Fluid and electrolyte balance in children

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Abstract

Safe intravenous fluid prescription 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. In this review we examine the indications for parenteral fluid management: maintenance requirements, correction of any deficit and replacement of ongoing losses. The role of non-osmotic secretion of antidiuretic hormone (ADH) is discussed and children at particular risk are identified. We review complications associated with intravenous fluid therapy, in particular hyponatraemic encephalopathy and discuss the management of this medical emergency. Other electrolyte abnormalities that may arise are highlighted. Fluid management in children with diabetic ketoacidosis is also reviewed.

Keywords Electrolytes; fluid therapy; hyponatraemia; intravenous; osmolality; paediatrics

Royal College of Anaesthetists CPD matrix: 1A01; 2D02; 2D04

Learning objectives

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

The aim of using intravenous fluids in children should be to provide water, electrolytes and glucose in sufficient amounts to:
- meet maintenance requirements
- replace deficit
- replace ongoing losses
- correct inadequate circulating volume leading to clinical shock.

In order to safely provide intravenous fluid therapy in children the prescription needs to be individually based on the child's weight and clinical condition. The need for intravenous fluids should be continually reassessed, as should the child's response to treatment.

Definitions

Safe and effective fluid management requires an understanding of the following terms.
- **Osmolality** is the concentration of a solution expressed as the number of solute particles per *kilogram* of solution.
- **Osmolarity** is the concentration of a solution expressed as the number of solute particles per *litre* of a solution.
- **Tonicity** is a measure of the effective osmolarity/osmolality between two fluid compartments separated from each other by a semi-permeable membrane.

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While certain intravenous fluids may be iso-osmolar (0.18% sodium chloride with 4% glucose) or hyperosmolar (0.45% sodium chloride with 5% glucose) relative to plasma they are hypotonic relative to the cell wall (Table 1). After infusion the glucose molecules are able to move freely across the cell wall and therefore cease to contribute to the relative osmolality. This can result in hypotonic plasma and the movement of water into the cell, which may lead to cell swelling and ultimately cellular damage. Within the brain this can result in cerebral oedema.

Antidiuretic hormone

Plasma osmolality is tightly maintained at around 280–295 mOsm/litre primarily through the action of antidiuretic hormone (ADH). ADH is secreted by the posterior pituitary in response to a detected increase in the plasma osmolality. The secreted ADH then acts on the collecting ducts of the renal tubules to increase water re-absorption and thus lower plasma osmolality to the normal range.

ADH may be secreted non-osmotically in response to the stress response associated with injury or surgery leading to an inappropriate retention of water and the possibility of developing hyponatraemia. Pain, nausea, vomiting, hypovolaemia, hypotension, pneumonia, opioid administration and volatile anaesthetics may also trigger non-osmotic ADH secretion. In fact most children in hospital receiving intravenous fluids belong to one of these categories and are therefore at risk of developing hyponatraemia.

Water requirements

Water is required to replace fluid loss in the body from a number of routes, mainly skin, respiratory tract, kidneys and the gastrointestinal tract. In 1957 Holliday and Segar published a formula for estimating the maintenance fluid requirements in children.[1] This was based on the calorific requirements for healthy children and estimated that, for every 1 kcal used in metabolism, 1 ml of water was required. For hospitalized children calorific requirements were defined as being halfway between basal metabolic rate and those estimated for normal activity. It is important to understand that, whilst this formula provides a useful calculation to guide the starting point for the volume of fluids to be administered, it may represent a significant over-estimation of maintenance requirements in ill children and the actual volume may need to be reduced. The daily electrolyte requirement was calculated from that contained in milk: 2–3 mmol/kg/day for sodium and 1 mmol/kg/day for potassium.

Glucose requirements

Maintenance glucose requirements in children vary with age but are generally accepted to be around 4–8 mg/kg/minute. Usually intravenous fluids in children are prescribed as a glucose-

Composition of commonly used intravenous solutions

Solution	Osmolality (mOsmol/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	Hypoosmolar	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

containing solution, for example 0.9% sodium chloride with 5% glucose. At standard clinical infusion rates this would be inadequate to prevent hypoglycaemia. However the majority of children will produce endogenous glucose to maintain a normal blood sugar.

Certain groups of patients are at particular risk of hypoglycaemia in the perioperative period. These include neonates (in whom 10% glucose solutions are normally used), children with a low body weight (less than 3rd centile) and those receiving higher concentrations of glucose-containing solutions preoperatively (e.g. parenteral nutrition). In addition the use of a central neuraxial block such as caudal, epidural or spinal may attenuate the expected stress response and cause hypoglycaemia due to a failure of catecholamine-driven glucose mobilization.[2]

Reasons for fluid administration

Fluids should be administered enterally whenever possible because this is considered to be the safest route. However many ill children in hospital are unable to either tolerate oral fluids or require parenteral fluid administration in the perioperative period, for example whilst fasting or following bowel surgery.

It is useful to consider intravenous fluid prescribing under the following three headings.

Maintenance

Fluid requirements can be calculated either daily or hourly by using the formulae shown in Table 2. The calculated daily volumes in larger children should not exceed those usually prescribed in adults. These calculations will give a guide to expected requirements but may need to be reduced in patients at risk of developing hyponatraemia secondary to secretion of ADH. If the serum sodium is unknown at the start of fluid administration then an isotonic fluid such as 0.9% sodium chloride, with added glucose if required, should be used. In fact most children can safely be managed with an isotonic fluid for their maintenance requirements, especially in the perioperative period. Although children receiving isotonic solutions are less likely to develop hyponatraemia, it can still happen, and close monitoring of electrolytes remains vitally important.[3] If the serum sodium concentration is elevated 0.45% sodium chloride with added glucose should be considered. The iso-osmolar 0.18% sodium chloride with 4% glucose should not be used as a maintenance fluid and its use should be restricted to specialist areas such as renal, high dependency or intensive care units.[4]

Calculation of water requirements

Body weight (kg)	Holliday and Segar	Oh[7]
0–10	4 ml/kg/hour	4 ml/kg/hour
10–20	40 ml/hour + 2 ml/kg/hour above 10 kg	20 +(2x kg) ml/hour
>20 kg	60 ml/hour + 1 ml/kg/hour above 20 kg	40 +(1x kg) ml/hour

Consider reducing to two-thirds calculated maintenance volume in children at risk of non-osmotic ADH secretion.

Table 2

Deficit

Fluid deficit sufficient to impair tissue oxygenation and cause shock must be recognized and quickly corrected with a bolus of an isotonic fluid. Shock is treated by administering an isotonic fluid bolus (20 ml/kg), with a re-assessment and further fluid bolus as indicated. In patients with trauma or diabetic ketoacidosis this fluid bolus is given in smaller aliquots of 10 ml/kg. After 40–60 ml/kg of fluid administration consideration should be given to the need for blood transfusion and/or intubation and ventilation to further support the circulation. Inotropes may be required. The FEAST trial has raised concerns about increased mortality following fluid bolus. It should be stressed however, that this trial was conducted in a resource-limited setting with 57% of the patients having malaria.[5] The impact of these findings has yet to be evaluated in other populations.

A more gradual loss of fluid, for example due to vomiting and diarrhoea, may result in dehydration that may be evaluated clinically. However clinical assessment of dehydration is notoriously difficult and inaccurate and the signs and symptoms listed in Table 3 may be mimicked by other causes. Given the inaccuracies associated with clinical assessment of dehydration it is safer to limit the predicted degree of dehydration to 8% at maximum in any calculations. If a recent weight is known then a more accurate assessment of dehydration can be made by evaluating weight loss.

After calculating the fluid deficit the volume of any fluid boluses administered should be subtracted from this. The remaining volume should be replaced over 48 hours using an isotonic fluid, in conjunction with maintenance fluids. More rapid