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Electrolyte imbalance is one of the most typical features of terminal renal disease. The serum potassium in particular tends to be elevated, and its level is in itself one of the indications for dialysis in uremic patients.

Although Spergel et al[1] stressed that serum potassium determinations do not represent actual intracellular values, hypokalemia and hyperkalemia are clearly defined entities in clinical practice and produce well-recognized electrocardiographic alterations.[2,3]

Since elevations of serum potassium occur during renal transplantation and may produce cardiac arrhythmias,[4-6] a study was undertaken in which determinations of serum potassium were performed hourly throughout these operations. Serum sodium values were simultaneously estimated for comparison.

Method

Included in this study were 12 consecutive male patients undergoing renal homografts from related living donors at the Denver Veterans Administration Hospital. All recipients were premedicated with diazepam, 0.08 mg/kg, and pentazocine hydrochloride, 0.5 mg/kg, intramuscularly. Anesthesia was induced with 2 mg/kg of thiopental sodium administered intravenously and followed by administration of succinylcholine chloride, 1 mg/kg, to facilitate endotracheal intubation. Thereafter, anesthesia was maintained with fluroxene in a mixture of oxygen and nitrous oxide. Muscle relaxation was achieved by intermittent injections of tubocurarine chloride.

An intravenous infusion of lactated Ringer's solution was given at an approximate rate of 2 ml/kg/hr. After revascularization of the homograft, the intravenously administered fluid was increased by an amount equal to the urinary output.

Bilateral nephrectomy and splenectomy were performed during the same surgical session through an upper abdominal incision, as described previously.[7] This procedure was immediately followed by renal transplantation through a lower abdominal incision into the extraperitoneal space.[7] Between 500 and 800 ml of blood were lost during the whole operation. The patients received 1,000 ml of whole blood to replace the surgical loss and also in an attempt to raise their hematocrit readings, which ranged preoperatively from 18% to 27%, with an average of 24.7%.

Venous blood samples were taken from major veins either in the upper extremities or the neck, centrifuged immediately, and the determinations of serum sodium and potassium performed within 24 hours by flame photometry.

Samples were obtained before and immediately after the final dialysis, which was done one day before surgery. Further samples were taken shortly before induction of anesthesia and then every hour until after blood flow was restored to the homograft, at which time the incision was usually being closed. More samples were procured three hours after the operation and on the first, second, and third postoperative day. In addition, blood specimens were taken from the transfused blood, all of which was obtained within 48 hours of transplantation. An electrocardiogram was monitored throughout the anesthetic period.

Results

Due to the anatomical differences between the donor and the recipient patients, the duration of the surgical procedures varied from 180 to 390 minutes, with an average of 250 minutes. Predialysis blood urea nitrogen values ranged from 49 to 128 mg per 100 cc, with a mean of 78 mg per 100 cc. These values decreased after dialysis to 31, 115, and 61 mg per 100 cc, respectively. On the day following transplantation, the same values were 17 to 105 mg per 100 cc, with a mean of 47 mg/100 cc.

The changes observed in serum sodium and potassium in all patients before and after dialysis, during surgery, and in the immediate postoperative period are shown in Table 1 and 2. Electrocardiographic abnormalities included tenting of the T-wave and prolonged P-R intervals in patient 8 and S-T depression in patient 4.

The serum sodium levels determined from the transfused blood varied from 134 to 143 mEq per liter, with an average value of 141 mEq/liter. Potassium values from the same sources were between 5.1 and 7.3 mEq per liter, with an average value of 6.1 mEq/liter.

Comment

The lack of correlation between levels of serum and total body potassium has been observed by Spergel et al.[1] They reported decreased levels of total exchangeable body potassium in patients with chronic uremia even though the serum potassium was often high. Goldner et al[8] emphasized the necessity of total body potassium estimations, although they recognized the importance of plasma potassium levels in maintaining normal cardiac rhythm.

In our recent analysis of anesthet-

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Table 1.—Changes of Serum Sodium (mEq/liter) in Renal Recipients

Case No.	Predialysis	Postdialysis		Under Anesthesia				3 Hours	Postoperative Day 1st	2nd	3rd
1	140	142		137	136	139	130	135	132	134	135
2	136	138	131	125	122	124	121	117	120	126	145
3	133	138	132	133	134	136	134	132	136	135	133
4	137	133	133	132*	132	135	132	130	125	125	131
5	140	140	134	132	135	136	130	130	132	134	134.
6	132	139		138	137	137	136	133	133	137	138
7	139	134	132	129	130	131	127	125	131	130	135
8	146	140	139	137*	133*	135	132	136	137	134	138
9	138	134	131	122	118	117	122	122	124	133	140
10	136	128	130	136	137	142	132	133	135	138	142
11	139	141	118	117	122	122	124	122	138	137	135
12	141	132		133	136	138	148	141	141	141	139
Means	138	137	131	131	131	133	131	130	134	134	137

Revascularization

* Times when electrocardiographic alterations were observed during surgery.

Table 2.—Changes of Serum Potassium (mEq/liter) in Renal Recipients

Case No.	Predialysis	Postdialysis		Intraoperative				3 Hours	Postoperative Day 1st	2nd	3rd
1	5.8	5.8		4.4	4.9	5.3	4.1	4.3	3.7	4.0	4.7
2	5.4	4.3	4.5	5.1	5.4	5.4	5.0	5.0	4.4	4.1	5.6
3	4.4	4.3	3.2	3.1	2.7	2.8	2.7	2.8	2.9	2.8	4.3
4*	7.4	4.7	6.4	6.7+	6.4	6.5	5.0	5.2	5.7	4.4	4.2
5*	4.0	3.5	4.2	4.2	4.0	3.8	3.8	3.8	4.1	4.2	4.1
6	5.6	5.2		3.7	4.2	4.7	4.1	4.1	3.8	3.9	3.6
7	5.3	3.7	5.1	5.7	5.3	5.4	4.5	4.2	4.4	3.8	3.9
8*	6.3	5.5	6.4	7.2+	7.1+	7.0	6.2	4.9	3.8	5.1	4.9
9	5.8	5.0	4.7	4.7	4.8	4.7	4.8	4.8	4.3	3.8	3.9
10*	6.8	6.5	5.5	5.4	6.6	6.6	4.9	3.7	4.4	4.9	4.5
11*	6.2	5.3	4.7	4.7	4.8	4.8	4.6	4.4	4.6	3.9	3.7
12*	6.3	4.9		6.3	6.4	6.2	5.3	4.9	4.8	3.6	4.8
Mean	5.6	4.8	5.1	5.1	5.1	5.2	4.6	4.3	4.2	4.1	4.7
Means of high predialysis values*	6.7	4.9	6.1	6.0	6.3	6.3	5.1	4.6	4.5	4.4	4.8
Means of the other patients	5.3	4.5	4.4	4.5	4.5	4.4	4.2	4.0	4.0	3.8	4.7

Revascularization

* Those patients with serum potassium values higher than 6.0 mEq/liter before dialysis.

ic-related morbidity in 260 recipient patients of renal homografts,[6] it was observed that cardiac arrhythmias and some cases of prolonged muscle weakness or instances of recurarization occurred in patients who had high serum potassium levels preoperatively. This observation prompted the present study in which predialysis and postdialysis, as well as preoperative, intraoperative, and postoperative values, of serum sodium and potassium were determined.

All the transplanted organs produced urine in the operating room, although the quantity varied. This early evidence of renal homograft function was confirmed by the decreases in blood urea nitrogen. The falls of serum potassium, which occurred in all these patients following revascularization of the homograft, indicated its elimination through the kidney.

Sodium levels usually decreased after dialysis and continued to fall during the first hours of surgery. After transplantation of the promptly functioning grafts, plasma sodium was lowered in nine patients and increased in three others. In the immediate postoperative period there was a tendency toward a slow rise or a plateau, followed by a gradual increase during the second or third postoperative day. It is probable that the decrease in sodium values observed in most cases prior to homograft revascularization was due to the hemodilution caused by the administration of solution intravenously (lactated Ringer's in 5% dextrose) or by the fluid shift from the interstitial to the intravascular compartment. The rise in sodium levels following transplantation has been studied recently (Popovtzner et al, unpublished data). They explained this change as due to free water clearance by the new kidney and a consequent relative increase in sodium concentration. Popovtzner et al showed that some patients in whom these physiological changes were exaggerated could develop clinically significant hyper-

natremia after several postoperative days.

Before the new kidney started functioning, elevated levels of serum potassium were found during operation in several patients who had normal preoperative values. When the predialysis potassium concentrations were correlated with this complication, a consistent pattern was evident. Of five patients with plasma potassium levels higher than 6 mEq/liter before the final preoperative dialysis, four came to the operating room with satisfactory concentrations. However, four of these recipients had a rebound hyperkalemia during operation. In contrast, although the patients who did not have pretransplantation problems of potassium control also had progressive increases in intraoperative potassium concentration, these were more gradual and usually did not exceed normal limits.

Since all 12 patients received fresh transfused blood, these infusions could have been a factor in the production of intraoperative hyperkalemia. However, the total serum potassium measured in the transfused blood did not exceed 7 mEq/liter, and the blood was given slowly. Consequently, the effect of this exogenous potassium was probably not important. It is likely that most of the rise in serum potassium came from an endogenous source in response to the trauma of operation and to pharmacological agents. Whatever the exact cause, there is apparently a release of intracellular potassium into the interstitial and intravascular compartments. Presumably, this occurs to a greater degree in patients with severe hyperkalemia, even though a dialysis just before operation may reduce the plasma concentration and thereby induce a false sense of security.

Since alarming rises in plasma potassium may occur during operation, the anesthesiologist's choice of drugs and techniques which may either exacerbate or minimize this problem is important. A good example would be the selection of muscle relaxants. In the presently reported series, tubocurarine chloride and hyperventilation were used in 11 of the 12 recipients. Hyperventilation has been reported to lower serum potassium concentrations in dogs,[9] and the same effect has been noted with inhalational anesthesia.[10]

By comparison, the influence of succinylcholine upon serum potassium must be considered undesirable since this agent has been reported to contribute to the mobilization of potassium,[10,11] as noted by Popovtzner et al (unpublished data). Such a mechanism might have been responsible for some of the arrhythmias noted by Bastrom et al[11] during induction and by Levine and Virtue[12] after succinylcholine administration, since the hyperkalemia induced by this relaxant reaches its peak shortly after muscle fasciculations and decreases thereafter.[13-15]

The greatest danger to a patient suffering from hyperkalemia is its effect on the heart. Continuous monitoring of an electrocardiograph would seem advisable to permit early recognition of this condition.

Synopsis-Abstract

Determinations of serum sodium and potassium were performed before and after the last pretransplantation hemodialysis, as well as preoperatively, intraoperatively, and postoperatively, in 12 consecutive recipients of renal homografts from related donors. Those patients with predialysis potassium levels above 6.0 mEq/liter tended to develop high potassium values during surgery, even though the immediate postdialysis determination had usually been within normal limits. In these recipients, preoperative dialysis reduced the plasma potassium concentration to normal, but it induced a false sense of security because potassium mobilization, apparently from intracellular sources, occurred very quickly. Two of these 12 patients had electrocardiographic signs of hyperkalemia. In every patient, plasma potassium values fell after revascularization of the homograft. Continuous monitoring of the electrocardiogram is suggested for patients with renal insufficiency. Serial plasma potassium determinations are recommended if predialysis serum concentrations of potassium exceed 6 mEq/liter.

Nonproprietary and Trade Names of Drugs

Diazepam—*Valium.*
Fluroxene—*Fluoromar.*
Pentazocine hydrochloride—*Talwin Hydrochloride.*

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