Fluid and electrolyte balance in children

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Abstract

Fluid administration to children is a ubiquitous part of the medical management of hospitalized children. In this review we examine the rationale for the use of various fluids including oral rehydration therapy. The basic physiology relating to distribution of infused fluids is discussed with regards to serum osmolality and tonicity. This review should guide safe prescription of appropriate volumes, rates of infusion and types of fluids. The potential complications of fluid therapy are discussed, in particular hyponatraemic encephalopathy. Children at particular risk of developing hyponatraemic encephalopathy are identified; the importance of frequent assessment and evaluation is highlighted and rational treatment of this medical emergency is reviewed. The use of a dehydration correction calculation is examined in the context of diabetic ketoacidosis. Finally the initial management of commonly occurring electrolyte disorders is examined.

Keywords administration; electrolytes; fluid therapy; hyperkalaemia; hyponatremia; intravenous; osmolality; pediatrics

Intravenous fluids are frequently administered to children in hospital. The aim of this therapy is to provide sufficient water, electrolytes and glucose to maintain normal homoeostasis during recovery from illness. Additionally any ongoing losses and previously established deficits will need replaced. Variations in age, size, underlying physiology and disease processes need to be considered; in general smaller children require more fluid per kilogram than older children. This is due to a combination of higher metabolic rate, higher body surface area to volume ratio promoting higher insensible losses and a reduction in renal concentrating ability in the very young. Total body water percentage also varies with age, with a higher percentage of body water in the very young compared to older children.

Definitions

Safe fluid prescription depends on an understanding of the following:

- Tonicity

Tonicity is a measure of effective osmolality between two fluid compartments separated from each other by a semi-permeable membrane, such as the cell membrane. Certain molecules will diffuse across the membrane, moving from a compartment that is hypotonic (lower number of osmotically active solute molecules) to one of higher tonicity (higher number of osmotically active solute molecules) until equilibration takes place. Certain intravenous fluids are isosmolar (0.18% sodium chloride with 4% glucose) or even hyperosmolar (0.45% sodium Chloride with 5% glucose) (Table 1). Although these solutions are isosmolar and hyperosmolar with respect to plasma they are hypotonic in relation to the cell wall, due of their lack of osmotically active solutes. This is due to the ability of the glucose molecules to freely cross the cell membrane, thereby no longer having the same effect on plasma osmolality. If the plasma becomes hypotonic with respect to the intracellular compartment due to the infusion of hypotonic fluids there may be free movement of water into the cells. This can lead to swelling of the cell and, if this exceeds compensatory mechanisms, cellular damage will occur. If this happens in the brain, cerebral oedema can develop. The main determinant of effective tonicity with respect to the cell membrane is the sodium content of the fluid. Following the National Patient Safety (NPSA) Alert in 2007 and the Medicines and Healthcare Products Regulatory Agency (MHRA) Drug Safety Update in 2012, 0.18% sodium chloride and 4% glucose should no longer be used in children, except in specialist settings, due to the risk of hyponatraemia associated with its use.

- Osmolality

Osmolality is the concentration of a solution expressed as the number of solute molecules per kilogram of solution. The normal plasma osmolality is usually tightly controlled between 280 and 295 mOsm/L, primarily through the action of anti-diuretic hormone (ADH). Under normal circumstances ADH is released by the posterior pituitary gland in response to changes in plasma osmolality, through a tightly regulated homoeostatic mechanism. ADH causes a reduction in free water excretion from the body, via its action on the renal collecting ducts. Plasma osmolality can be estimated at the bedside by adding the formula $2(Na + K) + urea + glucose$. Ill children can demonstrate non-osmotic secretion of ADH that can lead to water retention, with the risk of developing of dilutional hyponatraemia. The stress response induced by injury and surgery is a potent cause of non-osmotic ADH release. Other clinical situations in which non-osmotic ADH release occurs include pain, hypovolaemia, opioid use and nausea and vomiting. Dilutional hyponatraemia is more likely to occur in a situation where hypotonic fluids are used in excess of maintenance requirements, in association with extensive extrarenal losses of electrolyte containing fluid and in the presence of increased ADH secretion.

Routes of administration

The safest route of administration is generally considered to be by the enteral route. Even severe dehydration may be corrected in this way when using appropriate solutions. For example, the National Institute for Care and Health Excellence (NICE) recommends, in the treatment of gastroenteritis in children less than 5 years, the use of Oral Rehydration Therapy (ORT) as the

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Sodium content, osmolality and tonicity of commonly prescribed intravenous fluids

Fluid	Osmolality (mOsm/L)	Sodium content (mmol/L)	Osmolality compared with plasma	Tonicity compared with intracellular
0.9% Sodium chloride	308	154	Isosmolar	Isotonic
0.45% Sodium chloride	154	77	Hyposmolar	Hypotonic
0.45% Sodium chloride with 5% glucose	432	75	Hyperosmolar	Hypotonic
0.9% Sodium chloride with 5% glucose	586	150	Hyperosmolar	Isotonic
0.18% Sodium chloride with 4% glucose	284	31	Isosmolar	Hypotonic
Hartmann's solution	278	131	Isosmolar	Isotonic

Table 1

optimal method of treating dehydration caused by gastroenteritis as the first line of management. A low osmolarity solution (240–250 mOsm/l) is recommended, as this seems to be associated with reduced rehydration failure rates. Many children in hospital may, however, be unable to tolerate oral fluid therapy, or the enteral route may be contraindicated, for example, when oral fluids are withheld in the perioperative period. In such cases the intravenous route is chosen.

Water and electrolyte requirements

Water and electrolyte requirements are determined by the amounts lost from the body from a number of routes, including urine, faeces and insensible losses. Holliday and Segar (1957) have estimated normal maintenance requirements of water in children (Table 2). The authors based their calculations on the calorific requirements in healthy breast fed children and estimated that for every 1 kCal used in metabolism 1 ml of water was required. This allowed them to publish a formula relating body mass to metabolism and hence to daily water requirement. A criticism of this formula is that it is based on the maintenance requirement for normal healthy children and is probably a significant overestimation in ill children. From a pragmatic point of view however it provides a reasonable and easily applied starting point for calculating fluid requirements. However, maintenance requirements may need to be substantially reduced, depending on the clinical condition of the child. Electrolyte requirements, based on the electrolyte concentrations of milk feeds, led to an estimated sodium requirement of 2–3 mmol/kg/day and of potassium 1 mmol/kg/day.

Glucose requirements

The normal glucose maintenance requirement for children varies with age but is generally accepted to be in the region of 4–8 mg/kg/minute, with a reduction in requirements as adulthood is approached. Intravenous fluids in children are usually prescribed as glucose containing solutions, commonly as 0.9% or 0.45 % sodium chloride with 5% glucose. Although these requirements will not be met when these intravenous fluids are infused at clinically appropriate rates, the majority of children will not become hypoglycaemic. This is due to production of endogenous glucose from body stores via the process of gluconeogenesis.

Certain individuals are, however, well recognized as being at risk of developing hypoglycaemia. These include neonates (in whom 10% glucose solutions are normally prescribed), infants undergoing surgery who are already receiving high concentrations of glucose containing solutions preoperatively (for example TPN) and low body weight children (less than 3rd centile) undergoing prolonged fasting. Interestingly, the normal stress response to trauma usually contributes to the development of hyperglycaemia via catecholamine related mechanisms. This response can be attenuated or abolished with the use of anaesthetic techniques such as epidural or caudal anaesthesia. Children receiving this sort of anaesthetic, particularly those with low body weight, are at a greater risk of developing hypoglycaemia in the perioperative period.

Fluid requirements

- Shock

Signs of shock are those that suggest inadequate tissue perfusion such as tachycardia, prolonged capillary refill time, altered cerebration and a reduced urine output. These clinical findings may be supported by an increasing metabolic acidosis or elevated lactate. Shock, if present, should be treated with boluses of an isotonic fluid such as 0.9% sodium chloride 10–20 ml/kg. Following any fluid bolus clinical reassessment should guide the need for further boluses. Once shock is reversed it is then appropriate to consider further fluid therapy.

- Maintenance requirement

The formula in Table 2 is used to estimate of the daily maintenance fluid requirement. This has been refined in the final column of Table 2 to provide an hourly calculation. The initial fluid should be isotonic until the plasma sodium level has been determined. Most children can safely be managed with 0.45% sodium chloride with added glucose, the amount of glucose depending on the needs of the child. In clinical situations where non-osmotic ADH release is likely, particularly if the sodium level is below 135 mmol/L, an isotonic fluid (0.9% sodium chloride or Hartmann's Solution), with or without added glucose, is appropriate. Consideration should also be given to reducing maintenance fluid requirements to two thirds of the calculated requirements.

- Deficit

In addition to maintenance fluids some children may require replacement of a fluid deficit. Fluid loss resulting in dehydration can occur due to increased renal loss, such as diabetes insipidus, or large gastrointestinal losses, such as