Fluid and electrolyte balance in children

Mark Terris

Peter Crean

Abstract

Fluid therapy in children requires an understanding of certain basic principles to avoid adverse events. Careful consideration needs to be given to both the appropriate rate and composition of the fluids to be administered with frequent re-assessment. Parenteral fluid management is used to meet maintenance requirements, correct any deficit and replace ongoing losses. Non-osmotic secretion of antidiuretic hormone (ADH) may occur, particularly in critically ill children and those in the perioperative period, resulting in an inability to compensate for an inappropriate administration of free water. Excess free water administration may result in cerebral oedema, which is poorly tolerated in children due to the proportionally larger size of the brain within the skull, compared to adults. Hyponatraemic encephalopathy continues to occur in hospitalized children and is associated with severe morbidity and mortality. Early recognition and aggressive management of this condition is required with hypertonic sodium chloride and further care within a paediatric high-dependency/intensive care unit. In the perioperative period concerns over hypoglycaemia have resulted in routine use of dextrose-containing solutions. However for the majority of children the stress response coupled with dextrose supplementation is likely to result in hyperglycaemia. Current recommendations regarding perioperative dextrose management are reviewed.

Keywords Hypoglycaemia; hyponatraemia; intravenous fluids; paediatrics; perioperative fluids

The normal requirement for fluid varies in children of different ages. This is a result of changes in metabolic rate, the ratio of evaporative surface area to body weight, the degree of renal maturity and the amount of total body water at different ages. Intravenous fluids can provide the necessary electrolyte and fluid requirements; however, the appropriate fluid needs to be given and its effects monitored. The glucose content of intravenous fluids is usually only sufficient to prevent ketosis rather than meet the child's calorific requirement.

Mark Terris *MRCPCH FRCA is a Consultant in Paediatric Anaesthesia and Intensive Care at the Royal Belfast Hospital for Sick Children, Belfast, UK. Conflicts of interest: none declared.*

Peter Crean *MB FRCA is a Consultant Paediatric Anaesthetist at the Royal Belfast Hospital for Sick Children, Belfast, UK. Conflicts of interest: none declared.*

Learning objectives

After reading this article you should be able to:
- prescribe intravenous fluids to children
- understand electrolyte problems that can occur in children
- treat symptomatic acute hyponatraemia

Definitions

Safe fluid prescription depends on an understanding of the following:
- **Osmolarity** is the concentration of a solution, expressed as the number of solute particles per *litre* of solution.
- **Osmolality** is the concentration of a solution, expressed as the number of solute particles per *kilogram* of solution.
- **Tonicity** is a measure of *effective osmolarity* or *effective osmolality* relative to another fluid compartment across a semipermeable membrane.
- **Osmoles** are solute particles that are capable of exerting an osmotic pressure across a semipermeable membrane. Sodium is the major extracellular osmole and therefore the predominant determinant of extracellular fluid volume. Potassium is the major intracellular ion responsible for determining intracellular fluid volume. Urea and glucose pass freely across all cell membranes and therefore do not contribute to the effective tonicity of body fluid compartments, despite being determinants of plasma osmolality.

As shown in Table 1 the osmolality, sodium content, osmolality compared to plasma and tonicity of available intravenous fluids vary greatly. As can be seen the combined sodium chloride and glucose solutions, where the sodium content is less than 154 mmol/litre, are hypotonic in the body. Glucose passes freely across cell membranes and does not contribute to the effective tonicity.

Antidiuretic hormone (ADH)

Normal plasma osmolality is 280–295 mOsm/litre with tight auto-regulation around each individual's genetically determined set point. Variations in plasma osmolality are controlled primarily via ADH secretion from the posterior pituitary gland. An increase in plasma osmolality results in an increase in the release of ADH which acts upon the collecting ducts of the renal tubules to increase water re-absorption and therefore lower the plasma osmolality back towards normal. Similarly a fall in plasma osmolality reduces ADH secretion to minimal levels and leads to an increase in water excretion and an increase in plasma osmolality. ADH secretion is also triggered by other non-osmotic factors such as hypovolaemia, hypotension, pain, opioids, volatile anaesthetics, nausea and vomiting.

Water and electrolyte requirements

Water is required to replace obligatory insensible losses via skin and respiratory tract, and that lost via urine and faeces. In 1957 Holliday and Segar published a formula for calculating the maintenance water requirements in children.[1] This easy-to-use formula, or Oh's later simplification, continues to be widely used

Composition of commonly used intravenous solutions

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

Table 1

today[2] (Table 2). To generate this formula Holliday and Segar related the calorific requirements of infants and children to water requirements, with 100 ml of water being lost for every 100 kcal expended. For hospitalized children calorific requirements were defined as being halfway between basal metabolic rate and those estimated for normal activity. In addition daily electrolyte requirements were estimated in relation to the intake of electrolytes from differing types of milk required to meet calorific needs. From this the maintenance electrolyte requirements for sodium were 2–3 mmol/kg/day and potassium 1 mmol/kg/day.

Maintenance fluids

Where possible fluids should be given enterally. If parenteral fluid therapy is required then maintenance fluid requirements should be calculated using the Holliday and Segar formula based on weight. However this should only be used as a starting point and the individuals' response to fluid therapy should be monitored closely by clinical observation, fluid balance, weight and a minimum daily electrolyte profile. Fluid composition will vary according to clinical situation. Most children can safely be managed with a solution of 0.45% saline with added glucose (i.e. 0.45% saline with 5% glucose or 0.45% saline with 2.5% glucose) depending on glucose requirements.[3] Sodium chloride 0.18% with glucose 4% should not be used as a maintenance fluid and is restricted to specialist areas to replace ongoing losses of hypotonic fluids. These areas include high dependency, renal, liver and intensive care units.

Certain children are more at risk of developing hyponatraemia and will benefit from the use of isotonic solutions, such as 0.9% saline with or without glucose and Hartmann's solution. Those at particular risk include children with a low plasma sodium at time of commencing fluids, particularly if below 135, and those in danger of developing non-osmotic ADH secretion. This includes children in the perioperative period who may experience several of the non-osmotic triggers such as hypovolaemia, pain, opiates, nausea or vomiting.

Calculating water requirements

Body weight (kg)	Holliday and Segar	Oh
0–10	4 ml/kg/hour	4 ml/kg/hour
10–20	40 ml/hour + 2 ml/kg/hour above 10 kg	20 + (2 × kg) ml/hour
>20 kg	60 ml/hour + 1 ml/kg/hour above 20 kg	40 + (1 × kg) ml/hour

Table 2

Previously concerns regarding the risk of hypoglycaemia in children undergoing surgery led to the routine use of glucose-containing solutions. However, in the majority of children the stress response to starvation and surgery is more likely to result in hyperglycaemia. Current recommendations are that solutions without additional dextrose may be used intraoperatively in most patients whilst monitoring the blood glucose.[4] Those at risk of hypoglycaemia include:

- neonates in the first 48 hours of life
- preterm and term infants already receiving dextrose-containing solutions
- children on parenteral nutrition
- low body weight (<3rd centile) or undergoing prolonged surgery
- extensive regional blockade with attenuated stress response.

These at-risk groups will require a glucose-containing fluid or regular blood glucose checks intraoperatively. A solution containing 1–2.5% dextrose appears sufficient to prevent hypoglycaemia with a reduced risk of developing hyperglycaemia. However in the postoperative period this may be insufficient to prevent ketosis.[5]

Deficit

In addition to fluids required to meet maintenance requirements, children may require replacement of a fluid deficit. Fluid deficit sufficient to cause impaired tissue oxygenation, resulting in clinical shock, should be quickly corrected with a bolus of an isotonic fluid. For the majority of patients this bolus is given as 20 ml/kg. However in patients with trauma or diabetic ketoacidosis this should be given in smaller aliquots of 10 ml/kg. Following any fluid bolus clinical re-assessment should guide the need for repeated boluses with consideration to the use of blood after 40 ml/kg (see articles on Transfusion guidelines in children in this issue).

