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European Resuscitation Council Guidelines for Resuscitation 2015 Section 6. Paediatric life support

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Introduction

These guidelines on paediatric life support are based on three main principles: (1) the incidence of critical illness, particularly cardiopulmonary arrest, and injury in children is much lower than in adults; (2) the illnesses and pathophysiological responses of paediatric patients often differ from those seen in adults; (3) many paediatric emergencies are managed primarily by providers who are not paediatric specialists and who have limited paediatric emergency medical experience. Therefore, guidelines on paediatric life support must incorporate the best available scientific evidence but must also be simple and feasible. Finally, international guidelines need to acknowledge the variation in national and local emergency medical infrastructures and allow flexibility when necessary.

The process

The European Resuscitation Council (ERC) published guidelines for paediatric life support (PLS) in 1994, 1998, 2000, 2005 and 2010.[1–5] The latter three were based on the paediatric work of the International Consensus on Science published by the International Liaison Committee on Resuscitation (ILCOR).[6–10] This process was repeated in 2014/2015, and the resulting Consensus on Science with Treatment Recommendations (CoSTR) was published simultaneously in Resuscitation, Circulation and Pediatrics using the GRADE process.[11–13] The PLS Writing Group of the ERC has developed the ERC PLS Guidelines based on the 2015 CoSTR and supporting scientific literature. The guidelines for resuscitation of Babies at Birth are covered in the ERC GL2015 Babies at Birth.[14] Information pertaining to children are also found in the ERC GL2015 First Aid,[15] the ERC GL2015 chapter on Education[16] and in the GL2015 chapter on the Ethics of Resuscitation and End-of-Life Decisions.[17]

Summary of changes since 2010 Guidelines

Guideline changes have been made in response to convincing new scientific evidence and, by using clinical, organisational and educational findings, they have been adapted to promote their use and ease for teaching.

The 2015 ILCOR process was informed by librarians who helped paediatric experts in performing in-depth systematic searches on 21 different key questions relating to paediatric resuscitation. Relevant adult literature was also considered and, in a few cases, extrapolated to the paediatric questions when they overlapped with other Task Forces, or when there were insufficient paediatric data. In rare circumstances, appropriate animal studies were incorporated into reviews of the literature. However, these data were considered only when higher levels of evidence were not available. The topic areas that the paediatric COSTR questions dealt with related to: pre-cardiac arrest care, basic life support care, advanced life support during cardiac arrest and post-resuscitation care.

As in previous ILCOR deliberations, there remains a paucity of good-quality evidence on paediatric resuscitation with many gaps in knowledge about paediatric resuscitation having been identified in this round of the CoSTR process.

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These ERC GL2015 have included the recommendations from the ILCOR CoSTR 2015, updating the scientific base in addition to these recommendations and accompanied by points of clarification on matters about which there have been questions since 2010.[12,13]

This section of the ERC GL 2015 on Paediatric Life Support includes:

- Basic life support.
- Management of foreign bodies in the airway.
- Prevention of cardiac arrest.
- Advanced life support during cardiac arrest.
- Post resuscitation care.

New topics in the ERC GL2015 include those from CoSTR recommendations as well as the deliberations of the PLS Writing Group of the ERC.

These include:

In BLS

- The duration of delivering a breath is about 1 s, to coincide with adult practice.
- For chest compressions, the lower sternum should be depressed by at least one third the anterior–posterior diameter of the chest, or by 4 cm for the infant and 5 cm for the child.

In managing the seriously ill child

- If there are no signs of septic shock, then children with a febrile illness should receive fluid with caution and reassessment following its administration. In some forms of septic shock, restricting fluids with isotonic crystalloid may be better than the liberal use of fluids.
- For cardioversion of a supraventricular tachycardia (SVT), the initial dose has been revised to 1 J kg^{-1}.

In the paediatric cardiac arrest algorithm

- Many of the features are now common with adult practice.

In post resuscitation care

- Preventing fever in children who have return of spontaneous circulation (ROSC) from an out-of-hospital setting.
- Targeted temperature management of children post ROSC should comprise treatment with either normothermia or mild hypothermia.
- There is no single predictor for when to stop resuscitation.

Terminology

In the following text the masculine includes the feminine and child refers to both infants and children unless noted otherwise. The term newly born refers to a neonate immediately after delivery. A neonate is an infant within 4 weeks of being born. An infant is a child under one year of age (but does not include newly borns) and the term child refers to children between 1 year and onset of puberty. From puberty children are referred to as adolescents for whom the adult guidelines apply. Furthermore, it is necessary to differentiate between infants and older children, as there are some important differences with respect to diagnostic and interventional techniques between these two groups. The onset of puberty, which is the physiological end of childhood, is the most logical landmark for the upper age limit for use of paediatric guidance. If rescuers believe the victim to be a child they should use the paediatric guidelines. If a misjudgement is made and the victim turns out to be a young adult, little harm will accrue, as studies of aetiology have shown that the paediatric pattern of cardiac arrest continues into early adulthood.[18]

The terms paediatrician and paediatric nurse are used in this text as a generic term to represent clinicians who routinely manage ill or injured children, and could apply to others trained in the delivery of paediatric care, such as emergency department clinicians, or Paediatric Intensive Care Unit (PICU) specialists/paediatric anaesthetists.

Healthcare professionals are those people who look after patients and should have a higher level of training than lay people. This term relates particularly to the delivery of basic life support.

Paediatric basic life support

From the ILCOR CoSTR statement on the sequence for manoeuvres in BLS, there was found to be equipoise between the CAB sequence (compression for circulation, airway and breathing) and the ABC sequence (airway, breathing and compression for circulation).[19–21] Given that the ABC sequence has become an established and well recognised method for the delivery of CPR to children in Europe, the ERC PLS Writing Group determined that the use of this sequence should continue, particularly as the previous guidelines have led to its instruction to many hundreds of thousands of healthcare providers and lay people. This position will continue to be reviewed on the basis of any new knowledge that may be forthcoming.

Sequence of actions in BLS

Bystander CPR is associated with a better neurological outcome in adults and children.[22–26]

Rescuers who have been taught adult BLS or the chest compression-only sequence and have no specific knowledge of paediatric resuscitation may use this, as the outcome is worse if they do nothing. However, it is better to provide rescue breaths as part of the resuscitation sequence when applied to children as the asphyxial nature of most paediatric cardiac arrests necessitates ventilation as part of effective CPR.[25,26]

Non-specialists who wish to learn paediatric resuscitation because they have responsibility for children (e.g. teachers, school nurses, lifeguards), should be taught that it is preferable to modify adult BLS and perform five initial breaths followed by one minute of CPR before they go for help (see adult BLS guidelines).

BLS for those with a duty to respond

The following sequence is to be followed by those with a duty to respond to paediatric emergencies (usually health professionals) (Fig. 6.1).

Although the following sequence describes expired air ventilation, health professionals with a responsibility for treating children will usually have access to, and training in the use of bag mask ventilation systems (BMV), and these should be used to provide rescue breaths.

1. Ensure the safety of rescuer and child.
2. Check the child's responsiveness.

- Stimulate the child and ask loudly: Are you all right?

3A. If the child responds by answering, crying or moving:

- Leave the child in the position in which you find him (provided he is not in further danger).
- Check his condition and call for help.
- Reassess him regularly.

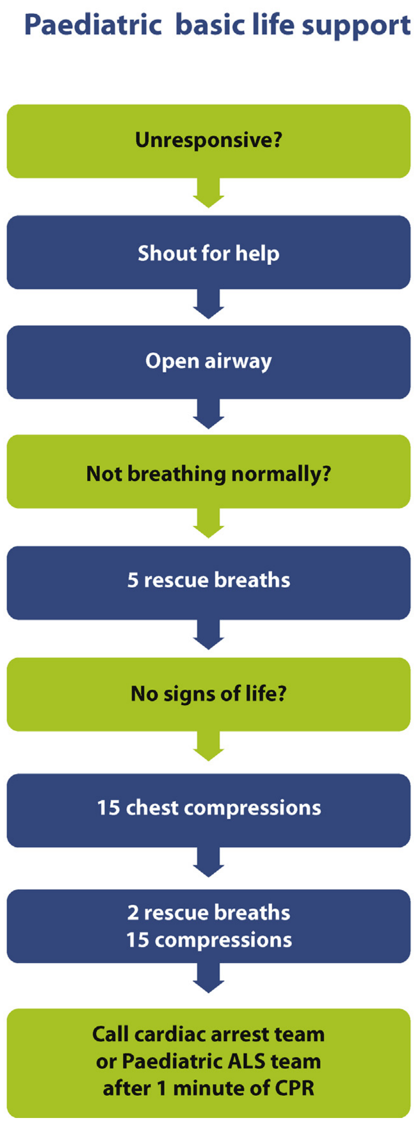

Fig. 6.1. Paediatric basic life support algorithm.

3B. If the child does not respond:

- Shout for help.
- Turn the child carefully on his back.
- Open the child's airway by tilting the head and lifting the chin.
- Place your hand on his forehead and gently tilt his head back.
- At the same time, with your fingertip(s) under the point of the child's chin, lift the chin. Do not push on the soft tissues under the chin as this may obstruct the airway. This is especially important in infants.
- If you still have difficulty in opening the airway, try a jaw thrust: place the first two fingers of each hand behind each side of the child's mandible and push the jaw forward.

Have a low threshold for suspecting an injury to the neck; if so, try to open the airway by jaw thrust alone. If jaw thrust alone does not enable adequate airway patency, add head tilt a small amount at a time until the airway is open.

4. Keeping the airway open, look, listen and feel for normal breathing by putting your face close to the child's face and looking along the chest:

Fig. 6.2. Mouth to mouth and nose ventilation–infant.

- *Look* for chest movements.
- *Listen* at the child's nose and mouth for breath sounds.
- *Feel* for air movement on your cheek.

In the first few minutes after a cardiac arrest a child may be taking slow infrequent gasps. Look, listen and feel for no more than 10 s before deciding—if you have any doubt whether breathing is normal, act as if it is not normal:

5A. If the child is breathing normally:

- Turn the child on his side into the recovery position (see below). If there is a history of trauma, cervical spine injury should be considered.
- Send or go for help—call the emergency services.
- Check for continued breathing.

5B. If breathing is not normal or absent:

- Carefully remove any obvious airway obstruction.
- Give five initial rescue breaths.
- While performing the rescue breaths note any gag or cough response to your action. These responses or their absence will form part of your assessment of 'signs of life', which will be described later.

Rescue breaths for an infant (Fig. 6.2)

- Ensure a neutral position of the head as an infant's head is usually flexed when supine, this may require some extension (a rolled towel/blanket under the upper part of the body may help to maintain the position) and a chin lift.
- Take a breath and cover the mouth and nose of the infant with your mouth, making sure you have a good seal. If the nose and mouth cannot be covered in the older infant, the rescuer may attempt to seal only the infant's nose or mouth with his mouth (if the nose is used, close the lips to prevent air escape).
- Blow steadily into the infant's mouth and nose for about 1 s, sufficient to make the chest visibly rise.
- Maintain head position and chin lift, take your mouth away from the victim and watch for his chest to fall as air comes out.
- Take another breath and repeat this sequence five times.

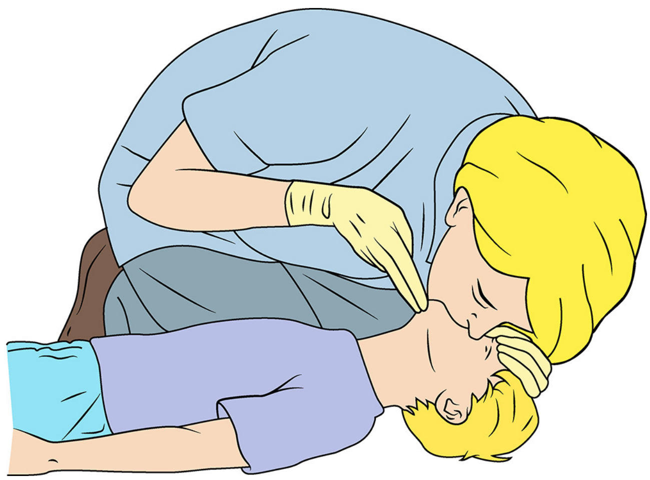

Fig. 6.3. Mouth to mouth ventilation–child.

Rescue breaths for a child over 1 year of age (Fig. 6.3):

- Ensure head tilt and chin lift.
- Pinch the soft part of the nose closed with the index finger and thumb of your hand on his forehead.
- Allow the mouth to open, but maintain chin lift.
- Take a breath and place your lips around the mouth, making sure that you have a good seal.
- Blow steadily into the mouth for about 1 s, watching for chest rise.
- Maintain head tilt and chin lift, take your mouth away from the victim and watch for his chest to fall as air comes out.
- Take another breath and repeat this sequence five times. Identify effectiveness by seeing that the child's chest has risen and fallen in a similar fashion to the movement produced by a normal breath.
- For both infants and children, if you have difficulty achieving an effective breath, the airway may be obstructed:
- Open the child's mouth and remove any visible obstruction. Do not perform a blind finger sweep.
- Reposition the head. Ensure that there is adequate head tilt and chin lift but also that the neck is not over-extended.
- If head tilt and chin lift has not opened the airway, try the jaw thrust method.
- Make up to five attempts to achieve effective breaths, if still unsuccessful, move on to chest compressions.

6. Assess the child's circulation

Take no more than 10 s to:

Look for signs of life—this includes any movement, coughing or normal breathing (gasps or infrequent, irregular breaths are abnormal). If you check the pulse, ensure that you take no more than 10 s. Pulse check is unreliable and therefore the complete picture of how the patient appears must guide whether BLS is required, i.e. if there are no signs of life, start BLS.[27,28]

7A. If you are confident that you can detect signs of life within 10 s

- Continue rescue breathing, if necessary, until the child starts breathing effectively on his own.
- Turn the child on his side (into the recovery position, with caution if there is a history of trauma) if he remains unconscious.
- Re-assess the child frequently.

7B. If there are no signs of life

- Start chest compressions.

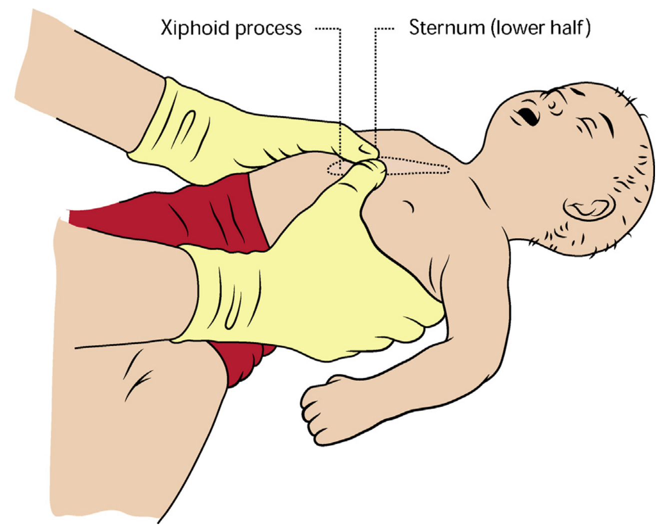

Fig. 6.4. Chest compression—infant.

- Combine rescue breathing and chest compressions at a ratio of 15 compressions to 2 ventilations.

Chest compressions

For all children, compress the lower half of the sternum. The compression should be sufficient to depress the sternum by at least one third of the anterior–posterior diameter of the chest. Release the pressure completely and repeat at a rate 100–120 min^{-1}. After 15 compressions, tilt the head, lift the chin, and give two effective breaths. Continue compressions and breaths in a ratio of 15:2.

Chest compression in infants (Fig. 6.4)

The lone rescuer compresses the sternum with the tips of two fingers. If there are two or more rescuers, use the encircling technique. Place both thumbs flat side by side on the lower half of the sternum (as above) with the tips pointing towards the infant's head. Spread both hands with the fingers together to encircle the lower part of the infant's rib cage. The fingers should support the infant's back. For both methods, depress the lower sternum by at least one third the anterior–posterior dimension of the infant's chest or by 4 cm.[29]

Chest compression in children over 1 year of age (Figs. 6.5 and 6.6)

To avoid compressing the upper abdomen, locate the xiphisternum by finding the angle where the lowest ribs join in the middle. Place the heel of one hand on the sternum one finger's breadth above this. Lift the fingers to ensure that pressure is not applied onto the child's ribs. Position yourself above the victim's chest and, with your arm straight, compress the sternum to at least one third of the anterior–posterior dimension of the chest or by 5 cm.[29,30]

In larger children or for small rescuers, this is achieved most easily by using both hands, with the rescuer's fingers interlocked.

Do not interrupt resuscitation until

- The child shows signs of life (starts to wake up, to move, opens eyes and to breathe normally).
- More healthcare workers arrive and can either assist or take over.
- You become exhausted.

Fig. 6.5. Chest compression with one hand—child.

When to call for assistance

It is vital for rescuers to get help as quickly as possible when a child collapses.

- When more than one rescuer is available, one starts resuscitation while another rescuer goes for assistance.

Fig. 6.6. Chest compression with two hands—child.

- If only one rescuer is present, undertake resuscitation for about 1 min or 5 cycles of CPR before going for assistance. To minimise interruption in CPR, it may be possible to carry an infant or small child whilst summoning help.
- If you are on your own, witness a child suddenly collapse and you suspect a primary cardiac arrest, call for help first and then start CPR as the child will likely need urgent defibrillation. This is an uncommon situation.

AED and BLS

Continue with CPR until the AED arrives. Attach the AED and follow the instructions. For 1–8 year old, use attenuated pads if available, as explained in the chapter on Basic Life Support and Automated External Defibrillation.[31]

Recovery position

An unconscious child whose airway is clear, and who is breathing normally, should be turned on his side into the recovery position.

There are several recovery positions; they all aim to prevent airway obstruction and reduce the likelihood of fluids such as saliva, secretions or vomit from entering into the upper airway.

There are important principles to be followed.

- Place the child in as near true lateral position as possible, with his mouth dependent, which should enable the free drainage of fluid.
- The position should be stable. In an infant, this may require a small pillow or a rolled-up blanket to be placed along his back to maintain the position, so preventing the infant from rolling into either the supine or prone position
- Avoid any pressure on the child's chest that may impair breathing.
- It should be possible to turn the child onto his side and back again to the recovery position easily and safely, taking into consideration the possibility of cervical spine injury by in-line cervical stabilisation techniques.
- Regularly change side to avoid pressure points (i.e. every 30 min).
- The adult recovery position is suitable for use in children.

Foreign body airway obstruction (FBAO)

Back blows, chest thrusts and abdominal thrusts all increase intra-thoracic pressure and can expel foreign bodies from the airway. In half of the episodes more than one technique is needed to relieve the obstruction.[32] There are no data to indicate which measure should be used first or in which order they should be applied. If one is unsuccessful, try the others in rotation until the object is cleared (Fig. 6.7).

The most significant difference from the adult algorithm is that abdominal thrusts should not be used for infants. Although abdominal thrusts have caused injuries in all age groups, the risk is particularly high in infants and very young children. This is due to the horizontal position of the ribs, which leaves the upper abdominal viscera more exposed to traumatic injury. For this reason, the guidelines for the treatment of FBAO are different between infants and children.

Recognition of foreign body airway obstruction

When a foreign body enters the airway the child reacts immediately by coughing in an attempt to expel it. A spontaneous cough is likely to be more effective and safer than any manoeuvre a rescuer might perform. However, if coughing is absent or ineffective

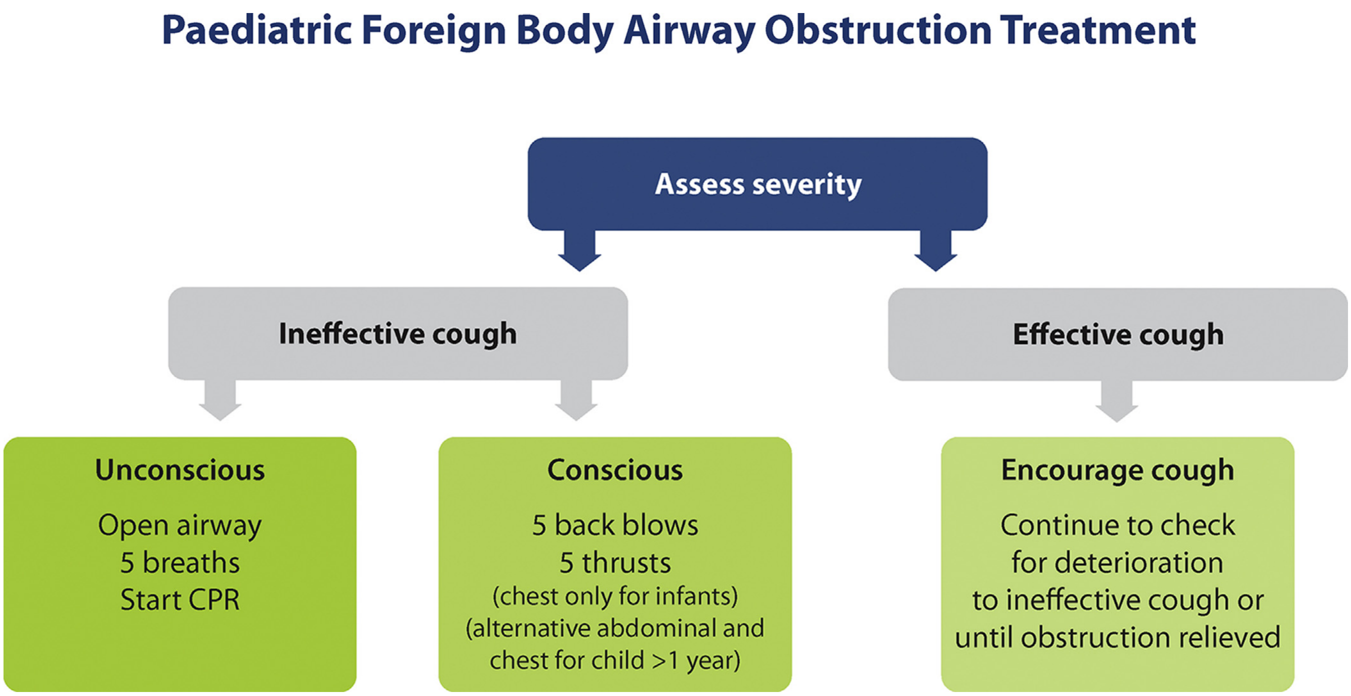

Fig. 6.7. Paediatric foreign body airway obstruction algorithm.

and the object completely obstructs the airway, the child will rapidly become asphyxiated. Active interventions to relieve FBAO are therefore required only when coughing becomes ineffective, but they then need to be commenced rapidly and confidently. The majority of choking events in infants and children occur during play or eating episodes, when a carer is usually present; thus, the events are frequently witnessed and interventions are usually initiated when the child is conscious.

Foreign body airway obstruction is characterised by the sudden onset of respiratory distress associated with coughing, gagging or stridor (Table 6.1). Similar signs and symptoms may be associated with other causes of airway obstruction such as laryngitis or epiglottitis; these conditions are managed differently to that of FBAO. Suspect FBAO if the onset was very sudden and there are no other signs of illness; there may be clues to alert the rescuer, e.g. a history of eating or playing with small items immediately before the onset of symptoms.

Relief of FBAO (Fig. 6.7)

Safety and summoning assistance. The principle of do no harm should be applied i.e. if the child is able to breath and cough, even with difficulty, encourage these spontaneous efforts. Do not intervene at this point as this may move the foreign body and worsen the problem, e.g. by causing full airway obstruction.

If the child is coughing effectively, no manoeuvre is necessary. Encourage the child to cough and continue monitoring the child's condition.

If the child's coughing is (or is becoming) ineffective, *shout for help* immediately and determine the child's conscious level.

Conscious child with FBAO. If the child is still conscious but has absent or ineffective coughing, give back blows.

If back blows do not relieve the FBAO, give chest thrusts to infants or abdominal thrusts to children. These manoeuvres create an artificial cough, increasing intrathoracic pressure and dislodging the foreign body.

Back blows for infants

- Support the infant in a head downward, prone position, to enable gravity to assist removal of the foreign body.
- A seated or kneeling rescuer should be able to support the infant safely across their lap.
- Support the infant's head by placing the thumb of one hand, at the angle of the lower jaw, and one or two fingers from the same hand, at the same point on the other side of the jaw.
- Do not compress the soft tissues under the infant's jaw, as this will worsen the airway obstruction.
- Deliver up to five sharp back blows with the heel of one hand in the middle of the back between the shoulder blades.
- The aim is to relieve the obstruction with each blow rather than to give all five.

Back blows for children over 1 year

- Back blows are more effective if the child is positioned head down.
- A small child may be placed across the rescuer's lap as with the infant.

Table 6.1
Signs of foreign body airway obstruction.

General signs of FBAO	
Witnessed episode	
Coughing/choking	
Sudden onset	
Recent history of playing with/eating small objects	
Ineffective coughing	Effective cough
Unable to vocalise	Crying or verbal response to questions
Quiet or silent cough	Loud cough
Unable to breathe	Able to take a breath before coughing
Cyanosis	Fully responsive
Decreasing level of consciousness	

- If this is not possible, support the child in a forward leaning position and deliver the back blows from behind.

If back blows fail to dislodge the object, and the child is still conscious, use chest thrusts for infants or abdominal thrusts for children. Do not use abdominal thrusts (Heimlich manoeuvre) in infants.

Chest thrusts for infants

- Turn the infant into a head downward supine position. This is achieved safely by placing your free arm along the infant's back and encircling the occiput with the hand.
- Support the infant down your arm, which is placed down (or across) your thigh.
- Identify the landmark for chest compressions (on the lower half of the sternum, approximately a finger's breadth above the xiphisternum).
- Give five chest thrusts; these are similar to chest compressions but sharper and delivered at a slower rate.

Abdominal thrusts for children over 1 year

- Stand or kneel behind the child; place your arms under the child's arms and encircle his torso.
- Clench your fist and place it between the umbilicus and the xiphisternum.
- Grasp this hand with the other hand and pull sharply inwards and upwards.
- Repeat up to five times.
- Ensure that pressure is not applied to the xiphoid process or the lower rib cage—this may cause abdominal trauma.

Following the chest or abdominal thrusts, reassess the child. If the object has not been expelled and the victim is still conscious, continue the sequence of back blows and chest (for infant) or abdominal (for children) thrusts. Call out, or send, for help if it is still not available. Do not leave the child at this stage.

If the object is expelled successfully, assess the child's clinical condition. It is possible that part of the object may remain in the respiratory tract and cause complications. If there is any doubt, seek medical assistance. Abdominal thrusts may cause internal injuries and all victims treated with abdominal thrusts should be examined by a doctor.[4]

Unconscious child with FBAO If the child with FBAO is, or becomes, unconscious, place him on a firm, flat surface. Call out, or send, for help if it is still not available. Do not leave the child at this stage; proceed as follows:

Airway opening Open the mouth and look for any obvious object. If one is seen, make an attempt to remove it with a single finger sweep. Do not attempt blind or repeated finger sweeps—these could push the object deeper into the pharynx and cause injury.

Rescue breaths Open the airway using a head tilt/chin lift and attempt five rescue breaths. Assess the effectiveness of each breath: if a breath does not make the chest rise, reposition the head before making the next attempt.

Chest compressions and CPR

- Attempt five rescue breaths and if there is no response (moving, coughing, spontaneous breaths) proceed to chest compressions without further assessment of the circulation.
- Follow the sequence for single rescuer CPR (step 7B above) for approximately a minute or 5 cycles of 15 compressions to 2 ventilations before summoning the EMS (if this has not already been done by someone else).
- When the airway is opened for attempted delivery of rescue breath, check if the foreign body can be seen in the mouth.
- If an object is seen and can be reached, attempt to remove it with a single finger sweep.
- If it appears the obstruction has been relieved, open and check the airway as above; deliver rescue breaths if the child is not breathing.
- If the child regains consciousness and exhibits spontaneous effective breathing, place him in a safe position on his side (recovery position) and monitor breathing and the level of consciousness whilst awaiting the arrival of the EMS.

Paediatric advanced life support

Assessment of the seriously ill or injured child—The prevention of cardiopulmonary arrest

In children, secondary cardiopulmonary arrests, caused by either respiratory or circulatory failure, are more frequent than primary arrests caused by arrhythmias.[22,33–42] So-called asphyxial arrests or respiratory arrests are also more common in young adulthood (e.g. trauma, drowning and poisoning).[25,43–56]

Without treatment, the ill/injured child's initial physiological responses involve compensatory mechanisms. This means the affected system tries to adapt to the underlying physiological disturbance. So, for a circulatory problem, the initial physiological response will be in the circulatory system, and if there is a respiratory problem, then respiratory changes may take place. As things worsen, the other systems may become involved as part of the compensatory process. However, the child may continue to deteriorate, leading to decompensated respiratory or circulatory failure. Further physiological deterioration to cardiopulmonary failure may occur with the then inevitable progression to cardiopulmonary arrest. As the outcome from cardiopulmonary arrest in children is poor, identifying the preceding stages of circulatory or respiratory failure is a priority as effective early intervention in these stages may be lifesaving.

The order of assessment and intervention for any seriously ill child follows the ABCDE principles.

- A indicates airway.
- B indicates breathing.
- C indicates circulation.
- D indicates disability.
- E indicates exposure.

The topics of D (disability i.e. neurological status) and E (exposure with any subsequent conditions that may be found e.g. non-blanching rashes) are beyond the remit of these guidelines but are taught in paediatric life support courses.

Interventions are made at each step of the assessment as abnormalities are identified. The next step of the assessment is not started until the preceding abnormality has been managed and corrected if possible.

The role of the team leader is to co-ordinate care and to anticipate problems in the sequence. Each team member must be aware of the ABC principles.[57] Should deterioration occur, reassessment based on ABCDE is strongly recommended, starting at A again.

Summoning a paediatric rapid response team or medical emergency team may reduce the risk of respiratory and/or cardiac arrest in hospitalised children outside the intensive care setting but the evidence is limited on this point as the literature tends not to separate out the team response alone from the other systems in place to identify early deterioration.[58–69] This team should ideally include at least one physician experienced in acute paediatric care and a paediatric nurse (see the definitions in the terminology section above for the clinicians involved), and be called to evaluate a potentially critically ill child not already in a paediatric intensive care unit (PICU) or paediatric emergency department (ED).[70,71]

The ERC PLS writing group recognised that there is national and regional variation in countries as to the compositions of such a team but it is clear that processes to detect the early deterioration are key in reducing the morbidity and mortality of seriously ill and injured children. These processes with subsequent intervention by attending nurses and doctors have a higher priority for implementation than there solely being a rapid response or medical emergency team.[29,72–74]

Specific scores can be used (e.g. the paediatric early warning score, PEWS),[70,75–96] but there is no evidence that these improve the decision making process, or the clinical outcome.[29,71]

Diagnosing respiratory failure: Assessment of A and B

Assessment of a potentially critically ill child starts with the assessment of airway (A) and breathing (B).

Respiratory failure can be defined as the body's inability to maintain adequate blood levels of oxygen and carbon dioxide. Physiological compensatory mechanisms may be seen, such as an increase in respiratory rate and heart rate, and increased work of breathing, but these signs are not always present.

The signs of respiratory failure, as features of those physiological responses, may include:

- Respiratory rate outside the normal range for the child's age—either too fast or too slow.[97]
- Initially increased work of breathing, which may progress to inadequate/decreased work of breathing as the child tires or compensatory mechanisms fail.
- Additional noises such as stridor, wheeze, crackles, grunting, or the loss of breath sounds.
- Decreased tidal volume marked by shallow breathing, decreased chest expansion or decreased air entry at auscultation.
- Hypoxaemia (without/with supplemental oxygen) generally identified by cyanosis but it is often detectable prior to this by pulse oximetry.

There are uncommon conditions that can be associated with respiratory failure in which there is an inability of the body to raise these physiological compensatory signs. These are mostly due to abnormal neurological conditions (e.g. intoxication or coma) or muscular conditions (e.g. myopathy) where owing to muscle weakness, the child may not have the capacity to increase the work of breathing. A history or the presence of any features of these conditions is important to take into account when assessing the patient.

There may be associated signs in other organ systems. Even though the primary problem is respiratory, other organ systems will be involved to try to ameliorate the overall physiological disturbance.

These are detectable in step C of the assessment and include:

- Increasing tachycardia (compensatory mechanism to increase tissue oxygen delivery).
- Pallor.
- Bradycardia (an ominous indicator of the loss of compensatory mechanisms).
- Alteration in the level of consciousness (a sign that compensatory mechanisms are failing) owing to poor perfusion of the brain.

Diagnosing circulatory failure: Assessment of C

Circulatory failure is characterised by a mismatch between the metabolic demand by the tissues, and the delivery of oxygen and nutrients by the circulation.[97,98] Physiological compensatory mechanisms lead to changes in heart rate, in the systemic vascular resistance, and in tissue and organ perfusion. In some conditions, there may be vasodilation as part of the body's response to illness, e.g. toxic shock syndrome.

Signs of circulatory failure might include:

- Increased heart rate (bradycardia is an ominous sign of physiological decompensation).[97]
- Decreased systemic blood pressure.
- Decreased peripheral perfusion (prolonged capillary refill time, decreased skin temperature, pale or mottled skin)—signs of increased vascular resistance.
- Bounding pulses, vasodilation with widespread erythema may be seen in conditions with decreased vascular resistance.
- Weak or absent peripheral pulses.
- Decreased intravascular volume.
- Decreased urine output.

The transition from a compensatory state to decompensation may occur in an unpredictable way. Therefore, the child should be monitored, to detect and correct any deterioration in their physiological parameters promptly.

Other systems may be affected, for example:

- The respiratory rate may be increased initially, as an attempt to improve oxygen delivery, later becoming slower; this is usually accompanied by decompensated circulatory failure.
- The level of consciousness may decrease owing to poor cerebral perfusion.
- Poor cardiac functioning can lead to other signs, such as pulmonary oedema, enlarged liver, raised jugular veins.
- Poor tissue perfusion, metabolic acidosis and increased/increasing blood lactate levels may become progressively worse without correction.

Diagnosing cardiopulmonary arrest

Signs of cardiopulmonary arrest include:

- Unresponsiveness to pain (coma).
- Apnoea or gasping respiratory pattern.
- Absent circulation.
- Pallor or deep cyanosis.

Palpation of a pulse is not reliable as the sole determinant of the need for chest compressions.[27,99–101] In the absence of signs of life, rescuers (lay and professional) should begin CPR unless they are certain that they can feel a central pulse within 10 s (infants—brachial or femoral artery; children—carotid or femoral artery). If there is any doubt, start CPR.[99,102–104] If personnel skilled in echocardiography are available, this investigation may help to detect cardiac activity and potentially treatable causes for the arrest.[100] However, echocardiography must not interfere with or delay the performance of chest compressions.

Management of respiratory and circulatory failure

In children, there are many causes of respiratory and circulatory failure and they may develop gradually or suddenly. Both may be initially compensated but will normally decompensate without adequate treatment. Untreated decompensated respiratory or circulatory failure will lead to cardiopulmonary arrest. Hence, the aim of paediatric life support is the early and effective intervention in children with respiratory and circulatory failure to prevent progression to full arrest.[105–110]

Airway and breathing

- Open the airway.
- Optimise ventilation.
- Ensure adequate oxygenation, start with 100% oxygen.
- Establish respiratory monitoring (first line – pulse oximetry/peripheral oxygen saturation – SpO_2).
- Achieving adequate ventilation and oxygenation—this may require the use of airway adjuncts ± bag-mask ventilation (BMV), the use of an LMA or other supraglottic airway, securing a definitive airway by tracheal intubation and positive pressure ventilation.
- For intubated children, it is standard practice that their end tidal carbon dioxide levels are monitored. End tidal carbon dioxide monitoring can be used in non-intubated critically ill patients.
- Very rarely, a surgical airway may be required.

Circulation

- Establish cardiac monitoring (first line—pulse oximetry/SpO_2, electrocardiography (ECG) and non-invasive blood pressure (NIBP)).
- Secure intravascular access. This may be achieved by peripheral intravenous (IV) or by intraosseous (IO) route. If already in situ, a central intravenous catheter should be used.
- Give a fluid bolus (20 ml kg^{-1}) and/or drugs (e.g., inotropes, vasopressors, anti-arrhythmics) to treat circulatory failure due to hypovolaemia, e.g. from fluid loss or maldistribution, as seen in septic shock and anaphylaxis.
- Consider carefully the use of fluid bolus in primary cardiac functioning disorders, e.g. myocarditis, cardiomyopathy.
- Do not give a fluid bolus in severe febrile illness when circulatory failure is absent.[29,111–113]
- Isotonic crystalloids are recommended as initial resuscitation fluid in infants and children with any type of shock, including septic shock.[29,114–119]
- Assess and re-assess the child repeatedly, beginning each time with the airway before proceeding to breathing and then the circulation. Blood gas and lactate measurement may be helpful.
- During treatment, capnography, invasive monitoring of arterial blood pressure, blood gas analysis, cardiac output monitoring, echocardiography and central venous oxygen saturation ($ScvO_2$) may be useful to guide the treatment of respiratory and/or circulatory failure.[120,121] Whilst the evidence for the use of these techniques is of low quality, the general principles of monitoring and assessing the impact of any interventions and those responses are key in managing seriously ill children.

Airway

Open the airway by using basic life support techniques. Oropharyngeal and nasopharyngeal airways adjuncts can help maintain the airway. An oropharyngeal airway may be helpful in the unconscious child, in whom there is no gag reflex. Use the appropriate size (as measured from the incisors to the angle of the mandible) to avoid pushing the tongue backward during insertion, as this may further obstruct the airway. The soft palate may be damaged by forceful insertion of the oropharyngeal airway—avoid this by inserting the oropharyngeal airway with care. Do not use force if the child resists.

The nasopharyngeal airway is usually tolerated better in the conscious or semi-conscious child (who has an effective gag reflex), but should not be used if there is a basal skull fracture or a coagulopathy. The correct insertion depth should be sized from the nostrils to the angle of the mandible and must be re-assessed after insertion. These simple airway adjuncts do not protect the airway from aspiration of secretions, blood or stomach contents.

Supraglottic airways devices (SADs) (including LMA)

Although BVM ventilation remains the recommended first line method for achieving airway control and ventilation in children, the SADs represent a range of acceptable airway devices that may assist providers trained in their use.[122,123] SADs may be particularly helpful in airway obstruction caused by supraglottic airway abnormalities, or if BVM ventilation is difficult or not possible.[124,125] SADs do not totally protect the airway from aspiration of secretions, blood or stomach contents, and therefore close observation is required.[126,127]

Tracheal intubation

Tracheal intubation is the most secure and effective way to establish and maintain the airway, prevent gastric distension, protect the lungs against pulmonary aspiration, enable optimal control of the airway pressure and provide positive end expiratory pressure (PEEP). The oral route for tracheal intubation is preferable during resuscitation. Oral intubation is quicker and simpler, and is associated with fewer complications than nasal intubation. In the conscious child, the judicious use of anaesthetics, sedatives and neuromuscular blocking drugs is essential to avoid multiple intubation attempts or intubation failure.[128–137] Only skilled and experienced practitioners should perform intubation.

The anatomy of a child's airway differs significantly from that of an adult, and tube sizes and insertion depth vary considerably with age; hence, intubation of a child requires special training and ongoing experience. Clinical examination and capnography should be used to ensure that the tracheal tube remains secured and vital signs should be monitored.[136] It is also essential to anticipate potential cardiorespiratory problems and to plan an alternative airway management technique in case the trachea cannot be intubated.

There is currently no evidence-based recommendation defining the setting-, patient- and operator-related criteria for pre-hospital tracheal intubation of children. Pre-hospital tracheal intubation of children may be considered if the airway and/or breathing is seriously compromised or threatened. The mode and duration of transport (e.g., air transport) may play a role in the decision to secure the airway before transport.

Anyone intending to intubate must be adequately skilled in advanced paediatric airway management including pre-oxygenation and the use of drugs to facilitate tracheal intubation.[138]

Intubation during cardiopulmonary arrest. The child who is in cardiopulmonary arrest does not require sedation or analgesia to be intubated. As previously stated, intubation of the seriously ill/injured child should be undertaken by an experienced and trained practitioner.

Tracheal tube sizes. Table 6.2 shows which tracheal tube internal diameters (ID) should be used for different ages.[139–144] This is a guide only and tubes one size larger and smaller should always be available. Tracheal tube size can also be estimated from the length of the child's body, as indicated by resuscitation tapes.[145,146]

Cuffed versus uncuffed tracheal tubes. Uncuffed tracheal tubes have been used traditionally in children up to 8 years of age but cuffed tubes may offer advantages in certain circumstances e.g. in facial burns,[147] when lung compliance is poor, airway resistance is high or if there is a large air leak from the glottis.[139,148,149] The use of

Table 6.2
General recommendation for cuffed and uncuffed tracheal tube sizes (internal diameter in mm).

	Uncuffed	Cuffed
Premature neonates	Gestational age in weeks/10	Not used
Full term neonates	3.5	Not usually used
Infants	3.5–4.0	3.0–3.5
Child 1–2 y	4.0–4.5	3.5–4.0
Child >2 y	Age/4 + 4	Age/4 + 3.5

cuffed tubes also makes it more likely that the correct tube size will be chosen on the first attempt.[139,140,147] The correctly sized cuffed tracheal tube is as safe as an uncuffed tube for infants and children (not for neonates) provided attention is paid to its placement, size and cuff inflation pressure.[148–150] As excessive cuff pressure may lead to ischaemic damage to the surrounding laryngeal tissue and stenosis, cuff inflation pressure should be monitored and maintained at less than 25 cm H_2O.[150]

Confirmation of correct tracheal tube placement. Displaced, misplaced or obstructed tubes occur frequently in the intubated child and are associated with an increased risk of death.[151,152] No single technique is 100% reliable for distinguishing oesophageal from tracheal intubation.[153–155]

Assessment of the correct tracheal tube position is made by:

- Laryngoscopic observation of the tube passing through the vocal cords.
- Detection of end-tidal CO_2 (preferably by capno*graphy* or by capno*metry* or colorimetry) if the child has a perfusing rhythm (this may also be seen with effective CPR, but it is not completely reliable).
- Observation of symmetrical chest wall movement during positive pressure ventilation.
- Observation of mist in the tube during the expiratory phase of ventilation.
- Absence of gastric distension.
- Equal air entry heard on bilateral auscultation in the axillae and apices of the chest.
- Absence of air entry into the stomach on auscultation.
- Improvement or stabilisation of SpO_2 in the expected range (delayed sign!).
- Improvement of heart rate towards the age-expected value (or remaining within the normal range) (delayed sign!).

If the child is in cardiopulmonary arrest and exhaled CO_2 is not detected despite adequate chest compressions, or if there is any doubt as to the tube position, confirm the placement of the tracheal tube by direct laryngoscopy. After correct placement and confirmation, secure the tracheal tube and reassess its position. Maintain the child's head in the neutral position. Flexion of the head drives the tube further into the trachea whereas extension may pull it out of the airway.[156] Confirm the position of the tracheal tube at the mid-trachea by chest X-ray; the tracheal tube tip should be at the level of the 2nd or 3rd thoracic vertebra.

DOPES is a useful acronym for the causes of sudden deterioration in an intubated child. It is also helpful in the case of a child who requires intubation and thereafter fails to improve following being intubated. When the cause is found, steps should be taken to remedy the situation.

Displacement of the tracheal tube (in the oesophagus, pharynx or endobronchially). **O**bstruction of the tracheal tube, or of the heat and moisture exchanger (HME) or the respirator pipes. **P**neumothorax and other **p**ulmonary disorders (bronchospasm, oedema, pulmonary hypertension, etc.). **E**quipment failure (source of gas, bag-mask, ventilator, etc.). **S**tomach (gastric distension may alter diaphragm mechanics).

Breathing

Oxygenation

Give oxygen at the highest concentration (i.e. 100%) during initial resuscitation.

Studies in newly borns suggest advantages of using room air during resuscitation.[14] In infants and older children, however, there is no evidence of benefit for using air instead of oxygen so use 100% oxygen for the initial resuscitation. Once the child is stabilised and/or there is ROSC, titrate the fraction of inspired oxygen (FiO_2) to achieve normoxaemia, or at least (if arterial blood gas is not available), maintain SpO_2 in the range of 94–98%.[157,158] In smoke inhalation (carbon monoxide poisoning) and severe anaemia, however, high FiO_2 should be maintained until the underlying disorder is ameliorated as in these circumstances, dissolved oxygen in the blood plays an important role in oxygen transport to tissues.

Ventilation

Healthcare providers commonly provide excessive ventilation during CPR and this may be harmful. Hyperventilation causes increased intrathoracic pressure, decreased cerebral and coronary perfusion, and there is some evidence of poorer survival rates in animals although other evidence suggests that survival rates are not worse.[159–166] A simple guide to deliver an appropriate tidal volume is to achieve normal chest wall rise. Use a ratio of 15 chest compressions to 2 ventilations and a compression rate of 100–120 min^{-1}.

Inadvertent hyperventilation during CPR occurs frequently, especially when the trachea is intubated and ventilations are given continuously along with asynchronous chest compressions.

Once the airway is protected by tracheal intubation, continue positive pressure ventilation at 10 breaths min^{-1} without interrupting the chest compressions. Take care to ensure that lung inflation is adequate during chest compressions. Once ROSC has been achieved, provide normal ventilation (rate/volume) based on the child's age, and by monitoring end-tidal CO_2 and blood gas values, to achieve a normal arterial carbon dioxide tension ($PaCO_2$) and arterial oxygen levels. Both hypocarbia and hypercarbia are associated with poor outcomes following cardiac arrest.[167] This means that the child with ROSC should usually be ventilated at 12–24 breaths min^{-1}, according to their age normal values.

In a few children the normal values for carbon dioxide and oxygenation levels may be different to that of the rest of the paediatric population; take care to restore the carbon dioxide and oxygen values to that child's normal levels, e.g. in children with chronic lung disease or congenital heart conditions.

Bag mask ventilation (BMV). Bag mask ventilation (BMV) is effective and safe for a child requiring assisted ventilation for a short period, i.e., in the pre-hospital setting or in an emergency department.[168,169] Assess the effectiveness of BMV by observing adequate chest rise, monitoring heart rate and auscultating for breath sounds, and measuring SpO_2. Any healthcare provider with a responsibility for treating children must be able to deliver BMV effectively.

Monitoring of breathing and ventilation

1.1.1.1. End-tidal CO_2. Monitoring end-tidal CO_2 ($ETCO_2$) with a colorimetric detector or capnometer confirms tracheal tube placement in the child weighing more than 2 kg, and may be used in pre- and in-hospital settings, as well as during any transportation of a child.[170–173] A colour change or the presence of a capnographic waveform for more than four ventilated breaths indicates that the tube is in the tracheobronchial tree both in the presence of a perfusing rhythm and during cardiopulmonary arrest. Capnography does not rule out intubation of a bronchus. The absence of exhaled CO_2 during cardiopulmonary arrest does not guarantee tube misplacement since a low or absent $ETCO_2$ may reflect low or absent pulmonary blood flow.[174–177]

In this circumstance, the tube placement should be checked by direct laryngoscopy and the chest auscultated for the sounds of air entry into the lungs.

Capnography may also provide information on the effectiveness of chest compressions and can give an early indication of ROSC.[178,179] Care must be taken when interpreting $ETCO_2$ values especially after the administration of adrenaline or other vasoconstrictor drugs when there may be a transient decrease in values[180–184] or after the use of sodium bicarbonate causing a transient increase.[185] Although an $ETCO_2$ higher than 2 kPa (15 mmHg) may be an indicator of adequate resuscitation, current evidence does not support the use of a threshold $ETCO_2$ value as an indicator for the quality of CPR or for the discontinuation of resuscitation.[29]

Peripheral pulse oximetry, SpO_2. Clinical evaluation to determine the degree of oxygenation in a child is unreliable; therefore, monitor the child's peripheral oxygen saturation continuously by pulse oximetry. Pulse oximetry can be unreliable under certain conditions, e.g. if the child is in circulatory failure, in cardiopulmonary arrest or has poor peripheral perfusion. In some circumstances the SpO_2 reading may not give a true assessment of the total amount of oxygen in the blood as it only measures the relative amount of oxygen bound to haemoglobin. Hence, in anaemia, methaemoglobinaemia or in carbon monoxide poisoning, SpO_2 values must be interpreted with caution.

Although pulse oximetry is relatively simple, it is a poor guide to tracheal tube displacement and must not be relied upon. Capnography detects tracheal tube dislodgement more rapidly than pulse oximetry and is the monitoring system of choice.[186]

Circulation

Vascular access

Vascular access is essential to enable drugs and fluids to be given, and blood samples obtained. Venous access can be difficult to establish during resuscitation of an infant or child. In critically ill children, whenever venous access is not readily attainable, intraosseous access should be considered early, especially if the child is in cardiac arrest or decompensated circulatory failure.[187–193] In any case, in critically ill children, if attempts at establishing intravenous (IV) access are unsuccessful after one minute, insert an intra-osseous (IO) needle instead.[190,194]

IO access. IO access is a rapid, safe, and effective route to give drugs, fluids and blood products.[195–205] The onset of action and time to achieve adequate plasma drug concentrations are similar to that achieved via the central venous route.[206–209] Bone marrow samples can be used to cross match for blood type or group for chemical analysis[210–212] and for blood gas measurement (the values may be comparable to central venous blood gases if no drug has been injected in the cavity).[206,209,211,213–215] However, these bone marrow samples can damage auto-analysers and should be used preferably in a cartridge analyser.[216] After taking blood samples, flush each given drug with a bolus of normal saline to ensure dispersal beyond the marrow cavity, and to achieve faster distribution to the central circulation. Inject large boluses of fluid using manual pressure or a pressure bag.[217] Maintain IO access until definitive IV access has been established.[107,192,203,218,219]

Intravenous access and other routes. Peripheral IV access provides plasma concentrations of drugs and clinical responses equivalent to central or IO access.[220–222] The intramuscular route is preferred for the administration of adrenaline in anaphylaxis.[223,224] Other routes are useful for different circumstances e.g. intranasal, buccal etc. but are beyond the remit of these guidelines.[225] Central venous lines provide more secure long-term access but, compared with IO or peripheral IV access, offer no advantages during resuscitation.[190,191,221,226,227] The tracheal route for the administration of drugs is no longer recommended.[228,229]

Fluids and drugs

When a child shows signs of circulatory failure caused by hypovolaemia, controlled volume administration is indicated.[230] For children with febrile illness and not showing signs of circulatory failure, adopt a cautious approach to fluid therapy with frequent reassessment of the child.[29,111–113] Isotonic crystalloids are recommended as the initial resuscitation fluid for infants and children with any type of circulatory failure.[231,232] If there are signs that the systemic perfusion is inadequate, give a bolus of 20 ml kg^{-1} of an isotonic crystalloid even if the systemic blood pressure is normal. Following each bolus, re-assess the child's clinical state, using the ABCDE system of assessment, to decide whether a further bolus or other treatment is required (and how much and how fast). In some children, early inotropic or vasopressor support may be needed.[108,233] In addition, owing to decreased/decreasing consciousness or progressive respiratory failure, some patients will need intubation and mechanical ventilation, so be prepared in case this occurs.

There is growing evidence to prefer the use of balanced crystalloids as these induce less hyperchloraemic acidosis.[234–237]

In life-threatening hypovolaemic shock, as may be seen in rapid blood loss in trauma, limiting the use of crystalloids in favour of a regime of massive blood transfusion may be required. There are varying regimes of combining plasma, platelets and other blood products in delivering massive blood transfusion,[238,239] so the regime used should be according to local protocols. Similarly, in other types of shock, when multiple boluses of crystalloids are given, timely blood products should be considered to treat dilutional effects. Avoid glucose containing solutions unless there is hypoglycaemia.[240–244] Monitor blood glucose levels and avoid hypoglycaemia; infants and small children are particularly prone to hypoglycaemia.[245]

Adenosine

Adenosine is an endogenous nucleotide that causes a brief atrioventricular (AV) block and impairs accessory bundle re-entry at the level of the AV node. Adenosine is recommended for the treatment of supraventricular tachycardia (SVT).[246] It has a short half-life (10 s); give it intravenously via upper limb or central veins to minimise the time taken to reach the heart. It causes asystole, which is usually short lived, hence adenosine must be given under ECG monitoring. Give adenosine rapidly, followed by a flush of 5 ml of normal saline.[247] Adenosine must be used with caution in asthmatics, second or third degree AV block, long QT syndromes and in cardiac transplant recipients.

Adrenaline (epinephrine)

Adrenaline is an endogenous catecholamine with potent α, β_1 and β_2 adrenergic actions. It plays a central role in the cardiac arrest treatment algorithms for non-shockable and shockable rhythms. Adrenaline induces vasoconstriction, increases diastolic pressure and thereby improves coronary artery perfusion pressure, enhances myocardial contractility, stimulates spontaneous contractions, and increases the amplitude and frequency of ventricular fibrillation (VF), so increasing the likelihood of successful defibrillation.

For cardiopulmonary resuscitation, the recommended IV/IO dose of adrenaline in children for the first and for subsequent doses is 10 micrograms kg^{-1}. The maximum single dose is 1 mg. If needed, give further doses of adrenaline every 3–5 min, i.e. every 2 cycles.

The use of single higher doses of adrenaline (above 10 micrograms kg^{-1}) is not recommended because it does not improve survival or neurological outcome after cardiopulmonary arrest.[248–252]

Once spontaneous circulation is restored, a continuous infusion of adrenaline may be required. Its haemodynamic effects are dose-related; there is also considerable variability in response between children; therefore, titrate the infusion dose to the desired effect. High infusion rates may cause excessive vasoconstriction, so compromising extremity, mesenteric, and renal blood flow. High-dose adrenaline can cause severe hypertension and tachyarrhythmias.[253] To avoid tissue damage it is essential to give adrenaline through a secure intravascular line (IV or IO). Adrenaline (and other catecholamines) is inactivated by alkaline solutions and should never be mixed with sodium bicarbonate.[254]

Amiodarone for shock-resistant paediatric VF/pulseless VT

Amiodarone can be used to treat paediatric shock-resistant VF/pulseless VT (pVT). Amiodarone is a non-competitive inhibitor of adrenergic receptors: it depresses conduction in myocardial tissue and therefore slows AV conduction, and prolongs the QT interval and the refractory period. Amiodarone can be given as part of the cardiac arrest algorithm in managing refractory VF/pVT. It is given after the third shock as a 5 mg kg^{-1} bolus (and can be repeated following the fifth shock). When treating other cardiac rhythm disturbances, amiodarone must be injected slowly (over 10–20 min) with systemic blood pressure and ECG monitoring to avoid causing hypotension.[255] This side effect is less common with the aqueous solution.[256] Other rare but significant adverse effects are bradycardia and polymorphic VT.[257]

Lidocaine has been suggested by COSTR as an alternative but most practitioners will have followed the guidance that has stated amiodarone is the drug of choice. The European Resuscitation Council advises that the clinician should use the drug with which they are familiar and for which they have knowledge of expected and unexpected listed side effects.

Lidocaine is a commonly used local anaesthetic as well as being a Class-1b antiarrhythmic drug. Lidocaine is an alternative to amiodarone in defibrillation-resistant VF/pulseless VT in children.[29,258–260] It can be used with a loading dose of 1 mg kg^{-1} (maximum dose 100 mg/dose) followed by continuous infusion at 20–50 micrograms kg^{-1} min^{-1}. Toxicity can occur if there is underlying renal or hepatic disease.

Atropine

Atropine accelerates sinus and atrial pacemakers by blocking the parasympathetic response. The commonly used dose is 20 micrograms kg^{-1}. It may also increase AV conduction. Small doses (<100 micrograms) may cause paradoxical bradycardia.[261] In bradycardia with poor perfusion unresponsive to ventilation and oxygenation, the first line drug is adrenaline, not atropine. Atropine is recommended only for bradycardia caused by increased vagal tone or cholinergic drug toxicity.[262–264] Its role in emergency intubation for the child is still unclear as there are no reported long-term benefits following ROSC.[29,265,266]

Calcium

Calcium is essential for myocardial function,[267] but the routine use of calcium does not improve the outcome from cardiopulmonary arrest.[268–272] Calcium is indicated in the presence of hypocalcaemia, calcium channel blocker overdose, hypermagnesaemia and hyperkalaemia.[46,272–274] Calcium supplementation may be required when massive blood transfusion is given, e.g. as in response to blood loss in trauma, or when any other large fluid volumes are given; the calcium levels must be monitored and replacement given to maintain normal blood levels.[238]

Glucose

Data from neonates, children and adults indicate that both hyper- and hypo- glycaemia are associated with poor outcome after cardiopulmonary arrest,[275,276] but it is uncertain if this is causative or merely an association.[241,276–278] Check blood or plasma glucose concentration and monitor closely in any ill or injured child, including after cardiac arrest. Do not give glucose-containing fluids during CPR unless hypoglycaemia is present.[245] Avoid hyper- and hypoglycaemia following ROSC.[279] In adults strict glucose control does not increase survival when compared with moderate glucose control[280,281] and it increases the risk of hypoglycaemia in neonates, children and adults.[282,283]

Magnesium

There is no evidence for giving magnesium routinely during cardiopulmonary arrest.[284,285] Magnesium treatment is indicated in the child with documented hypomagnesaemia or with torsade de pointes VT, (50 mg kg^{-1}) regardless of the cause.[286]

Sodium bicarbonate

There is no clear evidence for giving sodium bicarbonate routinely during cardiopulmonary arrest.[287–290] After effective ventilation and chest compressions have been achieved and adrenaline given, sodium bicarbonate may be considered for the child with prolonged cardiopulmonary arrest and/or severe metabolic acidosis. Sodium bicarbonate may also be considered in case of haemodynamic instability and co-existing hyperkalaemia, or in the management of tricyclic antidepressant drug overdose. Excessive quantities of sodium bicarbonate may impair tissue oxygen delivery and cause hypokalaemia, hypernatraemia, hyperosmolality and cerebral acidosis.

Procainamide

Procainamide slows intra-atrial conduction and prolongs the QRS and QT intervals. It can be used in supraventricular tachycardia (SVT)[291,292] or VT[293] resistant to other medications in the haemodynamically stable child. However, paediatric data are sparse and procainamide should be used cautiously.[294–297] Procainamide is a potent vasodilator and can cause hypotension: infuse it slowly with careful monitoring.[255,294]

Vasopressin—Terlipressin

Vasopressin is an endogenous hormone that acts at specific receptors, mediating systemic vasoconstriction (via V_1 receptor) and the reabsorption of water in the renal tubule (by the V_2 receptor).[298] There is currently insufficient evidence to support or refute the use of vasopressin or terlipressin as an alternative to, or in combination with, adrenaline in any cardiac arrest rhythm in adults or children.[299–306] These drugs may be considered in cardiac arrest refractory to adrenaline.

Some studies have reported that terlipressin (a long-acting analogue of vasopressin with comparable effects) improves haemodynamics in children with refractory, vasodilatory septic shock, but its impact on survival is less clear.[307–309] Two paediatric case series suggested that terlipressin may be effective in refractory cardiac arrest.[303,310]

Defibrillators

Defibrillators are either automated or manually operated, and may be capable of delivering either monophasic or biphasic shocks. Manual defibrillators capable of delivering the full energy requirements from neonates upwards must be available within hospitals and in other healthcare facilities caring for children at risk of cardiopulmonary arrest. Automated external defibrillators (AEDs) are pre-set for all variables including the energy dose.

Pad/Paddle size for defibrillation

Select the largest possible available paddles to provide good contact with the chest wall. The ideal size is unknown but there should be good separation between the pads.[311,312]

Recommended sizes are:

- 4.5 cm diameter for infants and children weighing <10 kg.
- 8–12 cm diameter for children weighing >10 kg (older than one year).

To decrease skin and thoracic impedance, an electrically conducting interface is required between the skin and the paddles. Preformed gel pads or self-adhesive defibrillation electrodes are effective and are recommended for maximal delivery of the energy. Self-adhesive pads facilitate continuous good quality CPR. Do not use saline-soaked gauze/pads, alcohol-soaked gauze/pads or ultrasound gel.

Position of the paddles

Apply the paddles firmly to the bare chest in the antero-lateral position, one paddle placed below the right clavicle and the other in the left axilla (Fig. 6.8). If the paddles are too large and there is a danger of charge arcing across the paddles, one should be placed on the upper back, below the left scapula and the other on the front, to the left of the sternum. This is known as the antero-posterior position and is also acceptable.

Optimal paddle force

To decrease transthoracic impedance during defibrillation, apply a force of 3 kg for children weighing <10 kg and 5 kg for larger children.[313,314] In practice, this means that the paddles should be applied firmly.

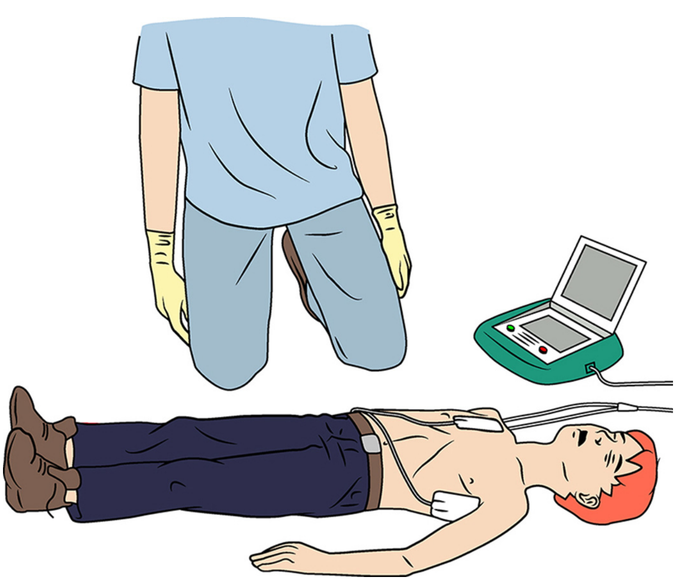

Fig. 6.8. Paddle positions for defibrillation—child.

Energy dose in children

The ideal energy dose for safe and effective defibrillation is unknown. Biphasic shocks are at least as effective and produce less post-shock myocardial dysfunction than monophasic shocks.[315] Animal models show better results with paediatric doses of 3–4 J kg^{-1} than with lower doses,[316] or adult doses,[317] but there are no data to support a different strategy to the current one of an initial dose of 2–4 J kg^{-1}. In Europe, for the sake of simplicity, we continue to recommend 4 J kg^{-1} for initial and subsequent defibrillation. Doses higher than 4 J kg^{-1} (as much as 9 J kg^{-1}) have defibrillated children effectively with negligible side effects.[318,319] When using a manual defibrillator, use 4 J kg^{-1} (preferably biphasic but monophasic waveform is also acceptable) for the first and subsequent shocks.

If no manual defibrillator is available, use an AED that can recognise paediatric shockable rhythms.[320–322] The AED should be equipped with a dose attenuator that decreases the delivered energy to a lower dose more suitable for children aged 1–8 years (50–75 J).[317,323] If such an AED in not available, use a standard adult AED and the pre-set adult energy levels. For children older than 8 years, use a standard AED with standard paddles. Experience with the use of AEDs (preferably with dose attenuator) in children younger than 1 year is limited; its use is acceptable if no other option is available.

Advanced management of cardiopulmonary arrest (Fig. 6.9)

A, B and C: Commence and continue with basic life support.

A and B	Oxygenate and ventilate with BMV • Provide positive pressure ventilation with a high concentration of inspired oxygen (100%) • Establish cardiac monitoring • Avoid rescuer fatigue by frequently changing the rescuer performing chest compressions
C	Assess cardiac rhythm and signs of life (+ check for a central pulse for no more than 10 s)

Non shockable—asystole, pulseless electrical activity (PEA)

- Give adrenaline IV or IO (10 micrograms kg^{-1}) and repeat every 3–5 min (every 2nd cycle) (Fig. 6.10).
- Identify and treat any reversible causes (4Hs & 4Ts).

Reversible causes of cardiac arrest

The reversible causes of cardiac arrest can be considered quickly by recalling the 4Hs and 4Ts:

- Hypoxia
- Hypovolaemia
- Hyper/hypokalaemia, metabolic
- Hypothermia
- Thrombosis (coronary or pulmonary)
- Tension pneumothorax
- Tamponade (cardiac)
- Toxic/therapeutic disturbances

Shockable—VF/pulseless VT

Attempt defibrillation immediately (4 J kg^{-1}) (Fig. 6.11):

- Charge the defibrillator while another rescuer continues chest compressions
- Once the defibrillator is charged, pause the chest compressions and ensure that all rescuers are clear of the patient. Minimise the delay between stopping chest compressions and delivery of the

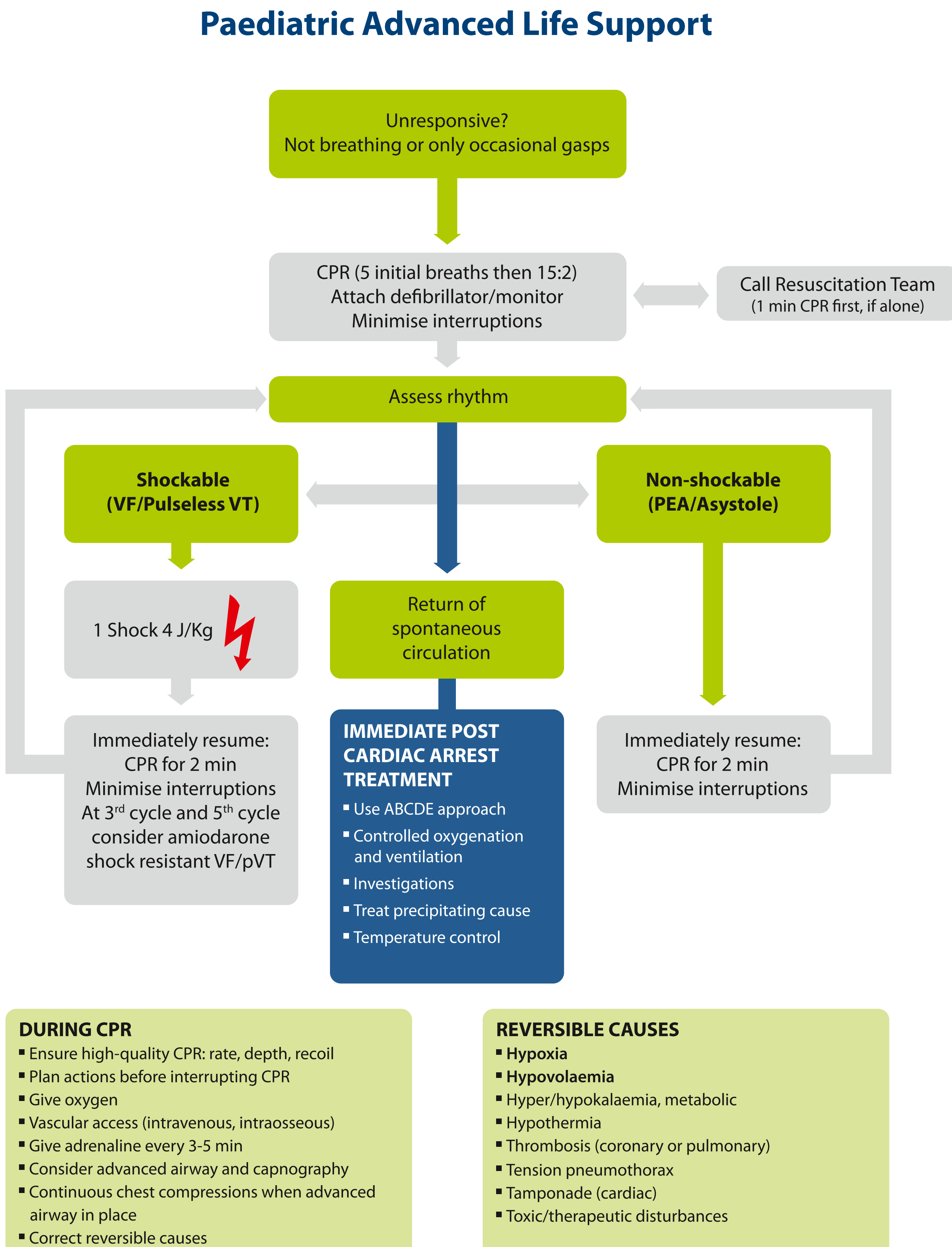

Fig. 6.9. Paediatric advanced life support algorithm.

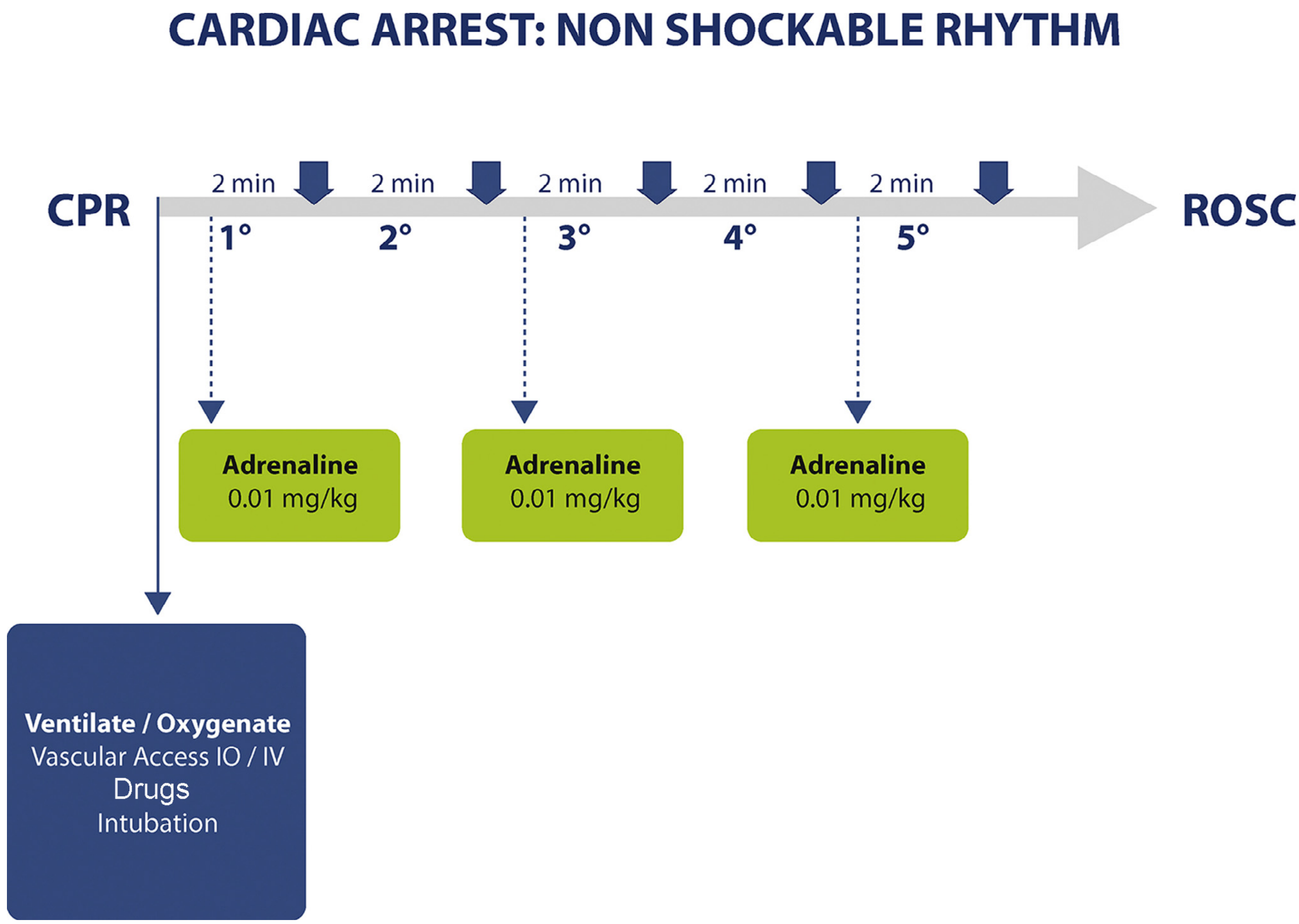

Fig. 6.10. Paediatric algorithm for non-shockable rhythm.

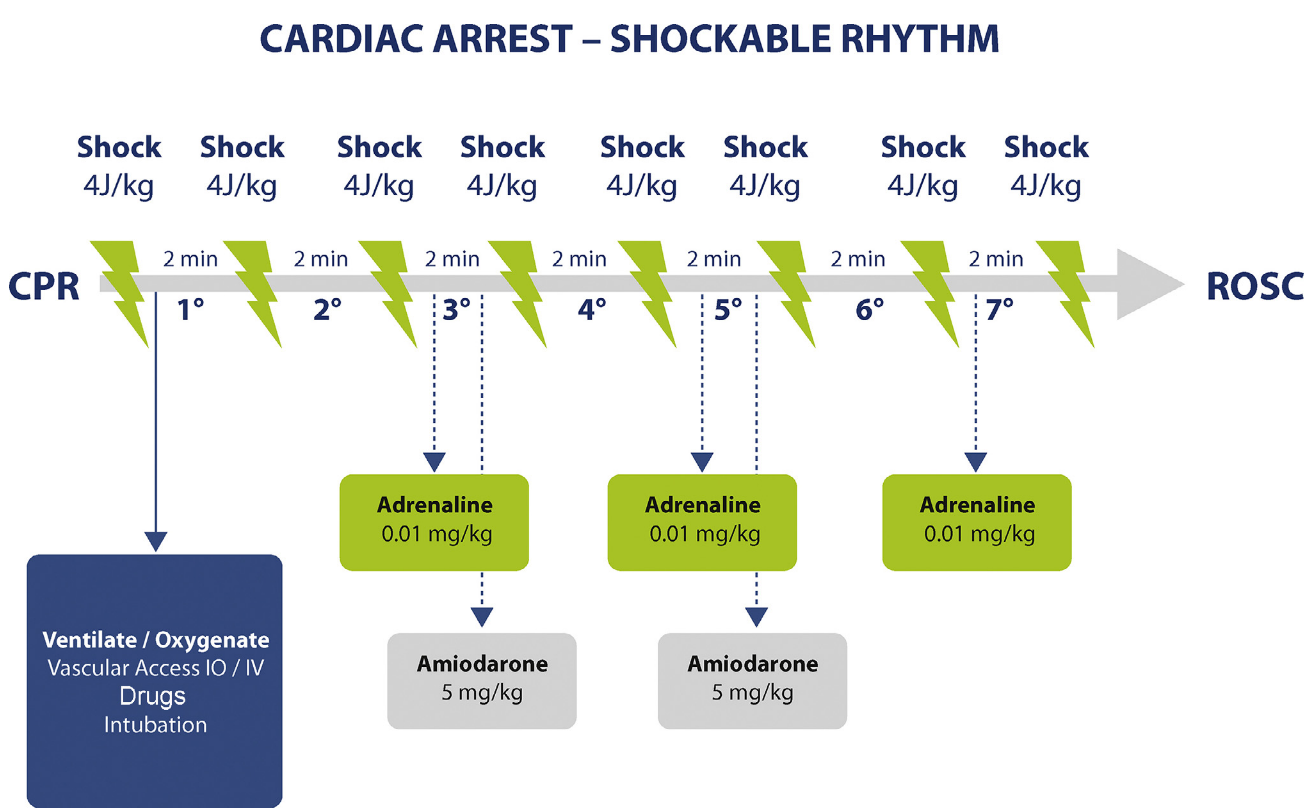

Fig. 6.11. Paediatric algorithm for shockable rhythm.

shock—even 5–10 s delay will reduce the chances of the shock being successful.
- Give one shock.
- Resume CPR as soon as possible without reassessing the rhythm.
- After 2 min, check briefly the cardiac rhythm on the monitor.
- Give second shock (4 J kg^{-1}) if still in VF/pVT.
- Give CPR for 2 min as soon as possible without reassessing the rhythm.
- Pause briefly to assess the rhythm; if still in VF/pVT give a third shock at 4 J kg^{-1}
- Give adrenaline 10 micrograms kg^{-1} and amiodarone 5 mg kg^{-1} after the third shock once CPR has been resumed.
- Give adrenaline every alternate cycle (i.e. every 3–5 min during CPR).
- Give a second dose of amiodarone 5 mg kg^{-1}[324] if still in VF/pVT after the fifth shock.

Lidocaine may be used as an alternative to amiodarone.

If the child remains in VF/pVT, continue to alternate shocks of 4 J kg^{-1} with 2 min of CPR. If signs of life become evident, check the monitor for an organised rhythm; if this is present, check for signs of life and a central pulse and evaluate the haemodynamics of the child (blood pressure, peripheral pulse, capillary refill time).

Identify and treat any reversible causes (4Hs & 4Ts) remembering that hypoxia and hypovolaemia have the highest prevalence in critically ill or injured children, and that electrolyte disturbances and toxicity are common causes of arrhythmia.

If defibrillation has been successful but VF/pVT recurs, resume CPR, give amiodarone or lidocaine and defibrillate again at the energy level that was effective previously.

Cardiac monitoring

Position the cardiac monitor leads or self-adhesive pads soon as possible to enable differentiation between a shockable and a non-shockable cardiac rhythm. Defibrillation paddles can be used to determine a rhythm if monitor leads or self-adhesive pads are not immediately available. Invasive monitoring of systemic blood pressure may help to improve the effectiveness of chest compression if present but it must never delay the provision or hamper the quality of basic or advanced resuscitation.

Non-shockable rhythms are pulseless electrical activity (PEA), bradycardia (<60 min^{-1} with no signs of circulation) and asystole. PEA and bradycardia often have wide QRS complexes.

Shockable rhythms are pVT and VF. These rhythms are more likely after sudden collapse in children with heart disease or in adolescents.

Non-shockable rhythms

Most cardiopulmonary arrests in children and adolescents are of respiratory origin.[325–327] A period of immediate CPR is therefore mandatory in this age group before searching for an AED or manual defibrillator, as its immediate availability will not improve the outcome of a respiratory arrest. The most common ECG patterns in infants, children and adolescents with cardiopulmonary arrest are asystole and PEA. PEA is characterised by electrical activity on the ECG, and absent pulses. It commonly follows a period of hypoxia or myocardial ischaemia, but occasionally can have a reversible cause (i.e., one of the 4Hs and 4Ts) that led to a sudden impairment of cardiac output.

Shockable rhythms

Primary VF occurs in 3.8% to 19% of cardiopulmonary arrests in children, the incidence of VF/pVT increases as the age increases.[48–56,328] The primary determinant of survival from VF/pVT cardiopulmonary arrest is the time to defibrillation. Prehospital defibrillation within the first 3 min of witnessed adult VF arrest results in >50% survival. However, the success of defibrillation decreases dramatically the longer the time until defibrillation: for every minute delay in defibrillation (without any CPR), survival decreases by 7–10%. Secondary VF is present at some point in up to 27% of in-hospital resuscitation events. It has a much poorer prognosis than primary VF.[329]

Drugs in shockable rhythms

Adrenaline (adrenaline). Adrenaline is given every 3–5 min, every 2 cycles by the IV or IO route.

Amiodarone or lidocaine. Either drug can be given in defibrillation-resistant VF/pVT.

Extracorporeal life support. Extracorporeal life support should be considered for children with cardiac arrest refractory to conventional CPR with a potentially reversible cause, if the arrest occurs where expertise, resources and sustainable systems are available to rapidly initiate extracorporeal life support (ECLS).

Arrhythmias

Unstable arrhythmias

Check for signs of life and the central pulse of any child with an arrhythmia; if signs of life are absent, treat as for cardiopulmonary arrest. If the child has signs of life and a central pulse, evaluate the haemodynamic status. Whenever the haemodynamic status is compromised, the first steps are:

(1) Open the airway.
(2) Give oxygen and assist ventilation as necessary.
(3) Attach ECG monitor or defibrillator and assess the cardiac rhythm.
(4) Evaluate if the rhythm is slow or fast for the child's age.
(5) Evaluate if the rhythm is regular or irregular.
(6) Measure QRS complex (narrow complexes: <0.08 s duration; wide complexes: >0.08 s).
(7) The treatment options are dependent on the child's haemodynamic stability.

Bradycardia

Bradycardia is caused commonly by hypoxia, acidosis and/or severe hypotension; it may progress to cardiopulmonary arrest. Give 100% oxygen, and positive pressure ventilation if required, to any child presenting with bradyarrhythmia and circulatory failure.

If a child with decompensated circulatory failure has a heart rate <60 beats min^{-1}, and they do not respond rapidly to ventilation with oxygen, start chest compressions and give adrenaline.

Cardiac pacing (either transvenous or external) is generally not useful during resuscitation. It may be considered in cases of AV block or sinus node dysfunction unresponsive to oxygenation, ventilation, chest compressions and other medications; pacing is not effective in asystole or arrhythmias caused by hypoxia or ischaemia.[330]

Tachycardia

Narrow complex tachycardia. If SVT is the likely rhythm, vagal manoeuvres (Valsalva or diving reflex) may be used in haemodynamically stable children. They can also be used in haemodynamically unstable children, but only if they do not delay chemical or electrical cardioversion.[331]

Adenosine is usually effective in converting SVT into sinus rhythm. It is given by rapid, intravenous injection as close as practicable to the heart (see above), and followed immediately by a bolus of normal saline. If the child has signs of decompensated shock with depressed conscious level, omit vagal manoeuvres and adenosine and attempt electrical cardioversion immediately.

Electrical cardioversion (synchronised with R wave) is also indicated when vascular access is not available, or when adenosine has failed to convert the rhythm. The first energy dose for electrical cardioversion of SVT is $1\,\mathrm{J\,kg^{-1}}$ and the second dose is $2\,\mathrm{J\,kg^{-1}}$. If unsuccessful, give amiodarone or procainamide under guidance from a paediatric cardiologist or intensivist before the third attempt. Verapamil may be considered as an alternative therapy in older children but should not be routinely used in infants.

Amiodarone has been shown to be effective in the treatment of SVT in several paediatric studies.[324,332–339] However, since most studies of amiodarone use in narrow complex tachycardias have been for junctional ectopic tachycardia in postoperative children, the applicability of its use in all cases of SVT may be limited. If the child is haemodynamically stable, early consultation with an expert is recommended before giving amiodarone. An expert should also be consulted about alternative treatment strategies because the evidence to support other drugs in the treatment of SVT is limited and inconclusive.[340,341] If amiodarone is used in this circumstance, avoid rapid administration because hypotension is common.

Wide complex tachycardia. In children, wide-QRS complex tachycardia is uncommon and more likely to be supraventricular than ventricular in origin.[342] Nevertheless, in haemodynamically unstable children, it must be considered to be VT until proven otherwise. Ventricular tachycardia occurs most often in the child with underlying heart disease (e.g., after cardiac surgery, cardiomyopathy, myocarditis, electrolyte disorders, prolonged QT interval, central intracardiac catheter).

Synchronised cardioversion is the treatment of choice for unstable VT with signs of life. Consider anti-arrhythmic therapy if a second cardioversion attempt is unsuccessful or if VT recurs.

Amiodarone has been shown to be effective in treating paediatric arrhythmias,[343] although cardiovascular side effects are common.[324,332,334,339,344]

Stable arrhythmias

Whilst maintaining the child's airway, breathing and circulation, contact an expert before initiating therapy. Depending on the child's clinical history, presentation and ECG diagnosis, a child with stable, wide-QRS complex tachycardia may be treated for SVT and be given vagal manoeuvres or adenosine.

Special circumstances

Life support for blunt or penetrating trauma

Cardiac arrest from major (blunt or penetrating) trauma is associated with a very high mortality.[345–352] The 4Ts and 4Hs should be considered as potentially reversible causes. There is little evidence to support any additional specific interventions that are different from the routine management of cardiac arrest; however, the use of resuscitative thoracotomy may be considered in children with penetrating injuries.[353–359]

Extracorporeal membrane oxygenation (ECMO)

For infants and children with a cardiac diagnosis and an in-hospital arrest ECMO should be considered as a useful rescue strategy if sufficient expertise and resources are available. There is insufficient evidence to suggest for or against the use of ECMO in non-cardiac arrest or for children with myocarditis or cardiomyopathy who are not in arrest.[29]

Pulmonary hypertension

There is an increased risk of cardiac arrest in children with pulmonary hypertension.[360,361] Follow routine resuscitation protocols in these patients with emphasis on high FiO_2 and alkalosis/hyperventilation because this may be as effective as inhaled nitric oxide in reducing pulmonary vascular resistance.[362] Resuscitation is most likely to be successful in patients with a reversible cause who are treated with intravenous epoprostenol or inhaled nitric oxide.[363] If routine medications that reduce pulmonary artery pressure have been stopped, they should be restarted and the use of aerosolised epoprostenol or inhaled nitric oxide considered.[364–368] Right ventricular support devices may improve survival.[369–373]

Post-resuscitation care

After prolonged, complete, whole-body hypoxia-ischaemia ROSC has been described as an unnatural pathophysiological state, created by successful CPR.[374] Post-cardiac arrest care must be a multidisciplinary activity and include all the treatments needed for complete neurological recovery. The main goals are to reverse brain injury and myocardial dysfunction, and to treat the systemic ischaemia/reperfusion response and any persistent precipitating pathology.

Myocardial dysfunction

Myocardial dysfunction is common after cardiopulmonary resuscitation.[374–378] Parenteral fluids and vasoactive drugs (adrenaline, dobutamine, dopamine and noradrenaline) may improve the child's post-arrest haemodynamic status and should be titrated to maintain a systolic blood pressure of at least >5th centile for age.[29,379–390]

Although the measurement of blood pressure has limitations in determining perfusion of vital organs, it is a practical and valued measurement of haemodynamic status. Alternative perfusion endpoints (such as serum lactate levels, measures of cardiac output, mean blood pressure) can be targeted but the evidence for each of them individually is still equivocal. Ideally, they should be considered as a part of a global 'gestalt' observation. The optimal strategy to avoid hypotension i.e. the relative use of parenteral fluids versus inotropes and/or vasopressors in children post ROSC following cardiac arrest currently remains unclear. The need to use agents to maintain a normal blood pressure is a poor prognostic factor.[390]

Finally, subgroups of children might respond differently to components of the above interventions, such as cardiac patients or trauma patients who may be particularly sensitive to preload status and changes in afterload. Any interventions must be monitored and adapted according to the child's physiological responses. Reassessment of the child is key in improving their outcome.

Oxygenation and ventilation goals

Aim for a normal PaO_2 range (normoxaemia) post-ROSC once a patient is stabilised.[167,391–393] Balance the titration of oxygen delivery against the risk of inadvertent hypoxaemia.[29] Further challenges for paediatrics include identifying what the appropriate targets should be for specific patient subpopulations (e.g. infants and children with cyanotic heart disease).

There is insufficient paediatric evidence to suggest a specific $PaCO_2$ target, however, $PaCO_2$ should be measured post-ROSC and adjusted according to patient characteristics and needs.[29,167,394,395]

Adult data do not suggest any added benefit of either hypocapnia or hypercapnia; hypocapnia has even been associated with worse outcome. It is sensible to aim in general for normocapnia, although this decision might be in part influenced by context and disease. For instance, it is unclear if a strategy of permissive mild hypercapnia could be beneficial in ventilated children with respiratory failure.

Temperature control and management post ROSC

Mild hypothermia has an acceptable safety profile in adults[396,397] and neonates.[398–403] Recently the THAPCA out of hospital study showed that both hypothermia (32–34 °C) and controlled normothermia (36–37.5 °C) could be used in children.[404] The study did not show a significant difference for the primary outcome (neurologic status at one year) with either approach. The study was, however, underpowered to show a significant difference for survival, for which the lower 95% confidence interval approached 1. Furthermore, hyperthermia occurred frequently in the post-arrest period; hyperthermia is potentially harmful and should be avoided. After ROSC, a strict control of the temperature must be maintained to avoid hyperthermia (>37.5 °C) and severe hypothermia (<32 °C).[29]

Glucose control

Both hyper- and hypoglycaemia may impair outcome of critically ill adults and children and should be avoided,[405–407] but tight glucose control may also be harmful.[408] Although there is insufficient evidence to support or refute a specific glucose management strategy in children with ROSC after cardiac arrest, it is appropriate to monitor blood glucose and to avoid hypoglycaemia and hyperglycaemia.[280,281,374]

Prognosis of cardiopulmonary arrest

Although several factors are associated with outcome after cardiopulmonary arrest and resuscitation there are no simple guidelines to determine when resuscitative efforts become futile.[29,394,409–414]

The relevant considerations in the decision to continue the resuscitation include the duration of CPR, cause of arrest, pre-existing medical conditions, age, site of arrest, whether the arrest was witnessed,[36,415] the duration of untreated cardiopulmonary arrest ('no flow' time), the presence of a shockable rhythm as the first or subsequent rhythm, and associated special circumstances (e.g., icy water drowning[416,417] exposure to toxic drugs). The role of the EEG as a prognostic factor is still unclear. Problems with the literature in this area to identify individual factors are that the studies have largely not been designed in this context and therefore there may be bias as to its use in determining poor or good outcomes. Guidance on the termination of resuscitation attempts is discussed in the chapter on Ethics in Resuscitation and End-of-Life Decisions.[17]

Parental presence

In some Western societies, the majority of parents want to be present during the resuscitation of their child.[418–440] Parental presence has neither been perceived as disruptive nor stressful for the staff.[418,420,436,441] Parents witnessing their child's resuscitation believe their presence to be beneficial to the child.[418–420,427,438,442,443] Allowing parents to be at the side of their child helps them to gain a realistic view of the attempted resuscitation and the child's death. Furthermore, they may have the opportunity to say goodbye to their child. Families who are present at their child's death show better adjustment and undergo a better grieving process.[419–421,438,439,443,444]

Parental presence in the resuscitation room may help healthcare providers maintain their professional behaviour, whilst helping them to see the child as a human being and a family member.[435,440] However, in out-of-hospital resuscitation, some EMS providers may feel anxious owing to the presence of relatives or are concerned that relatives may interfere with their resuscitation efforts.[445] Evidence about parental presence during resuscitation comes from selected countries and can probably not be generalised to all of Europe, where there may be different socio-cultural and ethical considerations.[446,447]

Family presence guidelines

When parents are in the resuscitation room, a member of the resuscitation team should be allocated to them and explain the process in an empathetic manner, ensuring that they do not interfere with or distract the resuscitation process. If the presence of the relatives is impeding the progress of the resuscitation, they should be sensitively asked to leave. When appropriate, physical contact with the child should be allowed and, wherever possible, the parents should be allowed to be with their dying child at the final moment.[435,448–451] The number of relatives present should be at the discretion of the resuscitation team leader.

The leader of the resuscitation team, not the parents, will decide when to stop the resuscitation; this should be expressed with sensitivity and understanding. After the event, the team should be debriefed, to enable any concerns to be expressed and for the team to reflect on their clinical practice in a supportive environment.

Collaborators

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Conflict of interest statement

The authors declare no conflict of interest.

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