EFFECTS OF ALTERING CALCIUM IN HAEMODILUTED PUMP PRIMES ON SODIUM AND POTASSIUM IN CHILDREN UNDERGOING OPEN-HEART OPERATIONS

A.E. JOHNSTON, M.D., F.R.C.P.(C), I.C. RADDE, M.D., PH.D., F.R.C.P.(C),
H.I.A. NISBET, M.D., CH.B., D.A.(ENG.), F.F.A.R.C.S.(ENG.), C.R.C.P.(C),
AND J. TAYLOR, B.SC.

INTRODUCTION

ELECTROLYTE ABNORMALITIES and changes in water excretion have been reported in several series of patients undergoing open-heart operations with cardiopulmonary bypass (CPB).¹⁻⁴ The present report deals with the effect of altering the available calcium in the haemodiluted pump prime during cardiopulmonary bypass on the monovalent cation status of children during and following open-heart operations. The divalent cation status of these same children has already been reported⁵ and will be briefly summarized under "Patients and Methods". Our hypothesis is that the maintenance of a normal level of ionic calcium during bypass influences favourably the distribution and excretion of monovalent cations, Na⁺ and K⁺. This may be primarily because of the membrane-stabilizing effect of normal ionized calcium levels.^{6,7}

PATIENTS, METHODS AND DIVALENT CATION STATUS

Thirty-two children about to undergo cardiopulmonary bypass were assigned to four groups (Table I). Patients of group D were perfused with the same priming fluid as those of group B, but received potassium chloride (2 mEq/kg body weight) intravenously during the first 24 hours postoperatively. Patients in groups A, B and D were perfused with acid-citrate-dextrose (ACD) blood-containing prime, whereas patients of group C were perfused with a priming fluid containing heparinized blood. The priming fluid of patients of group A contained 5 ml of 10 per cent calcium gluconate for each 500 ml of blood added to the prime; those of patients in groups B and D contained 5 ml of 10 per cent CaCl₂ per unit of blood; and those of patients in group C, consisting of heparinized blood, did not contain added calcium. The diluent in each case was 5 per cent dextrose in 0.2 per cent sodium chloride.

The Temptrol® disposable bubble oxygenator was primed to achieve 30 per-

Drs. Johnston and Nisbet are in the Department of Anaesthesia, The Hospital for Sick Children and The University of Toronto, Toronto, Ontario, and the Research Institute, The Hospital for Sick Children.

Dr. Radde is in the Research Institute, The Hospital for Sick Children, and Departments of Paediatrics and Pharmacology, University of Toronto, Toronto, Ontario.

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TABLE I
PATIENT GROUPS
MEAN (RANGE)

	Group A ACD* + Ca gluconate	Group B ACD* + CaCl ₂	Group C heparinized blood	Group D ACD* + CaCl ₂ + postop. KCl
No. of patients	9	10	5	8
Age (years)	9.2 (6-15)	8.9 (5-15)	3.0 (2.5)	8.6 (5-13)
Weight (kg)	27.9 (18.6-49.7)	23.2 (16.7-44.0)	13.5 (11.3-17.8)	22.2 (16.5-29.0)
Duration of CPB (min)	72 (20-126)	72 (15-141)	59 (41-97)	84 (39-125)

*Acid citrate dextrose blood.

cent haemodilution of the combined blood volumes of the patient and the prime during early cardiopulmonary bypass. Further samples were obtained 5 min after start of bypass, at mid-bypass, just before the end of bypass and after bypass just before the patient left the operating room. Postoperative specimens were drawn at 4-hourly intervals during the first postoperative day (specimens 1-6) and at 8-hourly intervals during the second postoperative day (specimens 7-9). Urine was collected during bypass and for 48 hours after the procedure, at 4-hourly intervals for the first 24 hours and at 8-hourly intervals during the second day. The entire procedure was carried out as described in detail in the earlier publication.⁵

Sodium and potassium concentrations were estimated in plasma and urine using an IL flame spectrophotometer and standard techniques. The degree of haemolysis was estimated from plasma haemoglobin measurements using the method of Hunter, Grove-Rasmussen and Soutter.⁶ In 12 patients continuous electrocardiographic monitoring was carried out during the first 48 hours post-operatively.

To relate the changes of monovalent cations reported under "Results" those of divalent cations will be briefly summarized.

In group A with calcium gluconate in the prime, plasma ionic calcium concentrations were low during bypass although total calcium was normal. In patients of groups B and D given calcium chloride with the prime, ionic calcium levels were generally low in the normal range but the total calcium was markedly elevated during bypass. Patients receiving heparinized blood in the priming fluid had values between these two. The differences in ionic calcium between the groups persisted into the first postoperative day but became insignificant thereafter.

The urinary volume was higher during operation in groups B and D than in groups A and C. Patients of groups B and D excreted an amount equal to the volume of diluent between the start of bypass and the end of the fourth post-operative hour: patients of the other two groups excreted $\frac{1}{4}$ to $\frac{1}{2}$ of the volume during this period. The combined excretion of divalent cations was higher in patients of groups B and D than in the other two groups during the operation and during the first postoperative day.

RESULTS

A. *Plasma levels of monovalent cations*1. *Potassium*

None of the patients were significantly hypokalaemic (less than 3.0 mEq/l) before bypass. Even mild hypokalaemia was infrequent. Only three of the 32 patients showed plasma potassium values between 3.0 and 3.4 mEq/l at this time (Table II). The mean plasma potassium concentration in the prime was lowest in group A and highest in group C and was intermediate in groups B and D.

Hyperkalaemia developed during cardiopulmonary bypass in a number of patients, particularly during the early bypass period (specimens P1 + P2). The incidence of hyperkalaemia was highest in group A (66 per cent) and lowest in groups B and D. The mean values of plasma potassium did not differ between groups B, C and D. Late during bypass and in the immediate postoperative period the incidence of hyperkalaemia decreased and in groups A, B and D approximately 1 in 5 of the patients developed mild hypokalaemia.

During the first 12 postoperative hours (samples 1-3, Table II) all groups showed variable degrees of hypokalaemia. This was apparent even in patients of group D in whom potassium therapy was started within the first hour postoperatively. With the exception of group C, more than one-half of the patients in the three remaining groups developed hypokalaemia and mean values were below 3.6 mEq/l in all groups. Patients of group A showed a considerably higher incidence of plasma K^+ levels below 3.0 mEq/l than those of the other three groups. In spite of the hypokalaemia particularly in patients of group A, no serious cardiac arrhythmias were observed in any of the patients during the period of observation.

During the remainder of the observation period (from 12 to 48 hours post-operatively) plasma potassium concentrations seen in patients of group D reflected the administration of K^+ as the mean values rose from the subnormal to the normal range by 12 hours. Mild hyperkalaemia (5.1-5.4 mEq/l) developed in only three instances in two patients of group D during potassium chloride administration. The improvement of plasma K^+ levels in patients of group D was carried through to the second postoperative day. The incidence of hypokalaemia in these patients was reduced to 18 per cent in contrast to the other three groups which had not received potassium during the first postoperative day (groups A, B, C) where the incidence was 50 per cent or higher.

B. *Plasma Sodium*

Almost all patients had normal plasma sodium values when the operation began and before bypass, but the sodium concentrations of the priming fluids were uniformly below 125 mEq/l (Table III). During the early bypass period (P1 + P2) plasma sodium concentrations were severely depressed in almost all patients but during the late bypass period and at the end of operation, about one quarter of values in groups B and D were normal, whereas none of groups A and C

TABLE II
PLASMA POTASSIUM CONCENTRATIONS (mEq/L) (MEAN $\pm$ SEM)

Group	Sample 1 + 2*	Prime	Sample P1 + P2	Sample P3 + OR*	Sample 1-3*	Sample 4-6*	Sample 7-9*
A	3.98 $\pm$ 0.11	3.30 $\pm$ 0.21	5.24 $\pm$ 0.19	4.54 $\pm$ 0.25	2.96 $\pm$ 0.07	3.29 $\pm$ 0.07	3.52 $\pm$ 0.09
B	4.16 $\pm$ 0.11	3.96 $\pm$ 0.64	4.65 $\pm$ 0.17	3.94 $\pm$ 0.14	3.30 $\pm$ 0.05	3.44 $\pm$ 0.06	3.42 $\pm$ 0.08
C	4.26 $\pm$ 0.16	4.52 $\pm$ 1.24	4.85 $\pm$ 0.25	4.51 $\pm$ 0.17	3.59 $\pm$ 0.10	3.48 $\pm$ 0.14	3.31 $\pm$ 0.10
D	4.22 $\pm$ 0.09	3.80 $\pm$ 0.62	4.75 $\pm$ 0.21	4.03 $\pm$ 0.18	3.26 $\pm$ 0.09	4.19 $\pm$ 0.16	3.93 $\pm$ 0.15
Incidence of normal and abnormal potassium values before, during and after CPB							
Group A (ACD + Ca gluconate)							
(mEq/l)							
>5.0	—	—	66%	33%	—	—	—
3.5-5.0N†	81%	42%	33%	52%	12%	36%	50%
3.0-3.4	19%	34%	—	15%	44%	48%	45%
<3.0	—	24%	—	—	44%	16%	5%
Group B (ACD + CaCl ₂)							
(mEq/l)							
>5.0	—	20%	16%	5%	—	—	—
3.5-5.0N†	94%	20%	84%	75%	21%	46%	42%
3.0-3.4	6%	10%	—	20%	65%	50%	46%
<3.0	—	50%	—	—	14%	4%	12%
Group C (Heparinized blood)							
(mEq/l)							
>5.0	10%	20%	30%	20%	—	—	—
3.5-5.0N†	90%	40%	70%	80%	57%	42%	33%
3.0-3.4	—	20%	—	—	43%	50%	56%
<3.0	—	20%	—	—	—	8%	11%
Group D (ACD + CaCl ₂ + postop. KCl)							
(mEq/l)							
>5.0	—	12%	27%	7%	—	4%	9%
3.5-5.0N†	100%	38%	61%	73%	39%	79%	73%
3.0-3.4	—	25%	6%	20%	39%	13%	9%
<3.0	—	25%	—	—	22%	4%	9%

*Sample 1 + 2 induction and pre-bypass.
P1 + P2 early bypass + mid bypass.
P3 + OR late bypass + chest closure.
†Normal range.

1-3 1st 12 postoperative hours.
4-6 2nd 12 postoperative hours.
7-9 2nd postoperative day.

TABLE III
PLASMA SODIUM CONCENTRATIONS (MEQ/L) (MEAN $\pm$ SEM)

Group	Sample 1 + 2*	Prime	Sample, P1 + P2*	Sample P3 + OR*	Sample 1-3*	Sample 4-6*	Sample 7-9*
A	135.0 $\pm$ 0.7	80.1 $\pm$ 3.1	116.4 $\pm$ 1.2	124.2 $\pm$ 1.6	132.9 $\pm$ 0.7	131.6 $\pm$ 0.5	130.2 $\pm$ 0.4
B	137.4 $\pm$ 0.6	87.0 $\pm$ 2.4	120.4 $\pm$ 0.9	128.6 $\pm$ 1.3	135.8 $\pm$ 0.6	133.0 $\pm$ 0.6	130.0 $\pm$ 0.6
C	137.1 $\pm$ 1.1	91.4 $\pm$ 4.0	117.8 $\pm$ 1.7	125.8 $\pm$ 1.6	131.9 $\pm$ 1.4	131.2 $\pm$ 0.7	129.6 $\pm$ 1.1
D	137.3 $\pm$ 0.7	87.4 $\pm$ 1.3	119.6 $\pm$ 0.7	128.4 $\pm$ 2.1	137.4 $\pm$ 0.9	135.0 $\pm$ 1.0	132.4 $\pm$ 1.2
Incidence of normal and abnormal sodium values before, during and after CPB							
<i>Group A (ACD + Ca gluconate)</i>							
(mEq/l)							
135-145N†	73%	—	—	—	30%	13%	—
130-134	20%	—	—	19%	52%	62%	70%
125-129	7%	—	—	29%	18%	25%	30%
<125	—	100%	100%	52%	—	—	—
<i>Group B (ACD + CaCl₂)</i>							
(mEq/l)							
135-145N†	94%	—	—	21%	68%	30%	12%
130-134	6%	—	5%	26%	32%	56%	42%
125-129	—	—	10%	21%	—	14%	42%
<125	—	100%	85%	32%	—	—	4%
<i>Group C (Heparinized blood)</i>							
(mEq/l)							
135-145N†	90%	—	—	—	42%	8%	—
130-134	—	—	—	33%	33%	67%	71%
125-129	10%	—	—	22%	8%	25%	29%
<125	—	100%	100%	45%	17%	—	—
<i>Group D (ACD + CaCl₂ + postop. KCl)</i>							
(mEq/l)							
135-145N†	81%	—	—	27%	79%	60%	20%
130-134	19%	—	—	20%	17%	36%	50%
125-129	—	—	—	7%	4%	4%	30%
<125	—	100%	100%	46%	—	—	—

*Sample 1 + 2 induction and pre-bypass.
† P1 + P2 early bypass + mid bypass.
P3 + OR late bypass + chest closure.
†Normal range.

Sample 1-3 postoperative hours 0-12.
4-6 postoperative hours 12-24.
7-9 postoperative hours 24-48.

TABLE IV
PLASMA HAEMOGLOBIN LEVELS RELATED TO PERFUSION TIME
WITH ACD-BLOOD-CONTAINING PRIME

	Total perfusion time (min)	Free haemoglobin (mg/100 ml) per 10 min perfusion time	Highest plasma K ⁺ during perfusion (mEq/l)
Group A (Ca gluconate)	20	15.0	5.7
	28	1.0	6.2
	53	3.4	5.8
	71	37.2	6.2
	79	6.1	4.9
	80	9.3	4.8
	86	14.9	5.5
	108	6.3	5.9
	126	7.3	6.4
m ± SEM	72.3 ± 11.5	11.21 ± 3.59	5.70 ± 0.20
Groups B and D (CaCl ₂)	15	10.7	4.3
	20	4.0	4.0
	39	6.2	5.1
	52	5.4	7.0
	55	4.4	4.8
	59	2.4	4.6
	67	11.3	5.8
	69	9.3	5.3
	72	4.4	7.0
	78	4.1	5.0
	90	5.1	5.1
	92	8.5	5.0
	98	6.1	4.4
	103	5.0	4.3
	105	6.5	4.7
	107	19.6	5.4
	125	8.3	5.4
	141	4.0	5.0
m ± SEM	77.1 ± 8.0 t = 0.04	6.96 ± 0.94 t = 1.14	5.07 ± 0.19 t = 2.42 p < 0.05

TABLE V
MONOVALENT CATION EXCRETION IN URINE
mEq/kg BODY WEIGHT
(MEAN ± SEM)

	Start of CPB until 4 h postop.	4-24 h postop.	24-48 h postop.
POTASSIUM			
Group A	0.97 ± 0.15	2.03 ± 0.30	1.02 ± 0.15
B	1.04 ± 0.09	1.39 ± 0.17	0.92 ± 0.15
C	0.88 ± 0.29	1.95 ± 0.32	1.21 ± 0.22
D	1.46 ± 0.22	2.04 ± 0.19	1.55 ± 0.28
SODIUM			
Group A	0.72 ± 0.27	1.77 ± 0.38	0.87 ± 0.23
B	1.29 ± 0.16	1.64 ± 0.36	1.25 ± 0.40
C	0.60 ± 0.18	2.30 ± 0.78	1.34 ± 0.31
D	1.64 ± 0.35	1.43 ± 0.57	1.15 ± 0.24

were so. This trend to higher plasma sodium levels in groups B and D became more marked in the early postoperative period. One-third of the patients of groups A and C had normal sodium values, whereas more than two-thirds of patients in groups B and D were within the normal range. During the 12th to 24th postoperative hours a difference in plasma sodium values between groups B and D became evident. The incidence of normal values in group D was twice that seen in group B. On the second postoperative day, 80 per cent of values of group D were again in the hyponatraemic range and differences between groups became insignificant.

C. Plasma Haemoglobin Concentrations

The absolute amount of free plasma haemoglobin increased with the length of CPB in the three groups with ACD blood-containing prime (A, B and D) but there was no correlation between the duration of CPB and the increment of free haemoglobin per unit of perfusion time (Table IV). For each unit of time haemolysis was slightly but not significantly less in those patient groups whose plasma ionized calcium levels had been maintained in or near the normal range during bypass (groups B and D), compared to values of group A. The maximal plasma potassium values observed during bypass, were however higher on the average in group A than in groups B and D.

D. Monovalent cation excretion in urine

1. Potassium

A period by period comparison of potassium excretion (mEq/kg) in patients of groups A, B and C showed no significant differences from start of bypass to the end of the fourth hour postoperatively (Table V), although urinary volumes were higher in patients of group B than in patients of group A. Patients of group A, however, excreted more potassium during the period 4 to 24 hours postoperative than did patients of group B. Patients of group C showed a pattern of potassium excretion similar to that seen in patients of group A. Patients of group D, given 2 mEq/kg body weight of potassium during the first day postoperatively excreted more potassium than those of the other three groups. However, patients in group D retained approximately 0.7 mEq/kg of the administered dose of KCl during the period 4 to 48 hours postoperative. This figure is the result of subtracting the potassium excretion of group B from that of group D, assuming that potassium balance was similar in the two groups except for the additional amount given to group D. Subtracting the difference from the known intake of 2.0 mEq/kg, patients of group D excreted only approximately 1.3 mEq/kg above the urinary potassium excretion of group B.

2. Sodium Excretion

During the period from start of bypass until the end of the 4th postoperative hour, sodium excretion (mEq/kg) was significantly less in groups A and C than in groups B and D (Table V). The latter patients also had a greater intraoperative diuresis. Patients of group C showed delayed natriuresis later on the first

postoperative day, corresponding to the delayed diuresis. Total sodium excretion during the entire period of observation was similar for groups B and D, but was significantly less in the patients of group A.

During the first 24 postoperative hours urinary excretion of sodium exceeded intake by at least 0.3 mEq/kg in the groups whose prime contained ACD blood. On the second postoperative day, however, the intake exceeded excretion by 0.3 mEq/kg; but this amount was not sufficient to prevent development of hyponatraemia.

DISCUSSION

This paper is concerned mainly with two aspects of intra-operative and post-operative biochemical change in children undergoing open-heart operations with cardiopulmonary bypass. These are (a) the effect on monovalent cation balance of maintaining normal ionized calcium levels throughout cardiopulmonary bypass and (b) the effect of postoperative potassium chloride therapy on changes in plasma and urinary electrolytes.

The pre-bypass potassium concentration in plasma in all but three of the thirty-two children was normal. This is unlike the findings in adult patients,^{2,9,10} who may have been receiving prolonged diuretic therapy. Whether pre-operative depletion of total body potassium stores in these children exists must be determined by direct measurement. The results should give us some insight into post-operative potassium requirements.

The present study shows that the maintenance of normocalcaemia (ionic fraction) during cardiopulmonary bypass influences plasma electrolyte concentrations as well as urinary excretion rates of monovalent cations, both intraoperatively and postoperatively. This can be explained either by a direct effect of calcium ions on membranes or indirect effects of calcium ions on fluid and ionic distribution in the body and electrolyte excretion.

The direct effects of calcium ions on membrane permeability may account for the different potassium concentrations in the prime and in plasma samples drawn during cardiopulmonary bypass. Plasma K^+ levels in the pump prime of patients of groups B and D are lower than those of patients of groups A and C. This can be explained by the calcium ions preventing passive diffusion of K^+ out of the cells after these ions have diffused into the erythrocytes during warming of the blood prime. Similarly, the membrane-stabilizing effects of higher plasma ionic calcium levels during bypass in patients of groups B and D (normal ionic calcium) may have contributed to the lesser incidence of hyperkalaemia during the procedure. Higher plasma Na^+ during bypass in patients of groups B and D probably are also related to membrane effects of ionic calcium preventing the diffusion of Na^+ across cell membranes.^{6,7,11}

In addition to the membrane-stabilizing effect of the normal calcium ion concentrations, the intraoperative natriuresis in patients receiving ACD blood and calcium chloride in the prime can be explained on the basis of competition of calcium and sodium ions for reabsorption in the renal tubule¹² or by the osmotic effects of excess total calcium in the glomerular filtrate.¹³ This osmotic effect in patients receiving ACD blood and $CaCl_2$ is reflected in the greater diuresis ac-

companying the natriuresis during bypass. Since the kidney excretes potassium by a different mechanism than that by which it excretes calcium and sodium, the diuresis was not accompanied by increased potassium excretion in urine during bypass. In spite of the higher sodium excretion in patients of groups B and D (CaCl_2 in prime) than in those whose prime contained calcium gluconate or heparin (groups A and C), plasma sodium levels remained normal more frequently in the former than in the latter groups.

Several investigators have reported hypokalaemia developing during cardiopulmonary bypass.^{1,4,14} In contrast, we found hyperkalaemia in patients with low plasma ionic calcium (groups A and C) and normokalaemia in patients with normal ionic calcium during bypass (groups B and D). This discrepancy may reflect differences in preoperative body stores of potassium between our patients and those discussed in the literature.

During the first 12 postoperative hours there may still be a carry-over of the membrane-stabilizing effect of calcium ions administered in the prime, partially reflected in the higher plasma potassium levels in group B than in group A. However, even patients whose treatment with KCl started during the first postoperative hour developed hypokalaemia which was not corrected until 12 hours of continuous potassium salt infusion. Our finding of a low incidence of serious cardiac arrhythmias in the presence of significant hypokalaemia in the early postoperative period agrees with those of Breckenridge *et al.*² who did not observe differences in potassium-treated and untreated adults.

One third of the potassium dose administered to patients of group D was retained during the period of observation and this was associated after 12 hours of infusion with almost complete correction of the postoperative hypokalaemia which developed in the other three groups (A, B and C) and persisted throughout the second postoperative day. The value of extended potassium treatment has been shown by Breckenridge and his colleagues² who found that adult patients when treated were in positive potassium balance by the third postoperative day, whereas untreated patients did not reach positive balance by this time.

The effect on plasma sodium levels of KCl administered postoperatively to patients of group D can be explained on the basis of ionic rather than fluid shifts. Concomitantly with the retention of a portion of the administered potassium and higher plasma potassium concentrations during the second 12 postoperative hours (specimens 4, 5, and 6), the incidence of hyponatraemia was less than that seen in the other three groups. Urinary sodium retention in patients of group D was not significantly increased over that of patients of group B during this period. On the second postoperative day (specimens 7-9) plasma sodium levels in all groups declined, although the decline was least in patients of group D treated with potassium chloride postoperatively. This trend to hyponatraemia is similar to findings of other investigators.^{15,16}

Because hyperkalaemia did not develop in patients given 2.0 mEq/kg body weight of KCl during the first postoperative day and since hypokalaemia and a certain degree of metabolic alkalosis developed in most patients of all groups on the second postoperative day, we suggest that KCl supplementation should be extended into the second day.

SUMMARY

The effects of low or normal calcium ion concentrations in the haemodiluted prime on plasma levels and urinary excretion of monovalent cations were contrasted in 32 children undergoing open-heart operations with cardiopulmonary bypass (CPB).

In patients in whom ionic calcium had been maintained near normal during bypass (Groups B and D, CaCl_2 in prime), the intra-operative incidence of hyperkalaemia and hyponatraemia was less than in patients whose ionic hypocalcaemia had not been adequately corrected (Groups A and C, calcium gluconate or heparinized blood in prime). An adequate intra-operative diuresis and natriuresis was also seen in patients with normal ionic calcium during cardiopulmonary bypass in contrast to patients with low ionic calcium.

During the first 12 postoperative hours most patients became hypokalaemic, but this abnormality was less marked with respect to values below 3.0 mEq/l in patients with normal ionic calcium during bypass (Groups B and D) than in patients with ionic hypocalcaemia (Group A).

Potassium chloride therapy (2 mEq/kg body weight/24 hours) during the first postoperative day corrected the hypokalaemia seen in patients of group D after the first 12 postoperative hours only, but the effect continued until the end of the observation period of 48 postoperative hours.

Almost all children of groups A and C and two-thirds of those of group B became hyponatraemic during the second half of the first postoperative day. In contrast, two-thirds of patients treated with potassium chloride (Group D) were able to maintain their plasma sodium concentrations within the normal range from the 12th to the 24th postoperative hour.

Thus, we emphasize the importance of maintaining normal ionic calcium concentrations in plasma during cardiopulmonary bypass by addition of sufficient amounts of CaCl_2 to ACD and heparinized blood primes. This treatment will minimize intraoperative and early postoperative electrolyte disturbances and will contribute significantly to an adequate diuresis and natriuresis during this time. Postoperatively, potassium chloride should be administered in the recommended dose (2 mEq/kg body weight/24 h) during the first and second day. This treatment will reduce the incidence of hypokalaemia starting during the latter part of the first postoperative day and will minimize the hyponatraemia and the alkalosis which may be associated with hypokalaemia.

RÉSUMÉ

Chez 32 enfants soumis à des opérations à cœur ouvert avec circulation extra-corporelle (C.P.B.), nous avons comparé les concentrations basses et normales d'ion calcium dans le liquide amorceur hémodilué et avons étudié leurs effets sur les taux de calcium dans le plasma et sur l'excrétion urinaire de cations monovalents.

Les malades, chez qui nous avons maintenu le calcium ionisé près de la normale durant la circulation extra-corporelle (les groupes B et D; Ca Cl_2 dans le liquide

amorceur) ces malades ont présenté une fréquence d'hypocalcémie et d'hyponatrémie moindre que les malades chez qui l'hypocalcémie ionique n'avait pas été corrigée adéquatement: (les groupes A et C, gluconate de calcium ou du sang hépariné dans le liquide amorceur). Nous avons également observé durant l'opération une diurèse et une natriurèse adéquates chez les malades qui avaient un taux de calcium ionisé normal durant la circulation extra-corporelle comparativement aux malades qui avaient un taux de calcium ionisé inférieur.

Durant les 12 premières heures après l'opération, la plupart des malades sont devenus hypokaliémiques; toutefois, cette déficience a été moins prononcée si l'on se reporte aux valeurs inférieures à 3 mEq/l chez les malades qui avaient un taux de calcium ionisé normal durant la circulation extra-corporelle (les groupes B et D) que les malades qui avaient une hypocalcémie (groupe A).

La thérapie au chlorure de potassium (2 mEq/kg de poids/24 heures) durant la première journée après l'opération a réussi à corriger l'hypokaliémie observée chez les malades du groupe D seulement après les 12 premières heures après l'opération; toutefois, l'effet a persisté jusqu'à la fin de la période d'observation de 48 heures après l'opération.

Presque tous les enfants des groupes A et C et les deux-tiers de ceux du groupe B sont devenus hyponatrémiques durant la deuxième moitié de la première journée après l'opération. Par contre, les deux-tiers des malades traités avec du chlorure de potassium (groupe D) ont réussi à maintenir leur concentration de sodium plasmatique dans les limites de la normale de la 12^{ème} à la 24^{ème} heure après l'opération.

En conséquence, nous insistons sur l'importance de maintenir des concentrations normales de calcium ionisé dans le plasma durant la circulation extra-corporelle en ajoutant des quantités suffisantes de chlorure de calcium (CaCl_2) au sang citraté (A C D) ou hépariné qui sert de liquide amorceur. Ce traitement contribuera à diminuer les déséquilibres électrolytiques au cours de l'opération et au cours des suites opératoires immédiates et contribuera également, de façon notable, durant cette période, à maintenir adéquates la diurèse et la natriurèse. Au cours des suites opératoires, nous recommandons de prescrire du chlorure de potassium à la dose de (2 mEq/kg de poids/24 heures) durant les deux premiers jours. Ce traitement réduira la fréquence de l'hyponatrémie et l'alcalose qui peut l'accompagner.

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REFERENCES

1. LOCKEY, E., LONGMORE, D.B., ROSS, D.N., & STURRIDGE, M.F. Potassium and open-heart surgery. *Lancet* 1: 671 (1966).
2. BRECKENRIDGE, I.M., DEVERALL, P.B., KIRKLIN, J.W., & DIGERNESS, S.B. Potassium intake and balance after open intracardiac operations. *J. Thorac. Cardiovasc. Surg.* 63: 305 (1972).
3. LINDER, E., SAKAI, Y., & PATON, B.P. Electrolyte changes during dilution perfusion. *Arch. Surg.* 88: 59 (1964).
4. MOFFITT, E.A., MAHER, F.T., & KIRKLIN, J.W. Effect of cardiopulmonary bypass and haemodilution on some constituents of blood. *Can. Anaesth. Soc. J.* 12: 458 (1965).
5. JOHNSTON, A.E., RADDE, I.C., NISBET, H.I.A., & TAYLOR, J. Effects on divalent cations of a hemodilution technique using ACD blood in pediatric patients undergoing bypass open-heart surgery. *Can. Anaesth. Soc. J.* 19: 498 (1972).
6. LEE, Y.C.P., RICHMAN, H.G., & VISSCHER, B. Extracellular calcium ion activity and reversible cardiac arrest. *Am. J. Physiol.* 210: 493 (1966).
7. LASSITER, W.E., FRICK, A., RUMRICH, G., & ULLRICH, K.J. Influence of ionic calcium on the water permeability of proximal and distal tubules in the rat kidney. *Pflügers Arch.* 285: 90 (1965).
8. HUNTER, F.T., GROVE-RASMUSSEN, M., & SOUTTER, L. A spectrophotometric method for quantitative hemoglobin in plasma or serum. *Am. J. Clin. Pathol.* 20: 429 (1950).
9. REMENCHIK, A.P., MILLER, C., TALSO, P., & WILLOUGHBY, E.D. Depletion of body potassium by diuretics. *Circulation* 33: 796 (1966).
10. MARCIAL, M.B., VEDOVA, R.C., ZERBINI, E.J., VERGINELLI, G., BITTENCOURT, D., & DO AMARAL, R.C. Potassium in cardiac surgery with extracorporeal perfusion. *Am. J. Cardiol* 23: 400 (1969).
11. MANN, J. & COLLIER, H.B. The effect of calcium ion on hypotonic hemolysis of human erythrocytes. *Life Sci.* 8: 1343 (1969).
12. EPSTEIN, F.H. Calcium and the kidney. *Am. J. Med.* 45: 700 (1968).
13. WOLF, A.V. & BALL, S.M. Effect of intravenous calcium salts on renal excretion in the dog. *Am. J. Physiol.* 158: 205 (1949).
14. SELMONOSKY, C.A. & FLEGE, J.B. JR. The effect of small doses of potassium on postoperative ventricular arrhythmias. *J. Thorac. Cardiovasc. Surg.* 53: 349 (1967).
15. MOFFITT, E.A., ROSEVEAR, J.W., & MCGOON, D.E. Myocardial metabolism in children having open-heart surgery. *J.A.M.A.* 211: 1518 (1970).
16. PACIFICCO, A.D., DIGERNESS, S., & KIRKLIN, J.W. Acute alterations of body composition after open intracardiac operations. *Circulation* 41: 331 (1970).