Review Article

Basics of fluid and blood transfusion therapy in paediatric surgical patients

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ABSTRACT

Perioperative fluid, electrolyte and blood transfusion therapy 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 is often misleading. Perioperatively, crystalloids, colloids and blood components are required to meet the ongoing losses and for maintaining cardiovascular stability to sustain adequate tissue perfusion. Recently controversies have been raised regarding historically used formulas and practices of glucose containing hypotonic maintenance crystalloid solutions for perioperative fluid therapy in children. Paediatric intraoperative transfusion therapy, particularly the approach to massive blood transfusion (blood loss ≥ one blood volume) can be quite complex because of the unique relationship between the patient's blood volume and the volume of the individual blood product transfused. A meticulous fluid, electrolyte and blood transfusion management is required in paediatric patients perioperatively because of an extremely limited margin for error. This article reviews the basic concepts in perioperative fluid and blood transfusion therapy for paediatric patients, along with recent recommendations. For this review, Pubmed, Ovid MEDLINE, HINARI and Google scholar were searched without date restrictions. Search terms included the following in various combinations: Perioperative, fluid therapy, paediatrics, blood transfusion, electrolyte disturbances and guidelines. Only articles with English translation were used.

Key words: Fasting, fluid therapy, hyperglycaemia, hypoglycaemia, hyponatraemia, massive blood transfusion, perioperative, transfusion therapy

INTRODUCTION

Perioperative fluid management in paediatric surgical patients has been the focus for considerable interest and debate.[1] It is a medical prescription for which both the volume and composition should be adapted as per patient status, type of operation and the expected events in the perioperative period. The total body water of a newborn is 75–80% and decreases gradually as fat and muscle content increase with age to the adult level of approximately 60%. The extracellular fluid (ECF) fluid represents 45% of body weight in term neonates and 30% by the age of 1 year, compared with 20% in adults.[2] 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.[3] A meticulous fluid management is required in paediatric patients because of an extremely limited margin for error.

CRYSTALLOIDS: THE "4/2/1" RULE

Holliday and Segar in 1957 first presented a practical method to prescribe IV fluids based on the estimated metabolic requirements for patients at bed rest.[4] The calorie expenditure calculated was 100 kcal/kg for infants weighing 3–10 kg, 1000 kcal +50 kcal/kg for each kilogram over 10 kg but <20 kg for children ranging from 10 to 20 kg, and 1500 kcal +20 kcal/kg

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for each kilogram over 20 kg for children 20 kg and above. Under normal conditions, 1 ml of water is required to metabolise 1 kcal, taking into account insensible water losses across the skin and respiratory tract, and urinary water loss. Therefore, in the awake child, calorie and water consumption are considered equal and the corresponding weight-based rule for hourly water requirement evolved into what is termed the "4 / 2/1 rule" for maintenance fluid therapy in children [Table 1].[5] In the same study, Holliday and Segar defined daily maintenance electrolyte requirements considering the electrolyte composition of same volume of human milk and cow's milk; they recommended 2 mEq/100 kcal/day of both potassium and chloride and 3 mEq/100 kcal/day of sodium. These electrolyte requirements are theoretically met by the hypotonic maintenance fluid commonly used in hospitalised children by 5% dextrose (D5) with 0.45% normal saline (NS). For many decades, the fluid given to children by paediatricians was one-fourth to one-third strength saline based on this concept.[6] Recent studies have shown that use of hypotonic solutions along with stress-induced increased secretion of antidiuretic hormone (ADH) perioperatively can lead to hyponatraemic encephalopathy, permanent neurological damage and even death in children.[7-9]

PREOPERATIVE ESTIMATION OF FLUID DEFICIT: FACTS AND CONTROVERSIES

Historically, the accepted intraoperative practice has been to administer IV fluids to meet maintenance requirements as well as to replace the preoperative deficits and ongoing losses incurred during the surgical procedure.[6] Conventionally, as a result of the fasting state, children are presumed to develop preoperative fluid deficits secondary to continuing insensible losses and urine output. In 1975, Furman *et al.* proposed calculating the preoperative deficits by multiplying the hourly rate, as per 4 / 2/1 rule method, by the number of hours the patient was nil per oral (NPO).[10] They then suggested replacing half of this volume during the first hour of surgery, followed by the other half over the next 2 h. In 1986, Berry simplified the method of Furman *et al.* by delivering a bolus of basic salt solution to otherwise healthy children over the first hour of surgery. Berry concluded that children 3 years and younger should receive 25 ml/kg, whereas children 4 years and older should receive 15 ml/kg.[11] These practices were adopted for many years without questioning their utility. However, considerable debate has recently occurred regarding the amount of deficit generated by the NPO status and the existence of "third space losses."[1]

The methods of both Furman *et al.* and Berry were developed based on the assumption that patients had been NPO for at least 6–8 h.[10,11] The debate about the significance of preoperative dehydration secondary to NPO status has become less important due to the new fasting guidelines for elective surgery published by the American Society of Anaesthesiologists (ASA), allowing administration of clear liquids up to 2 h before anaesthesia [Table 2].[12] Despite this, children may still present for surgery having been NPO for more than 2 h or having significant deficits related to their disease process. Whereas there are no data to determine the exact amount of fluid deficit that occurs in normal fasting children, strong evidence suggests that healthy adult patients will maintain normal intravascular volumes despite a prolonged fast.[13]

Estimation of degree of preoperative dehydration is based on classical clinical signs [Table 3]. In an acute clinical situation, the weight loss of the child is usually a very good indication of total water loss. The most important sign of normal hydration status is kidney function.[3] Thus, monitoring of urinary output is essential for evaluating and treating any fluid deficit. Correction of 1% of dehydration requires about 10 ml/kg of fluids.[6] Rate of fluid administration depends on seriousness and on rapidity of dehydration. In the dehydrated paediatric patient requiring resuscitation, a bolus of Ringer's lactate (LR) 20 ml/kg should be administered intravenously as soon as possible. This bolus may need to be repeated in cases of more severe dehydration.[6] The ultimate goal of perioperative fluid therapy is to maintain a correct

Table 1: Hourly (4/2/1 rule) and daily maintenance fluids according to child's weight

Weight (kg)	Hourly fluid requirements	Daily fluid requirements
<10	4 ml/kg	100 ml/kg
10–20	40 ml+2 ml/kg	1000 ml+50 ml/kg
	Above 10 kg	Above 10 kg
>20	60 ml+1 ml/kg	1500 ml+25 ml/kg
	Above 20 kg	Above 20 kg

Table 2: Fasting guidelines for elective surgery

Ingested material	Minimum fasting period (h)
Clear liquids	2
Breast milk	4
Infant formula	4 (<3 months) 6 (>3 months)
Nonhuman milk	6
Light meal	6

Table 3: The clinical assessment for degree of dehydration

Severity of dehydration	Percentage dehydration		Clinical signs and symptoms
	Infant (%)	Child (%)	
Mild	5	3–4	Increased thirst, tears present, mucous membranes moist, ext. jugular visible when supine, capillary refill >2 seconds centrally, urine specific gravity >1.020
Moderate	10	6–8	Tacky to dry mucous membranes, decreased tears, pulse rate may be elevated somewhat, fontanelle may be sunken, oliguria, capillary refill time between 2 and 4 seconds, decreased skin turgor
Severe	15	10	Tears absent, mucous membranes dry, eyes sunken, tachycardia, slow capillary refill, poor skin turgor, cool extremities, orthostatic to shocky, apathy, somnolence
Shock	>15	>10	Physiological decompensation: insufficient perfusion to meet end-organ demand, poor oxygen delivery, decreased blood pressure

fluid and electrolyte balance and, as a consequence, normal cardiovascular stability. Indeed, dehydration and some medical conditions associated with third space sequestration of fluids (e.g. intestinal occlusion) will in turn affect vascular fluid volume. Restoration of an adequate vascular fluid volume is essential to maintain cardiovascular stability, organ perfusion and adequate tissue oxygenation. Isotonic transfer of fluid from the extracellular compartment to a non-functional interstitial space forms third space volume. Replacement of intravascular volume losses should be performed by administration of normotonic and normo-osmolar solution. Crystalloid solutions such as LR or NS, or even a colloid solution, can be used during the initial resuscitation period.[14]

INTRAOPERATIVE FLUID MANAGEMENT

Intraoperative fluid therapy is aimed at providing basal metabolic requirements (maintenance fluids), compensating for preoperative deficits and replacing losses from surgical field [Table 4].[6,15] Third space losses refers to the sequestration of fluid to a non-functional extracellular space that is beyond osmotic equilibrium with the vascular space. These losses in paediatrics may vary from 1 ml/kg/h for a minor surgical procedure to as much as 15–20 ml/kg/h for major abdominal procedures, or even up to 50 ml/kg/h for surgery of necrotising enterocolitis in premature infants.[14] The younger the child, the greater is the relative proportion of losses because of the large ECF volume in young infants compared with older children and adults. Third space losses should be replaced with crystalloids (NS or LR). Large amounts of NS are responsible for hyperchloraemic metabolic acidosis, whereas this does not occur after LR administration.[15] However, a recent review of predominantly adult literature concludes that a classic "third space" does not exist.[16] Several studies using multiple blood samples and steady-state tracer kinetics revealed that the functional fluid space is either unchanged or expanded rather than contracted after surgery.[17-19] Substantial amounts of fluid accumulate in the interstitial space secondary to factors including volume overload with crystalloid infusions and iatrogenic deterioration of the vascular barrier.[16] There is little evidence regarding this in paediatric patients and it is possible that our traditional practice of liberal isotonic fluid delivery in major paediatric surgeries may have adverse implications.[14] Individualised goal-directed fluid management using only the amount of crystalloid and/or colloid necessary to optimise flow-related variables such as stroke volume can alter the incidence of postoperative complications such as it might reduce the amount of tissue oedema previously thought to generate a third space and improve recovery from surgery.[20,21] However, perioperative studies in paediatric patients using the oesophageal Doppler, pulse contour analysis, or mixed venous oxygen saturation to guide and determine optimum fluids are lacking.

Table 4: Guidelines for fluid administration of balanced salt solution in children according to the age and to the severity of tissue trauma

First hour (plus item 3 below)
25 ml/kg in children aged 3 years and below
15 ml/kg in children aged 4 years and over
All other hours (plus item 3 below)
Maintenance + trauma = basic hourly fluid
Maintenance volume =4 ml/kg/h
Maintenance + mild trauma =6 ml/kg/h
Maintenance + moderate trauma =8 ml/kg/h
Maintenance + severe trauma =10 ml/kg/h
Blood replacement 1:1 with blood or colloid or 3:1 with crystalloids

PERIOPERATIVE DEXTROSE: RATIONALE FOR AVOIDING BOTH HYPOGLYCAEMIA AND HYPERGLYCAEMIAS

Hypoglycaemia as well as hyperglycaemia, depending on the severity, can have devastating effects in paediatric patients. Low blood glucose invokes a stress response and alters cerebral blood flow and metabolism.

Permanent neurodevelopmental impairment can result if hypoglycaemia goes unrecognised and untreated.[22] Studies have further demonstrated that cerebral injury is caused not only by severe prolonged hypoglycaemia (blood glucose level <45 mg/dl or 2.6 mmol/l), but also by mild hypoglycaemia combined with mild hypoxia or ischaemia.[23] The incidence of preoperative hypoglycaemia has been shown to be between 0% and 2.5%, and is usually associated with fast durations from 8 to 19 h, well beyond the current ASA recommended guidelines.[12] Hyperglycaemia has also been recognised as detrimental for the nervous system, especially in the setting of an ischaemic or hypoxic event due to the anaerobic metabolism of excess glucose causing an accumulation of lactate, a decrease in intracellular pH, and subsequently severely compromised cellular function that may result in cell death.[24] In addition, hyperglycaemia can induce an osmotic diuresis that may lead to dehydration and electrolyte abnormalities in the paediatric population.[25]

At present, there is a growing consensus to selectively administer intraoperative dextrose only in those children at greatest risk for hypoglycaemia and, in such situations, to consider the use of fluids with lower dextrose concentrations (e.g. 1% or 2.5%) with LR (LRD1 and LR½ D2.5).[25-27] The highest risk of hypoglycaemia is in neonates, children receiving hyperalimentation, and those with endocrinopathies, in whom monitoring blood glucose levels and adjusting the rate of infusion is also recommended. Glucose infusion at a rate of 120–300 mg/kg/h is sufficient to maintain an acceptable blood glucose level and to prevent lipid mobilisation in hypoglycaemia-prone infants.[28] Routine dextrose administration is no longer advised for otherwise healthy children receiving anaesthesia even in neonatal period.[6,14,26]

VOLUME REPLACEMENT DURING INFANCY: INDICATIONS AND CHOICE OF CRYSTALLOIDS AND COLLOIDS

When determining the particular crystalloid or colloid fluid to administer, the type of fluid deficit (fluid loss or plasma loss) and the effect that these replacement fluids might have on the intravascular volume, coagulation cascade, microcirculation and any possible allergic reactions must be considered.[14,26] Crystalloids are first administered to treat absolute or relative blood volume deficits observed during surgery in children. Most anaesthesiologists now use either NS or LR for both maintenance and deficit fluid replacement in the operating room setting.[29] Their advantages include low cost, lack of effect on coagulation, no risk of anaphylactic reaction and no risk of transmission of any known or unknown infectious agent. Normally, 15–20 ml/kg/h of LR/NS solution over 15–20 min will re-establish cardiovascular stability. After administration of a total of 30–50 ml/kg of crystalloid solution, the administration of a colloid solution (albumin or synthetic colloid) to maintain intravascular osmotic pressure is indicated.[30] It is recommended that intraoperative fluid in children should have an osmolarity close to the physiological range in order to avoid hyponatraemia, an addition of 1–2.5% glucose in order to avoid hypoglycaemia, if indicated, and should also include metabolic anions (i.e. acetate, lactate or malate) as bicarbonate precursors to prevent hyperchloraemic acidosis especially in neonates.[31,32] Many a time, neonates and infants present to operating room with various paediatric solution infusions (Isolyte P, D5%+ NS0.45%., etc.) already started by paediatricians. Anaesthesiologist must check the composition of these solutions [Table 5]. Some of these contain potassium and glucose in high concentration and are not suitable for rapid or bolus infusion intraoperatively.

COLLOIDS

Colloid fluids can be divided into natural protein colloids (albumin) and synthetic colloids (hydroxyethyl starches (HESs), gelatins and dextrans). Albumin occurs naturally and is regarded as the colloid "gold standard." An albumin 5% solution is osmotically equivalent to an equal volume of plasma, whereas a 25% solution causes intravascular volume expansion 3–5 times because of fluid translocation from the interstitial compartment. However, in subjects with increased intravascular permeability (e.g. critically ill, sepsis, trauma and burn), the colloids may actually leak into the interstitial space, thereby worsening oedema. Weak anticoagulation effects of albumin through inhibition of platelet aggregation or heparin-like effects on antithrombin III are clinically insignificant if volume replacement with it is kept below 25% of the patient's blood volume.[33,34] Recently, its use as plasma expander in neonates and infants is declining.[35,36] Data supporting the continued use of albumin for general fluid resuscitation in children are lacking, and in children with traumatic brain injury, it may actually be harmful.[37] Its utility may exist in specific subgroups such as neonates and patients undergoing cardiac surgery.[36,38]

Table 5: Composition of frequently used IV fluids

Fluid	pH	Na+ mEq/l	Cl− mEq/l	K+ mEq/l	Ca2+ mEq/l	Other	mOsm/l	Comments
0.9% NaCl (NS)	5.5	154	154	0	0	0	308	Fluid choice for replacement, watch for hyperchloraemic acidosis
Lactated ringer (LR)	6.5	130	109	4	3	Lactate 28 mEq/l	275	Fluid choice for replacement
Dextrose 5% (D5%)	4.5	0	0	0	0	Dextrose 50 g/l	285*	Free water, hypotonic
D5% LR	5	130	109	4	3	Dextrose 50 g/l	275	Initial post-op maintenance
D5% NS	4	154	154	0	0	Dextrose 50 g/l	308	Initial post-op maintenance
D5% NS4.5%	4	77	77	0	0	Dextrose 50 g/l	154+285*	Hypotonic
D5% NS2.5%	4	34	34	0	0	Dextrose 50 g/l	68+285*	Hypotonic
Isolyte P in D5%	5	23	29	20	0	Mg^{2+} =3, HPO_4^{2-} =3, $acetate^-$ =23 mEq/l, dextrose =50 g/l	75+265*	170 cal/l hypotonic, excess may result in metabolic alkalosis
Plasmalyte A	7.4	140	98	5	0	Mg^{2+} =3, $acetate^-$ =27, gluconate =23 mEq/l	294	Isotonic, perioperative fluid replacement

*Does not contribute towards tonicity as dextrose and acetate are metabolised

HESs are synthetic colloids prepared with modified natural polysaccharides made resistant to hydrolysis by circulating amylases. As a rule, the solutions with a higher molecular weight and molar substitution ratio have a prolonged volume effect, but also have greater side effects like coagulation abnormalities (interference with the function of von Willebrand factor, factor VIII and platelets), worsen renal function (induce renal tubular cell swelling and create a hyperviscous urine) and pruritus (accumulation and storage of the HES in the skin).[38-40] Newest-generation HES fluids are designed with low molecular weight and molar substitution ratios to minimise side effects, as well as a high C2:C6 hydroxyethylation ratio to prolong the duration of action (4–6 h). One potential side effect of HES reported is a decrease in the anion gap as well as an increase in the chloride concentration. A low anion gap caused by HES infusion could mask a high anion gap acidosis signifying acute renal failure (ARF) or sepsis during paediatric surgery.[41] Moderate doses of HES (130 / 0.42 / 6:1) for perioperative plasma volume replacement seem to be safe even in neonates and small infants. Changes in acid–base balance may be decreased when HES is used in an acetate-containing balanced electrolyte solution instead of NS.[42]

Gelatins are polypeptides produced by degradation of bovine collagen and from a haemostatic point of view, they are preferable to HES.[43] However, they also effect coagulation and should be avoided in children with bleeding disorders. Gelatins cause increase in blood volume less than the infused volume because of the rapid but transient passage of gelatins into the interstitial space, rapid glomerular filtration and susceptibility to enzymatic cleavage by proteases. A multicentre study done in preterm infants showed no adverse short-term outcomes related to gelatin use.[44] Some studies have reported concern over risk of developing necrotising enterocolitis in preterm infants and worsening capillary leak syndrome in septic newborns with the use of gelatins.[45,46]

Dextran is a water-soluble glucose polymer (polysaccharide) synthesised by specific bacteria from sucrose. The current formulations available are 10% dextran-40 and 6% dextran-70. Dextran induces a dose-dependent von Willebrand-type syndrome and enhances fibrinolysis that is worse with the high molecular weight dextrans. Other side effects are ARF in patients with acute ischaemic strokes and anaphylactoid reactions as a result of dextran reactive antibodies.[47,48] The current suggestion is to limit the use of dextrans to 20 ml/kg/day in children. Patients pre-treated with a hapten inhibition prior to the infusion of a dextran have shown decreased incidence of allergic reactions.[48]

Hypertonic saline

In children with traumatic brain injury, hypertonic saline (4 ml/kg) was shown to increase cerebral perfusion pressure in the 3 days after head trauma, when compared with LR.[49] Side effects include possibility of the development of osmotic demyelination syndrome, rebound increases in intracranial pressure, and ARF from an increase in serum osmolarity.[50] Peterson *et al.* reported that no child developed ARF after the use of hypertonic saline; however, hyperkalaemia and a

non-anion gap metabolic acidosis were the common electrolyte abnormalities associated with its use. Both were not clinically relevant if the serum sodium was kept below 155 mmol/l.[51]

POSTOPERATIVE FLUID THERAPY

If oral intake should be delayed (e.g. after abdominal surgery), fluid therapy should be administered on a peripheral venous access if duration of intravenous infusion is not expected to exceed 5 days or on a central venous access when long-term parenteral nutrition is necessary. Fluid therapy should provide basic metabolic requirements, and compensate for gastrointestinal losses (e.g. gastric suctioning) and additional losses (e.g. fever). Postoperative hyponatraemia is the most frequent electrolyte disorder in the postoperative period.[7,8] Severe hyponatraemia (<120–125 mmol/l) may result in transient or permanent brain damage. The postoperative hyponatraemia observed in most of the ASA 1 children is due to the administration of hypotonic fluids when capacities of free water elimination are impaired due to increased ADH secretion as a result of hypovolaemia, stress, pain, or traction of dura mater.[52] Postoperative hyponatraemia should be prevented by avoiding hypotonic solutions during surgery and in the early postoperative period.[9,53]

INTRAOPERATIVE PAEDIATRIC BLOOD TRANSFUSION THERAPY

Paediatric patients have higher oxygen consumption and a higher cardiac output to blood volume ratio than adults. The neonatal myocardium that operates at near maximum level of performance as a baseline may be unable to compensate for a decreased oxygen carrying capacity by increasing cardiac output in the event of falling haemoglobin. The normal term neonate haemoglobin value (range 14–20 gm%) gradually decreases over the first several months of life such that the physiologic nadir for haemoglobin occurs at approximately 2–3 months of age [Table 6].[54] Term infants with haemoglobin levels <9 gm% and preterm infants with haemoglobin values <7 gm% around this nadir should be investigated for the cause, and if concern over adequate oxygen carrying capacity exists, an elective procedure may be postponed pending evaluation and treatment. Premature infants have higher percentages of foetal haemoglobin (HbF) than their full-term counterparts (97% vs. 70% of total haemoglobin) and decreased erythropoietin production which inhibits them from responding to anaemia appropriately. HbF production diminishes during the first few months of life until only a trace is present at 6 months of age. Red blood cells (RBCs) containing HbF have a shorter life span (90 days vs. 120 days in adult) and high oxygen affinity (P_{50} of 19 mmHg vs. 26 mmHg in adult). In clinical terms, younger infants have higher fraction of HbF, and thus lower oxygen delivering capacity. In the presence of congenital heart disease or lung disease, neonates may have a decreased ability to oxygenate blood also. It is for these reasons that haemoglobin levels that are adequate for the older patient may be suboptimal in the younger infant or neonate and the threshold for transfusing RBCs to a neonate should be at a higher haemoglobin trigger than an older child or healthy adult. Maintaining higher haemoglobin levels will increase oxygen carrying capacity, and in the premature infant, may protect from post-anaesthetic apnoea of prematurity.[55]

Table 6: Normal haemoglobin values for full-term and premature infants

	Full term (g/dl of blood)	Premature (g/dl of blood)
Birth	19.3	Slightly less than full term
0.5 months	16.6	15.4
1 month	13.9	11.6
Age at haemoglobin nadir	9–12 weeks	6–10 weeks
Mean haemoglobin at nadir	11.2	9.4
4 months	12.2	11.7
6 months	12.5	12.4

Although most of the complications associated with paediatric blood transfusions are similar to those encountered in adults, however, metabolic complications occur more readily and with a greater frequency in children (e.g. hypocalcaemia, hyperkalaemia and hypothermia). Hence, in the operating room, the decision to initiate RBC transfusion should be based upon a constellation of factors such as the rapidity of the blood loss, the presence of impaired oxygenation (pulmonary or cardiac in origin), metabolic consequences, infectious disease transmission risks and the general medical condition of the child.[56] Administration of RBCs to infants less than 4 months of age may be either type specific or O negative, and does not require further cross matching because major haemolytic reactions do not occur. For the first 3–4 months of life, infants are unable to form allo-antibodies to RBC antigens with the exception of exposure to the Rh-D antigen.[57]

Massive blood transfusion and allowable blood loss

Massive blood transfusion is defined as the loss of one or more circulating blood volumes.[58] It is, therefore, important to calculate the patient's estimated blood volume (EBV) and to relate this to the volume of blood products and other fluids administered. The patient's EBV is generally related in part to the patient's age as well as body habitus [Table 7]. In addition, the anaesthesiologist should estimate maximal allowable blood loss (MABL) that may be allowed before the initiation of packed RBC transfusion.

$$MABL = [(\text{starting haematocrit} - \text{target haematocrit}) \div \text{starting haematocrit}] \times EBV$$

MABL can be replaced with a balanced salt solution such as LR in a volume of 3:1, or with 5% albumen or hetastarch 1:1. Once the estimated blood loss reaches this target value, then RBC cell transfusion should be initiated. Obviously preterm and term infants, children with cyanotic congenital heart disease, large ventilation/perfusion mismatch, high metabolic demand, and children with respiratory failure may benefit from having the haematocrit maintained at a higher target value. Since the haematocrit in packed RBCs is approximately 70%, each 100 ml of packed RBCs transfused will provide 70 ml of RBCs. Replacement would be made for additional blood loss (say XBL) above the MABL according to the following formula:

$$\text{Volume of 100\% RBCs blood to be transfused} = XBL \times \text{desired haematocrit (30\%)}$$

As the approximate haematocrit in packed RBCs is 70%, the volume of packed RBCs in millilitres to be transfused will be = [XBL × desired haematocrit (suppose 30%)] ÷ 0.70

This can usually be simplified by transfusing approximately 0.5 ml packed RBCs for each millilitre of blood loss beyond the MABL; this will result in a slightly higher haematocrit than the target 30%, but since all of these calculations are estimates, the end result is usually close to the desired value.[58]

Table 7: Estimated circulating blood volume versus age or weight

Age	Estimated blood volume (ml/kg)
Premature infant	90–100
Term infant–3 months	80–90
Children older than 3 months	70
Very obese children	65

While transfusing blood, one should always consider coagulopathy of massive blood transfusion due to dilutional thrombocytopenia and reduction in clotting factors. In general, a patient will lose about 40% of the starting platelet count with the first blood volume lost, another 20% with the second blood volume lost, and so on. Thus, at three blood volumes lost with no platelet replacement, the platelet count would be expected to be reduced by approximately 70% from baseline values.[59] Hence, it is important to have a baseline platelet count when massive blood loss is anticipated since patients who begin with a low platelet count are at risk for pathological bleeding even after only one blood volume loss. The coagulopathy secondary to dilution of clotting factors depends upon the type and volume of transfused blood product. Whole blood contains all clotting factors including fibrinogen at normal values except for the labile factors (V and VIII); even these factors are present in 20–50% of their normal values. Therefore, with transfusion of whole blood, pathological coagulation generally does not occur until three or more blood volumes have been lost. However, such large quantities of whole blood are rarely used; instead the blood loss is replaced with albumen, starch, crystalloid and packed RBCs. With this type of replacement, multiple clotting factor deficiencies should be anticipated once blood loss exceeds one blood volume of the patient.[60]

OTHER PRACTICAL TIPS

Beside the volume and composition of fluid administered, here are a few other practical considerations:

i. Always get rid of air bubbles in the intravenous administration set (risk of paradoxical air embolism via patent cardiac shunts)
ii. Use "flush" syringe to negate dead space when administering intravenous drugs
iii. Warm intravenous fluids where possible
iv. Hidden fluid administration used to dilute antibiotics or analgesics should be taken into account, especially in neonatal anaesthesia where margin for error is miniscule
v. Always administer calculated volumes accurately using a burette or syringe driver.

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