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MANAGEMENT OF HYPERKALEMIA WITH A CATION-EXCHANGE RESIN*

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IN patients with advanced renal insufficiency hyperkalemia may lead to death by its myocardial effects.[1,2] Glucose and insulin solutions, calcium and hypertonic sodium salts, intestinal and peritoneal lavage, extracorporeal hemodialysis, hormone administration, infusion of alkali salts such as sodium bicarbonate and sodium lactate and cation-exchange resins have been used in the management of this problem.[3-5] This report describes the use of a sulfonic polystyrene cation-exchange resin in the sodium cycle‖ for the control of hyperpotassemia in both acute and chronic renal disease.

Synthetic ion-exchange resins were first made available to industry in 1935 and have since been extensively adapted to biologic and medical purposes.[6] Dock,[7] in 1946, first suggested the use of a cation-exchange resin as a therapeutic agent to reduce the amount of sodium ion available for absorption in the gastrointestinal tract of patients with congestive heart failure. Subsequent clinical studies clearly demonstrated that either carboxylic or sulfonic cation-exchange resins could bind both sodium and potassium ions in the gastrointestinal tract for excretion in the stool.[8] Elkinton and his co-workers,[9] in 1950, successfully employed a carboxylic resin, in the ammonium cycle, in 3 patients with hyperkalemia. Further studies by other investigators have repeatedly demonstrated the effectiveness of polystyrene cation-exchange resins in various cycles in controlling potassium retention associated with either acute or chronic renal disease.[10-15]

PHARMACOLOGY

An ion-exchange resin is a crosslinked polymer containing acidic or basic structural units that can exchange either cations or anions respectively on contact with a solution. Cation-exchange resins have been used to bind sodium, potassium and ammonium ions in congestive heart failure, uremia and hepatic coma, respectively. The sulfonic or carboxylic groups may be saturated initially with hydrogen, ammonium, sodium, potassium or calcium or combinations of these ions, the exact choice depending chiefly on the clinical situation and the palatability of the resultant preparation. In the acid environment of the stomach the original cation of the resin exchanges chiefly for hydrogen ion. As the resin passes into the jejunum, ileum and colon, this ion exchanges for those present in greater concentration, such as sodium, potassium and ammonium, and is then excreted in the stool in this form.[16] The order and effectiveness in which binding will occur in the gastrointestinal tract depends not on the type of resin used but rather on the availability and concentration of the exchanging cations.

Binding of potassium by these resins in the lower gastrointestinal tract has been uniformly effective. Greenman et al.[17] report an in vivo efficiency of potassium binding that is 50 per cent higher than that of sodium, even when the diet contains appreciable amounts of sodium. Presumably, this percentage

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could be greater in the usual low-electrolyte diet of patients with renal insufficiency. Field et al.[18] suggest that the sodium transport via the colonic mucosa is more active than potassium and competes with the resin for the available sodium, leaving more potassium for binding and subsequent excretion in the stool.

renal disease were studied. A sodium-cycle sulfonic polystyrene cation-exchange resin was administered either orally or by rectum. Dosage varied with the clinical situation and the degree of hyperkalemia. Whenever feasible, the resin was given orally in divided doses, totaling 20 to 60 gm. per day. The resin, a finely ground powdered preparation, was suspended

TABLE 1. *Results of Cation-Exchange Resin in Hyperkalemia.*

CASE NO.	DIAGNOSIS	DURATION OF RESIN THERAPY	DOSE	OTHER AGENTS	STAGE OF RENAL FAILURE
		days	*gm.*		
Oral administration:					
1	Postoperative acute renal failure	1	40	None	Oliguric
2	Acute renal failure due to carbon tetrachloride	2	40	None	Oliguric
3	Acute glomerulonephritis	4	60	None	Oliguric
4	Acute glomerulonephritis	2	40	None	Oliguric
5	Acute renal failure (etiology unknown)	6	40	None	Oliguric
6	Postoperative acute renal failure	1	40	None	Oliguric
7	Renal-artery thrombosis; acute renal failure.	2	40	None	Oliguric
8	Infection; acute renal failure.	2	40	None	Oliguric
9	Postoperative acute renal failure	2	40	None	Oliguric
10	Crush injury; acute renal failure.	1	20	None	Oliguric
11	Acute renal failure due to *Cl. welchii*	4	40	Sodium bicarbonate	Oliguric
12	Acute glomerulonephritis	4	40	Sodium bicarbonate	Oliguric
13	Acute renal failure due to *Cl. welchii*	2	40	None	Oliguric
14	Acute glomerulonephritis	1	40	None	Oliguric
15	Acute glomerulonephritis	2	40	None	Oliguric
16	Acute renal failure (etiology unknown)	5	40	Sodium bicarbonate	Oliguric
17	Chronic glomerulonephritis	4	45	None	Chronic
18	Diabetic glomerulosclerosis	4	45	None	Chronic
19	Diabetic glomerulosclerosis	4	30	None	Chronic
20	Chronic glomerulonephritis	4	45	None	Chronic
21	Chronic pyelonephritis	6	45	None	Chronic
22	Chronic pyelonephritis	4	45	None	Chronic
Rectal administration:					
23	Postoperative acute renal failure	2	160	Sodium bicarbonate	Oliguric
24	Acute renal failure due to *Cl. welchii*	3	40	None	Oliguric
25	Postoperative acute renal failure	3	60	Glucose insulin	Oliguric
26	Postoperative acute renal failure	1	80	Glucose insulin	Oliguric
27	Chronic glomerulonephritis	2	10	None	Chronic
28	Postoperative acute renal failure	1	30	Sodium bicarbonate	Oliguric
29	Acute renal failure due to *Cl. welchii*	3	120	Glucose insulin	Oliguric
30	Acute renal failure due to *Cl. welchii*	4	120	None	Oliguric
Long-term oral administration:					
31	Diabetic glomerulosclerosis	35	10*	None	Chronic
32	Chronic pyelonephritis	280	10*	None	Chronic

*3 times/wk.

The resin used in this study is a sodium-cycle polystyrene cation-exchange resin with a theoretical binding capacity of 3.1 milliequiv. per gram of resin.[19] Using a similar preparation, Evans and his coworkers[12] and Bull et al.[11] reported a range of exchange up to 1.2 milliequiv. per gram of resin. The difference from the theoretical binding capacity observed in these clinical studies may be attributed to small amounts of calcium, magnesium, iron, organic cations, lipids, steroids and proteins occupying positions on the resin.

MATERIALS AND METHODS

Thirty-two patients with either acute or chronic

in 100 to 200 ml. of water and was found to be a palatable mixture also suitable for nasogastric-tube administration when indicated. For rectal administration 10 to 40 gm. of resin suspended in a small amount of water was given by retention enema and repeated in four to twelve hours as necessary. The range and trend of pretherapy plasma potassium levels were usually available. Frequent determinations of plasma electrolyte values were made throughout the study and follow-up periods.

In all patients potassium intake was restricted, those in the oliguric phases receiving approximately 600 ml. of 20 per cent dextrose and water intravenously each day and small oral supplements of a

high-calorie, low-potassium diet. In patients with chronic renal disease, intake consisted of a low-potassium, low-salt diet containing approximately 30 to 45 milliequiv. of potassium per day. The use of other therapeutic agents depended on the clinical situation and in general was confined to digitalis, anticonvulsants and antimicrobials. In 3 patients in the oliguric phase of acute renal failure, glucose and insulin was given, and in 4 patients sodium bicarbonate was administered concomitantly with the sodium-exchange resin to alleviate the immediate effects of hyperkalemia.

Plasma sodium and potassium values were determined with a Baird atomic flame photometer using a lithium internal standard, and plasma chloride by the method of Schales and Schales as modified by Summerson. Carbon dioxide combining power was measured with a Thomas Van Slyke manometric apparatus, and venous-blood pH with a Cambridge Research meter, a temperature correction of 0.0147° being used for each degree of Centigrade to correct values to body temperature. Blood urea nitrogen was determined by the Van Slyke and Cullen method as modified by Summerson.

Results

The results are summarized in Table 1. Twenty-three patients were in the oliguric phase of acute renal failure, with a urinary output of less than 400 ml. per day. Infection, including postabortive *Clostridium welchii* involvement, played a significant part in precipitating acute renal failure in 7 patients. Six patients were in an immediate postoperative period. Five had a diagnosis of acute glomerulonephritis, and 1 each had crush injury, carbon tetrachloride toxicity and bilateral renal-artery thrombosis. In 2 cases the cause of renal failure was unknown. The remaining 9 patients had manifestations of chronic renal disease: 3 with a diagnosis of chronic pyelonephritis; 3 with diabetic glomerulosclerosis; and 3 with chronic glomerulonephritis.

The patients are placed in three categories, depend-

Table 1 *(Concluded).*

Case No.	Before Resin Treatment						After Resin Treatment				Decrease in Potassium in 1st 24 Hr.
	Range of plasma potassium			Plasma carbon dioxide combining power	Blood pH	Blood urea nitrogen	Plasma potassium	Plasma carbon dioxide combining power	Blood pH	Blood urea nitrogen	
	milliequiv./liter	*milliequiv./liter*	*milliequiv./liter*	*millimols/liter*		*mg./100 ml.*	*milliequiv./liter*	*millimols/liter*		*mg./100 ml.*	*milliequiv./liter*
1	6.3	7.2	6.6	—	—	—	6.2	19.0	—	200	0.4
2	5.9	5.0	5.3	25.0	—	97	3.7	25.0	—	118	0.8
3	6.7	7.0	7.1	18.4	7.34	163	4.6	16.3	—		1.9
4	6.0	6.2	6.1	19.6	7.29	95	3.3	18.9	7.29	111	1.2
5		6.5	7.4	14.0	—	93	2.3	25.0	—	91	1.0
6			7.3	—	—	90	6.5	—	—		0.8
7		5.0	4.9	15.8	7.46	66	3.0	11.2	7.25	—	1.1
8	6.1	7.8	7.8	17.0	7.24	277	3.7	16.0	7.35	—	2.8
9		3.7	3.6	26.0	—	44	2.1	24.0	—	87	1.7
10		5.7	6.9	25.0	—	126	6.0	33.0	7.36	—	0.9
11		6.7	6.9	22.0	7.29	159	5.0	13.0	7.44	225	0.5
12		6.7	6.7	13.0	7.29	142	4.9	22.0	7.37	117	1.4
13	5.7	6.0	6.2	16.0	7.38	128	5.8	16.0	7.32	140	0.4
14		7.8	7.7	15.0	7.33	140	5.9	15.0	7.34	200	1.2
15		5.2	5.2	18.0	—	50	5.5	13.0	—	80	0.0
16	7.1	5.8	5.5	13.0	7.27	—	5.7	20.0	7.38	267	0.0
17	5.8	6.4	7.3	13.0	—	85	4.3	18.0	—	71	1.0
18	4.2	5.1	5.2	29.0	7.38	37	2.9	29.0	—	76	0.3
19	6.5	8.5	7.4	24.0	—	60	5.4	22.0	7.26	—	1.2
20	6.2	5.9	6.7	24.0	—	164	3.8	19.0	—	182	0.5
21	6.0	6.0	6.0	19.0	7.26	53	3.9	20.0	7.28	—	0.6
22	6.5	6.7	7.1	—	—	65	5.9	22.0	—	53	1.0
										Mean value	1.0
23		4.7	5.8	28.0	—	111	6.8	—	—	—	0.0
24		5.4	5.4	—	7.41	126	5.3	15.0	—	160	0.0
25	6.6	7.1	7.0	27.0	7.42	67	8.3	25.0	7.38	106	0.0
26		6.3	7.4	18.0	7.39	—	6.5	18.0	7.36	169	0.9
27	7.9	7.3	7.0	15.0	—	—	3.9	15.0	—	62	1.6
28	7.5	9.3	9.2	12.0	—	216	7.1	11.0	—	274	2.1
29			6.4	21.0	7.35	180	5.1	22.0	7.34	210	0.9
30			5.2	27.0	7.36	80	4.7	26.0	7.37	110	0.3
										Mean value	0.8
31	6.9	6.2	6.7	17.0	—	70	6.3	18.0	—	62	—
32	6.6	7.5	8.0	26.0	—	50	4.2	23.0	—	50	—

*3 times/wk.

ing on the method of administration of the resin. Twenty-two patients received the drug orally, and 8 by rectal administration, and 2 additional patients were given the resin by mouth over a period of a few months.

Plasma electrolyte values are tabulated to include the period immediately preceding the onset of therapy and that approximately twenty-four hours after resin therapy was stopped. A range of plasma potassium values is given to establish the magnitude and progression of the hyperpotassemia and represents a period of one to three days.

As shown in Table 1, 30 patients either demonstrated a significant fall in plasma potassium or failed to show any increase in these values during the period observed. Twenty-three patients showed a drop in plasma potassium of at least 0.4 milliequiv. per liter in the first twenty-four hours, with a mean value for the entire group of 1.0 milliequiv. per liter for oral administration and 0.8 milliequiv. per liter for administration by retention enema. This change was associated with a reversion of the electrocardiogram toward normal in every case. The resin was found to be ineffective in controlling a rising plasma potassium in 2 postoperative patients (Cases 23 and 25) despite additional sodium bicarbonate and glucose and insulin therapy. In the 2 patients who received the resin over a prolonged period a satisfactory control of plasma potassium values was obtained. The occurrence of constipation after oral administration of the resin was occasionally encountered and easily controlled with enemas or cathartics. Fecal impaction was not observed. No vitamin deficiency or calcium-depletion symptoms were observed.

Discussion

The cation-exchange resin used in this study appears to be an effective agent in lowering plasma potassium levels associated with renal insufficiency. A significant reduction of plasma potassium was usually observed within the first twenty-four hours of administration of 20 to 60 gm. of resin per day orally or 10 to 40 gm. of resin per day by rectum, with a continued fall in these values for at least twenty-four hours after cessation of therapy. Even in patients who did not show a fall in plasma potassium, a desirable therapeutic effect was achieved by prevention of further progression of hyperpotassemia.

Resin therapy was instituted when the plasma potassium exceeded 5.0 milliequiv. per liter in oliguric patients. Resin administration averaged 40 gm. in four divided doses orally or 60 gm. by rectum daily and depended on the daily determination of plasma potassium levels and the course of renal failure. To avoid the occurrence of hypokalemia resin therapy was usually discontinued when the plasma potassium level was below 5.0 milliequiv. per liter.

The use of a sulfonated cation-exchange resin offers no advantage over the carboxylic forms except perhaps by increasing palatability. By administration of either resin in the sodium cycle, however, acidosis and mouth ulceration associated with resins in the ammonium and hydrogen cycles are minimized.[17,20] Problems due to the sodium absorbed from the resin were not observed in this group of patients, although appreciable amounts of this ion are theoretically available.[21] Careful restriction of fluid intake was considered to be the major factor in preventing congestive heart failure.

Both the oral and rectal routes of administration have been found to be effective within the first twenty-four hours, with a mean fall in plasma potassium of 1.0 and 0.8 milliequiv. per liter, respectively. Rectal administration by a retention enema was limited to patients who were too ill to take fluids by mouth. Other investigators have found the rectal route of administration to be more effective,[13] but these findings were not confirmed in this group of patients.

Failure of the resin to control hyperkalemia was seen in clinical situations associated with excessive tissue damage or infection, as illustrated in Cases 23 and 25, in which higher doses of the resin might have been more effective.

Although tetany has been described[22] after the prolonged use of cation-exchange resins in children, there was no evidence of calcium depletion or muscular irritability due to the resin therapy in our patients. Untoward reactions were limited to occasional nausea and vomiting from the irritative effects of the drug, constipation and hypopotassemia.

Summary

The use of a sodium-cycle sulfonic polystyrene cation-exchange resin in 32 patients with acute and chronic renal disease is reported. Resin therapy was found to be effective in controlling hyperkalemia in these patients with either oral or rectal administration of this drug. No serious toxic effects were observed.

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PROGNOSIS OF THE MEDICALLY TREATED SMALL GASTRIC ULCER*

I. Comparison of Follow-up Data in Two Series

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AT the Mayo Clinic, partial gastrectomy is the treatment of choice in most cases of apparently benign gastric ulcer. This is so because 10 per cent of patients whose ulcers prove cancerous are thereby given the best chances of "cure," the morbidity due to benign ulcer is terminated promptly, the results of surgical treatment of the benign ulcer are excellent, and the risk of surgical treatment is small (mortality of 1 to 2 per cent[1,2]).

TABLE 1. *Comparison of Clinical Material in the Two Series.*

CLINICAL MATERIAL	1ST SERIES (1940-1945)		2D SERIES (1948-1952)	
	NO. OF CASES	PERCENTAGE	NO. OF CASES	PERCENTAGE
Patients with gastric ulcer	1863		1122	
Patients treated medically	463	24.8	299	26.6
Hospitalized in Rochester for treatment	152		102	
Traced	451	97.4*	285	95.3*
Follow-up study incomplete†	38	8.4‡	34	11.9‡
Results of medical management known	413	91.6‡	251	88.1‡

*Percentage of patients treated medically.

†Follow-up study disclosed only whether patient living or dead.

‡Percentage of patients traced.

In the remaining cases medical treatment is instituted, in some with the approval of the physician, in some at the insistence of the patient, and in others because of the presence of coexisting disease. In all these cases medical treatment is started at the Mayo Clinic, but in most it is continued elsewhere. Management, therefore, varies widely in strictness because many physicians with different points of view are ultimately responsible for treatment.

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CLINICAL MATERIAL

In 1952 Cain and his co-workers[3] reviewed the records of 1863 patients seen in the years 1940 through 1945 in whom the clinical diagnosis of gastric ulcer was made on the basis of clinical and roentgenologic findings (Table 1). A period of medical management was received by 463 of these patients, and on 413 of these information was obtained about the results of treatment five to eleven years after the initial examination.

TABLE 2. *Age and Sex Distribution.*

AGE	TOTAL		MALES		FEMALES	
	NUMBER	PERCENTAGE	NUMBER	PERCENTAGE	NUMBER	PERCENTAGE
yr.						
10-19	1	0.1	1	0.2	0	—
20-29	12	1.8	9	1.8	3	2.0
30-39	84	12.7	69	13.4	15	10.0
40-49	164	24.7	134	26.1	30	20.0
50-59	216	32.5	168	32.6	48	32.0
60-69	126	19.0	94	18.3	32	21.3
70-79	51	7.7	32	6.2	19	12.7
80-89	10	1.5	7	1.4	3	2.0
Totals	664	100.0	514	100.0	150	100.0
Mean	53.3 yr.		52.6 yr.		55.7 yr.	
Percentage	100.0		77.4		22.6	

We have examined the records of an additional 1122 patients with gastric ulcer diagnosed in the years 1948 through 1952. On 251 of the 299 patients who initially received medical management, follow-