5–20 micrograms/kg/minute (maximum of 1.2 grams in 24 hours).

Consider stopping the infusion 4–8 hours after the SVT has resolved.

If tachycardia recurs after stopping amiodarone, give a further loading dose and recommence infusion, continuing for at least 1 day after tachycardia resolution.

As amiodarone has a large number of side effects, consider switching to either a beta-blocker or flecainide once the tachycardia has been controlled and the child is haemodynamically stable.

Make up the amiodarone infusion as follows:
15 mg/kg in 50 mL of 5% dextrose (1 mL/hour = 5 micrograms/kg/hour: such a slow infusion will need an electrically driven syringe pump).

Amiodarone is incompatible with sodium chloride. Therefore do not make up with and do not flush lines with this solution.

Amiodarone can be given through a peripheral line, but serious tissue damage may be caused by the drug if extravasation occurs, so central access is preferred. If peripheral access is used, dilute the infusion to a concentration between 600 micrograms/mL and 2 mg/mL. This dilution will be more appropriate in situations where electrically driven syringe pumps are not available, but the infusion needs close monitoring.

Congenital complete heart block

- Consider this in any newborn who has a consistent bradycardia without apparent cause, such as terminal respiratory failure or very severe shock.
- P waves are dissociated from QRS complexes on the 12-lead ECG.
- Perform an echocardiogram to exclude structural heart disease.
- Check for anti-Ro and anti-La antibodies in the child’s mother (the underlying cause in the majority of cases).
- Monitor the heart rate for 24–48 hours.
- Assess perfusion and blood pressure, and examine for signs of heart failure.
- Arrange for a permanent pacemaker if there is inadequate cardiac output, heart failure, structural heart disease or the heart rate is < 50 beats/minute.
- Atropine 20 micrograms/kg or isoprenaline infusion 0.02–0.2 micrograms/kg/minute can be used for emergency treatment of severe bradycardia with inadequate cardiac output.

5.5 Shock

5.5.A Shock

Introduction

‘Shock’ occurs when the circulatory system fails to deliver adequate amounts of primarily oxygen, but also nutrients, to the tissues, and fails to remove unwanted metabolites from the tissues for excretion.

Pathology at cell level

At a cellular level, the end result of shock is anaerobic metabolism (oxygen-depleted metabolism). This is an inefficient mechanism and requires much more energy than aerobic metabolism (the normal oxygen-dependent system). In addition, anaerobic metabolism builds up excess toxic acid products in the cells which cannot be removed by the failed circulation. Cellular function deteriorates and there is a downward spiral of increasing loss of homeostasis, the onset of disseminated intravascular coagulation, and after a short while so much cell death occurs in vital organs that recovery is impossible and the patient dies.

In the early stages of shock the body has mechanisms to try to combat this process. The circulatory system is under the control of the sympathetic nervous system. This system regulates the flow of blood in health and in disease to all organs so as to respond to demands on different organs. In health, more blood is sent to muscles if a person is exercising, more to the digestive system if they are eating, and more to the skin if their body is too warm.

In shock, the sympathetic nervous system attempts to protect the vital organs by diverting blood away from muscle, skin and the digestive system and directing it to the heart, brain and kidneys. This gives rise to some of the earlier signs of shock, such as cold peripheries, increased capillary refill time, cerebral anxiety or agitation, tachycardia to increase cardiac output, and reduced urine output as the kidneys conserve fluid.

Later signs such as depressed consciousness, weak pulses, falling blood pressure and acidotic breathing show that the body’s compensation mechanisms are failing. It can be seen that it is vital to recognise and treat shock in the patient as soon as possible, as this will give the best chance of patient recovery.

Clinical diagnosis of shock

The signs of shock are listed below, although not all of them are present in all types of shock.

- **Tachycardia** (best measured with a stethoscope).
● Weak pulse (ideally central – brachial, femoral or carotid, but difficult to gauge).
● Low blood pressure (this is a late sign and very difficult to measure in young children).
● Extreme central pallor (severe anaemia).
● Raised respiratory rate (due to acidosis).
● Cold skin with poor circulation.
● Prolonged capillary refill time (CRT) > 3 seconds.
● Increased skin sweating in some cases.
● Agitation and anxiety (this is an early sign).
● Reduced conscious level.
● Reduced urine output (this is an early sign).

The WHO diagnosis of shock includes all of the above signs that are highlighted in bold type.

It is vital that if any of these early signs are noted in a patient that they are not dismissed as some unrelated cause, but are seriously considered as likely to be indicating the development of shock.

This is why it is so useful to have regular vital signs (pulse, respiration, conscious level, temperature and blood pressure) observations on patients, so that abnormal trends can be detected early.

It is also important to note that shock is not diagnosed on the basis of one physical sign alone, but on the basis of several signs occurring together. For example, a tachycardia alone does not diagnose shock, but if you note a tachycardia, you should look for cold limbs, prolonged capillary refill time, or a history suggestive of a cause of shock, such as a fever, severe diarrhoea or bleeding.

Pathological mechanisms that can cause shock

The circulatory system is complex, so there are many causes of shock. The organs, systems and pathologies that can be the primary cause of the shock include the heart itself, the blood vessels, restriction to the flow of blood, failure of the oxygen-carrying capacity of the blood, and loss of blood or fluid from the body. The main mechanisms of shock can be summarised as follows:

● loss of fluid or blood: hypovolaemic shock (e.g. diarrhoea, blood loss)
● failure of the heart pump: cardiogenic shock (e.g. dysrhythmias, cardiomyopathy, myocarditis, malnutrition)
● abnormal function of vessels supplying nutrients and oxygen to tissues: distributive shock (e.g. sepsis, anaphylaxis)
● inadequate capacity of the blood to release oxygen: dissociative shock (e.g. severe anaemia, carbon monoxide poisoning)

In an individual with shock, often several of these mechanisms may coexist. Therefore the clinician must consider which emergency treatments will be effective and which will be harmful for any particular patient. One of the most difficult situations is in the anaemic malnourished child with sepsis, where fluid is required to expand the circulating volume, but the heart is already failing and cannot cope with a rapid fluid infusion (see Section 5.5, B).

Basic management of shock

Shock is managed according to the following principles:

● High concentrations of oxygen are safe and must be given regardless of the cause of shock.
● Airway and breathing stability or support must be established promptly first (the only exception is to control exsanguinating external bleeding in trauma or major obstetric haemorrhage concurrently with airway and breathing; see Sections 7.3.A, 2.5.D.i and 2.5.D.iv).
● Frequent reassessment, at least after every therapeutic manoeuvre, is vital to avoid both under-infusing and over-infusing fluids.
● The underlying pathology must be treated to arrest the pathological process.

The clinical diagnosis of the cause of shock is not easy or definitive. Shock is a spectrum of conditions and mechanisms, and it is a clinical challenge.

Immediate resuscitation is needed to maintain oxygenation and perfusion of vital organs. Once this is under way, the cause of shock needs to be found and treated.

Diagnosis depends on history, clinical examination, and response to treatment given. It is often possible to identify the cause of shock with a good history and a careful examination.

Investigations

● Haemoglobin measurement is essential.
● Blood glucose measurement is essential, as some signs of shock are the same as signs of hypoglycaemia.
● Plasma electrolyte measurements are helpful, especially sodium and bicarbonate.
● Lactate measurement is helpful (if available).
● Central venous pressure (CVP) measurement is useful. If skilled staff are available to undertake the procedure and measurement (not an emergency procedure, but helpful if in high-dependency care).

Choice of intravenous fluid

Fluid infused into the circulation should approximate to plasma in its electrolyte content, osmolality and pH.

Dextrose-only fluids

It is clear that although glucose or dextrose is necessary to prevent or manage hypoglycaemia, fluids containing only dextrose should never be used for IV fluid replacement.
or maintenance, or for the emergency management of shock.

The reason for this is that the dextrose is rapidly metabolised, so the effect of a dextrose-only IV fluid on the child’s body is as if pure water had been given. The outcome of this treatment would be severe hyponatraemia, which could quickly lead to brain damage or death.

In addition, this pure water is rapidly moved out of the circulation and into the cells, and the state of shock is then worse than before the infusion.

**Sodium-containing fluids**

The fluid traditionally infused into the circulation for the management of shock has been ‘normal saline’ (0.9% sodium chloride, NaCl). This fluid has increasingly been shown to be potentially dangerous, especially in the sick patient. An infusion of normal saline causes a hyperchloraemic acidosis (a high chloride concentration leading to an acidosis), which in the shocked patient, who is already acidotic, causes a deterioration in the health of cells in vital organs, even though perfusion of the cells has been improved by the increased circulating volume.

There are sodium-containing alternatives to normal saline which are safer as they approximate more closely to human serum in content (see Table 5.5.A.2), although they are a little more expensive. We recommend the use of either of these alternatives (Ringer-lactate and Hartmann’s solution are widely available) for all fluid replacement. Recognising that not all hospitals will have access to these solutions immediately, there may sometimes be no alternative but to start fluid replacement with normal saline. However, if more than 20 mL/kg needs to be given, one of the safer alternatives should be used in these very sick children if at all possible.

**Note that hospitals and clinics will need to have access to some 0.9% NaCl (normal saline), usually in 5 mL or 10 mL ampoules. This will be used for dissolving or diluting drugs for IV injection. If a specific fluid is indicated as the diluent for a particular drug (e.g. 0.9% NaCl, 5% dextrose, water for injection), this fluid must be used. If drugs are infused using the wrong fluid, their effect on the patient may be altered.**

**Clinicians should try to ensure that their hospital facility does have access to these safer infusion fluids, such as Ringer-lactate or Hartmann’s solution.**

<table>
<thead>
<tr>
<th>TABLE 5.5.A.1 Diagnostic pointers to the clinical causes of shock (each is discussed in the sections indicated)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diarrhoea and/or vomiting with signs of severe dehydration</td>
</tr>
<tr>
<td>Fever, non-blanching (purpuric) rash</td>
</tr>
<tr>
<td>Urticaria, wheeze, oedema, exposure to allergen</td>
</tr>
<tr>
<td>Trauma</td>
</tr>
<tr>
<td>Major obstetric haemorrhage in children who are pregnant</td>
</tr>
<tr>
<td>Burns</td>
</tr>
<tr>
<td>Pallor, tachycardia, severe malaria, severe acute malnutrition</td>
</tr>
<tr>
<td>Fever, signs of shock and a very sick child</td>
</tr>
<tr>
<td>Baby &lt; 4 weeks old: cyanosis, with no response to oxygen, very weak pulses</td>
</tr>
<tr>
<td>Very fast pulse, heart failure</td>
</tr>
<tr>
<td>Dehydration, polyuria, polydipsia, high glucose levels</td>
</tr>
<tr>
<td>History of sickle-cell disease or diarrhoeal illness and low haemoglobin levels</td>
</tr>
</tbody>
</table>

**Initial management of shock**

Even though it may be clear on initial inspection that the child is in shock, the first priority must still be to call for help, manage the airway, manage breathing and then manage the circulation. Call for help.

**TABLE 5.5.A.2 Comparison of electrolytes, osmolality and pH levels in IV fluids with those in human serum**

<table>
<thead>
<tr>
<th>Fluid</th>
<th>Na⁺ (mmol/litre)</th>
<th>K⁺ (mmol/litre)</th>
<th>Cl⁻ (mmol/litre)</th>
<th>Ca²⁺ (mmol/litre)</th>
<th>Lactate or bicarbonate (mmol/litre)</th>
<th>Osmolarity (mOsm/litre)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human serum/plasma</td>
<td>135–145</td>
<td>3.5–5.5</td>
<td>98–108</td>
<td>2.2–2.6</td>
<td>22–30</td>
<td>276 to 295</td>
<td>7.35–7.45</td>
</tr>
<tr>
<td>Ringer-lactate or Hartmann’s solution</td>
<td>131</td>
<td>5.0</td>
<td>111</td>
<td>2.0</td>
<td>29</td>
<td>279</td>
<td>6.0</td>
</tr>
<tr>
<td>0.9% ’normal’ saline</td>
<td>154</td>
<td>0</td>
<td>154</td>
<td>0</td>
<td>0</td>
<td>310</td>
<td>5.4</td>
</tr>
</tbody>
</table>
Airway
At this stage also stop any obvious exsanguinating bleeding.
Assess the airway by the simple technique of asking the child “Are you all right?”
Any vocalisation such as a reply or crying indicates an open airway and some ventilation. In the absence of a response, formally open the airway with a head tilt/chin lift or a jaw thrust manoeuvre (see Section 1.12), and assess breathing by looking, listening and feeling for its presence.
Stop any obvious exsanguinating bleeding by applying external pressure (or in the case of postpartum haemorrhage, see Section 2.5.D.iv).

Breathing
All children with suspected shock must receive high-flow oxygen.
In the absence of spontaneous breathing, give assisted ventilation with a bag-mask (see Section 1.13).

Circulation
Intravenous access with a short wide-bore venous cannula, or placement of an intra-osseous line (see Section 8.4.B), is vital. More than one line is preferable, as rapid fluid resuscitation may be needed, although always start treatment as soon as the first access has been achieved and insert the second line when possible. Take blood samples for the

---

**FIGURE 5.5.A.1** Pathway of care for the child with shock that is not cardiac in origin.
following investigations: full blood count, glucose levels, electrolytes, blood culture (and, if relevant, cross-matching and malarial parasite test).

**Nutritional status**

While starting to give fluid, assess the child's nutritional status (see Section 5.10.B). Look for visible severe wasting or marasmus. The WHO recommended criteria are as follows: “Look at the arms, legs and chest. The marasmic child does not look just thin, but appears to be all skin and bone. The skin looks too large for the body, there is no fat on the child and you will see the outlines of the ribs. There is also severe muscle wasting of the arms, legs and buttocks. The head may appear relatively large because of wasting of the body.” Use the mid upper arm circumference (MUAC) (see Section 9) to assess marasmus, as the urgency of the child’s need for treatment precludes a weight and height measurement.

Look also for kwashiorkor. Check for oedema of both feet. Look at the bare feet. Press the top of the foot gently with your thumb for a few seconds. Oedema is present if a definite dent is left in the tissues. Look and feel to determine whether the child has oedema of both feet.

Some assessment of weight will be necessary to calculate the amounts of fluid and antibiotics to be given. If the child is not malnourished, use the following formula:

\[
\text{weight in kg} = 2 (\text{age in years} + 4).
\]

If the child is malnourished, this formula can still be used, but perhaps a percentage such as 25–50% subtracted from the result.

**Severe anaemia**

In very anaemic children (with either obviously pale palms or haemoglobin levels of less than 3–4 grams/dL), crystalloid alone will worsen oxygen delivery to the tissues. These children need blood, either packed cells or a partial exchange transfusion, in addition to initial slow fluid resuscitation (see Section 5.10.B, Section 5.11.A and Section 8.4.B).

The next step is to give fluid intravenously. In most cases this should be a crystalloid such as Hartmann’s or Ringer-lactate solution, but give normal saline (0.9%) if this is all that is available. In children, the volume of fluid to be given is usually 20 mL/kg, which is 25% of the child’s circulating volume (10 mL/kg in severe anaemia or severe malnutrition while awaiting blood for transfusion). Shock is not usually clinically evident until 25% of the circulation has been lost, so any child with signs of shock must have lost at least this amount of fluid from the circulation.

The concept of targeted crystalloid fluid resuscitation is important if the cause of hypovolaemic shock in a child is haemorrhage from a penetrating injury. Here the initial boluses of IV crystalloids required to treat shock should only be given to keep the vital organs (especially the brain, heart and kidneys) perfused before life-saving surgery and blood transfusion can be undertaken. Fresh blood is particularly useful to combat the coagulopathy that occurs in major blood loss if specific coagulation components such as platelets are unavailable.

Giving too large a volume of IV fluids can increase the blood pressure and thus increase bleeding by disrupting early clot formation. IV crystalloid also dilutes the red cells in the circulation, but whether or not this could reduce oxygen-carrying capacity requires further research.

We suggest that when giving boluses of crystalloid or blood to patients in shock due to bleeding, only the amount needed to keep the blood pressure at a level sufficient to perfuse the vital organs should be given. There is no clear evidence to indicate the precise blood pressure that should be achieved in a child in shock due to haemorrhage from penetrating injury. Adequate perfusion of vital organs may best be indicated by the following: in the child over 2–3 years of age, a radial pulse that can be palpated and a conscious level of A or V on the AVPU scale (i.e. the child is either awake or will respond by opening their eyes when spoken to). In children under 2–3 years of age the radial pulse may be difficult to feel, and in children with shock due to haemorrhage the presence of a palpable brachial pulse may be the best available indicator at present.

In this situation, therefore, and to maintain a palpable radial or brachial pulse, start with IV boluses of 10 mL/kg of crystalloid, or ideally blood, and reassess after each bolus.

The next very important step is to reassess the patient’s vital signs to see whether the fluid has helped, and to ensure that circulatory overload has not given rise to a situation where more IV fluids may produce very dangerous heart failure (see below for clinical signs of this).

During this reassessment, give IV antibiotics, as shock without obvious fluid loss is probably sepsis (see Section 5.5.C).

At this point, some children will need more crystalloid fluid, while others will not, or they will need other fluids (e.g. plasma expanders such as albumin or blood). Many will need additional treatments. The next two sections (Sections 5.5.B and 5.5.C) deal with two of the commonest causes of shock in children, and the reader is referred to the sections indicated in Table 5.5.A.1 for details of the various other causes of shock.
5.5.B The child with shock from dehydration

**BOX 5.5.B.1 Minimum standards**
- Oral rehydration solution (ORS), including ReSoMal.
- Crystalloid infusion fluids (preferably Hartmann's solution or Ringer-lactate solution, but normal saline may be used if it is the only available alternative).
- Blood transfusion.
- Antibiotics.
- Furosemide.
- MUAC tapes.

**Dehydration**
- Dehydration is loss of water, sodium and other essential electrolytes.
- The most common cause in resource-limited countries is gastroenteritis (from a number of different organisms; see Section 5.12.A).
- Most cases can be treated with low-osmolarity oral rehydration solution (ORS) administered by mouth or nasogastric tube.
- In children with severe malnutrition, use a solution with lower sodium content, such as ReSoMal.
- It is important to also consider diabetic ketoacidosis (see Section 5.8.A) and surgical causes of dehydration, such as intussusception and volvulus (see Section 5.19).

**Dehydration classification**
Dehydration is classified by estimating the percentage of body water lost according to clinical criteria (except in malnutrition, where clinical signs are more difficult to interpret; see below).

**‘No dehydration’**
If there is less than 3% weight loss there are no clinical signs.

**‘Some dehydration’**
If there is 3–9% weight loss, the following signs are seen:
- increased thirst
- drinks eagerly
- dry mucous membranes
- loss of skin turgor, tenting when pinched
- sunken eyes
- sunken fontanelle in infants
- restless or irritable behaviour
- decreased capillary refill time (> 3 seconds)
- decreased urine output.

**‘Severe dehydration’**
If there is a 10% weight loss, the following signs are seen:
- more pronounced signs than those seen in moderate dehydration
- lack of urine output
- lack of tears when crying
- inability to drink or drinking poorly (because of reduced conscious level)
- lethargy

- rapid and weak low-volume pulse (radial pulse may be undetectable) (use a stethoscope for measuring heart rate)
- altered consciousness or coma
- low or undetectable blood pressure
- cool and poorly perfused extremities
- severe nail bed or sternum decreased capillary refill time
- peripheral cyanosis
- rapid deep breathing (from acidosis).

It is important to realise that the above classification is made only to guide the start of treatment. **Levels of dehydration** are a continuous spectrum, not three separate and distinct categories. The only way to be absolutely certain about the percentage dehydration of a child is to compare an accurate weight measured just before the onset of the diarrhoeal illness with an accurate current weight. It is very unlikely in most cases that the former weight will be available. In the case of the shocked patient, immediate treatment takes precedence over weighing the child (estimate the child's weight from the formula:

\[
\text{weight (kg)} = 2 \times (\text{age in years} + 4)
\]

for previously well children before puberty, or read it from a weight/age chart (see Section 9).

However, if the clinical situation is not so critical, the weight of the child on presentation is very helpful for subsequent management, and should be measured and recorded as a daily routine.

**Emergency treatment of severe dehydration: principles of treatment**
- Recognise and treat shock.
  - Give a fluid bolus, 20 mL/kg IV of Hartmann's or Ringer-lactate solution (0.9% saline, or ‘normal’ saline, can be used if there is no alternative; see Section 5.5.A).
  - A second bolus may be needed if the child does not respond (see the ‘shock’ pathway in Figure 5.5.A.1).
  - It is unusual to need more than two boluses in cases of dehydration due to gastroenteritis alone, unless they are due to cholera (see Section 5.12.A).
  - Consider other causes, such as septicaemia, diabetic ketoacidosis (check blood sugar levels), volvulus or intussusception (check whether vomit is bile-stained, and whether there is fresh blood in stools; see Section 5.19).
  - If septicaemia is suspected, treat with IV antibiotics.
- Think of the most likely cause of the dehydration.
- Estimate the level of dehydration (see above) to calculate the fluid deficit, maintenance needs and ongoing losses (see below).

**Shock recognition and treatment**
Children with shock associated with dehydration will have a high and increasing heart rate, weak pulse, poor
skin circulation time with prolonged capillary refill time (> 3 seconds), depressed conscious level, and low or even unmeasurable blood pressure.

These children require immediate resuscitation (ABC) and emergency treatment.

Call for help (summon an anaesthetist if possible).

Airway (in cases of reduced conscious level)
Use an opening manoeuvre if the airway is not open or if it is partially obstructed. Keep the airway open. If there is immediate improvement but the airway closes without active opening support, consider airway adjuncts to support the airway.

Suction if necessary under direct vision, but not routinely.
If the child is deeply unconscious (P or less on the AVPU scale), the airway may need to be secured by intubation using experienced senior help (if available).

Breathing
Give 100% oxygen (using a mask with reservoir and a flow rate of at least 6 litres/minute) regardless of SpO2 (this increases oxygen delivery as well as improving tissue oxygenation). For inadequate ventilation or depressed conscious level (check with the AVPU scale) with hypventilation, respiration should be supported with oxygen via a bag and mask, and experienced senior help should be summoned (if available).

Circulation
- Obtain vascular access to give IV boluses quickly. Insert an IV cannula and send blood for a full blood count, urea and electrolytes, cross-matching (if the patient is anaemic) and clotting. If peripheral veins are difficult to access, the external jugular vein or long saphenous vein cut-down are good alternatives, as is an intra-osseous infusion (see Section 8.4.B). If a skilled operator is available, an internal jugular or femoral vein central line is ideal, as it can also allow central venous pressure (CVP) measurements (if available).

Some assessment of weight will be necessary to calculate the amounts of fluid and antibiotics to be given. If the child is not malnourished, use the formula:

\[
\text{weight (kg)} = 2 \times (\text{age in years} + 4).
\]

If the child is malnourished, this formula can still be used but perhaps a percentage such as 25–50% subtracted from the result.

Children with normal nutrition
- If the child is not malnourished, give an initial rapid bolus of 10–20 mL/kg of Ringer-lactate or Hartmann's solution, but give normal saline (0.9%) if this is all that is available. It is essential that the bolus is given as rapidly as possible. Do not use 5% glucose or 0.18% saline/4% glucose solutions for resuscitation, which can be dangerous (risk of hypernatraemia and cerebral oedema). Boluses should be manually pushed in using a 20- to 50-mL syringe (with a three-way tap and linked to an IV giving set).
- When this bolus of fluid has been given, review the child's condition, looking to see whether there has been any improvement in pulse rate, conscious level, respiratory rate, capillary return and limb warmth, and blood pressure.
- A further 10–20 mL/kg bolus will be required if signs of shock remain. Once a total of 40 mL/kg of boluses has been given IV, complications such as pulmonary oedema are more likely to occur. In a child with shock from severe dehydration caused by diarrhoea, it would be unusual to need more than 40 mL/kg to improve the child's circulation, unless cholera was the cause. In severe cases, where more than a total of 40 mL/kg is considered essential, intubation, ventilation, CVP monitoring and inotrope support might be indicated (if available), but the diagnosis should be reviewed as this need is unusual in straightforward gastroenteritis. Reconsider the diagnosis. For example:
  - surgical abdominal pathology, such as intussusception, peritonitis or volvulus (bile-stained vomiting, abdominal distension or tenderness) (see Section 5.19)
  - additional pathology, severe anaemia, septicemia or a cardiac problem.

Children with severe malnutrition or severe anaemia
- If the child is malnourished and/or has severe anaemia, fluid must be given much more carefully. Give 15 mL/kg IV over 1 hour. The recommended solution is Ringer-lactate or Hartmann's solution, each with 5% glucose (insert 50 mL of 50% dextrose into a 500-mL bag of the bolus fluid, ideally after first removing 50 mL from the bag: not essential), but give normal saline (0.9%) if this is all that is available, also with 5% dextrose. At the same time, insert a nasogastric tube and give ReSoMal, 10 mL/kg/hour. Monitor carefully for signs of over-hydration: reassess the respiratory and heart rates every 15 minutes. It is also wise to give IV antibiotics in this situation, as it can be very difficult to distinguish septic shock from dehydration shock in children with malnutrition.

Nutritional status
- While starting to give fluid, assess the child's nutritional status (see Section 5.10.B). Look for visible severe wasting or marasmus. Follow the WHO criteria: ‘Look at the arms, legs and chest. The marasmic child does not look just thin, but appears to be all skin and bone. The skin looks too large for the body, there is no fat on the child and you will see the outlines of the ribs. There is also severe muscle wasting of the arms, legs and buttocks. The head may appear relatively large because of wasting of the body.’
- Use the mid upper arm circumference (MUAC) (see Sections 5.10.B and 9) to assess marasmus, as the urgency of the child’s need for treatment precludes a weight and height measurement.
- Look also for kwashiorkor. Check for oedema of both feet. Look at the bare feet. Press the top of the foot gently with your thumb for a few seconds. Oedema is present if a definite dent is left in the tissues. Look and feel to determine whether the child has oedema of both feet.

Severe anaemia
In very anaemic children (with either obviously pale palms or haemoglobin levels less than 3–4 grams/dL), crystalloid...
alone may worsen oxygen delivery to the tissues. These children need blood, either packed cells or a partial exchange transfusion, in addition to initial slow fluid resuscitation (see Section 5.10.B and Section 8.4.B).

- If after 1 hour the child is improving but still severely dehydrated, stop the IV fluids, but continue nasogastric ReSoMal 10 mL/kg/hour for up to 5 hours (see Section 5.10.B for further details).
- A child with a haemoglobin level of less than 5 grams/dL will also need a transfusion of 10 mL/kg of packed cells over 4 hours, watching continuously for evidence of pulmonary oedema. If pulmonary oedema develops, furosemide 1 mg/kg IV may be required, but if possible pulmonary oedema of severity requiring diuretics should be avoided by a slow and vigilant approach to therapy in these very sick children.
- Keep the patient warm, but do not overheat them, as this will cause peripheral vasodilatation and reduce the blood supply to vital centres. Hypothermia will exacerbate poor peripheral perfusion, acidosis and coagulation abnormalities.
- Elevate the patient’s legs (raise the foot of the bed).
- A central venous pressure (CVP) line is potentially helpful for avoiding under-transfusion or fluid overload. Insertion should not delay initial resuscitation, but if peripheral access is inadequate this route may be used for volume replacement. If disseminated intravascular coagulation (DIC, a clotting disorder) has become established, CVP insertion is hazardous, must be undertaken by an expert, especially via the subclavian vein.
- If the child has a reduced level of consciousness or has a convulsion, particularly if they are an infant or a young child, hypoglycaemia may be present. Always measure the blood glucose concentration in this situation. However, if blood glucose measurement is not possible, always treat as for presumed hypoglycaemia and, in addition to the IV fluids given above, give 5 mL/kg of 10% glucose IV or, if there is no IV access, by intra-osseous needle.

While treating shock, reassess the child, ideally continuously, until signs of shock have resolved.

When signs of shock have resolved

When shock has resolved and the patient’s level of consciousness has returned to normal, the remaining estimated fluid deficit MUST be taken by mouth or by gastric tube, especially if there is malnutrition and/or anaemia (due to the danger of a large IV fluid volume). Use WHO Plan B (see Appendix to Section 5.12.A).

- Check the serum sodium concentration, and if it is higher than 155 mmol/litre, reduce it slowly with oral rehydration solution over 48 hours. Too rapid a reduction in sodium levels leads to cerebral oedema.
- Further tests might include abdominal X-ray or ultrasound scanning, if there is concern about a distended abdomen.
- A surgical opinion is needed if there is bile-stained vomiting or abdominal signs.

Fluid requirements

WHO Plans A, B and C for gastroenteritis in children (see Appendix to Section 5.12.A) include estimates of total fluid requirements, and assume that most children will be drinking by 4 hours into treatment and thus able to ‘self-regulate’. For patients for whom this is not the case, the following guidelines can be used.

Estimating fluid requirements

The amount of fluid needed in a 24-hour period must be calculated. It is the sum of:

- estimated fluid deficit + maintenance requirements + ongoing losses.

Deficit

If an accurate recent pre-illness weight is available, subtract the current weight to estimate lost fluid (1 kg = 1 litre of fluid).

For example, a child who weighed 9.2 kg is seen with diarrhoea and a weight of 8.3 kg. The estimated fluid loss in this case is (9.2 – 8.3) kg = 0.9 kg = 900 mL deficit, i.e. 10% dehydrated.

If no recent reliable weight is available:

1. Estimate the degree of dehydration.
2. Weigh the child or estimate their weight from their age as follows:
   \[ \text{weight (kg)} = 2 \times [\text{age (years)} + 4]. \]
3. Use the formula: percentage dehydration \( \times \) weight (kg) \( \times \) 10 = deficit (in mL).

For example, a child whose weight is estimated to be 10 kg is 10% dehydrated. The estimated fluid loss in this case is \( 10 \times 10 \times 10 = 1000 \text{ mL} \) (i.e. 40 mL/hour if replaced over 24 hours).

Maintenance

The estimated maintenance fluid requirements based on body weight for a child are shown in Table 5.5.B.1.

<table>
<thead>
<tr>
<th>Table 5.5.B.1 Fluid requirements per day</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body weight</strong></td>
</tr>
<tr>
<td>First 10 kg of body weight</td>
</tr>
<tr>
<td>Second 10 kg</td>
</tr>
<tr>
<td>Subsequent kg</td>
</tr>
</tbody>
</table>

Ongoing losses

Estimated ongoing fluid losses are shown in Table 5.5.B.2.

<table>
<thead>
<tr>
<th>Table 5.5.B.2 Estimates of ongoing fluid losses in gastroenteritis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>For each diarrhoea stool</strong></td>
</tr>
<tr>
<td><strong>For each vomit</strong></td>
</tr>
<tr>
<td><strong>For nasogastric tube aspirates</strong></td>
</tr>
</tbody>
</table>
**Over-hydration**

Signs of over-hydration, especially if there is cardiac failure (e.g., in severe malnutrition) are as follows:
- Tachycardia, increased respiratory rate, oedematous (puffy) eyelids, crepitations at lung bases, enlarged liver and raised jugular venous pressure (JVP)
- Pulmonary oedema on chest X-ray.

**Management**
- Stop giving IV fluids or oral rehydration solution, but give breast milk or plain water and food.
- Do not give a diuretic unless there is pulmonary oedema (crepitations in lungs), in which case give furosemide 1 mg/kg IV.

**Reassess:**
- ABC.
- The state of intravascular rehydration.
- Plasma electrolytes (if possible).
- Urine output and urine electrolytes.
- Glucose levels.

Reduce fluid intake and continue to monitor, responding to changes in the child’s condition as described above.

---

**5.5.C The child with septic shock**

**BOX 5.5.C.1 Minimum standards**
- High-dependency care.
- Ringer-lactate or Hartmann’s solution (or 0.9% saline if no other crystalloid is available).
- Urgent blood transfusion.
- Antibiotics: cefotaxime, flucloxacillin, gentamicin, metronidazole and penicillin.
- Dopamine and adrenaline.
- MUAC tapes.

**Introduction**

Septic shock develops when a number of different mechanisms of shock operate in the context of an invasive bacterial infection (an exception is dengue, which is caused by a viral agent; see Section 6.2.B). These mechanisms are as follows:
- Hypovolaemic: there is abnormal capillary permeability, fever and accompanying vomiting and diarrhoea.
- Distributive: there is loss of the normal sympathetic nervous system control of vascular tone, so that blood is lost from vital organs into non-vital areas.
- Cardiogenic: there is impaired cardiac function secondary to hypovolaemia and the toxic effects of the pathogen.

These multiple factors make septic shock difficult and complex to treat, and they contribute to a high mortality rate in these conditions.

The bacteria that cause septic shock include *Meningococcus, Staphylococcus, Streptococcus pneumoniae* and *Streptococcus pyogenes*, together with Gram-negative organisms such as *E. coli* which particularly affect patients who are at risk due to lower immunity, such as the newborn, those with HIV/AIDS, and the malnourished.

**Diagnosis of septic shock**

The early recognition and treatment of septic shock is key to a good outcome, so a high degree of vigilance for this condition is necessary.

In a child who has an infection, with a fever (although the at-risk group mentioned above may have a normal or subnormal temperature), the development of a change in mental status, such as irritability, drowsiness, lack of interaction or reduced or absent eating or breastfeeding is often the first feature to alarm parents, and is the result of the effect of poor cerebral perfusion and possible accompanying hypoglycaemia on the child’s brain.

The signs which should then be sought include the following:
- Tachycardia (best measured with a stethoscope).
- Weak pulse (ideally central – brachial, femoral or carotid, but difficult to gauge).
- Reduced urine output (this is an early sign).
- Cold skin with poor circulation, or sometimes peripheral skin vasoconstriction.
- Prolonged capillary refill time (CRT) > 3 seconds.
- Agitation and anxiety.
- Increased skin sweating in some cases.
- Extreme central pallor (in cases with severe anaemia).
- Raised respiratory rate (due to acidosis).
- Reduced conscious level (this is a serious and dangerous sign).
- Low blood pressure (this is a late sign and difficult to measure in young children; the correct-sized cuff is needed).

**Difficulties in managing septic shock**

In well-resourced countries or well-resourced areas of countries with specialist paediatric intensive care units (PICUs) or high-dependency units, some cases of septic shock are still difficult to manage and some children die.

In resource-limited countries the following additional difficulties need to be taken into account:
- Severe malnutrition: this makes the diagnosis of septic shock more difficult, as the child’s malnourished body does not respond with the same physical signs as that of a well-nourished child. In addition, malnourished children may have poor myocardial function and almost always have severe anaemia. This will result in cardiac failure and probable death if rapid infusions of large and repeated boluses of fluid (an important part of septic shock management) are given (see Section 5.10.B).
- Severe anaemia: as shock is a failure of oxygen delivery to the tissues, clearly anaemia will make this worse. Rapid crystalloid fluid infusion will dilute the blood further and worsen the heart failure which may be present in severe anaemia. These children need early fresh
whole blood transfusion, where the red blood cells will improve oxygen-carrying capacity, and the plasma will support the circulation and supply coagulation factors. If only stored blood is available, it should be packed to provide predominantly red blood cells. In the absence of a suitable centrifuge, hanging the bag vertically allows the red cells to fall to the bottom of the pack and these can be transfused first.

- **HIV/AIDS:** again diagnosis may be difficult, as physical signs and laboratory tests may be unreliable. A low threshold for treatment of suspected sepsis with broad-spectrum antibiotics is recommended (see Section 6.2.D).

- **Lack of PICU or high-dependency care facilities:** even in children with good nutrition, no severe anaemia and no other long-term debilitating condition, the amount of fluid infusion required to successfully treat some cases of septic shock is sufficient to induce heart failure and pulmonary oedema. If facilities are available, intubation and ventilation, IV infusion of inotropic drugs such as dopamine and adrenaline, invasive cardiovascular monitoring, renal dialysis and other aspects of paediatric intensive care are required. The absence of these facilities limits the treatment that can be offered to children with septic shock.

### Initial management of septic shock

Even though it may be clear on initial inspection that the child is in shock, the first priority must still be to call for help, manage the airway, manage breathing, and then manage the circulation.

**Airway**

Assess the airway by the simple technique of asking the child ‘Are you all right?’ Any vocalisation such as a reply or crying indicates an open airway and some ventilation. In the absence of a response, formally open the airway with a head tilt/chin lift or a jaw thrust manoeuvre (see Section 1.12), and assess breathing by looking, listening and feeling for its presence.

**Breathing**

All children with suspected shock must receive high-flow oxygen.

If possible, this should be given through a mask with a reservoir to achieve the higher concentrations. In the absence of spontaneous breathing give assisted ventilation with a bag-mask (see Section 1.13).

**Circulation**

Some assessment of weight will be necessary to calculate the amounts of fluid and antibiotics to be given. If the child is not malnourished, use the following formula:

\[
\text{weight in kg} = 2 \times (\text{age in years} + 4)
\]

If the child is malnourished, this formula can still be used, but perhaps a percentage such as 25–50% subtracted from the result.

**Intravenous access** with a short wide-bore venous cannula, or placement of an *intra-osseous line* (see Section 8.4.B), is vital. More than one line is preferable, as rapid fluid resuscitation may be required, and other drugs may need to be given simultaneously, but start IV treatment as soon as the first line is in place before seeking additional IV access (unless sufficient staff are available). Take blood for the following investigations: full blood count, glucose levels, electrolytes (including calcium and lactate levels if possible), blood grouping and blood cross-matching in all cases. Treat hypoglycaemia if it is identified (see Section 5.8.B).

**Nutritional status: severe malnutrition**

While starting to give fluid, assess the child’s nutritional status (see Section 5.10.B). Look for visible severe wasting or marasmus. Follow the WHO criteria: ‘Look at the arms, legs and chest. The marasmic child does not look just thin, but appears to be all skin and bone. The skin looks too large for the body, there is no fat on the child and you will see the outlines of the ribs. There is also severe muscle wasting of the arms, legs and buttocks. The head may appear relatively large because of wasting of the body.’ Use the mid upper arm circumference (MUAC) (see Section 9) to assess marasmus, as the urgency of the child’s need for treatment precludes a weight and height measurement.

Look also for kwashiorkor. Check for oedema of both feet. Look at the bare feet. Press the top of the foot gently with your thumb for a few seconds. Oedema is present if a definite dent is left in the tissues. Look and feel to determine whether the child has oedema of both feet.

**Severe anaemia**

In very anaemic children (with either obviously pale palms or haemoglobin levels of less than 3–4 grams/dL), crystalloid alone will worsen oxygen delivery to the tissues. These children need blood, either packed cells or a partial exchange transfusion, in addition to initial slow fluid resuscitation (see Section 5.10.B, Section 5.11.C and Section 8.4.B).

**First fluid**

The next step is to give fluid and antibiotics intravenously.

**Malnourished and/or severely anaemic children**

- **If the child is malnourished and/or anaemic** (haemoglobin concentration < 5 grams/dL), fluid must be given much more carefully. Give 10 mL/kg IV over 30–60 minutes. The recommended solution is Ringer-lactate solution or Hartmann’s solution, each with 5% glucose (insert 50 mL of 50% dextrose into a 500-mL bag of the bolus fluid), but give normal saline (0.9%) if this is all that is available, also with 5% dextrose. For antibiotic treatment, see below.

  - **Give a bolus of 10 mL/kg of fresh blood (if available)** or stored blood over 15 minutes as soon as possible.
  - **Assess the child and if they are not in clinical heart failure**, give another 10 mL/kg bolus of fresh or stored blood over 15 minutes.
    - **If the child is in heart failure**, give 10 mL/kg of blood as packed red cells over 2–3 hours, or use a partial exchange transfusion as follows: using a cannula in a large vein, withdraw 5–10 mL of the patient’s anaemic blood (depending on the child’s size) and infuse 10–20 mL, respectively, of new blood over 5 minutes and repeat 10 times.
    - **If the child is not improving after having been given the above treatment and antibiotics** (see below), further
**Clinical interventions must be determined by the individual situation.**

**Normal nutrition**
- **If the child is not malnourished,** infuse a crystalloid such as Hartmann’s or Ringer-lactate solution as quickly as possible, but give normal saline (0.9%) if this is all that is available. In well-nourished children, the initial bolus volume of fluid to be given is usually 20 mL/kg, which is 25% of the child’s circulating volume. Shock is not usually clinically evident until 25% of the circulation has been lost, so any child with signs of shock must have lost at least this amount of fluid from the circulation. For example, a child weighing 12 kg would need 240 mL of crystalloid. This fluid should be given as quickly as possible, usually over 5–10 minutes. It is easily given by pushing the fluid in using a 50-mL syringe.

**Antibiotics**
- While giving the first bolus of IV fluid, also give IV antibiotics if sufficient staff are available to avoid introducing delays with the first fluid bolus. The choice of antibiotics will depend on the clinical clues as to the infecting organism. In the presence of a purpuric rash (and in a non-endemic dengue area), meningococcus is the likely organism. Otherwise Streptococcus or Staphylococcus or Gram-negative organisms are candidates. A third-generation cephalosporin such as ceftriaxone or a combination of gentamicin and a penicillin would be advisable. Flucloxacillin should be added if Staphylococcus is suspected (e.g. if there are boils or a known abscess). In newborn infants or children with suspected intra-abdominal sepsis, Gram-negative organisms are likely. Metronidazole should be given to cover anaerobic organisms if clinically appropriate.

**Reassessment**
- The next very important step before a second IV bolus is given is to **reassess the patient’s vital signs** to see if the fluid has helped. Check the pulse rate, capillary return, limb temperature and blood pressure, and pay particular attention to the child’s mental status. Observe the parent–child interaction. Is the child more or less part of the parent? Look for signs of heart failure (i.e. raised jugular venous pressure, enlarged liver, and crackles in the lung bases).
- If the child still shows the signs of shock, give further fluid. If there are signs of fluid overload with or without heart failure, stop the IV fluid.

**Further fluid**
- If there has been a little improvement or no improvement, give a further bolus of 10–20 mL of fluid. Reassess the child after each 10 mL/kg of fluid, checking the pulse rate, capillary return, limb temperature, blood pressure and alertness, and looking for signs of heart failure, raised jugular venous pressure, enlarged liver, and crackles in the lung bases.
- Once a total of 40 mL of fluid have been given, there is an increasing risk that you will cause fluid overload with pulmonary oedema, which will make the child worse, not better. The problem is that there may still be leakage of fluid out of the circulation (into which you have been infusing the crystalloid or other fluid), which makes the tissues oedematous but leaves the circulation still hypovolaemic and the tissues under-perfused.

**Inotropes**
- One response to this situation is to give an infusion of a drug that stimulates the heart to pump harder and supports the circulation (an inotrope). **Dopamine is a very potent drug and must be given carefully.** It should be given into a peripheral vein or intra-cesseously at a starting dose of 5 micrograms/kg/minute. The dose can be increased in steps up to 20 micrograms/kg/minute if lower doses do not help.

**Dopamine infusion**
- Make up 0.3 mg/kg of dopamine in 500 mL of Ringer-lactate or Hartmann’s solution or normal saline. This will give 0.1 microgram/kg/minute if run at a rate of 1 mL/hour. Use an 100-mL paediatric burette in the infusion line for this fluid. The burette can then be filled with a further 100 mL and a further dose of dopamine added when necessary. To give 5.0 micrograms/kg/minute, give 50 mL/hour of this dilution for a child. Do not forget that the fluid that you are using for the infusion must be included in your calculations of total fluid given. If higher doses of dopamine are needed, a more concentrated solution of dopamine should be used or too much fluid will be given.
- If dopamine is not available or is not having any significant effect in the larger doses, then adrenaline, which is more potent than dopamine, may be tried.

**Intermittent adrenaline infusions**
- Dissolve 0.1 mL of 1 in 1000 adrenaline or 1 mL of 1 in 10000 adrenaline in 10 mL of 0.9% saline and give 1 mL IV in a child (100 microgram) or 0.2 mL in an infant (20 micrograms). Check the response (in particular of blood pressure), and repeat after 15–30 minutes if it helps to improve perfusion. Then intermittently give further doses as required (1 mL of this solution contains 100 micrograms).
- It must be emphasised that in the absence of paediatric intensive care, the above infusions of inotropic (circulation-supporting) drugs are an attempt to save a child in extremis, and may not be effective.
- Once the infusion of inotropes has been started and the child’s vital signs reassessed, fluid may cautiously be continued, reassessing frequently and stopping the infusion if signs of heart failure appear:
  - If there is a skilled operator (an anaesthetist or surgeon) available, the placing of a central venous line would be very helpful for monitoring the venous pressure (around + 8 mmHg is a good target) and for infusing the dobutamine or adrenaline centrally.
  - Once 60 mL/kg have been given in total along with inotropes, further fluid is unlikely to be beneficial unless skilled ventilation is available.
  - In this situation, provided that adequate facilities and expertise are available, positive pressure ventilation through an endotracheal tube (usually with positive end-expiratory pressure) can assist the circulation and help to manage the effects of any pulmonary oedema.
Section 5.6

Reviewing the full blood count and biochemistry

- Blood tests were taken at the beginning of treatment, but it is useful to check the blood tests again (taking the blood from a vein with no IV in place).
  - Check the haemoglobin level to see whether there is now a need for a blood transfusion (fresh blood would be best). Studies have shown that the haemoglobin concentration should ideally be above 10 grams/dL when treating shock in children.
  - Check the blood glucose level and treat with 2 mL/kg of 10% dextrose in a neonate and 2–5 mL/kg of 10% dextrose in an older infant or child if the level is less than 2.5 mmol/litre. Also add glucose to any infusion fluid.
  - Check the calcium level, and if the concentration of ionised calcium is less than 1 mmol/litre, give 0.3 mg/kg of 10% calcium gluconate IV slowly (over 30 minutes, as calcium can cause cardiac arrest if given too quickly).

- Consider giving 0.5–1 mmol/kg of sodium bicarbonate (0.5–1 mL/kg of 8.4% sodium bicarbonate) over 15 minutes IV for refractory acidosis that is not responding to fluid resuscitation and effective ventilation.

Steroids

- There is some evidence that IV steroids can be helpful in some cases of septic shock. If the suspected organism is meningococcus or the child has previously been on a prolonged course of steroid treatment (e.g. for nephrotic syndrome), IV hydrocortisone can be given at a dose of 1–2 mg/kg/day in divided doses or as a continuous infusion. Occasionally higher doses up to 50 mg/kg/day have been used.

Further treatment

- Many children with septic shock may respond to the above treatments. For those who have not done so, paediatric intensive or high-dependency care is needed. If this is available, contact should be made with the PICU team as soon as it becomes clear that the child has septic shock. Advice on their care can then be given by experts and arrangements made, if possible, for the child to be ‘retrieved’ by the intensive care team coming to stabilise and transfer them.

5.6 Renal disorders

5.6.A Medical renal disorders

**BOX 5.6.A.1 Minimum standards**

- Accurate weight-measuring scales.
- Fluid input and output charts.
- Urine microscopy, culture and sensitivity.
- Antibiotics: trimethoprim, cephalosporins, amoxicillin, nitrofurantoin, gentamicin, penicillin.
- Blood biochemistry: urea, creatinine, sodium, potassium, chloride, bicarbonate.
- Urinary electrolytes.
- Full blood count.
- Ultrasound scan.
- Blood pressure measurement.
- Furosemide and chlorothiazide.
- Nifedipine or amlodipine, hydralazine, propranolol or atenolol, captopril or enalapril.
- Prednisolone, levamisole and cyclophosphamide.
- IV albumin.
- Analgesia: morphine.
- IV Ringer-lactate solution, Hartmann’s solution, phosphamide and 5% albumin.
- IV glucose 10% and insulin.
- Sodium bicarbonate, calcium gluconate, calcium reso-nium and calcium carbonate.
- Antihypertensive drugs.

**Introduction**

**Common renal investigations: plasma or serum biochemistry**

**Electrolytes**

Sodium (Na⁺) and potassium (K⁺) assays are essential for the logical management of children with kidney dysfunction. Bicarbonate (HCO₃⁻) is also extremely helpful, but more difficult to measure.

Problems with fluid and electrolyte balance are common in ill children. They can occur in a wide variety of clinical situations and with a wide range of underlying diagnoses. A methodical approach to history taking and clinical examination is therefore essential, and interpretation of biochemical results must always be done in the context of the clinical situation.