Fluid requirements differ between infants and older children, therefore it is essential that children’s nurses have a sound understanding of fluid balance. This article aims to update children’s nurses’ knowledge of fluid balance and provides guidance on taking the appropriate action when clinical problems arise.

Fluid balance: Anatomy and physiology

The content and distribution of water in the human body changes with age (see Table 1). Total body water also varies with body fat content. Fat cells contain very little water, therefore children with more body fat have a lower proportion of body water than children with less fat.

Table 1. Normal body water content in children (Metheny and Snively 1983)

<table>
<thead>
<tr>
<th>Age group</th>
<th>Approx water content in body</th>
</tr>
</thead>
<tbody>
<tr>
<td>Premature infant</td>
<td>90%</td>
</tr>
<tr>
<td>Newborn infant</td>
<td>70-80%</td>
</tr>
<tr>
<td>12-24 months</td>
<td>64%</td>
</tr>
<tr>
<td>Adult</td>
<td>60%</td>
</tr>
</tbody>
</table>

The water in body tissues is contained within ‘compartments’ (see Figure 1). Intracellular fluid is water contained within the cells. Extracellular fluid is water outside the cells. Extracellular fluid is further subdivided into:

- Intravascular fluid (plasma);
- Interstitial fluid (fluid surrounding tissue cells); and
- Transcellular fluid (e.g. cerebrospinal, sinovial, pleural, peritoneal fluid).

Infants have a greater proportion of extracellular fluid than older children and adults (Table 2 and Figure 2). Because extracellular fluid is more easily lost from the body than intracellular fluid, infants are more at risk of developing dehydration than older children and adults (infants also have a larger surface area to body mass ratio).

Blood volume can be estimated as 90ml/kg in neonates, 80ml/kg in infants and children and about 65ml/kg in adults (Davenport 1996). Adequate systemic perfusion depends (among other factors) upon...
adequate intravascular volume. However, infants and children can compensate for relatively large losses in circulating volume, and signs and symptoms of shock may be difficult to detect if a child has lost less than 25 per cent of the circulating volume.

The movement of fluid between the vascular space and the tissues depends on osmotic pressures, oncotic pressures, hydrostatic pressures, and changes in capillary permeability. Understanding these factors is important when trying to anticipate changes in the child’s intravascular volume (Hazinski 1988).

**Osmotic force or pressure** is directly related to the number of particles dissolved in a fluid. The number of particles per litre of water is called the osmolality. These particles are mainly electrolytes and proteins. An electrolyte (or ion) is a substance that carries an electrical charge when dissolved in water. Cations are positively-charged electrolytes, e.g. Na⁺, K⁺ and anions are negatively-charged electrolytes, e.g. Cl⁻, HCO₃⁻ (Table 3). Proteins also carry an electric charge.

Sodium is the major cation that determines intravascular osmotic pressure, and acute changes in sodium concentration can result in acute changes in intravascular osmotic pressure. Changes in the concentration of other molecules, such as glucose and urea, can also cause changes in osmotic pressure. Free water moves from an area of low osmotic pressure to an area of higher osmotic pressure (see Figure 3).

Normally the osmotic pressure of intravascular, interstitial and intracellular fluids will be equal. However, if there is a sudden fall in the osmotic pressure of the intravascular compartment, such as an acute fall in sodium concentration, or loss of protein in the urine, the water will move out of the intravascular compartment into the tissues. If water moves from the blood vessels into the cerebral tissues, cerebral oedema will result (which may lead to raised intracranial pressure and convulsions). Movement of water out of the vascular space may contribute to hypovolaemia and poor systemic perfusion.

Increased serum osmotic pressure, such as in acute hypernatraemia, will cause a shift of free water out of the tissues and into the vascular space. If water moves out of the brain very rapidly, the brain tissue will shrink and pull away from the meninges causing stretching and tearing of blood vessels and intravascular bleeding (this is very rare). Severe hyperglycaemia will also cause an increase in serum osmotic pressure, producing a shift of fluid from the intravascular space, however, hyperglycaemia also causes osmotic diuresis leading to dehydration. Intravenous mannitol has a similar effect, increasing the serum osmotic pressure, drawing water out of the tissues into the intravascular space, and stimulating diuresis (Hazinski 1988). This is why it is used as a treatment for cerebral oedema.

**Oncotic pressure** is the ability of plasma proteins to ‘hold’ water. Water held by proteins will not be able to leave the vascular space. If a child’s plasma protein concentration falls acutely (as in nephrotic syndrome), the plasma oncotic pressure will fall, water will move from the plasma into the tissues and tissue oedema and hypovolaemia may result (Hazinski 1988).

**Hydrostatic pressure** is the pressure of water in the blood vessels or tissues. The force of the heart pumping the blood through the blood vessels causes a hydrostatic pressure in the blood capillaries that is slightly higher than the hydrostatic pressure in the

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**Table 2. Fluid distribution according to age**

<table>
<thead>
<tr>
<th>Age</th>
<th>Intracellular fluid</th>
<th>Extracellular fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Newborn infant</td>
<td>47%</td>
<td>53%</td>
</tr>
<tr>
<td>12 months</td>
<td>53%</td>
<td>47%</td>
</tr>
<tr>
<td>24 months</td>
<td>60%</td>
<td>40%</td>
</tr>
<tr>
<td>Adult male</td>
<td>67%</td>
<td>33%</td>
</tr>
</tbody>
</table>

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**Fig. 2. Fluid distribution according to age**

- N on-water
- Intracellular
- Intravascular
- Interstitial

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TIME OUT 1

Calculate the circulating volume of a 2.5kg premature infant. What are the implications for the baby of blood loss of 56ml during surgery?

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This pressure, however, is counteracted by the oncotic pressure, and there is no net loss of fluid into the tissue spaces. In congestive heart failure, return of blood to the heart is impeded by the inefficiency of the heart muscle. For example, in left-sided heart failure, blood will not be able to return efficiently to the heart from the lungs, causing 'backpressure' in the pulmonary veins and increasing the hydrostatic pressure in the pulmonary capillaries. The increased pressure will squeeze fluid out of the capillaries into the surrounding tissues resulting in pulmonary oedema (Hazinski 1988).

Normal infants and children, and even neonates, need relatively more fluid intake than older infants and children. The kidneys in neonates have small immature glomeruli and for this reason the glomerular filtration rate is reduced (about 30ml/min/1.73m² at birth to 100ml/min/1.73m² at nine months). The loops of Henle are short and the distal convoluted tubules are relatively resistant to aldosterone, leading to a limited concentrating ability (Davenport 1996). For oral feeding with standard formula milk, pre-term babies may need 200ml/kg per day initially. Term babies need approximately 150ml/kg per day until fully weaned. Children and adolescents may drink up to 2-3 litres of fluid per day.

Hourly maintenance fluid requirements can be calculated using the following guide (Advanced Life Support Group 1997, Nichols et al 1996):

- 4ml/kg/hr or 100ml/kg/day for first 10kg body weight
- 2ml/kg/hr or 50ml/kg/day for second 10kg body weight
- 1ml/kg/hr or 20ml/kg/day for each additional kg body weight

The recommended volume of oral feeds is greater than that calculated using this guide so that adequate calorie and protein intake can be achieved.

Fluid balance in the ill child

Maintenance fluid requirements must be modified according to the child’s clinical condition. All types of fluid intake and output must be measured (Table 4). If the child is dehydrated or has excessive fluid losses, fluid intake must be increased. For zero fluid balance, fluid losses = fluid intake. Insensible fluid loss is fluid lost from the body in perspiration and breathing, and is proportional to body temperature.
surface area (BSA). It is approximately 300ml/m²/day and may be slightly higher in infants and young children, warm air temperature, pyrexia, tachypnoea, etc.

Body surface area can be calculated using the formula:

\[
\text{BSA} = \frac{\sqrt{\text{wt} \times \text{ht}}}{3600}
\]

Therefore:

\[
\text{In sensible fluid loss (ml per day)} = 300 \times \frac{\sqrt{\text{wt} \times \text{ht}}}{3600}
\]

**TIME OUT 3**

For a child who you are caring for who is taking several oral or intravenous medicines, calculate how much fluid he/she is taking over 24 hours in medications (include saline flushes with intravenous drugs).

**Assessing hydration (see Table 5)**

Capillary refill time - press with a finger on the child’s forehead or sternum for five seconds. Normally, when the pressure is released, colour returns to the area within two seconds. A slower refill time than this indicates poor skin perfusion (Advanced Life Support Group 1997) which may be due to hypovolaemia.

The central - peripheral temperature gap can be measured using a rectal temperature probe and a skin temperature probe attached to a finger or toe. If a child is well perfused, and the hand or foot on which the peripheral temperature is measured is wrapped up, the temperature gap should be less than 2°C (Hui Lam 1998). A gap of more than 2°C at normal room temperature may indicate inadequate peripheral perfusion caused by hypovolaemia.

Tissue turgor in the child is best seen in the abdominal areas and on the insides of the thighs. In a normal situation, pinched skin will fall back to its normal place when released. In a child with 3%-5% weight loss due to dehydration, the skin may remain slightly raised for a few seconds. Severe malnutrition in infants can cause depressed skin turgor in the absence of dehydration. Obese infants with dehydration often have a deceptively normal skin turgor appearance. Infants with hypernatraemic dehydration tend to have firm, thick-feeling skin (Metheny 1992).

**Oedema**

can be seen in puffiness over the eyes, swollen ankles, a swollen abdomen, or fluid collection in the tissues in the back in children and babies lying down. If a thumb or finger is pressed on the oedematous area (not eyelids) for five seconds then released, an indentation will remain in the tissues.

**Weight**

should be measured on the same scales at the same time of the day, preferably in the morning before the child has had breakfast and after she/he has been to the toilet. Babies should be weighed completely naked, older children should be weighed in minimal clothing. Children with severe fluid balance problems should be weighed 12 hourly. Scales need to be checked regularly for accuracy. Fluid loss or gain can be measured by subtracting the child’s previous weight from their present weight: 1ml water weighs 1gram, 1 litre of water weighs 1 kilogram.

**Dehydration**

is the result of abnormal fluid losses from the body which are greater than the amount for which the kidneys can compensate. The major causes of dehydration in children are diarrhoea and vomiting, diabetic ketoacidosis, and more rarely, some renal disorders in which the kidneys are unable to concentrate the urine (Advanced Life Support Group 1997).

Dehydration can be divided into three types:
1. Isotonic dehydration (serum sodium 130-
150mmol/l) – sodium and water are lost in proportion to each other.

2. Hyponatraemic dehydration (serum sodium <130mmol/l) – a greater proportion of sodium than water is lost.

3. Hypernatraemic dehydration (serum sodium >150mmol/l) – a greater proportion of water than sodium is lost (Advanced Life Support Group 1997).

The percentage dehydration can be roughly estimated by observing the signs and symptoms described in Table 5 (Advanced Life Support Group 1997, Davenport 1996).


<table>
<thead>
<tr>
<th>Assessment</th>
<th>Normal hydration</th>
<th>Mild dehydration &lt;5%</th>
<th>Moderate dehydration 5-10%</th>
<th>Severe dehydration &gt;10%</th>
<th>Inappropriate fluid distribution</th>
<th>Hypovolaemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>General appearance</td>
<td>Alert, good muscle tone</td>
<td>Alert, good muscle tone</td>
<td>May be irritable or lethargic, sunken eyes, sunken anterior fontanelle</td>
<td>Confused, floppy, sunken eyes, reduced eyeball tugor, sunken anterior fontanelle</td>
<td>May be lethargic</td>
<td>May be lethargic</td>
</tr>
<tr>
<td>Colour</td>
<td>Consistent, pink lips, palms of hands, nail beds</td>
<td>Pink lips, palms of hands</td>
<td>Pale</td>
<td>Mottled/pale/grey</td>
<td>May be pale</td>
<td>Normal</td>
</tr>
<tr>
<td>Temperature of extremities (in warm environment)</td>
<td>Warm</td>
<td>Normal or cool</td>
<td>Cool</td>
<td>Cold</td>
<td>May be cool</td>
<td>Warm</td>
</tr>
<tr>
<td>Periphera! pulses</td>
<td>Strong</td>
<td>Strong</td>
<td>May be weak</td>
<td>Weak</td>
<td>May be weak</td>
<td>May be strong</td>
</tr>
<tr>
<td>Mucous membranes</td>
<td>Pink, moist</td>
<td>May be dry</td>
<td>Dry</td>
<td>Pale, dry</td>
<td>May be pale</td>
<td>Pink, moist</td>
</tr>
<tr>
<td>Capillary refill time (in warm environment)</td>
<td>1 - 2 seconds</td>
<td>1 - 2 seconds</td>
<td>May be &gt;2 seconds</td>
<td>&gt; 2 seconds</td>
<td>1 - 2 seconds</td>
<td>1 - 2 seconds</td>
</tr>
<tr>
<td>Respiration</td>
<td>Normal for age</td>
<td>Normal for age</td>
<td>Normal or elevated</td>
<td>Elevated</td>
<td>May be elevated</td>
<td>May be elevated</td>
</tr>
<tr>
<td>Skin turgor/observable oedema</td>
<td>Pinched skin immediately falls back to normal</td>
<td>Pinched skin immediately falls back to normal</td>
<td>Pinched skin slowly falls back to normal</td>
<td>Pinched skin remains tented</td>
<td>May have peri-orbital/ankle oedema</td>
<td>May have peri-orbital/back/ankle oedema</td>
</tr>
<tr>
<td>Heart rate</td>
<td>Normal for age</td>
<td>Normal for age</td>
<td>May be raised</td>
<td>Marked tachycardia</td>
<td>May be tachycardic</td>
<td>May be normal</td>
</tr>
<tr>
<td>Urine output</td>
<td>Infant 2ml/kg/hr Child 1ml/kg/hr Adolescent 0.5ml/kg/hr</td>
<td>Reduced</td>
<td>Reduced</td>
<td>Reduced or anuric</td>
<td>May be reduced</td>
<td>Elevated</td>
</tr>
<tr>
<td>Urine S.G.</td>
<td>1.005 - 1.020</td>
<td>May be &gt; 1.020</td>
<td>&gt; 1.020</td>
<td>&gt; 1.020</td>
<td>May be &gt; 1.020</td>
<td>&lt; 1.005</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>Normal for age</td>
<td>Normal</td>
<td>Normal</td>
<td>May be normal or low</td>
<td>May be normal or low</td>
<td>Normal or raised</td>
</tr>
<tr>
<td>Temperature gap</td>
<td>&lt;2°C in warm environment</td>
<td>May be wide</td>
<td>May be wide</td>
<td>May be wide</td>
<td>Normal</td>
<td></td>
</tr>
<tr>
<td>SPO2</td>
<td>97 - 100%</td>
<td>97 - 100%</td>
<td>97 - 100% if recordable</td>
<td>May not be recordable</td>
<td>May be low or not be recordable</td>
<td>May be low</td>
</tr>
<tr>
<td>Chest X-ray</td>
<td>Clear</td>
<td>Clear</td>
<td>Clear</td>
<td>Clear</td>
<td>May show pulmonary oedema</td>
<td>May show pulmonary oedema/enlarged heart</td>
</tr>
<tr>
<td>Abdominal X-ray</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>May show ascites</td>
<td>May show ascites/hepatomegaly</td>
</tr>
<tr>
<td>CVP (Rt atrium)</td>
<td>N0 - 5 mmHg</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal or low</td>
<td>May be normal or low</td>
<td>&gt; 5 - 8 mmHg</td>
</tr>
<tr>
<td>Body weight</td>
<td>Fairly stable (&lt;1% body weight gain or loss per day)</td>
<td>Weight loss &lt;50g/kg</td>
<td>Weight loss 50 - 100g/kg</td>
<td>Weight loss &gt;100g/kg</td>
<td>May be stable</td>
<td>Weight gain &gt; 1%</td>
</tr>
</tbody>
</table>

While dehydration is being corrected, the child also needs to receive maintenance fluid. If the child is not vomiting, mild dehydration can usually be corrected using oral fluids. Water containing a very small amount of sodium and glucose is better absorbed than plain water (Advanced Life Support Group 1997).

When there is evidence of shock (see below), it is recommended that children with moderate and severe dehydration are given an immediate fluid bolus of 20ml/kg colloid or 0.9% saline to restore the circulating volume and alleviate the signs and symptoms.
of shock. Then they can be rehydrated over 24 hours (with oral fluids if possible). Very low or very high serum sodium should be brought back to normal slowly to avoid large variations in osmotic pressure.

It is important to monitor systemic perfusion, urine output and neurological status frequently (half hourly to hourly) during the rehydration period. Repeated estimation of serum electrolytes may also be required.

**TIME OUT**

A 15kg child is admitted to your ward with signs and symptoms of moderate isotonic dehydration. Calculate the child's maintenance fluid requirements, then calculate the rehydration fluid requirements over 24 hours assuming the child is 7% dehydrated (a fluid loss of 70ml/kg). What would be the total hourly fluid rate for the initial 24 hours? Describe how you would monitor the child.

In hypernatraemic dehydration it is very important not to allow serum sodium concentration to fall more than 5mmol/l in 24 hours as there is a danger of cerebral oedema and death. This requires very careful monitoring of neurological status. Rehydration should be done slowly over at least 48 hours (longer if the serum sodium is very high), and the serum sodium concentration should be checked four hourly.

**Overhydration**

Overhydration occurs when fluid intake exceeds fluid losses, for example, in a child with impaired renal function. A life-threatening complication of overhydration is pulmonary oedema, and prompt action must be taken. Signs and symptoms of overhydration may be oedema, hypertension, complaint of headache and breathlessness (and blood oxygen saturation below 95% in pulmonary oedema). A chest X-ray will confirm the presence of pulmonary oedema.

Overhydration may be corrected by the use of diuretics, and restricting fluid intake to only essential fluids such as drugs. In severe renal failure, where diuretics may be ineffective, haemofiltration or dialysis will be required to remove fluid.

**Inappropriate fluid distribution**

Fluid may leak out of the intravascular space into the interstitial space due to low serum albumin (e.g. nephrotic syndrome), or increased permeability of blood capillaries. This will lead to tissue oedema and hypovolaemia, even though the child is not dehydrated or overloaded.

Collection of fluid in the tissues may lead to pulmonary oedema, respiratory insufficiency and possibly death; or cerebral oedema and possibly death. Hypovolaemia may lead to shock. It is therefore important that a child with inappropriate fluid distribution is carefully monitored to prevent/treat shock or pulmonary oedema, and management appropriate to the underlying disease is instituted rapidly.

**Shock**

When loss of circulating volume in the intravascular compartment reaches 25 per cent, the child starts to show signs and symptoms of shock (Advanced Life Support Group 1997). Shock is the body's response when inadequate amounts of nutrients, especially oxygen, are delivered to the tissues, and there is inadequate removal of waste products (Advanced Life Support Group 1997).

Shock is progressive, but can be divided into three phases: compensated, uncompensated, and irreversible.

Compensated shock. Initially, the child's heart rate increases, and blood vessels supplying non-vital organs constrict, such as the skin (causing pallor, coldness and clamminess) and the gut. This will conserve the blood volume for essential organs such as the heart and brain. Secretion of angiotensin and vasopressin are increased, allowing the kidneys to conserve water and salt. Water is also reabsorbed from the gut. The child will appear pale, cold, tachycardic, have a capillary refill time of more than two seconds, and may be anxious, agitated or confused.

Uncompensated shock. As the compensatory mechanisms start to fail, insufficient oxygen and glucose is supplied to the tissues for normal metabolism, and lactic acid and carbonic acid is produced leading to acidosis. This reduces the contractility of the heart muscle. Tissue cells start to deteriorate and die. The sluggish flow of blood in the small blood vessels leads to platelet aggregation and bleeding tendency. A number of chemicals are produced in the tissues which reduce tissue perfusion further, and increase capillary permeability allowing fluid to escape from the blood vessels into the tissue spaces, further decreasing the circulating volume.

Irreversible shock has occurred when damage to the brain and other vital organs is so severe that death occurs.

**Conclusion**

Infants are more at risk of dehydration than older children and adults as they have a greater proportion of extracellular fluid and a relatively large surface area. If a child or infant loses more than 5 per cent of his/her body water, he/she will start to show signs and symptoms of dehydration. It is important to correct this state before the dehydration becomes worse, or the child will start to show signs of shock. Conversely, children who are fluid overloaded are at risk of pulmonary oedema. Shock and pulmonary oedema are life-threatening situations.

With a good understanding of fluid balance, the children's nurse is able to recognise these problems and take appropriate action.