CHAPTER 5
Fluids and Electrolyte Therapy in the Paediatric Surgical Patient

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Introduction

Perioperative fluid and electrolyte management for infants and children can be confusing due the numerous opinions, formulas, and clinical applications, which can result in a picture that is not practical and often misleading. The basic principles of fluid and electrolyte management are similar in the neonate and the paediatric patient if one considers the exceptions, which include renal maturity, body composition, physiological losses, delivery issues, and autonomic nervous system differences. Understanding the ability of the neonate and older paediatric patient to compensate for fluid and electrolyte alterations due to the surgical pathology is addressed here after an overview of normal fluid and electrolyte metabolism.

Perioperative fluid and electrolyte management addresses dehydration, fasting status, intraoperative fluid management, postoperative issues, and transfusion therapy. When practicing in a resource-limited medical practice setting, one needs to be able to manage extremes of fluid and electrolyte issues with less laboratory and investigative infrastructure in patients who may have delayed presentation after their surgical pathology presented itself. The physician who cares for the surgical needs of the neonate and paediatric patient population must be keenly aware of the perioperative needs regarding fluid and electrolyte metabolism requirements. This understanding will increase the goal of a successful and safe surgical course for both the paediatric patient and the patient's parents.

Renal Function

Physiology of the Newborn

The neonatal renal function is not at adult levels until after the age of 1–2 years due to many factors. The renal blood flow (RBF) reaches adult levels (20% of cardiac output (CO)) around the age of 2 years, whereas the glomerular filtration rate (GFR) shows the effects of increasing in size, not number, of the glomeruli after the age of 1 year (Table 5.1). Although the neonate is able to cope with routine fluid and electrolyte requirements, it is during times of dehydration, acidosis, trauma, excessive fluid, and solute load that the neonate demonstrates immaturity in renal function. This immaturity in renal function is even more evident in patients who are less than 34 weeks gestational age at birth; studies demonstrate that when a newborn is between 25 and 28 weeks gestational age, it takes 8 weeks for their GFR to reach that of term infants.[1]

The term and preterm neonate will not have a complete diuretic response to a water load until after 5 days of age, and the preterm will have an even slower response when compared to an adult response. Newborns may have an altered ability to concentrate urine, tend to have lower thresholds for glucose excretion, have unnecessary excretions of sodium, and have poor tolerances for fluid loads, all of which are amplified in the preterm infant. By 1 month of age, the full-term infant's kidney is about 70–80% mature in comparison to that of a healthy adult patient. One of the primary homeostatic functions of the kidney is to maintain proper sodium levels in the body.

Term infants in nonphysiological stressful situations can maintain normal sodium levels, but preterm infants less than 32 weeks gestational age would be considered "salt losers". Their ability to conserve sodium is even further altered by hyperbilirubinaemia, hypoxia, and increased intraperitoneal pressure, which may decrease RBF and thus produce a state of hyponatraemia. In the desire to replace the sodium that may be lost in the gastric, due to intestinal obstructional loss, or by diarrhoea, the physician may give the neonate an excessive load of sodium, which may override the tubular functions of the immature renal system and even produce a state of hypernatraemia. Complications, including reopening of the ductus arteriosus and cerebral bleed, can be caused by hypertonicity due to the elevated sodium load.

Table 5.1: Glomerular filtration rate.

	GFR by postnatal age (mean ± SD)		
Gestational age	**1 week**	**2–8 weeks**	**>8 weeks**
Normal GFR (ml/min/1.73 m^2)	11.0 ± 5.4^{a}	15.5 ± 6.2^{a}	$47.4 \pm 21.5^{a,b}$
25–28 weeks	10	26	9
No. of subjects	6	9	26
Mean – 1 SD^{c}	15.3 ± 5.6^{a}	$28.7 \pm 13.8^{a,b}$	51.4
29–34 weeks	27	27	1
No. of subjects	10	15	
Mean – 1 SD	40.6 ± 14.8	65.8 ± 24.8^{b}	95.7 ± 21.7^{b}
38–42 weeks	26	20	28
No. of subjects			
Absolute GFR (ml/min)	0.64 ± 0.33^{a}	0.88 ± 0.42^{a}	5.90 ± 5.92^{a}
25–28 weeks	1.22 ± 0.45^{a}	$2.43 \pm 1.27^{a,b}$	10.83
29–34 weeks	5.32 ± 1.99	11.15 ± 5.21^{b}	20.95 ± 6.40^{b}
38–42 weeks			

[a] Significantly less than corresponding value in full-term infants.
[b] Significant increase compared with previous age group.
[c] Mean – 1 SD represents lower cutoff value.

Table 5.2: Clinical significance of newborns' physiological presentations.

Physiology	Clinical significance
Low glomerular filtration due to Low perfusion pressure High renal vascular resistance	Poor tolerance volume load Poor tolerance sodium level
Only juxtamedullary glomeruli are functional Fewer and smaller glomeruli Smaller glomerular pore size	
Diminished proximal tubular function Low blood flow to juxtamedullary nephron tubules Less tubular mass per nephron Glomerular-tubular imbalance	Tendency to excrete filtered sodium Low threshold for glucose excretion
Diminished proximal tubular function Low blood flow to juxtamedullary nephron tubules Less tubular mass per nephron Glomerular-tubular imbalance	Inability to concentrate urine

Potassium balance in the preterm infant can be an issue if the excretion of potassium and the extracellular movement of potassium occur after acidosis. This situation can easily be seen in many situations that would prompt the need for surgical intervention, especially if the presentation to a health care facility is delayed. Usually the newborn can manage with a potassium level of approximately 6 mmol/l, and the technique of taking the blood sample needs to be determined due the common occurrence of haemolysed blood cells and a falsely elevated potassium level.

Additional factors that may influence the renal function include maternal oligohydramnios, maternal drug use (indomethacin), polycystic disease in the family, and some forms of urinary obstruction. Any situation whereby the infant has hypoxia, hypotension, or haemorrhage may lead to a decreased RBF and a subsequent drop in the normal urine output. All of these factors point toward the reminder that infants (especially preterm) must have their fluid status closely monitored so that homeostasis is maintained, or approached, in the circumstance surrounding the need for surgical intervention. The lack of urine pH monitoring and more extensive laboratory testing abilities should not determine the impact that a detailed history and basic renal function monitoring can have on the improvement of surgical outcome, which involves renal function immaturity.

Table 5.2 presents the clinical significance of newborns' physiological presentations.

Clinical Evaluation of Renal Function

The physical characteristics of the newborn may give the examiner a clue as to a possible renal dysfunction. Low-set ears, flattened nose, and VATER (Vertebrae, Anus, Trachea, Esophagus, and Renal) or VACTERAL (Vertebral and spinal cord, Anorectal, Cardiac, TracheoEsophageal, Renal and other urinary tract, Limb) syndrome may heighten the suspicion of renal function issues. The occurrence of an elevated systolic blood pressure, or systolic blood pressure greater than 90 mm Hg in the term infant, may indicate renal insufficiency, but usually these findings are associated not with renal problems but with other issues such as pain or hunger. An accurate measurement of blood pressure is sometimes difficult, but equally necessary, so that the more subtle findings can be helpful in the diagnosis of renal disease.

The absence of abdominal wall musculature can indicate prune belly syndrome, and the evidence of one umbilical artery connecting to the placenta correlates with an increased incidence of cardiac and renal malformations. The examination of the placenta is an easy task that could benefit the care of the newborn surgical or nonsurgical patient when renal function is in question. Oedema in the newborn, which is abnormal in the term child, can also indicate renal disease related to an underlying cardiac problem, hypoxia due to respiratory insufficiency, or low albumin levels, among the list of causes that may include renal dysfunction. The infant with liver failure may present with signs of oedema that are unrelated to any renal problems. A history of asphyxia commonly leads to a marked decrease in urine output. Sepsis is the other common cause of acute renal failure in the neonate. A syndrome of inappropriate antidiuretic hormone (ADH) may accompany asphyxia, which may lead to fluid and electrolyte abnormalities. Once hypotension and oxygen needs are addressed, fluids may need to be restricted until diuresis occurs with fluids.

The perioperative patient who arrives late in the progression of a surgical disease may present with signs of severe dehydration, and it often is difficult to get a detailed history regarding urine output in the neonate. The clinical evaluation of the neonate, which would include alertness, skin turgor, anterior fontanelle size or dimensions, heart rate, blood pressure, and presence or lack of urine, would assist in the determination of renal function and fluid status. Routinely, if the urine output history is questionable, the placement of gauze near the urethra opening could be weighed to assist in obtaining the objective information needed to determine urine output preoperatively.

Laboratory Evaluation of Renal Function

Obtaining the serum creatinine level, which is available in most hospital settings, is the simplest method of determining the glomerular function in the infant. Initially, the creatinine and even sodium level in the newborn is a representation of the maternal electrolyte balance and renal function. A number of factors determine newborn creatinine levels such as maternal levels, gestational age, muscle mass, and fluid balance. Increasing creatinine levels over the first few days of life indicates some form of renal dysfunction. If an infant is born at a gestational age of 25–28 weeks, it will take approximately 8 weeks before the GFR, and thus serum creatinine levels, approach the levels of a term infant.[1]

On a clinical note, the use of gentamicin in the perioperative surgical newborn, if the levels of gentamicin are not measured due to resource constraints, can potentially increase the amount of renal dysfunction in this patient population. In a recent study in India, dosing of gentamicin with the following neonate weights was considered safe:[2]

- 10 mg every 48 hours for the neonate weighing less than 2000 grams
- 10 mg every 24 hours in the neonate weighing 2000–2249 grams
- 13.5 mg every 24 hours for the neonate weighing more than 2500 grams

Gentamicin interval errors are the most common drug error reported in a recent neonatal intensive care unit (NICU) study from the United States, and certainly the effect on renal function is amplified in a setting where drug levels cannot be measured.[3] Gentamicin and ampicillin are the two most commonly prescribed antibiotics in the NICU environment, and inappropriate dosing can cause clinically significant renal damage.

Sodium excretion, which is directly correlated to GFR and indirectly to gestational age, becomes an issue in situations where there is sodium load or the need to retain sodium arises. The kidney's ability to retain sodium in preterm infants will not reach the term infant's level until they reach the gestational age of a term infant. Clinically, this can produce situations of appropriate release of ADH and reabsorption of water in a setting where the patient is getting a volume of hypotonic fluid, such as 0.25% saline in 5% dextrose. If the sodium level goes below 120 mEq/l, then the patient could show signs of neurologic injury, which can be nonreversible.

A urinalysis that shows colour (concentration, presence of bilirubin), red blood cells, white blood cells, protein, and glucose can help to diagnose some renal problems. The observation of protein in the urine can be normal in the first few days of life and then can become expected in cases of hypoxia, congenital cardiac problems, and dehydration. Small amounts of glycosuria can be detected secondary to a low tubular reabsorption with a glucose load, and the glucose load can even result in an osmotic diuresis and dehydration. Glucose in the urine may be an early sign of sepsis, especially in the presence of other factors.

Normal Fluid and Electrolyte Metabolism

Total Body Water

At birth, the infant is suddenly separated from the source of water found in the in utero environment, and now is in an environment with significant water loss from the skin and respiratory tract, thus promoting a potential for early dehydration. During this period of transition, water intake and renal conservation of fluids needs to maintain a homeostatic state to survive.

Total body water compromises intracellular water (ICW) and extracellular water (ECW), with the ECW having an intravascular and interstitial component. With advancing gestational age, the amount of total body water declines from 94% of body weight in the third trimester to approximately 78% at term. In the immediate postnatal period, the amount of extracellular fluid decreases and the percentage of intracellular fluid increases, although the newborn has a large interstitial reserve volume during times of decreased fluid intake. The term infant can compensate more than the preterm infant, but newborns with a large surface-to-weight ratio, higher total water content, limited renal ability to concentrate, greater insensible water loss from thin skin, and high blood flow all can become clinically dehydrated in a very short period of time. The added water loss associated with radiant warmers, which are commonly found in the treatment of the newborn and especially preterm infants, can result in a rapid and progressive level of dehydration without close observation and appropriate fluid intake adjustments.[1]

Fluid Requirements

Fluid requirements in the newborn or older child depend upon multiple factors, but the majority are determined by the insensible water loss and the newborn's metabolic rate. The evaporation of water from the skin and the respiratory tract has environmental factors, such as air and incubator temperature, humidity, and air flow across the child's body, as well as infant factors, such as patient position, metabolic rate, and elevation in temperature.

Many studies have indicated that water loss from the premature infant is significantly greater than from the term infant, possibly due to decreased subcutaneous fat and increased permeability through the skin. The combination of increased water loss in the premature infant and the use of radiant warmers without humidity, which occurs in many settings, can result in a severely dehydrated premature infant who may need resuscitation. The insensible water loss can increase 50–200% with the use of radiant warmers in the preterm infant. This can have an significant impact on the intraoperative course, as the patient may arrive in the operating theatre dehydrated even though receiving maintenance fluids in the immediate preoperative period. The low-tech approach to humidity can be achieved merely by keeping an open container of water near the newborn while under warming lights. Fluid chambers need to be cleaned and changed routinely in an effort to decrease infection in the nursery unit, and the fluid level of radiant warmers, which may vary depending upon the manufacturer, needs to be monitored.

Many formulas exist to determine the maintenance fluid levels for the neonate or small child. The formula of the "4-2-1 rule" works well for determining the maintenance fluids for weight groups that are less than 30 kg. In this formula, the first 10 kg of body weight is multiplied by 4 ml/hr; the second 10 kg is multiplied by 2 ml/hr; and any additional kilograms of weight are multiplied by 1 ml/hr.[4] Table 5.3 provides examples that apply to newborns and older children to determine maintenance fluids. Intraoperative fluid management is discussed in a later section of this chapter that describes translocated fluid and blood loss. Typically, if one has a 1-ml blood loss, then this 1 ml is replaced by 3 ml of crystalloid, which could be normal saline or Ringer's lactate solution. This amount of replacement allows for the intravascular volume to be maintained, even during times of decreasing intravascular volume, which could be surgery.

Table 5.3: Sample 4-2-1 rule for maintenance fluids for newborns and older children.

Child's body weight	Volume
9 kg	4 × 9 = 36 2 × 0 = 0 1 × 0 = 0 36 cc/hr
15 kg	4 × 10 = 40 2 × 5 = 10 1 × 0 = 0 50 cc/hr
26 kg	4 × 10 = 40 2 × 10 = 20 1 × 6 = 6 66 cc/hr

Table 5.4: Signs and symptoms of dehydration.

Percent of body weight	Signs and symptoms of dehydration
1–5% (mild)	• History of 12–24 hours of vomiting and diarrhoea • Dry mouth • Decreased urination
6–10% (moderate)	• Tenting skin • Sunken eyes, fontanelle • Oliguria • Lethargy
11–15% (severe)	• Cardiovascular instability: mottling, hypotension, tachycardia • Anuria • Sensorium change
20%	• Coma • Shock

Glucose Requirements

Carbohydrate reserves are relatively low in the newborn and certainly will drop to low levels during the prolonged labour course often seen in some areas of Africa. Thirty percent of the glucose reserves are stored as glycogen in the liver, but this cushion is less evident in the low-birth-weight or preterm infant. Within the first four hours of life, the newborn must be given some form of glucose. With prematurity and a gestational age of less than 34 weeks, the ability to swallow is low, so the patient may need an intravenous (IV) line or a feeding tube. Adequate and frequent measurement of the glucose levels of the newborn, especially the newborn pending surgery, is cost effective and will help manage the hypoglycaemia and hyperglycaemia episodes that may harm the infant.

Children who are small for gestational age (SGA), have chronic illnesses, had a prolonged NPO (nothing by mouth) period, premature infants, and infants of diabetic mothers are all at risk for hypoglycaemia during their hospital course. In SGA infants, hypoglycaemia usually occurs 24–72 hours after birth, when the glycogen stores are depleted and the breast milk production may not yet meet demand. In Kenya, we use D 10 (80 ml) mixed with normal saline (NS; 20 ml) in a buretrol of 100 ml and then begin our maintenance fluids and monitor blood glucose levels. The 60 drops per ml buretrols allow us to give the appropriate volume of fluids, which will prevent volume overload (never place more than the volume for 4 hours of maintenance fluids in the buretrol) while adapting the amounts of dextrose and normal saline based upon basic lab values.

Glucose level instability is commonly seen in those patients who are septic or have had a period of hypotension or asphyxia. These patients need close monitoring every hour in the operating theatre to adjust glucose levels; they all need glucose in their operative fluids to prevent the severe complications associated with hypoglycaemia. Intraoperative glucose administration is controversial but, in general, 5% dextrose is adequate because the metabolic stress response to surgery will avoid the patient becoming hypoglycaemic. Neurosurgical cases need very close glucose control due to cerebral ischaemia issues and hyperglycaemia.

Perioperative Fluid and Electrolyte Management

Dehydration

The severity of dehydration should be estimated based upon the history and clinical findings. There are no unique lab values that can accurately determine the severity of dehydration, but certainly an experienced medical care provider becomes adept at the estimation of dehydration in the paediatric population. Oliguria, lethargy, and cardiovascular instability are all symptoms commonly seen when a paediatric patient has severe dehydration.[4] Some common surgical paediatric issues that can cause severe dehydration include bowel obstruction, acute burns, intestinal perforation, myelomeningocele (open), and trauma. Table 5.4 presents signs and symptoms of dehydration by percentage of body weight.[5]

The compensatory mechanisms for dehydration that are seen in the adult population are less well defined in the term infant and even less so in the preterm infant. The body's primary mechanism for compensation is the renin-angiotensin-aldosterone system, which attempts to absorb sodium and water. Renin is released from the kidneys, which then prompts the release of aldosterone and ADH, which then allows for the water and sodium to be reabsorbed. The newborn is able to allocate some of the extracellular fluid to the plasma volume, but this compensation is limited and will result in the loss of skin turgor. The newborn's cardiac output is determined by the heart rate because the intrinsic heart muscle is noncompliant, therefore making the adjustment in preload volume very difficult. If a patient arrives in a state of severe dehydration and shock, then the infusion of 20–30 ml/kg of normal saline must be started while others monitor for the improvement in fluid status. Urine output and concentration (appearance) will be the most accurate and cost-effective measurements that will allow for the monitoring of the overall fluid status. The placement of an intraossaeous line is now preferred if a peripheral intravenous line cannot be placed quickly during the resuscitation time in a severely dehydrated child. Studies have shown that normal saline is as good a volume resuscitator as any fluid available (Table 5.5), and it certainly is cost effective; therefore, there is no need to use the more expensive colloids during fluid resuscitation.

NPO Period in the Paediatric Population

There has been considerable debate about NPO status in children, and NPO guidelines have undergone adjustment. At this time, we no longer use the former prolonged times that once produced surgical patients who were relatively volume depleted upon the start of surgery. It has been shown that clear liquids given 3 hours before surgery results in a lower gastric volume and no change in gastric acidity. A clear liquid is one that has no particulate matter, which means that you can see through the fluid if held up to the light without obstruction.

Infants who are on formula need 6 hours, and breast-feeding infants need 4 hours, at our institution in Kenya, but at some hospitals this would be considered a "clear" liquid and only 3 hours are required for NPO. These modifications have allowed for situations in which the children's veins are more distended and, hopefully, children and parents who are happier during the preoperative period. The type of surgery and reason for the surgical intervention will also dictate the ability to take fluids by mouth. Many neonates who need emergency surgery have never been on any fluids, and NPO is not an issue, but if the patient has a bowel obstruction, for example, then the need for a rapid sequence induction (anaesthesia) may override any NPO concerns.

Intraoperative Fluids

The calculation of intraoperative fluid requirements can be allocated into the following sections: maintenance fluids, preoperative fluid deficit, insensible losses, and estimated blood loss (Table 5.6). Maintenance fluids per hour required based upon a patient's weight was discussed earlier; typically, normal saline or Ringer's lactate are the fluids of choice, as they most closely represent the plasma components. The preoperative deficit will be the patient's weight in kilograms multiplied by the number of hours without any fluids. The insensible losses depend upon many factors, but primarily will be based upon the size of the incision and whether exposure of the bowel or viscus is involved, as this will increase fluid loss (see Table 5.6). The estimated blood loss needs to be replaced as well, with a ratio of 3 ml of normal saline for every 1 ml of blood loss.

Table 5.5: Composition of intravenous crystalloid solutions.

Solution	Glucose (g/l)	Na^+ (mEq/l)	K^+ (mEq/l)	Cl^- (mEq/l)	Lactate (mEq/l)	Ca^{+2} (mEq/l)	pH	Osm
5% dextrose	50	–	–	–	–	–	4.5	253
Ringer's	–	147	4	155	–	4	6.0	309
Lactated Ringer's	–	130	4	109	28	3	6.3	273
D_5 lactated Ringer's	50	130	4	109	28	3	4.9	525
D_5 0.22% NSS*	50	38.5	–	38.5	–	–	4.4	330
D_5 0.45% NSS*	50	77	–	77	–	–	4.4	407
0.9% NSS*	–	154	–	154	–	–	5.6	308

Note: NSS = normal saline solution

Table 5.6: Intraoperative fluid requirements.

1. Estimated fluid requirement (EFR) per hour (maintenance fluids)	0–10 kg = 4 ml/kg/hr + 10–20 kg = 2 ml/kg/hr + >20 kg = 1 ml/kg/hr (e.g., 23-kg child = 40 ml + 20 ml + 3 ml, so EFR= 63 ml/hr)
2. Estimated preoperative fluid deficit (EFD)	EFD = Number of hours NPO × weight (in kg) (e.g., 23-kg child NPO for 8 hours EFD = 8 × 23 = 184 ml) 1st hour = ½ EFD + EFR 2nd hour = ¼ EFD + EFR 3rd hour = ¼ EFD + EFR
3. Insensible losses (IL): (add EFR and EFD)	Minimal incision = 3–5 ml/kg/hr Moderate incision with viscus exposure = 5–10 ml/kg/hr Large incision with bowel exposure = 8–20 ml/kg/hr
4. Estimated blood loss	Replace maximum allowable blood loss (ABL) with crystalloid 3:1

The estimated blood loss is extremely difficult to determine in the newborn surgical patient, and the anaesthesia care provider needs to calculate the estimated blood volume and allowable blood loss for every patient before surgery. The surgery team must closely monitor blood loss and, with sponge observation, determine the blood loss at many points during the surgical procedure. Invasive monitoring, even in large surgical procedures, is rare in most areas of Africa, so the use of noninvasive blood pressure, urine output, elevations in heart rate, and capillary perfusion need to provide clues to the overall fluid status of the patient during a surgical procedure. If a pulse oximeter is available, then the waveform changes can help with the perfusion pulse pressure, which may indicate a change in blood volume, cardiac output, or temperature.

If the blood loss is above the allowable blood loss based upon the starting haemoglobin, then fresh whole blood is the most commonly transfused component in Africa. The development of a "walking blood bank" should be an aspect of each hospital involved in operative procedures. This would entail a group of donors known by the hospital lab who can donate blood for emergencies; the opportunity to use warm, fresh (nonstored) blood in the paediatric surgical patient can be life-saving. The inability to adequately warm stored blood is always an issue when a neonate is requiring blood in surgery. If stored (cold) blood is required, a warm bath of water with the tubing within the bath is often useful to help warm the fluids. Hypothermia in a paediatric patient can result in slow awakening and, in the extreme case, cardiac arrhythmias. The use of the buretrol and a three-way stopcock is the most useful manner to give blood in a newborn or very small paediatric patient. A 10- or 20-ml syringe is applied to the stopcock, and the exact amount of blood or volume of other fluid can be given, with this amount accurately recorded. Blood products should be initially given in 10 ml/kg increments and as needed based upon heart rate and blood pressure; more should be added to maintain a normal intravascular blood volume.

The estimated blood volume in the paediatric patient is as follows:

Premature infant	90–100ml/kg
Full-term infant	80–90 ml/kg
3 months–1 year	75–80 ml/kg
>1 year	70–75 ml/kg

Complications that can occur in the surgical neonate or paediatric patient in regard to fluids and electrolytes intraoperatively include fluid overload and pulmonary oedema; hypocalcaemia with large amounts of blood transfusions; elevated potassium levels; hypothermia due to the infusion of cold fluids; hypotension secondary to hypovolaemia; and low sodium levels if D 10 is infused without the addition of any electrolytes. It should be noted that at any sign of bradycardia in the surgical neonate, one must first verify the condition of the respiratory system because bradycardia is one of the first signs of poor oxygenation. Principles for therapy for fluid overload in the paediatric patient include fluid restriction, salt restriction, diuresis or even dialysis, and albumin that is salt poor to help with the fluid status.[4]

Postoperative Fluid Management

In the neonate, postoperative hypothermia is frequently an issue that will affect the recovery time as well as the ability to use fluids that are not warm because this may further decrease the body temperature. *A clinical note:* The cold betadine that is used for surgical procedures can prompt hypothermia because the patient can be soaking in the fluid left over from the initial prep during the length of the procedure. If this sterilisation agent is not removed from the skin of a newborn after the surgery, the patient can develop a chemical burn that can add to the patient's perioperative morbidity.

Electrolytes, glucose, and haemoglobin levels, as well as the documentation of good urine output should be determined within the first few hours after surgery. The normal urine output of >0.5 ml/kg/hr should be measured to help guide the fluid status; at times, a small feeding tube placed in the bladder may be the only method available to measure urine output accurately. The immaturity of the renal system needs to be considered with the intraoperative fluid shifts, which may not promote a diuresis, as expected in older patients. The use of radiant warmers will help with the hypothermia but also add to insensible fluid losses; therefore, removal of these warmers will need to be considered once the temperature returns to a more normal level.

Nausea and vomiting can be seen in the paediatric postoperative patient, but usually this is not an issue in a newborn. Third spacing from the surgical procedure (i.e., loss of fluid from an open abdomen during surgery) is an ongoing issue in the immediate postoperative period, which may influence the overall fluid replacement in this period. The opportunity for the newborn to resume breast milk intake will be dictated by the surgical procedure and the surgeon's preference. Successful surgery in the newborn period is one in which the patient is reunited with the parents so that normal bonding can resume and the patient can quickly return to the family home or village.

Summary of Fluid and Electrolyte Balance

Fluid Balance

- Normal maintenance fluid: Ringer's lactate at rates shown in Table 5.3.
- Resuscitation fluid: 20–30ml/kg bolus using normal saline.
- Preoperative dehydration caused by: vomiting, bowel obstruction, overheating, acute burns, intestinal perforation, myelomeningocele (open), open wounds, abdominal wall defects, and trauma.
- Overhydration: may be iatrogenic.
- Fluid imbalance assessment: see Table 5.6.

Sodium Balance

- Normal sodium requirement: 2–4 mmol/kg per day.
- Normal serum sodium: 135–140 mmol/l.
- Causes of hyponatraemia: iatrogenic with hypotonic solutions, laboratory error, polyuric renal failure, diuretic treatment, congestive cardiac failure, Addison's disease, and maternal hyponatraemia.
- Signs of hyponatraemia: failure to thrive, seizures, and cerebral oedema.
- Causes of hypernatraemia: iatrogenic infusion, laboratory error, dehydration, and maternal hypernatraemia.
- Signs of hypernatraemia: dehydration and seizures.
- Treatment of sodium imbalance: by appropriate usage and adjustment of fluid therapy.

Potassium Balance

- An intracellular ion with a normal requirement of 1–3 mmol/kg per day.
- Normal serum potassium: 3.5–5.5 mml/l.

Hyperkalaemia

- Causes: bruising, haemolysis, renal failure, hypoglycaemia, tissue hypoxia and poor peripheral perfusion, haemolysed blood sample, and inappropriate potassium supplementation.
- Exacerbating factors: hypocalcaemia, hyponatraimia, and acidosis.
- Treatment required for serum potassium levels >7.0 mmol/l:
  - 7.0–8.0 mmol/l without ECG changes: remove potassium source and give calcium resonium 0.5–1 g/kg in divided doses per rectum or orally.
  - >8.0 mmol/l and/or ECG changes (depressed P waves, peaked T waves, wide QRS complexes): emergency treatment required.
  - Emergency treatment for hyperkalaemia:
    1. Remove source of potassium.
    2. 10% calcium gluconate: 1.0 ml/kg IV (dilute 50:50, give over at least 2 minutes). This has a transient effect on electrocardiogram (ECG), not on K+ concentration.
    3. Salbutamol: 4 µg/kg over 10 minutes.
    4. $NaHCO_3$: can be tried, especially if acidotic. Dose is 2 mmol/kg (= 4 ml/kg 4.2% NaHCO3) at 1–2 mmol per minute.
    5. Glucose: 0.5 g/kg per dose: 5 ml/kg of 10% dextrose or 2 ml/kg of 25% dextrose or 1 ml/kg of 50% dextrose, over 15–30 minutes.
    6. Insulin: 0.2 unit per gram of glucose, 1.0 unit/kg insulin with 4ml/kg 25% dextrose over 30 minutes.

Hypokalaemia

- Serum potassium: <3.0 mmol/l.
- Causes: inadequate intake, intestinal obstruction, vomiting, diarrhoea, diuretics, polyuric renal failure, and alkalosis.
- Presentation: cardiac arrythmias, paralytic ileus, urinary retention, and respiratory distress.
- Treatment: by supplementation.

Acid–Base Balance

- Normal: pH is 7.4 and bicarbonate is 25 mmol/l.
- Metabolic acidosis causes: asphyxia, tissue ischaemia, acute renal failure, diarrhoea, dehydration, and stoma losses. Treat cause and bicarbonate infusion is rarely used.
- Metabolic alkalosis causes: vomiting, pyloric stenosis, and upper gastrointestinal obstruction. Correction by fluid, sodium, and potassium replacement.

Glucose Balance

- Normal serum levels: 2.5–7.0 mmol/l.
- Hypoglycaemia: <2–2.5 mmol/l.
- Hypoglycaemia presents with: apnoea, lethargy, seizures, and coma.
- Hypoglycaemia is caused by: poor intake, vomiting, hypothermia, sepsis, and Beckwith-Wiedemann syndrome associated with exomphalos.
- Hypoglycaemia treatment includes: feeding or bolus of 10% dextrose by intravenous infusion (IVI).
- Hyperglycaemia: >14mmol/l.
- Hyperglycaemia is caused by: excess infusion, and should be lowered with less concentrated dextrose solution (5%).

Calcium Balance

- Normal serum values: 2.5 mmol/l.
- Hypocalcaemia may present with: seizures, jitters, and ECG changes of long Q-T interval.
- Treatment includes: calcium supplement orally or calcium gluconate infusion.

Evidence-Based Research

Table 5.7 comments on a paper on the maintenance need for water in parenteral fluid therapy.

Table 5.7: Evidence-based research.

Title	The maintenance need for water in parenteral fluid therapy.
Authors	Holliday MA, Segar WE
Institution	Department of Pediatrics, University of California, San Francisco, California, USA
Reference	Pediatrics 1957; 19:823–832
Problem	Fluid and electrolytes in children.
Historical significance/ comments	Classic paper describing the use of intravenous fluids in the paediatric population involving the perioperative setting to some degree.

Key Summary Points

1. Fluid management in the paediatric surgical population can be a real challenge, especially in the preterm infant with an immature physiological state.
2. With the small circulating blood volume in the paediatric patient, fluid management is a critical aspect of each patient who presents for surgery, and vigilance is critical.
3. Many paediatric patients who present for surgery in Africa have a delayed presentation and need a normal saline (NS) fluid bolus with glucose measurement prior to the onset of surgery.
4. Bowel obstruction in the paediatric patient commonly presents with metabolic acidosis due to delayed presentation.
5. A surgeon preparing the paediatric patient for surgery must determine whether sodium or potassium levels are abnormal and attempt correction prior to surgical management because these abnormalities are much more common than in the adult population.
6. Fluid overload in the paediatric surgical patient is not uncommon, and strict observation of maintenance and third space fluids are essential to avoid this problem.

References

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