signs of hyperpotassemia parallels more closely the correction of blood pH than it does alteration in plasma carbon dioxide combining power. The results suggest that the infusion of hypertonic sodium bicarbonate in patients with hyperpotassemia, acidosis, and electrocardiographic signs of cardiac toxicity has proved a safe and practical measure in the emergency management of this common problem in the uremic syndrome.

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**Summario in Interlingua**

In 4 patientes uremic con sever acidosis clinica, associate con signos electrocardiographic de hyperkalemia, le administration intravenose de bicarbonato de natrium de 5 pro cento resultava in le correction del acidosis, un reduction del kalium del plasma, e un reversion del signos electrocardiographic. Le effecto de iste tractamento non dependeva de alterationes in le natrium del plasma o in le excretion renal o del correction del dishydratation.

In le tractamento de sever acidosis, le reversion del signos electrocardiographic de hyperkalemia es plus strictemente correlatiionate con le correction del pH del sanguine que con alterationes in le potencia del plas-


Acute peptic ulceration following cardiac surgery has been demonstrated in 4 patients and clinically suspected in 3 others. This was a most serious complication, 4 of the patients having died. Another survived only after emergency gastric resection. Prompt diagnosis is essential for a favorable outcome and may be attained only by a constant alertness to the possibility of an acute ulcer in any postoperative cardiac patient who is not doing well. Early surgery rather than a more conservative program of therapy may be lifesaving in these patients and should not be withheld merely because the patient has recently undergone cardiac surgery. The exact mechanism responsible for an acute ulceration of the gastrointestinal tract following surgery is not well understood but it is believed that it represents a response to the alarm reaction described by Selye. Prolonged hypotension with resulting ischemia is an important factor in the pathogenesis and since many patients following cardiac surgery develop prolonged periods of hypotension, this particular complication is not altogether unexpected. It should be emphasized that this complication generally arises without any obvious background of peptic ulceration and without any prodromata. Melena, hematemesis, shock, or evidence of perforation may be the initial findings. In a group of patients who died following cardiac surgery from various causes, necropsy findings revealed an incidence of acute ulcerative lesions of the gastrointestinal tract of greater than 15 per cent.

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