

Medical Intelligence

Specific Therapy in Water, Electrolyte and Blood-volume Replacement during Pediatric Surgery

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RECENT REPORTS and reviews¹⁻⁴ outline problems associated with management of blood, water and electrolyte therapy during pediatric surgery. Although several studies^{3,6} have specified requirements for volume and electrolyte replacement, they have not provided practical guides for their intraoperative use. We have developed such a guide, utilizing serial arterial blood sampling, and used it successfully in clinical management of more than 2,500 pediatric surgical patients over a period of two years.

Basic Assumptions (See Figure 1)

Based on preoperative body weight (kg) and hematocrit (Hct) we calculate:

Estimated blood volume (ml) (EBV)⁷ = 80 ml/kg body weight. The average figure of 80 ml/kg is used. The range is from 90 ml/kg in neonates to 65 ml/kg in teenagers. Extremes of the range are used only in special circumstances.

Estimated erythrocyte mass (ml) (ERCM) = EBV × Hct.

Estimated erythrocyte mass 30 (ml) (ERCM₃₀) = the estimated erythrocyte mass at Hct 30 per cent = 0.3 × EBV.

Acceptable erythrocyte loss (ml) (ARCL) is calculated as ERCM - ERCM₃₀. It represents the volume of erythrocytes present in excess of the theoretical value at a hematocrit of 30 per cent. We have arbitrarily chosen this value as the minimum desirable hematocrit to be achieved at the end of an operation.⁸

"Acceptable" blood loss (ml) (ABL) = ARCL × 3.

Estimated fluid requirement (ml) (EFR)⁹ = 4 ml/kg/hr. The average value of 4 ml/kg/hr is used except for premature infants and neonates, for whom 2.5 ml/kg/hr is used.

Estimated fluid deficit (ml) (EFD) = EFR × number of hours since last fluid intake. It is assumed that oral intake balanced previous normal fluid requirements.

These figures are recorded before induction of anesthesia.

Measurements

During operation, heart sounds (precordial or esophageal) sphygmomanometer-cuff blood pressure, body temperature (rectal, axillary or esophageal) and ECG are monitored in every child. Blood loss is estimated in terms of suction losses, sponge losses, and unmeasured losses. These are recorded in cumulative fashion in the space provided on the chart.

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NON PEDIATRIC ANESTHESIA
BLOOD VOLUME MANAGEMENT
Date _____

Name _____ Age _____ Ht. _____ cm. Wt. _____ kg.
Unit # _____ Hct. _____

Procedure _____ Estimated _____
Anesthetist _____ Blood Volume _____
Surgeon _____ Red Cell Mass # JOL _____
Accept. Red Cell Loss _____
Accept. Blood Loss _____

Sampling Method _____ Fluid Req. _____
Replacement Prop. _____ Fluid Deficit _____
Replacement Hct. _____

SAMPLE	TIME (MIN)	1	2	3	4	5	6	7	8	9	10	
1	Baseline											
2	Baseline											
3	Baseline											
4	TOTAL											
5	HCT											
6	TOTAL											
7	Solids											
8	Plasma Cells											
9	Whole blood											
10												
11												
12	Plasma Lactate											
13	Plasma Lactate											
14	TOTAL											
15	FiO ₂											
16	PO ₂											
17	PCO ₂											
18	pH											
19	Cl ₂											
20	Ca ⁺⁺											
21	Na ⁺											
22	K ⁺											
23	Protein											
24	Urea											
25	Volume											
26	Urea											
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*Other: KCl, NaHCO₃, CaCl₂

FIG. 1. Blood volume management chart.

Urinary catheterization is used only when operation is expected to last longer than two hours, or if major fluid shifts are expected. Urine flow is then measured at the head of the table by connecting a small-bore collecting tube (iv set) to the bladder catheter.

Radial-artery cannulation⁹ is performed on every patient who might require infusion of a blood product. Blood is sampled at half-hourly intervals, or more frequently if necessary. To guide in blood-volume replacement, arterial hematocrit,⁵ serum proteins (g/100 ml), and serum osmolality (mOsm/l) are obtained.¹⁰ These values serve as a basis for administration of erythrocytes, protein or electrolyte solution and free water. Using micropipettes, a microcentrifuge, and a refractometer,⁵ these tests require less than

0.5 ml of blood¹¹ and are obtainable within minutes from a laboratory in or near the operating room.¹² Using 2.5 ml of blood, blood gases, serum sodium and serum potassium concentrations are also provided rapidly whenever required.

Principles of Therapy

Maintenance of an appropriate blood volume is attempted via replacement with specific components based on the measurements and calculations described. Evaluation commences with the preanesthetic visit, when orders regarding cessation of preoperative intake are written. Intake stops after a sweet

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HIGH PEDIATRIC ANESTHESIA

BLOOD VOLUME MANAGEMENT

Date 2/2/71

Name A.S. Age 2 yr. Ht. 70 cm. Wt. 11.7 kg.
 Unit # 156-61-80 Hct. 12%
 Procedure Salivary-Renal Shunt Estimated
 Anesthetist VP, Z. J. F. Blood Volume 316 ml
 Surgeon H Red Cell Mass 280
 Red Cell Mass # 304 280
 Accept. Red Cell Loss 0
 Accept. Blood Loss 0
 Sampling Method 223 Minikath Rad. Artery Fluid Req. 45 ml/hr
 Replacement Prop. Frozen Cells Fluid Deficit 180 ml
 Replacement Hct. _____

SAMPLE	1	2	3	4	5	6	7	8	9	10	TOTAL
TIME (MINS)	0	75	120	165	210	255	300	345	390	435	
1. Suction	0	0	5	10	25	40	120	260	210	210	
2. Spontaneous	0	0	80	110	150	170	210	230	230	240	
3. Misc.	20	25	30	35	40	45	50	50	55	120	
4. TOTAL	20	25	115	155	215	255	390	550	500	730	730
5. HCT	25	27	32	32	34	35	35	36	36	34	
6. TOTAL	50	68	368	500	735	900	1365	1950	1800	2480	6000
7. Colloid	0	0	0	0	0	0	0	0	0	0	0
8. Facked Cells	0	0	0	0	0	0	0	0	0	0	0
9. Whole Blood	0	0	0	0	0	0	0	0	0	0	0
10. C. Cl. ppg	0	0	0	0	0	0	0	0	0	0	0
11. Ringers Lactate	0	0	0	0	0	0	0	0	0	0	0
12. D5 Ring. Lact.	0	0	0	0	0	0	0	0	0	0	0
13. TOTAL	240	250	255	265	280	300	390	500	500	500	2500
14. FIO ₂	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	
15. PO ₂	130	144	88	173	162	154	155	155	165	173	
16. PCO ₂	51	39	40	38	35	38	32	34	34	35	
17. pH	7.29	7.38	7.36	7.39	7.42	7.41	7.42	7.43	7.42	7.38	
18. O ₂ Sat.	95.5	95.0	95.0	95.5	96.0	96.0	96.0	96.0	96.0	95.0	
19. Na ⁺	135	141	140	142	144	143	143	143	145	145	
20. K ⁺	3.2	2.7	3.7	3.0	2.8	3.1	3.0	3.8	3.4	3.3	
21. Protein	5.9	5.7	6.2	6.2	5.9	5.7	5.8	5.7	0	5.4	
22. Bas.											
23. Volume											
24. Dsm.											
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FIG. 3. Intraoperative record, Patient 2.

lyte would dilute the arterial hematocrit to 30 per cent (ABL). In the absence of arterial monitoring, the calculated acceptable blood loss (ABL) serves as a guide to replacement. Reconstituted frozen erythrocytes are administered as necessary to restore hematocrit to the desired level. When serial arterial hematocrit is measured, erythrocytes are administered when the calculated ERCM falls below the ERCM₃₀.^{14,15}

Fresh frozen erythrocytes are preferred over packed erythrocytes stored in ACD solution owing to a well-maintained level of 2,3-diphosphoglyceric acid (2,3-DPG), which generally diminishes with duration of storage in ACD. The hematocrit of the reconstituted cells is measured, and the exact quantity required to restore the ERCM is infused from a syringe.

Illustrative Cases

Patient 1 (fig. 2). Bilateral ureteral reimplantation was done in an 11-year-old girl weighing 50.3 kg. Anesthesia time was 4½ hours. Hematocrit was 36 per cent; EBV, 3,520 ml; ABL, 630 ml; EFR, 125 ml/hr; EFD, 750 ml.

During 4½ hours of anesthesia, the patient lost 505 ml of blood (15 per cent EBV). This was replaced with 500 ml 5 per cent albumin in saline solution. The total electrolyte solution required was EFD (750 ml) + EFR (125 ml/hr × 4½ hr) = 1,300 ml. This volume was replaced with 750 ml Ringer's lactate solution and 250 ml 5 per cent glucose in Ringer's lactate solution. The hematocrit of arterial blood decreased from 36 to 31.5 per cent, serum proteins from 6.2 to 5.8 g/100 ml. Urine flowed from ureters throughout operation. The patient made an uneventful recovery and received no blood transfusions postoperatively despite losing 15 per cent of her estimated "blood" volume.

Patient 2 (fig. 3). A 2-year-old child was treated

[illegible]

FIG. 4. Intraoperative record, Patient 3.

by spleno-renal shunt. The patient weighed 11.7 kg. Fluid requirement was 45 ml/hr. Anesthesia time was 8 hours.

During the 8 hours of anaesthesia, the patient lost 730 ml of blood (78 per cent EBV). This was replaced with 350 ml of 5 per cent albumin in saline solution and 250 ml (frozen) packed erythrocytes. Losses occurred, and the final arterial blood hematocrit was 31 per cent. Total electrolyte solution required was EFD (180 ml) + EFR (45 ml/hr \times 8 hr) = 540 ml. This volume was replaced with 250 ml 5 per cent glucose in Ringer's lactate solution and 400 ml Ringer's lactate solution. Serum proteins changed little (from 5.9 to 5.4 g/100 ml). Despite the use of Ringer's lactate solution containing 4 mEq/l, serial serum K^+ measurements decrease to 2.8 mEq/l in the absence of acid-base disturbance. Correction of low serum K^+ was provided by calculating the dose that would raise extracellular K^+ concentration by 0.5 mEq. (Extracellular volume (l)) = 0.3 \times body weight (kg). K^+ required = $4l \times 0.5 \text{ mEq/l} = 2 \text{ mEq}$. The calculated dose is placed in the iv tubing close to the

patient and given as repeated boluses of 0.5 mEq at 30–60-second intervals. We have observed that patients who need large volumes of blood replacement also require supplemental K⁺ even during infusion of Ringer's lactate solution, particularly since the present therapeutic regimen does not include "old" plasma with high K⁺ levels.

Patient 3 (fig. 4) Urinary tract exploration and pyeloplasty was done in a 3-year-old patient weighing 14 kg. Preoperative hematocrit was 22 per cent. Fluid requirement was 55 ml/hr. Anesthesia time was 6 hours.

This child had chronic renal failure because of a grossly abnormal renal collecting system, and had to be maintained on a special diet. During 6 hours of anesthesia, the patient lost 135 ml of blood (± 12 per cent EBV). However, the starting hematocrit was 22 per cent, calculated to represent a deficit of 90 ml of erythrocytes from ERMCS³⁵. Replacement of 200 ml of (frozen) packed erythrocytes adjusted the final hematocrit to 32 per cent. No colloid was given. Total electrolyte solution required was EFD (330 ml) + EFR (55 ml/hr \times 6 hr) = 660 ml.

(These values are based on a nonedematous body weight and should not be applied to a child with nephrosis and edema.) This volume was replaced with 250 ml of 5 per cent glucose in Ringer's lactate solution and 250 ml Ringer's lactate solution.

When serum K^+ rose from 4.8 mEq/l to 5.9 mEq/l while a base excess of -5 mEq/l was calculated, 25 ml $NaHCO_3$ (1 mEq/l) was infused ($NaHCO_3$ mEq = $\frac{1}{2} \times BE \times$ body weight in kg). pH rapidly rose to 7.57 (P_{aCO_2} = 39 torr) and serum K^+ decreased to 5.5 mEq/l. Half an hour later, arterial blood-gas analysis showed pH 7.39, P_{aCO_2} 37 torr, and serum K^+ 4.5 mEq/l.

Results

In a little more than 2 years since the regimen was introduced, more than 2,500 patients have been managed with this formula for intraoperative replacement and support of intravascular volume, water and electrolyte balance. During that period there have been one intraoperative fatality and two episodes of cardiac arrest, both occurring in patients who were resuscitated successfully. None of these was related to blood or fluid replacement. The ages of the patients and the magnitudes of surgery have varied widely from a premature infant with esophageal atresia to a 16-year-old patient undergoing decortication and fusion of 18 vertebrae.

Few postoperative circulatory or fluid complications occurred. Hemoglobinuria occurred in five patients not undergoing renal surgery who received large quantities of frozen blood. It appears that frozen erythrocytes are more prone to mechanical damage after processing, but each patient had rapid uneventful urinary clearing (4 to 6 hours) after intravenous injection of a diuretic (ethacrynic acid or furosemide) and electrolyte solution to replace urinary losses.

During the earliest period of the present management, inadvertent use of salt-poor albumin resulted in one instance of pulmonary edema. A 3-kg newborn with duodenal atresia was given 40 ml salt-poor albumin to maintain blood volume. Immediately on cessation of positive-pressure ventilation, pulmonary edema became evident. Phlebotomy, intermittent positive-pressure ventilation and diuresis returned the patient's cardiorespiratory system to normal within 8 hours.

Postoperative water overload with pulmo-

nary edema appeared in two children. On each occasion, deterioration of arterial oxygenation (increase in the A-a oxygen gradient) provided the clue to the problem. This was treated with the aid of diuretic therapy and fluid restriction, and the children recovered uneventfully. Continuing undiminished postoperative urinary flow proved particularly useful after renal-tract surgery.

Discussion

The therapeutic principles of this approach are based on our understanding of intraoperative physiology,^{3,16} heavy use of the acute-care laboratory,¹² and volume replacement with specific blood components rather than whole blood.¹⁷⁻²²

Although some have suggested the use of central venous blood samples,¹⁵ we have found⁹ that radial-artery monitoring is simple, effective, and more informative, particularly when blood gases are required and blood pressure must be measured directly. In neonates, percutaneous radial-artery cannulation is often easier to institute than central venous catheterization, and in our hands it has been used without incident.

Previous discussions of the value of serial microhematocrit measurement^{10,23} have failed to consider its use as a guide to therapeutic restoration of circulating blood volume. Using our calculations, we are able to replace the components needed to restore any deficit. While no data substantiate our use of 30 per cent as a correct minimum desirable hematocrit, this figure was adopted by consensus of surgeons, pediatricians and anesthesiologists of the Children's Service.

After an introductory period when the activities of all involved services (blood bank, anesthesia laboratories, pediatric surgical division) were correlated, it was decided that only packed cells would be prepared for pediatric surgical patients unless specific indications arose. Within one year we have changed to the use of frozen cells for nearly every patient. This was accomplished to reduce the potential risk of hepatitis,²⁴ to diminish the quantity of ACD given, and to decrease the potential incidence of pulmonary vascular reactions to donor leukocytes.²⁵ The need for heparinized blood in patients

with liver disease or immaturity, with its attendant collection, banking and wastage factors, is no longer a consideration in scheduling, operating room utilization or patient care. Fresh frozen plasma is readily available to provide physiologic clotting factors whenever these are required.

The use of 5 per cent glucose in Ringer's lactate solution is limited to 250 ml. This provides 12.5 g glucose to the fasting patient. Rapid infusions of large quantities of glucose may cause undesirable hyperglycemia and osmotic diuresis. Further electrolyte solution is provided by Ringer's lactate solution alone, unless additives, such as glucose, K^+ , σHCO_3^- are specifically indicated. Ringer's lactate solution provides 3 mEq/l of calcium.

An approach to the intraoperative management of blood volume, fluid and electrolyte balance in pediatric surgical cases is described, based on recent advances in our knowledge of salt and water balance in the child, improvement in blood component therapy, and reliance on intraoperative monitoring of changes in blood composition. It is believed that the combination of these three factors ensures more successful management, particularly for the critically ill child.

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