Fluid Requirements for Neonatal Anesthesia and Operation

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Thirty-six neonates undergoing anesthesia and major surgical operations in the first 24 hours of life were studied to determine whether requirements for fluids and electrolytes were similar to those of adults and how the neonates could handle sodium and water given during anesthesia and the postoperative period. During operation, 5 per cent dextrose in lactated Ringer's solution was administered at the rate of 8 ml/kg body weight/hr. Postoperatively, fluid replacement was at the rate of 100 ml/kg/day, one-fifth to two-fifths of this volume as 5 per cent dextrose in lactated Ringer's solution and the remainder, 5 per cent dextrose in water. Abnormal losses were replaced with isotonic saline solution and/or blood and/or albumin. Potassium supplementation was routine. Balance studies carried out over four postoperative days showed a tendency to hyponatremia and an inability to conserve sodium even with adequate volume administration. Findings suggest that the neonate requires increased amounts of multi-electrolyte solution during major surgical operations and continued administration of sodium in the postoperative period. (Key words: Neonates; Fluids; Anesthesia; Surgical operation.)

A REVIEW of methods of dealing with fluid requirements for neonates undergoing major surgery shows divergent opinions. Several authors favor the administration of 5 or 10 per cent dextrose in water.[1-4] In other reports, emphasis has been placed on plasma,[5,6] blood,[7] lactated Ringer's solution,[8,9] or omission of intraoperative fluids.[10-13] It appears that the major consensus is for no fluids at all.[14-18] Much of the disagreement arises from misunderstanding of renal function in the neonate.[19-21] The traditional concept of renal function in the neonatal period is one of immaturity of function, inability to excrete sodium loads, and inability to concentrate urine.[22] (The neonatal period is defined usually as the first 28 days following birth of the full-term mature infant.)

In this study of fluid requirements for the neonate undergoing anesthesia and operation, we included 36 newborn infants who underwent surgical operation within the first 24 hours of life. Fluid balance studies of all these patients were carried out. Neonates 26 through 36 were studied more extensively than Neonates 1 to 25.

In the balance studies reported here, we found that the neonatal kidney lacks the ability to retain sodium despite hyponatremia, that fluid and electrolyte shifts during operation are apparently similar to those in adults, and that fluid therapy during surgical operations on neonates should include sodium administration. The neonatal kidney normally excretes sodium and concentrates urine, though these functions are not as well developed as in the adult kidney.

Studies

After tracheal intubation, the neonates were anesthetized either with nitrous oxide–oxygen, in a one-to-one relationship, plus intravenous *d*-tubocurarine, or with nitrous oxide–oxygen, one-to-one, maintained with halothane, 1 per cent or less. The technique included controlled ventilation. The basic apparatus was the Rees variation of Ayre's T piece.[23]

Body weight, hemoglobin, fluid administration, urinary output, urinary specific gravity and *p*H, volume of gastric aspirate, and serum electrolyte findings were recorded. Studies of Neonates 1 through 25 were performed on either the second or the third postoperative

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Received from the Department of Anesthesiology, The University of Texas (Southwestern) Medical School and Children's Medical Center, Dallas, Texas. Accepted for publication January 26, 1970.

TABLE 1. Results of Retrospective Studies of Charts of Eleven Consecutive Newborn Infants, October 1967–January 1968

Neonate No. and Diagnosis	Weight (kg)	Operative					Postoperative								
		Time (min)	Blood		Fluids		Gastric tube present	Maximum weight change (g)	Average Fluids/Day			Average Urine Volume (ml/day)	Serum Electrolytes		Day Discharged from Hospital
			Loss (ml)	Administered (ml)	H_2O (ml)	Na^+ (mEq)			H_2O (ml)	Na^+ (mEq)	K^+ (mEq)		Postoperative First Day Na^+ (mEq/l)	Subsequent Days Na^+ (mEq/l)	
1. Intestinal malrotation	2.4	60	20	0	200	28	+	+100	380	28	12	220	149	140	7
2. Ileal atresia	2.4	130	30	0	110	14	+	− 40	320	8	0	180	135	134	8
3. Pierre-Robin syndrome (two operative															
sites:	1.9			0		10	−	− 80	200	6	4	175	137	136	21
intraoral and		30	5		20										
abdominal)		45	5		0										
4. Meningomyelocele	2.6	55	100	70	70	9	−	+ 30	140	9	0	120	132	136	20
5. Omphalocele	3.0	50	5	0	10	1	−	−470	210	7	0	130	134	131	24
6. Meconium ileus	2.3	145	25	20	325	45	+	+ 80	190	7	5	135	132	121	5*
7. Rectourethral fistula and imperforate anus	2.2	45	20	0	70	10	+	− 50	250	10	2	140	130	134	16
8. Duodenal atresia	1.9	70	6	0	25	3	+	− 30	175	8	0	110	134	125	11
9. Obstruction, middle lobe, right lung	3.2	70	10	0	50	7	−	− 80	230	7	5	160	136	130	2
10. Teratoma of tongue	3.3	50	20	0	100	13	−	+ 65	250	8	1	145	136	131	7
11. Meningomyelocele	3.3	60	10	0	100	14	+	− 30	250	7	1.5	130	132	130	10

* Death due to aspiration pneumonia.

TABLE 2. Results of In-hospital Observations and Studies of Fourteen Consecutive Newborn Infants, February–July, 1968

Neonate No. and Diagnosis	Weight (kg)	Operative					Postoperative								
		Time (min)	Blood		Fluids		Gastric tube present	Maximum weight change (g)	Average Fluids/Day			Average Urine Volume (ml/Day)	Serum Electrolytes		Day Discharged from Hospital
			Loss (ml)	Administered (ml)	H_2O (ml)	Na^+ (mEq)			H_2O (ml)	Na^+ (mEq)	K^+ (mEq)		Postoperative First Day Na^+ (mEq/l)	Subsequent Days Na^+ (mEq/l)	
12. Upper GI bleeding	2.7	35	10	0	145	7	+	− 10	300	10	0	180	130	132	5
13. Cystic kidney	3.1	85	20	0	60	8	−	+ 10	200	12	3	140	134	138	6
14. Anular pancreas	1.8	125	10	0	470	38	+	+125	250	18	5	155	134	130	17
15. Intestinal malrotation	3.3	65	30	25	150	22	+	+ 50	380	12	10	215	135	134	9
16. Omphalocele	4.0	45	10	0	0	0	−	− 60	200	20	0	0	126	—	1*
17. Tracheoesophageal fistula	2.1	80	20	0	100	9	−	+100	250	7	0	165	134	132	10
18. Diaphragmatic hernia	3.5	120	30	0	400	52	−	+145	250	10	0	135	130	134	10
19. Meconium ileus	2.5	90	50	60	100	13	+	+420	270	8	0	180	134	131	9
20. Volvulus	2.6	100	15	0	100	13	+	−100	240	4.6	2	155	134	127	7
21. Imperforate anus	2.4	75	10	0	15	2	+	−230	250	8.5	0.5	140	137	134	7
22. Duodenal web	2.2	40	8	0	40	5	+	−410	280	14.5	3	145	133	128	6
23. Jejunal atresia	2.1	60	10	0	40	5	+	−120	290	12	1	185	134	127	8**
24. Jejunal atresia	2.1	110	10	0	80	11	+	−145	320	12	3	215	132	127	8
25. Gastroschesis	2.8	75	15	0	90	12	+	− 80	280	11	3	180	130	125	10

* Death due to hyaline membrane disease.
** Death due to peritonitis and septic shock.

TABLE 3. Results of Balance Studies by Protocol of

Neonate No. and Diagnosis	Weight (kg)	Operative						Postoperative	
			Blood		Fluids				
		Time (min)	Loss (ml)	Administered (ml)	H_2O (ml)	Na^+ (mEq)		Gastric tube present	Maximum weight change (g)
26. Tracheoesophageal fistula	2.3	225	30	0	110	23		−	+ 7[illegible]
27. Intestinal malrotation	3.4	60	15	0	30	4		+	+ 2[illegible]
28. Imperforate anus	3.2	100	20	0	60	8		+	− 9[illegible]
29. Duodenal obstruction due to anular pancreas	2.6	125	15	0	50	6		+	−110
30. Esophageal atresia	2.2	50	10	0	20	2.5		−	− 8[illegible]
31. Hirschsprung's disease (colostomy)	3.5	45	10	0	25	3.5		+	− 6[illegible]
32. Omphalocele	3.0	75	10	0	35	4.5		−	− 4[illegible]
33. Duodenal atresia	2.2	70	35	0	40	5		+	− 1[illegible]
34. Intestinal malrotation	3.5	55	15	0	25	3		+	+ 3[illegible]
35. Duodenal atresia	2.5	120	30	0	50	6.5		+	− 5[illegible]
36. Intestinal malrotation	2.4	105	25	0	110	23		+	+ 9[illegible]

day. For Neonates 26 through 36, balance studies were carried out daily through the fourth postoperative day.

Tables 1 and 2 supply data from all neonates who underwent surgical operations between October, 1967, and July, 1968, except those undergoing cardiac surgery. Neonates 1 to 25 included eight premature infants weighing less than 2.3 kg. Some of the neonates had multiple defects, although the tables indicate only those diagnoses for which operation was scheduled. Table 3 lists eleven neonates (four of them premature) who had no abnormalities except the conditions for which operation was planned.

Fluid Administration

Intraoperative

Mean volume requirements: Five per cent dextrose in lactated Ringer's solution was given, 8 ml/kg/hr, based on a normal maintenance requirement of 4 ml/kg/hr* plus replacement of insensible loss in the anesthetic system,[26] plus estimated translocation of ECF at the site of operation.[27]

Additional intraoperative requirements:

1. Aspirated gastric volumes were measured and replaced with equal volumes of 0.9 per cent NaCl.[28] Circulatory shifts or losses such as those resulting from edema, peritonitis, and ileus were replaced by lactated Ringer's solution, by estimation.

2. Acidosis was treated with $NaHCO_3$, 10 mEq (in 10 ml solution), repeated as indicated by blood gas studies.[14]

3. Unless otherwise indicated by clinical signs, whole-blood replacement was delayed until there had been an estimated loss of 20 per cent of the blood volume, at which time the total loss was replaced.

4. Five per cent albumin, 2.5 or 5.0 g, in lactated Ringer's solution, was administered to those neonates who still had clinical signs of hypovolemia despite replacement of a calculated volume of crystalloid solution.

Postoperative

Maintenance requirements for water and electrolytes for the normal neonate are often expressed in terms of surface area rather than body weight. Usually, however, the ill newborn scheduled for operation has a smaller body surface area and weighs less than the mature newborn. Consequently, we administered fluids on a weight basis of 100 ml/kg body weight/day to avoid over-replacement. (Otherwise, basic fluid maintenance requirements are calculated on the basis of 1.5 l/m²/day,[24, 25] recognizing that the surface area of the mature neonate closely approximates 0.2 m² and that of the average premature neonate

* 1.5 l/m²/day for the neonate with 0.2 m² body surface[24, 25] or 3 kg body weight.

Eleven Selected Newborn Infants, January–May, 1969

Postoperative														
Average Fluids/Day			Urine					Serum Electrolytes						Day Discharged from Hospital
								Postoperative First Day			Average/Day			
H_2O (ml)	Na^+ (mEq)	K^+ (mEq)	Average Volume/Day (ml)	Specific gravity	Na^+ (mEq)	K^+ (mEq)	Cl^- (mEq)	Na^+ (mEq)	Cl^- (mEq)	K^+ (mEq)	Na^+ (mEq)	Cl^- (mEq)	K^+ (mEq)	
200	6	2	130	1.015	8	8	4	136	98	5	136	90	5	11
250	22	5	140	1.005	8	4	8	131	94	5	123	98	7	8
220	7	4	120	1.021	5	4	5	138	95	4	135	101	6	7
260	13	3	180	1.003	11	8	13	135	93	5	132	100	4.5	14
260	6	3	140	1.006	4.5	7	4	142	104	6	137	103	3	11
220	14	4	140	1.015	9	6	4.5	135	98	6	132	100	5	9
250	6.5	2	140	1.008	8	8	4	137	104	5.5	132	98	5.5	20
260	13	4	120	1.015	6	4	2	130	94	5	136	112	5.5	8
270	7	2	130	1.018	7	7	5	137	98	5	134	112	5	7
220	11	4	130	1.020	5.5	5.5	3	130	96	4	122	98	6	9
200	10	4	170	1.013	9	8	4	136	98	5.5	138	92	6.5	7

is 0.15 m^2.[29]) Dextrose was given in quantities of 5 gm/kg/day to minimize protein catabolism and potassium loss.

In the uncomplicated postoperative course, a fifth of the calculated volume was given as 5 per cent dextrose in lactated Ringer's solution and the remainder as 5 per cent dextrose in distilled water. For those neonates who had been operated upon for obstructive bowel lesions, peritonitis, or other causes of abdominal distention, two-fifths of the volume was given as lactated Ringer's solution and the remainder as 5 per cent dextrose in water.[8, 30] This schedule was followed, also, for those who had elevated temperatures during the postoperative course or who were hyperventilating for any reason. Potassium as KCl, 16 mEq/l, was added to the intravenous fluid as a routine postoperative supplement.

For the complicated postoperative course, additional fluid requirements were met by 5 per cent dextrose in 0.9 per cent NaCl or by giving additional potassium in the following circumstances:

1. When there was a measured tendency toward hyponatremia, as shown by falling serum sodium measurements in the range of 135 down to 130 mEq/l, two-fifths of the daily maintenance volume was given as lactated Ringer's solution with 5 per cent dextrose.

2. For those patients having definite hyponatremia (serum sodium less than 130 mEq/l), correction volumes of 0.9 per cent sodium chloride were calculated on the basis of restoring total body water (75 per cent of body weight[31]).

3. For metabolic alkalosis, two-fifths of the daily volume was given as 0.9 per cent NaCl with additional potassium calculated from serum levels.

4. Obvious abnormal losses resulting from gastric suction, gastric lavage, chest tubes and peritoneal drains were replaced with equal volumes of 0.9 per cent NaCl, plus replacement of potassium (2–4 mEq/day) in addition to the normal postoperative supplement.

The neonates were placed in special incubators in which temperature and humidity were controlled. We assumed, therefore, that insensible water loss was at the lower limits of normal, compensated for by basic fluid maintenance. (With fever and hyperventilation, insensible losses in a dry atmosphere could amount to 70 ml/kg/day. Although exhaled air normally does not contain electrolytes, sweat losses in the feverish neonate may amount to 2.0 mEq of Na^+/kg/day.[24]).

Results

Neonates 1 through 25 represent all those who underwent surgical operations during the period from October, 1967, through July, 1968.

Salient facts are summarized in table 4. Neonates 1 through 11 represent retrospective studies of anesthesia records and charts. The one death recorded was that of a neonate operated upon for meconium ileus, with death on the fifth postoperative day attributed to aspiration pneumonia.

Neonates 12 through 25 include those for whom data were collected during the operative and postoperative courses. In this group there were two deaths. One underwent repair of an omphalocele, and died of hyaline membrane disease on the first postoperative day. The other death was that of a premature neonate operated upon for jejunal atresia; death on the eighth postoperative day was attributed to peritonitis and septic shock.

There were no deaths in neonates 26 through 36, anesthetized after July, 1968, selected for complete studies. They had no defects other than the conditions for which they were operated upon.

The mean volume of intraoperative fluids for neonates 1 through 25 was 115 ml with 14 mEq sodium, with a range from 10 to 470 ml, and a range of sodium from 1 to 52 mEq. Neonate 5, who received only 10 ml volume and 1 mEq sodium, had a serum sodium concentration of 134 mEq/l, which fell to 131 mEq/l as larger volumes were used for hydration in postoperatively. Obviously, insufficient volume and electrolytes were given during operation.

Neonate 14, a premature infant weighing 1.8 kg, underwent duodenoduodenostomy because of an anular pancreas. Intravenous administration of half-strength NaCl was begun in the operating room before induction of anesthesia, and unintentionally 470 ml with 38 mEq sodium was given. This constituted a gross fluid overload, but was well tolerated, as judged by a weight gain of only 125 gm on the first postoperative day. Adequate urinary output compensated for this volume.

Neonate 18, weighing 3.5 kg, had severe respiratory distress because of a congenital diaphragmatic hernia. For correction of severe acidosis, he was given 10 mEq $NaHCO_3$, repeated three times, and 260 ml 5 per cent dextrose in water. Since clinical signs still indicated hypovolemia (continued low blood pressure and rapid, weak pulse) he was given 5 gm albumin diluted to 100 ml with lactated Ringer's solution. Because of anticipated ventilatory problems, he was maintained on a volume-controlled ventilator for 24 hours postoperatively. During this time he showed obvious signs of hypotonic fluid overload (water intoxication) despite having received 52 mEq sodium during operation, the largest intraoperative administration of sodium in the series. (Signs of water overload include rapid, full pulse, salivation, full fontanelles, copious diuresis, and "fingerprinting" on the forehead. This last, valuable, sign indicates a hypotonic interstitial-fluid overload and can be differentiated from the usual pitting edema resulting from isotonic interstitial overload. The sign usually is elicited on the forehead and the sternum, although in this case surgical dressings precluded the latter.)

In Neonates 26 through 36, the average intraoperative fluid intake was 50 ml, with 5 mEq of sodium.

Of the 36 neonates, only four received blood intraoperatively in addition to the mean volume requirements of 8 ml/kg/hr of saline solution. Neonate 4, a 2.6-kg infant undergoing repair of a meningomyelocoele, lost 100 ml of blood and received 70 ml as replacement; Neonate 6, a 2.3-kg premature infant with meconium ileus and cystic fibrosis, received 20 ml for a loss of 25 ml; Neonate 15, a 3.3-kg infant with intestinal malrotation, lost 30 ml and had 25 ml as replacement; Neonate 19, a 2.5-kg infant with meconium ileus, had a 50-ml loss and received a replacement of 60 ml.

Discussion

For many reasons, there have been misconceptions and confusion about intraoperative administration of fluid and electrolytes to the newborn infant. Various yardsticks have been recommended, as illustrated in a symposium in 1959,[21] in which eight different techniques for fluid administration were suggested.

One approach is to use neonatal body weight as a percentage of adult body weight, but there are defects in this system. This formula does not take into account reduced glomerular filtration rate or the apparent decreased concentrating ability of the neonatal

TABLE 4. Summary of Tables 1, 2, and 3

Neonate Nos.	Premature	Mature	Intra-abdominal Operation	Extra-abdominal Operation	Mortality Rate
1–25	9(2 deaths)	16(1 death)	17	9	12 per cent
26–36	3	8	9	2	0 per cent

kidney. In addition, body water comprises a greater percentage of body weight in the infant than in the adult, and there is a more rapid turnover of water. Since the metabolic rate per kilogram of body weight in the infant is about three times that of the adult, the water requirements per kilogram of body weight are greater. For both infants and adults, the lean body mass contains 73 per cent water. However, the total body water of the lean adult male is considered to be 60 per cent of body weight, a third distributed in extracellular fluids and two-thirds intracellularly. By comparison, the body water of the newborn approaches 80 per cent of body weight, divided almost equally between the extracellular and intracellular compartments.

A comparison of kidney function in the adult and that in the neonate on the basis of percentages of extracellular fluid is valid since functional maturity of the kidney is achieved before the end of the first month of life. An important exception is that the neonatal kidney will continue to excrete sodium despite hyponatremia.

In Neonates 26 through 36, mean daily intravenous therapy consisted of 240 ml, containing 10.5 mEq sodium. The serum sodium on the first postoperative day averaged 136 mEq/l (range 130–142 mEq/l), a mean decrease in subsequent daily determinations of 4 mEq/l. Average daily urinary volume was 140 ml, with a specific gravity of 1.012, containing sodium, 7.3 mEq, potassium, 6.4 mEq, and chloride 5 mEq. Nine patients in this study had definite hyponatremia below 130 mEq/l. Two of these, listed in table 2, had mean urinary sodium concentrations of 8.0 and 5.5 mg daily. These findings bolster our opinion that the neonatal kidney lacks the ability to retain sodium despite hyponatremia, and that fluid therapy during major surgical operations on neonates should include sodium administration.

The average electrolyte excretion in the urine of this group averaged 460 mOsm, indicating a concentrating ability compared with a normal extracellular fluid value of approximately 280 mOsm/l. The newborn infant operated upon and maintained on salt-free liquid may develop severe changes resulting from salt loss and water overload. The quantity of electrolytes excreted in urine indicates that the neonatal kidney does have the ability to concentrate urine. The kidney of the normal newborn infant usually does not concentrate urine simply because there is a brisk diuresis, representing the normal response to a normally large extracellular fluid volume.[32] All ill neonate who has hypohydration and fever can produce urine with a specific gravity as high as 1.030, with return to the usual range after fever has subsided and adequate fluid intake is re-established.

In adults, a loss of salt-containing extracellular fluid from the circulation resulting from tissue trauma, excess blood loss, or hemorrhagic shock has been shown by isotope measurements (in the early equilibration stage). Excretion of salt in the urine of the adult diminishes greatly under these circumstances. It is common practice to administer a balanced salt solution (the constituents similar to plasma but without protein) to adults during anesthesia to replace that which is translocated from the circulation in the body. We feel that extracellular fluid also becomes translocated in neonates undergoing major operations with tissue trauma, and that these patients need to have salt replacement to compensate for losses. In addition, we have shown that urinary sodium loss continues in the neonate.

In minor surgery associated with little tissue trauma or blood loss in the neonate there is less indication for fluid replacement of any kind. Because of the relative abundance of extracellular fluid in the neonate, minor disturbances of salt and fluid balance are rather easily compensated.

Operations on these 36 neonates were done for the following conditions, all of which we classify as major procedures necessitating fluid administration: duodenal atresia, six patients; intestinal malrotation, five; small-intestinal atresia or volvulus, five; omphalocoele, three; imperforate anus, three; meningomyelocele, two; tracheoesophageal fistula, two; meconium ileus, two; and one patient each, the Pierre-Robin syndrome, teratoma of the tongue, colostomy, lung bleb, cystic kidney, esophageal atresia, diaphragmatic hernia, and upper gastrointestinal bleeding. For these we believed there were compelling indications for fluid and electrolyte administration.

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