Perioperative fluids in children

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INTRODUCTION

Starvation, surgery and anaesthesia cause stress and alter physiology. Intravenous fluids are administered perioperatively to maintain homeostasis during this period. Water and electrolytes are required to correct deficits and ensure adequate intravascular volume, cardiac output and ultimately tissue oxygen delivery. Calories in the form of dextrose may be needed to prevent hypoglycaemia.

The majority of healthy children undergoing minor surgery (e.g. circumcision, hernia repair) will be able to drink in the early postoperative phase and will not need intravenous fluids before, during or after surgery. Fasting times should be observed so that children are not left without fluid intake for longer than necessary. The fasting guidelines for elective surgery are shown in Table 1.

Patients undergoing longer or more major procedures, or anyone compromised by underlying problems, will need intravenous fluids during surgery.

Fluids are given for three reasons:

- Resuscitation: to correct pre-existing hypovolaemia or dehydration.

- Maintenance: to provide water, electrolytes and glucose during starvation.

- Replacement: of ongoing losses due to evaporation from an open wound or via the humidification of dry inspired gases, bleeding, pyrexia, gastrointestinal and third space losses (fluid leak into tissues) during surgery and into the post-operative period.

RESUSCITATION

Any child who is dehydrated or hypovolaemic should be resuscitated prior to surgery unless the nature of the illness and operation precludes this. In this case rapid correction of hypovolaemia should commence at, or as soon as possible after induction to maintain circulating volume and cerebral perfusion.

Hypovolaemia (losses from the intravascular space) should be corrected rapidly, initially with boluses of 10-20ml.kg^{-1} isotonic crystalloid (0.9% saline, Hartmann's, Ringer's lactate, Plasma-Lyte). Blood should be considered if the haemoglobin or haematocrit are low (Hct less than 25%) or more than 40ml.kg^{-1} of fluid is required.[2]

Summary

This article is a revision of one written for Update 10 years ago. Changes in the intervening years include greater awareness and more defined acknowledgement of the dangers of using hypotonic fluids, and increasing evidence that isotonic crystalloids (0.9% saline, Hartmann's, Ringer's lactate, Plasma-Lyte) are the fluid of choice for resuscitation and maintenance during surgery. New on the horizon is the Fluid Expansion as Supportive Therapy (FEAST) study for African children with severe infection; this will be considered at the end of this article.[1]

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Table 1. *Fasting guidelines for elective surgery*

Type of food/fluid	Minimum fasting time (hours)
Clear liquids	2
Breast milk	4
Infant formula	4 (<3 months old)
	6 (> 3 months old)
Non-human milk	6
Light meal	6

Dehydration (total body water loss) should be corrected more slowly, preferably by the oral route if tolerated and time allows, but otherwise intravenously. The rapid rehydration technique advocated by Assadi and Copelovitch describes an initial rapid (1-2 hours) infusion of isotonic saline up to 60-100ml.kg^{-1} as required to correct hypovolaemia.[3] This is followed by a slower correction of dehydration over 24-72 hours with 0.9%, 0.45% or 0.2% saline depending on measured plasma sodium. The plasma sodium should be measured at regular intervals (at least 6 hourly if outside the normal range). Too rapid correction of dehydration with hypotonic fluid will result in cerebral oedema secondary to hyponatraemia.

An otherwise healthy child starved pre-operatively will have a fluid deficit. The size of the deficit may be calculated by multiplying the hourly maintenance requirement (see table 2) by the number of hours starved. The majority of children do not require replacement of this deficit if the period of starvation for fluid is short. If the child has been starved for a longer period, for instance overnight, and has not had any fluid orally preoperatively, the deficit can be replaced during surgery using a bolus of 10-20ml.kg^{-1} isotonic crystalloid. For children undergoing minor day case surgery this ensures the child is well hydrated and may possibly reduce postoperative nausea and vomiting.

MAINTENANCE FLUIDS – THE '4,2,1 RULE'
Maintenance fluid requirements have been calculated a number of ways including by estimation of expenditure of calories and body surface area. The simplest and most commonly used formula was devised by Holliday and Segar and modified by Oh, and is known as the '4,2,1' rule'.[4,5] The formula relates energy (calorie) expenditure, and volume of fluid required to the weight of the child in kg (see Table 2 below).

Electrolyte and glucose requirements were also estimated depending on the weight of the child (dietary sodium and potassium = 1.2mmol.kg^{-1}.day[-1]). An "ideal" maintenance solution was proposed that contained the maintenance requirements for water and sodium in one bag, with dextrose added to make the fluid isotonic with the vessels (0.2% saline in 5% dextrose in the US, 0.18% saline in 4% dextrose in the UK, with added potassium chloride (KCl) 20mmol.l^{-1} if required). This solution became the mainstay of IV maintenance fluid for many years, however its validity has recently been questioned and the use of isotonic fluid advocated instead, particularly in the perioperative period.[7,8,9,10]

Neonates (up to 44 weeks post-conceptual age) have a slightly different fluid requirement. They are born physiologically "waterlogged" but then lose up to 10% of their body weight in the first week of life.

They must not be given too much water or sodium on the first few days of life, so much smaller maintenance volumes are prescribed initially, which then increase over the next few days. Premature or low birth weight babies have a greater surface area to weight ratio, lose more water by evaporation and consequently require more replacement fluid (Table 3). The fluid is usually given as 10% dextrose with saline added only after the postnatal diuresis has occurred (i.e around day 3 of life).[11]

REPLACEMENT
Measured losses should be replaced with a similar fluid to that lost. This will usually be isotonic crystalloid or blood to replace haemorrhage and to avoid unacceptably low haemoglobin levels.

Table 1. *Holliday and Segar formula and Oh modification*

	Holliday and Segar	**Oh**
Body weight		
1-10kg	4ml.kg^{-1}.hour[-1]	4ml.kg^{-1}.hour[-1]
10-20kg	40ml.hour[-1] + 2 ml.kg^{-1}.hour[-1] for each kg above 10kg	20 + (2 x weight in kg) in ml.hour[-1]
>20kg	60ml.hour[-1] + 1ml.kg^{-1}.hour[-1] for each kg above 20kg	40 + (weight in kg) in ml.hour[-1]

For example a child of:

9kg requires 4 x 9 = 36 ml.hour[-1]

18kg requires 40 + (2 x 8) = 56ml.hour[-1]

or, using the Oh version of the formula:

20 + (2 x 18) = 56 ml.hour-1

36kg requires 60 + 16 = 76ml. hour[-1]

or, using the Oh formula:

40 + 36 = 76ml. hour[-1]

Table 3. *Paediatric surgical unit fluid guidelines for neonates at Sheffield Children's Hospital, taking postnatal weight and age into account*

Age	Fluid requirement (ml.kg^{-1}.day^{-1})			
	<1.0kg	*1.0-1.5kg*	*1.5-2.0kg*	*>2.0kg*
Day 1	100-200	80-100	60-80	40-60
Day 2	120-150	110-130	90-110	60-90
Day 3	150-170	140-160	120-140	80-100
Day 4	180-200	160-180	140-160	100-120
Day 5	180-200	170-200	150-180	120-150

Fluid evaporation from an open wound or 3rd space losses varies depending on the operation and may be up to 20 ml.kg^{-1}.hour^{-1}. Loss of fluid via the respiratory tract due to humidification of inspired gas may be reduced by using a circle system or HME (heat and moisture exchange filter) in the breathing circuit.

Neonates have a large ECF volume relative to adults so greater 3rd space losses. Replacement with colloids (specifically 4.5% albumin) is more common in neonatal practice than in older children.

Blood or other fluid loss is often difficult to measure especially when irrigation fluids are used. For this reason the child's clinical state should be monitored continuously looking at heart rate, capillary refill time and blood pressure. In longer or more complicated cases core-peripheral temperature gradient, urine output (volume and osmolarity), invasive blood pressure and central venous pressure should be measured. In a warm and otherwise stable child with good analgesia, a rise in heart rate and prolonged capillary refill time are reliable indicators of fluid loss; hypotension due to hypovolaemia occurs relatively late.

WHICH FLUIDS AND WHY?

Isotonic fluids
An isotonic fluid contains the same concentration of solutes as plasma, and therefore exerts an equal osmotic force. Dextrose is metabolised in blood, so although 5% dextrose solution is isosmolar to plasma, and isotonic in vitro, once given, the dextrose is metabolised and it effectively becomes water. Dextrose solutions, unless they contain electrolytes of an equivalent amount to plasma are therefore termed hypotonic fluids. Table 4 shows the electrolyte content of different IV fluids.

Hyponatraemic encephalopathy in children
Children given hypotonic fluid may become hyponatraemic.[7,8,9,10] Ordinarily the kidneys will excrete a free water load rapidly, and homeostasis is maintained. When the body is subjected to stress such as surgery, pain, nausea or hypovolaemia, antidiuretic hormone (ADH) levels rise. ADH blocks the renal excretion of water; water is conserved, and plasma sodium levels fall. Even the relatively mild hypovolaemia of pre-operative starvation causes a rise in ADH levels.[12] If the plasma sodium falls rapidly to a low level (acute hyponatraemia), water moves into the cells in compensation and causes swelling of the cells. The brain is particularly vulnerable to acute hyponatraemia; this can manifest as cerebral oedema, raised intracranial pressure, and can cause brain stem herniation, coning and death. Prepubertal children are particularly susceptible to brain damage associated with postoperative hyponatraemic encephalopathy. Retrospective analyses of patients with acute hyponatraemia have shown that more than 50% of children develop symptoms when the plasma sodium is less than 125mmol.l^{-1}, and that there is a mortality of 8.4% for severe acute hyponatraemia.[7,8]

Acute hyponatraemic encephalopathy typically presents with non-specific features such as nausea, vomiting and headache; if untreated, this will progress to reduced level of consciousness, seizures, respiratory depression and death. Nausea, vomiting and drowsiness may be attributed to the side effects of anaesthesia, but unfortunately by the onset of seizures and respiratory depression it may be too late to salvage the situation. A high index of suspicion should be maintained in all children receiving IV fluids; hypotonic fluids should NEVER be given in the perioperative period (see below). If there are any concerns about hyponatraemia, plasma electrolytes should be measured urgently.

Acute symptomatic hyponatramia presenting with seizures is a medical emergency. A typical case is as follows:

A healthy 9-year-old presented for routine elective surgery. He was given 4% dextrose 0.18% saline at maintenance rate during the operation, and the fluid was continued postoperatively. He was slow to get going after surgery, complaining of headache and nausea. IV fluids were continued. At 4.00am he suddenly developed a seizure. Electrolytes taken at this time showed a plasma sodium of 123mmol.l^{-1}.

Table 4. *Electrolyte content of different IV fluids*

Fluid	Na$^+$ mmol.l^{-1}	K$^+$ mmol.l^{-1}	Cl$^-$ mmol.l^{-1}	HCO$_3^-$ mmol.l^{-1}	Osmolality mOsm.l^{-1}	Tonicity*	Other	pH
5% dextrose	0	0	0	0	252	Hypotonic	Dextrose 50g	4.0
4% dextrose 0.18% saline	30	0	30	0	284	Hypotonic	Dextrose 40g	4.0
5% dextrose 0.45% saline	75	0	75	0	432	Hypotonic	Dextrose 50g	4.0
5% dextrose 0.9% saline	150	0	150	0	586	Hypotonic	Dextrose 50g	4.0
0.9% saline	150	0	150	0	308	Isotonic	-	5.0
Ringer's lactate	130	4	109	28 (as lactate)	273	Isotonic	Ca^{2+} 2 mmol.l^{-1}	6.5
Hartmann's	131	5	111	29 (as lactate)	255	Isotonic	Ca^{2+} 2 mmol.l^{-1}	6.5
Plasma-Lyte 148®	140	5	98	27 (as acetate)	294	Isotonic	Mg^{2+} 1.5 mmol.l^{-1} Gluconate 23mmol.l^{-1}	4-6.5
4.5% albumin in saline	100-160	<2	150	0	275	Isotonic		7.4
Gelofusine	154	<0.4	120	0	274	Isotonic	Gelatin 40g	7.4
Haemaccel	145	5	145	0	293	Isotonic	Gelatin 35g	7.4

* with respect to plasma.

This child must be treated immediately with hypertonic saline (3% saline) to correct the plasma sodium, not an isotonic fluid (and definitely not a hypotonic fluid). Ideally, the child should be cared for in a PICU and 3% saline administered as follows:[6]

- Give 3% NaCl 2ml.kg^{-1} over 10 minutes.

- Repeat as necessary 1-2 times.

- Recheck plasma Na$^+$ after second bolus or 2 hours.

- Stop therapy when the patient is symptom free (awake, alert, responding to commands, resolution of nausea and headache); a rise of Na$^+$ 5-6mmol is achieved; or there is an acute rise in Na$^+$ of 10mmol.l^{-1} in the first 5 hours.

- Do not exceed a correction of Na+ more than15-20mmol.l^{-1} in 48 hours.

What about dextrose?
Dextrose may be required to prevent hypoglycaemia while the child is starved, although this appears to be less of a problem than was previously thought.

The diurnal variation in cortisol levels effects blood glucose levels. Cortisol levels are higher in the morning than the afternoon, so children starved overnight have a higher blood glucose than those starved during the day.[13] The stress response to surgery may result in hyperglycaemia in children as young as two weeks of age, even if no dextrose-containing fluids are given.[14] Although less catastrophic than severe hypoglycaemia, hyperglycaemia also has detrimental effects, and should be avoided. In the ischaemic or hypoxic brain hyperglycaemia may result in accumulation of lactate, cellular acidosis and compromised cellular function. Hyperglycaemia also causes an osmotic diuresis, which may lead to dehydration and electrolyte disturbance. Routine administration of dextrose-containing fluids during surgery should be reserved for those at risk of hypoglycaemia.

Recent studies have shown that hypoglycaemia during surgery is rare in most children. Exceptions to this are premature

infants, neonates less than 48 hours old, neonates in whom a preoperative glucose infusion is interrupted and children below the 3rd centile in weight.[16] Children with an extensive regional block or surgery of greater than 3 hours duration may also be at risk of intraoperative hypoglycaemia and these groups of children should be maintained on dextrose infusions without prolonged interruption.[16]

However, if children are given dextrose free solutions postoperatively, they may become hypoglycaemic, or they may metabolise lipids and develop ketosis, particularly if they are less than 6 years of age.[10]

The majority of children can therefore be given dextrose free isotonic crystalloid solutions such as Hartmann's/Ringer's Lactate during surgery. After surgery, all children should receive maintenance fluids containing dextrose. Any child perceived to be at risk of hypoglycaemia should have their blood glucose monitored at regular intervals.

A low concentration of dextrose should be used (1%-2.5%) if dextrose is required for a child at risk of hypoglycaemia during surgery; 0.9% saline with 5% dextrose may result in moderate to marked hyperglycaemia. Isotonic crystalloid solutions containing 1% or 2.5% dextrose are commercially available in some countries. As an alternative, solutions can be made up as follows:

- Hartmann's 1% dextrose – add 10ml 50% dextrose to 500ml Hartmann's

- Hartmann's 2.5% dextrose – add 25ml 50% dextrose to 500ml Hartmann's

Choice of isotonic cystalloid during surgery; saline or balanced salt solution?

Saline has a greater chloride content than plasma, also than Hartmann's, Ringer's or Plasma-Lyte, and may cause hyperchloraemic acidosis (see Table 4).

Balanced salt solutions such as Hartmann's or Ringer's are slightly hypotonic and may result in a fall in serum sodium if given in large quantities. The clinical impact of hyperchloraemic acidosis is uncertain, but it is common practice to use a balanced salt solution such as Hartmann's, Ringer's or Plasma-Lyte during surgery. Always check electrolytes with prolonged use of any IV fluids.

Crystalloid or colloid?

The use of crystalloids or colloids has been controversial for many years. Recently, concerns have been raised about the use of intravenous starch solutions in patients with sepsis and/or at risk for renal failure. There is little evidence in children (and even less evidence to support the use of intravenous gelatins in children). Colloid solutions also cause a greater fall in plasma haemoglobin than an equivalent volume of crystalloid solution, and may increase the requirement for blood transfusion. Colloids are more expensive than crystalloids, gelatins may be associated with increased risk of anaphylaxis, and the long term side-effects of starch solutions in children are not known. A pragmatic approach suggests that a balanced salt solution should be used in preference to colloids during surgery, with blood transfused when required.

Trigger for transfusion?

Most children undergoing surgery are healthy with normal cardiorespiratory function, and excellent tissue oxygen delivery, particularly during infancy when their cardiac output is relatively high, and they tolerate anaemia well. However, newborns have high levels of HbF and require a higher haemoglobin level, as HbF is less efficient at off-loading oxygen to the tissues; similarly, children with cyanotic heart disease have less effective tissue oxygen delivery. It is difficult to be prescriptive about the haemoglobin level that should be the 'trigger' for transfusion, but suggested levels are shown in Table 5. Ideally, the haemoglobin level should be measured regularly during surgery; blood should be transfused to minimise donor exposure, usually in a dose of 10-20 ml.kg^{-1}. A useful formula to predict the haemoglobin rise is as follows:

- Transfusion 8ml.kg^{-1} whole blood raises the haemoglobin by 1g.dl^{-1}

- Transfusion 4ml.kg^{-1} packed cells raises the haemoglobin by 1g.dl^{-1}

POSTOPERATIVE MAINTENANCE FLUIDS

The choice of maintenance fluids in the postoperative period

Table 5. *Suggested trigger haemoglobin for blood transfusion in children*

	Haemoglobin level that should trigger blood transfusion g.l^{-1}
Healthy child	70
Newborn (untransfused) - high HbF	120
Cyanotic heart disease	100-120
Early severe sepsis	100
Chronic anaemia	To maintain normal baseline haemoglobin

remains controversial; the choice of both sodium content and dextrose needs to be considered. Hypotonic fluids containing 0.18% saline in 4% dextrose must NOT be used at any time in the perioperative period.[1]

Children younger than 6 years require a source of dextrose postoperatively to avoid hypoglycaemia and to avoid lipolysis.[10] Hypotonic fluids should not be administered if the plasma sodium is less than 140 mmol.l^{-1}, although measurement of electrolytes may not always be possible. If a hypotonic fluid containing 0.45% saline is given in the immediate postoperative period, the plasma sodium tends to fall due to the effect of raised ADH. If the plasma sodium is already low, it will remain low if 0.45% saline is used. When the plasma electrolytes are not known it is safer to give 0.9% saline to a patient with an elevated plasma sodium, than it is to give hypotonic fluids to a hyponatraemic patient. A pragmatic approach therefore suggests that isotonic solutions containing dextrose, such as 0.9% saline 5% dextrose, or Hartmann's/Ringer's/Plasma-Lyte 5% dextrose should be used for maintenance fluids in the immediate postoperative period.

It is essential that fluid balance and vital signs continue to be monitored in the post-operative period, ideally including urine output, and daily plasma electrolytes and the weight of the child. Abnormal losses such as naso-gastric tube or wound drain losses should be measured and replaced ml for ml with 0.9% saline + 10mmol KCl. KCl should not be added to maintenance fluids until urine output is established (usually day 2 postoperatively). Intravenous fluids should be stopped as soon as possible in the postoperative period; it is much better for the child to control their own fluid balance.

Suggested perioperative fluid regimen:

- During surgery; use Hartmann's/Ringer's/Plasma-Lyte and/or blood as clinically indicated. Give fluid boluses of 10-20ml.kg^{-1} and assess clinical signs.

- Low dose dextrose may be required for neonates and those at risk of hypoglycaemia; check the blood sugar regularly.

- Postoperative maintenance fluids; give an isotonic fluid with 5% dextrose and calculate the fluid requirement using the Holliday and Segar '4:2:1' rule.

- Give additional fluids to correct deficits, measured or suspected ongoing losses using 0.9% saline, Hartmanns/ Ringer's/Plasma-Lyte, colloid or blood as indicated.

THE FEAST STUDY

The FEAST study was a large randomised controlled study carried out in six hospitals in Africa (Kenya, Uganda and Tanzania), published in 2011.[1] Children aged 2 months to 12 years with a diagnosis of a severe febrile illness (impaired consciousness and/or respiratory distress with impaired perfusion) were randomised to receive a fluid bolus of 20ml.kg^{-1} 0.9% saline or 20ml.kg^{-1} 5% albumin when they were admitted to hospital, or they were included in a control group and treated with routine maintenance fluids using the'4,2,1' rule. More than 3000 children were included in the trial, which is the largest study of its kind in fluid resuscitation in children. Children with gastroenteritis, burns or requiring surgery were NOT included in the study.

The results were surprising, and lead to the trial being stopped early on safety grounds. Children who received a fluid bolus were 3.3% more likely to die in the first 48 hours after admission than the control group children who received routine maintenance fluids. The children in the study were all severely unwell (76% had impaired consciousness, 83% had respiratory distress); 57% had malaria and 32% had a haemoglobin <5g.dl^{-1}, but the adverse effect of a fluid bolus was still seen in those without malaria and those who did not have severe anaemia. The reason for the excess mortality in those receiving a fluid bolus is not clear; the children appeared to do well initially, but the clinical benefit was not maintained. There were no intensive care facilities in the study hospitals and the terminal event in most cases was cardiogenic shock. It may be that shock is an important adaptive response in this setting, and that administration of a fluid bolus overrides this adaptation; or perhaps there are subtle effects of a fluid bolus related to hyperchloraemic acidosis. More research is required.

The important conclusion from this study is that critically ill children with sepsis in Africa should NOT receive rapid fluid resuscitation with saline or albumin, but should receive IV fluids at normal maintenance rates whilst definitive treatment for sepsis is started (e.g. antibiotics or antimalarials). The authors state that children with acute gastroenteritis or burns or surgical conditions may still require resuscitation fluids, and the recommendations do not apply to these patients. The relevance of the FEAST study to children in high-income countries is still uncertain, but current treatment protocols must re-evaluated in the light of this important study.

CONCLUSIONS

Children should not be starved for prolonged periods before surgery, and oral fluids should be given wherever possible. Intravenous fluids should be prescribed carefully, as for any drug:

- The majority of healthy children undergoing minor surgery will re-establish oral intake in the early postoperative phase and will not need routine intravenous fluids.

- Hypovolaemia should be corrected by rapid infusion of isotonic fluid while dehydration is corrected more slowly over 14-72 hours as appropriate. Ongoing losses should be measured and replaced.

- During surgery the majority of children over 1 month of age will maintain a normal blood glucose if isotonic, non-dextrose containing fluids are given.

- Hypotonic fluids should be used with care in the perioperative period, and must not be infused in large volumes or at greater than maintenance rates. 0.18% saline 4% dextrose must NOT be used.

- Ideally, plasma electrolytes, glucose and haemoglobin (or haematocrit) should be measured regularly in any child receiving large volumes of IV fluid, or who remains on IV fluids for more than 24 hours.

- Critically ill children with sepsis should receive IV fluids at normal maintenance rates whilst definitive treatment is started. They must not receive IV fluid boluses for resuscitation.

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