**Blended Learning – Fluid Management in Children**

**Abstract**

A broad understanding of the principles of fluid and electrolyte homeostasis is essential for ensuring safe and effective prescribing of fluids. Inappropriate prescribing can lead to unnecessarily prolonged hospital stays and in extreme cases can lead to morbidity & mortality. Generally, infants have a much higher surface area to body mass ratio than older children and adults. This combined with the fact that they have a relatively higher proportion of extracellular water, means that they are more likely to become dehydrated. Hence stopping fluid intake for more than short periods of time will affect the body’s ability to maintain fluid homeostasis. In such patients drinking water may not be sufficient to replace deficits within a safe timeframe, and intravenous (IV) fluid administration may become essential to correct acute losses.

Intravenous fluid therapy can be divided into two categories depending on the aim of treatment: to correct existing fluid deficits (fluid replacement/resuscitation) or to replace normal losses (routine maintenance). Most indications for IV fluid replacement are the same for children as for adults however there are some that are specific to paediatrics, relating in particular to neonates. The amount of IV fluid required by a child will depend on the current level of dehydration, the indication and any comorbidity. Another important factor is age. Neonates require relatively more fluid intake (on mL/kg basis) than infants or older children.

Potential complications of IV fluid therapy include hyponatraemia, hypernatraemia, over hydration, and inappropriate fluid distribution.

**Background and basic principles**

A broad understanding of the principles of fluid and electrolyte homeostasis is essential for ensuring safe and effective prescribing of fluids. Inappropriate prescribing can lead to unnecessarily prolonged hospital stays and in extreme cases can lead to morbidity & mortality.

Water is essential for transporting nutrients, electrolytes, hormones and proteins around the body, as well as enabling the excretion of water soluble waste products. The human body is able to maintain relatively constant levels of fluid and electrolytes through a number of homeostatic mechanisms. Fluid is primarily gained from the intake of food and water. It is removed by excretion of urine, faeces and sweat, as well as through smaller (insensible) losses via the lungs and skin (transepidermal).

**Total body water**

The total amount of water in the body as a percentage of lean body weight varies with age. On average, adults are made up of 60% water by weight. This percentage is greatly increased in children.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Pre-term** | **Full-term** | **One year** | **Adult** |
| Total body water | 85 - 90% | 75% | 70% | 60% |
| Fat content | 3% | 12% | 30% | 18% |

Table 1

Note how the amount of total body water varies with the amount of body fat. This is because fat has lower water content than muscle.

**Body fluid compartments**

 Figure 1 

The total body water is distributed between two fluid compartments, defined as intracellular or extracellular. Two-thirds of the body water is found inside cells (the intracellular compartment), helping to maintain their structure. The remaining one third is found in the extracellular compartment, comprising of the blood (intravascular fluid i.e. plasma) and the fluid between the cells (interstitial fluid), in an approximate 2:1 ratio. This ratio varies according to age. Generally, infants have a greater proportion of extracellular water (mainly interstitial water) than older children and adults. Extracellular water is more easily lost from the body than that held within the cells. This together with the fact that infants have a much higher surface area to body mass ratio means that they are more likely to become dehydrated compared to older children or adults.

**Fluid Distribution in Children**

 Figure 2 

Willock J, Jewkes F. Making sense of fluid balance in children. Paediatric Nursing, 2000; 12(7): 37-42**2**

**Fluid balance physiology**

Cell membranes allow water to move freely between the extracellular and intracellular compartments, enabling osmotic equilibrium, i.e. the osmolality (mmol/kg) of both is roughly the same. Osmolality refers to the number of particles (e.g. Na+, K+) per litre of water which is directly related to the osmotic pressure. Free water will always move from an area of low osmotic pressure to an area of high osmotic pressure. This free movement of water also means that any osmolality changes in extracellular fluid can significantly affect the osmolality of intracellular fluid, leading to problems with normal cell functioning. For example, if the plasma sodium level drops suddenly, or there is a loss of protein in the urine, water will move out of the intravascular compartment and into the tissue cells. This will result in oedema (e.g. cerebral oedema) but also contributes to hypovolaemia and reduced systemic perfusion. Conversely, if the plasma sodium level increases suddenly, it will cause free water to move from the intracellular compartment into the vascular space. Severe hyperglycaemia has a similar effect, but also triggers an osmotic diuresis which leads to dehydration. This is the rationale behind using intravenous mannitol to treat cerebral oedema.

Sodium is the main extracellular cation, and is a major contributor to plasma osmolality. In healthy individuals any increase in sodium absorption (e.g. through ingestion) will initially result in increased osmolality in the blood. This will give rise to transient thirst and stimulate antidiuretic hormone (ADH) secretion. ADH is responsible for increasing water reabsorption (i.e. more concentrated urine is produced) leading to an increase in body water and a normalisation of extracellular sodium concentration (i.e. less concentrated blood plasma). Conversely, a low plasma osmolality will suppress the release of ADH, resulting in decreased water reabsorption and more concentrated plasma.

Other important agents involved with volume homeostasis include renin, angiotensin, aldosterone, β-naturetic peptide and catecholamines (epinephrine, norepinephrine, dopamine).

**Does my patient require fluid replacement therapy?**

The body is extremely sensitive to small changes in the volume of total body water, but it is particularly responsive to changes in the vascular compartment as this is responsible for maintaining blood pressure and organ perfusion. Stopping fluid intake for more than short periods of time will affect the body’s ability to maintain fluid homeostasis. This occurs far more rapidly in infants, young children and the elderly compared to adults. For these groups of patients, drinking water may not be sufficient to replace deficits within a safe timeframe, and intravenous (IV) fluid administration may become essential to correct acute losses.

**Indications for IV fluid treatment**

Common indications for requiring IV fluid therapy include**4**:

* Prolonged failure of oral intake such as ‘nil by mouth’, reduced absorption, mucositis or poor care by self or others
* Excessive loss of water, e.g. profuse diarrhoea or vomiting, fistula, exposure to extreme heat, profound diuresis (diabetes insipidus or diabetic ketoacidosis), or blood loss from trauma or surgery
* Insensible losses can increase during fever or after suffering burns caused by the skin’s impaired barrier function
* Where the oral route is not available, e.g. reduced consciousness following surgery, accident or illness or following head and neck surgery
* Accumulation of fluid into spaces that normally contain minimal fluid volumes (e.g. peritoneal or pleural cavities), during surgery or as a result of inflammatory conditions such as sepsis. This is known as ‘third spacing’ and can result in a reduction of fluid in the vascular compartment.

Most indications for IV fluid replacement are the same for children as for adults however there are some that are specific to paediatrics:

* Insensible losses are likely to be greater in jaundiced neonates undergoing phototherapy to conjugate bilirubin
* Premature neonates are at increased risk of insensible losses through the skin due to the very thin and delicate nature of the stratum corneum
* Premature neonates have an immature gastrointestinal system which reduces the absorption of enteral feeds
* Neonates born with gastrointestinal abnormalities such as gastroschisis (birth defect in which the baby's intestines extend outside of the body through a hole next to the belly button) or malrotation (a congenital anatomical anomaly that results from an abnormal rotation of the gut, causing twisting of the intestine and can lead to obstruction)

**Assessing fluid requirements**

**Identifying clinical dehydration and hypovolaemic shock in children**

Dehydration in children is usually identified through assessing specific clinical features**4**:

Reduced skin turgor (elasticity) – in a normal healthy child pinched skin will immediately fall back to its normal place when released. However, in a child that is dehydrated, the skin will remain tented or fall back to its normal place very slowly.

Thirst – Usually a child will not feel thirsty if only mildly dehydrated

Altered respiratory pattern – Nasal flaring, deep respirations & tachypnoea:

Respiratory rate >50/min age 6-12 months and >40/min age >12 months

Increased capillary refill time – pressing a finger on the child’s forehead, sternum or thumb nail for 5 seconds and then releasing the pressure should allow the colour to return to the area within two seconds. A slower refill time indicates poor skin perfusion that may be due to hypovolaemia

Dry mucous membranes – eyes and lips appear dry, reduced tears

Sunken fontanelle (in infants less than two years old) – a fontanelle is a membranous space between the bones of the skull in an infant, where ossification is not complete and the sutures not fully formed. If this soft spot noticeably sinks inwards (appears sunken), it signifies the presence of dehydration.

Altered level of consciousness – the child does not respond normally to social cues, is lethargic, drowsy, wakes only after prolonged stimulation or is irritable

Reduced urinary output – can be usually assessed by fewer wet nappies

Cold extremities – a difference of more than 2o C between the core body temperature and the temperature measured by a probe attached to a finger or toe may indicate inadequate peripheral perfusion caused by hypovolaemia

Weight loss – a body weight loss of between 3 and 8% can occur in moderate dehydration. Children with severe fluid balance problems should be weighed twice a day. Fluid loss or gain can be assessed by the change in weight (assuming 1mL water weighs 1gram).

Cardiac symptoms – severe fluid depletion will cause the heart rate to increase, which helps to increase cardiac output and raise the blood pressure, thereby maintaining tissue oxygenation. Blood pressure will only fall as a response to a 20-30% decrease in intravascular volume.

All of these signs and symptoms must be evaluated as a whole rather than in isolation to get a true picture of the level of dehydration. See also NICE guidelines **7, 9, 10**:

<https://www.nice.org.uk/guidance/ng29/chapter/Recommendations#assessment-and-monitoring-2>

<https://www.nice.org.uk/guidance/cg84/chapter/1-Guidance#assessing-dehydration-and-shock>

<https://www.nice.org.uk/guidance/cg160/chapter/recommendations#table-1-traffic-light-system-for-identifying-risk-of-serious-illness>

The amount of IV fluid required by a child will depend on the current level of dehydration, the indication and any comorbidity. Another important factor is age. Neonates require relatively more fluid intake (on mL/kg basis) than infants or older children. This could be due to:

* Neonates having small immature kidneys with limited concentrating ability, increasing the amount of water lost in the urine. In addition, the eGFR is around 30mL/min/1.73m2 at birth, which means that neonates are unable to cope with either dehydration or water overload.
* Whether the neonate is being nursed in an incubator or an open care system
* Environmental conditions such as temperature, humidity, radiant heat, convection currents, phototherapy, etc.
* Optimum temperature and humidity of respiratory gases – very dry and very cold conditions will cause increased respiratory losses
* Very premature neonates have an immature skin with a thin stratum corneum. This means significant loss of water can occur through the transepidermal route until the skin matures by around 2 weeks of age. The potential for these losses is low in term infants as their skin has already keratinised**3**. <http://fn.bmj.com/content/89/2/F108>
* How much the skin is covered – neonates that are nursed naked under radiant warmers are vulnerable to significant water loss through the skin that may exceed urine volume
* Although stool water loss is small and usually only 5-10 ml/kg/day, neonates are at increased risk of having watery loose stools if they are undergoing phototherapy

IV fluid requirements are calculated according to the child’s body weight. Hence, all children receiving IV fluids should have their fluid balance checked. This involves measuring the body weight (at base line, then once a day) as well as the types and volumes of fluid input & output, recorded hourly with running totals.

**Fluid types**

Parenteral administration of water is generally avoided as it is hypotonic compared with body fluids. For this reason various IV fluids have been developed that minimise the risk of damage to the vasculature and cells within the circulatory system. The two main types of fluid available in the UK are crystalloids and colloids**5**.

**Crystalloids**

Crystalloids are solutions of small molecules in water such as sodium chloride, glucose, potassium chloride and Hartmann’s. Due to their size, these molecules can pass freely through semi-permeable membranes, hence can distribute readily into the various body fluid compartments. Sodium chloride distributes into the extracellular space (intravascular & interstitial spaces), while glucose solutions can distribute into both extracellular and intracellular compartments. The glucose itself gets metabolised quite rapidly, and in effect just provides free water.

The two most commonly used crystalloids are sodium chloride 0.9% and glucose 5%, both of which are isotonic. This means that they exert the same osmotic pressure as plasma and so do not damage cells within the blood or those lining the blood vessels. Consequently, isotonic solutions can be safely administered into small veins. Mixtures of the two solutions are also available to allow greater flexibility. Although both sodium chloride 0.9% and glucose 5% are isotonic with plasma, their electrolyte composition is very different. For a solution to be ‘balanced’, its electrolyte composition must also be more aligned with that of plasma. An example of this is compound sodium lactate (Hartmann’s solution) which contains potassium, calcium magnesium and lactate in addition to sodium chloride. Hartmann’s is less likely to cause fluid overload problems due to lower sodium content.

Hypertonic solutions of glucose (10-50%) are used when glucose substitution is required (e.g. for use in intravenous feeding regimens or to treat hypoglycaemia). Prolonged administration of such solutions is usually through a central catheter into a larger vein, where the greater flow of blood can rapidly dilute the solution thereby minimising damage to the vein wall.

In addition, both hypo and hypertonic solutions of sodium chloride are available, but their use is limited. Hypotonic sodium chloride is used to treat hypernatremia, and hypertonic sodium chloride is sometimes used to correct hyponatraemia. Both require careful monitoring. Hypotonic solutions containing sodium chloride 0.18% with glucose 4% are no longer advocated in children as the risk of developing hyponatraemia is greatly increased.

**Colloids**

Colloids are also known as plasma substitutes. Their large molecules are too big to easily diffuse through the blood vessel walls into other compartments, meaning that they are initially retained in the blood and help to expand the plasma volume. The duration of action depends on the molecular size (the larger the molecule, the longer the duration), the rate of degradation and the extent of blood vessel permeability. Examples of colloids include modified fluid gelatin (derived from animal collagen), dextran solution (synthetic polysaccharides), albumin (naturally occurring protein) and esterified starches. They are mainly used in intensive care or accident and emergency.

There is very little evidence to support the use of colloids in children**5**. Any evidence that is available relates to adults, and appears to show that colloid solutions do not have a proven benefit compared to crystalloid solutions. This view is also supported by a recent Cochrane review addressing the question, for all indications and all types of colloids in adults**12**. <http://onlinelibrary.wiley.com/doi/10.1002/14651858.CD000567.pub6/epdf/abstract>

Furthermore, colloids are more expensive and are more likely to cause adverse effects**14**. Despite this, the use of colloids such as albumin may be justified in highly specialised settings such as in nephrotic syndrome or severe sepsis**13**.

**Intravenous fluid therapy**

Intravenous fluid therapy can be divided into two categories depending on the aim of treatment: to correct existing fluid deficits (fluid replacement/resuscitation) or to replace normal losses (routine maintenance).

**Routine maintenance therapy (rehydration)**

Maintenance fluids are usually given to well children, who have healthy kidneys and no co-morbidities that could affect fluid homeostasis, such as reduced cardiac output**4**. The aim is to meet normal fluid and electrolyte requirements, and provide hydration for a short period of time until enteral or parenteral nutrition can be initiated. Children at low risk of developing hyponatraemia (with normal renal and cardiac function) can be given a ready-mixed solution of 0.45% sodium chloride plus glucose 5%. For children who are at higher risk of developing hyponatraemia, only isotonic solutions should be used such as 0.9% sodium chloride or 0.9% sodium chloride with 5% glucose. There is inconclusive evidence around which strength of glucose to use. Potassium requirements of children with normal renal function can be adequately met with solutions containing 20mmol/litre of potassium chloride. This can be increased to 40mmol/litre in case of hypokalaemia.

Routine maintenance IV fluid rates for *term* neonates can be calculated according to their age, using the following as a guide**7**:

* From birth to day 1: 50–60 ml/kg/day.
* Day 2: 70–80 ml/kg/day.
* Day 3: 80–100 ml/kg/day.
* Days 5–28: 120–150 ml/kg/day.

<https://www.nice.org.uk/guidance/ng29/chapter/Recommendations#assessment-and-monitoring-2>

However, due to their specific requirements, prescribing of fluids for neonates should be calculated by a neonatologist**4**.

For children over 1 month, fluid requirements are calculated as outlined below**1**:

|  |  |
| --- | --- |
| Body weight | 24-hour fluid requirement |
| Under 10 kg | 100mL/kg |
| 10-20kg | 100mL/kg for the first 10kg + 50mL/kg for each 1kg body-weight over 10kg |
| Over 20kg | 100mL/kg for the first 10kg + 50mL/kg for each 1kg body-weight between 10-20kg + 20mL/kg for each 1kg body-weight over 20kg(Max. 2litres in females and 2.5litres in males) |
| The baseline fluid requirements should be adjusted to take account of factors that reduce water loss (e.g. increased ADH, renal failure, hypothermia and high ambient humidity), or increase water loss (e.g. pyrexia or burns). |

Table 2

Plasma electrolytes levels should be measured prior to initiating maintenance fluids and at least every 24 hours thereafter.

**Fluid replacement or resuscitation**

Patients will require fluid resuscitation if they experience acute circulatory shock or depletion of the intravascular volume. Replacing lost fluid rapidly will help to quickly restore the circulating blood volume as well as to increase cardiac output, which ultimately restores tissue perfusion and oxygen delivery. The choice of fluid to be used depends largely on the body compartment that requires replenishing and the type of fluid that has been lost. Other factors to consider include renal and cardiac function, glucose levels, acid-base balance and electrolyte levels**5**.

Suspected or confirmed shock in children and young people should be treated with a rapid intravenous infusion of 20mL/kg of 0.9% sodium chloride solution given over less than 10 minutes. Term neonates should be administered a bolus of 10-20mL/kg over less than 10 minutes. Smaller fluid volumes may be needed if there is reduced renal or cardiac function. Glucose-free solutions must be used for fluid replacement regimens. This is because glucose will distribute throughout total body water, i.e. across all compartments, and can exacerbate interstitial oedema while not fully restoring the intravascular volume.

In certain cases fluid volumes of 40-60mL/kg may be needed as part of initial fluid resuscitation. An important point to bear in mind is that due to the relatively large volume of replacement fluid that is administered, it may take several days to redistribute and clear from the body, especially in patients with impaired homeostasis.

**Potential complications**

**Hyponatraemia**

Children being given intravenous fluids must be appropriately monitored as hyponatraemia can develop rapidly. This is defined as a serum sodium < 130 mmol/L. The clinical signs of hyponatraemia include headache, nausea & vomiting, confusion & disorientation, seizures, irritability, lethargy and apnoea. Acute symptomatic hyponatraemia requires immediate expert input, e.g. from the paediatric intensive team. In most patients however, these symptoms may not be present. If asymptomatic hyponatraemia develops during intravenous fluid therapy this is best managed with isotonic fluids such as sodium chloride 0.9%. Fluid restriction may also be beneficial as this will reduce the amount of free water, and lead to an increase in sodium levels. Alternatively fluids can be reduced based on calculations of insensible losses and reduced urine output.

A common cause of hyponatraemia is the unintentional over prescribing of fluids to counteract the effects of elevated antidiuretic hormone (ADH). Levels of ADH rise significantly in the immediate post-operative period leading to activation of the renin-aldosterone-angiotensin system. Aldosterone is responsible for actively reabsorbing salt and water from the kidney resulting in reduced urine output and raised sodium levels. If hypotonic sodium chloride is used to address this it becomes a source of free water and will cause hyponatraemia. Following the report of several deaths in children due to the administration of hypotonic solutions, the National Patients Safety Agency (now incorporated into NICE) issued an alert in 2007**15**. This recommended that hypotonic solutions, including the then commonly used sodium chloride 0.18% plus glucose 4%, should be removed from paediatric surgical areas and not be routinely used for fluid maintenance in children.

Certain conditions can increase the risk of children developing hyponatraemia**4**. These include hypovolaemia, head injury, sepsis, salt wasting syndromes (e.g. cystic fibrosis), bronchiolitis, hypotension and surgery.

**Hypernatraemia**

Hypernatraemia should be managed according to whether the child is dehydrated or not. If there is no evidence of dehydration, and an isotonic solution is currently being used, treatment should be switched to a hypotonic solution such as sodium chloride 0.45% with glucose. If the child is dehydrated as well as hypernatraemic, the fluid deficit should be replaced using sodium chloride 0.9% over 48 hours. Hypotonic solutions such as sodium chloride 0.45% with glucose should only be considered if the hypernatraemia worsens or remains unchanged despite replacing the deficit.

**Over hydration**

Over hydration can arise if the volume of fluid administered exceeds the fluid losses, especially in patients with reduced kidney function or pre-existing ventricular impairment**5**. Fluid overload can lead to heart failure as a consequence of being unable to cope with the demand exerted on the heart by the expanded circulatory volume. This will inevitably lead to pulmonary oedema, which requires prompt action. Other aftereffects of fluid overload include abdominal compartment syndrome and acute respiratory distress syndrome. Over hydration can be corrected with the use of diuretics and fluid restriction. If the patient has severe renal impairment, haemofiltration or dialysis may be required.

**Inappropriate fluid distribution**

The distribution of fluid and electrolytes becomes unbalanced as a result of injury. This is because vascular permeability increases as result of inflammation associated with sepsis, trauma, surgery or burns. Plasma proteins, electrolytes and water are therefore able to leak out of the intravascular space into the interstitial compartment. The end result is the accumulation of fluid in the tissues (oedema) with a corresponding reduction in fluid in the vasculature (hypovolaemia), even though the child may not be dehydrated or overloaded.

Oedema can manifest as puffy eyelids, swollen ankles, or more seriously as pulmonary oedema and cerebral oedema. Hypovolaemia can lead to shock, which is the body’s response when inadequate amounts of nutrients are delivered to the tissues. The lack of oxygen and glucose disables normal metabolism, leading to the production of lactic and carbonic acids and gives rise to acidosis. Other chemical processes further increase capillary permeability which exacerbates the reduction in circulating volume. This downward spiral ultimately leads to irreversible shock and death.

It is therefore imperative that children with vascular leakage and inappropriate fluid distribution are monitored carefully to prevent pulmonary oedema or shock. Affected patients may need large volumes of fluids to maintain adequate perfusion and restore the intravascular volume.

**Biochemical disturbances**

Administration of large volumes of sodium chloride 0.9% can result in over provision of sodium and chloride ions. Patients with increased lactate levels following surgery or those with CO2 retention secondary to respiratory failure may be at increased risk of developing acidosis, and excess levels of chloride ions can easily tip them into severe metabolic acidosis. For this reason, many clinicians prefer the use of balanced solutions in critically ill patients. Risks are also associated with rapid correction of both hyponatraemia (resulting in shrinkage of brain cells) and hypernatraemia (resulting in cerebral oedema).

**Allergic reactions**

Allergic reactions have been associated with synthetic colloids, but these are rarely used in children.

**Haemodilution**

Administration of large volumes of intravenous fluids will cause dilution of the blood plasma and a consequent drop in haemoglobin levels. Depending on the patient’s condition, the sudden drop may require a blood transfusion. However, in most cases haemoglobin levels will return to normal within a few days once the kidneys have removed the excess fluid from the system.

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**Key Words**

Fluid Balance, Children, Dehydration, Fluid replacement, Hyponatraemia, Fluids, Intravenous

**Reflective Questions**

1. Under what circumstances would you consider initiating intravenous fluid replacement therapy in children?
2. What factors should be considered when assessing a child’s fluid requirements?
3. What are the potential complications of intravenous fluid therapy and how might these be avoided or minimised?