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European Resuscitation Council Guidelines for Resuscitation 2010 Section 6. Paediatric life support

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Introduction

These guidelines on paediatric life support are based on two main principles: (1) the incidence of critical illness, particularly cardiopulmonary arrest, and injury in children is much lower than in adults; (2) most paediatric emergencies are served 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 and 2005.[1–5] The latter two were based on the International Consensus on Science published by the International Liaison Committee on Resuscitation (ILCOR).[6–8] This process was repeated in 2009/2010, and the resulting Consensus on Science with Treatment Recommendations (CoSTR) was published simultaneously in Resuscitation, Circulation and Pediatrics.[9,10] The PLS Working Party of the ERC has developed the ERC PLS Guidelines based on the 2010 CoSTR and supporting scientific literature. The guidelines for resuscitation of babies at birth are now covered in Section 7.[11]

Summary of changes since the 2005 Guidelines

Guideline changes have been made in response to convincing new scientific evidence and to simplify teaching and retention. As before, there remains a paucity of good-quality evidence on paediatric resuscitation. Therefore to facilitate and support dissemination and implementation of the PLS Guidelines, changes have been made only if there is new, high-level scientific evidence or to ensure consistency with the adult guidelines. The feasibility of applying the same guidance for all adults and children remains a major topic of study. Major changes in these new guidelines include:

Recognition of cardiac arrest

Healthcare providers cannot reliably determine the presence or absence of a pulse in less than 10 s in infants or children.[12,13] Therefore pulse palpation cannot be the sole determinant of cardiac arrest and the need for chest compressions. If the victim is unresponsive, not breathing normally, and there are no signs of life, lay rescuers should begin CPR. Healthcare providers should look for signs of life and if they are confident in the technique, they may add pulse palpation for diagnosing cardiac arrest and decide whether they should begin chest compressions or not. The decision to begin CPR must be taken in less than 10 s. According to the child's age, carotid (children), brachial (infants) or femoral pulse (children and infants) checks may be used.[14,15]

Compression ventilation ratios

The compression ventilation (CV) ratio used for children should be based on whether one, or more than one rescuer is present.[16] Lay rescuers, who usually learn only single-rescuer techniques, should

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be taught to use a ratio of 30 compressions to 2 ventilations which is the same as the adult guidelines and enables anyone trained in basic life support (BLS) to resuscitate children with minimal additional information. Rescuers with a duty to respond should learn and use a 15:2 CV ratio as this has been validated in animal and manikin studies.[17–21] This latter group, who would normally be healthcare professionals, should receive enhanced training targeted specifically at the resuscitation of children. For them, simplicity would be lost if a different ratio was taught for the scenario when one or two or more rescuers were present. However, those with a duty to respond can use the 30:2 ratio if they are alone, particularly if they are not achieving an adequate number of compressions because of difficulty in the transition between ventilation and compression. Ventilation remains a very important component of CPR in asphyxial arrests.[22] Rescuers who are unable or unwilling to provide mouth-to-mouth ventilation should be encouraged to perform at least compression-only CPR.

CPR quality

The compression technique for infants includes two-finger compression for single rescuers and the two-thumb encircling technique for two or more rescuers.[23–27] For older children, a one- or two-hand technique can be used, according to rescuer preference.[28] The emphasis is on achieving an adequate depth of compression: at least 1/3 of the anterior-posterior chest diameter in all children (i.e., approximately 4 cm in infants and approximately 5 cm in children). Subsequent complete release should also be emphasised. Chest compressions must be performed with minimal interruptions to minimise no-flow time. For both infants and children, the compression rate should be at least 100 but not greater than 120 min^{-1}.

Defibrillation

Automated external defibrillators

Case reports indicate that automated external defibrillators (AEDs) are safe and successful when used in children older than 1 year of age.[29,30] Automated external defibrillators are capable of identifying arrhythmias in children accurately; in particular, they are extremely unlikely to advise a shock inappropriately.[31–33] Consequently, the use of AEDs is indicated in all children aged greater than 1 year.[34] Nevertheless, if there is any possibility that an AED may need to be used in children, the purchaser should check that the performance of the particular model has been tested against paediatric arrhythmias. Many manufacturers now supply purpose-made paediatric pads or software, which typically attenuate the output of the machine to 50–75 J[35] and these are recommended for children aged 1–8 years.[36,37] If an attenuated shock or a manually adjustable machine is not available, an unmodified adult AED may be used in children older than 1 year.[38] The evidence to support a recommendation for the use of AEDs in children aged less than 1 year is limited to case reports.[39,40] The incidence of shockable rhythms in infants is very low except when they suffer from cardiac disease.[41–43] In these rare cases, the risk/benefit ratio may be favourable and use of an AED (preferably with dose attenuator) should be considered.

Manual defibrillators

The treatment recommendation for paediatric ventricular fibrillation (VF) or paediatric pulseless ventricular tachycardia (VT) remains immediate defibrillation. In adult advanced life support (ALS), the recommendation is to give a single shock and then resume CPR immediately without checking for a pulse or reassessing the rhythm (see Section 4).[44–47] To reduce the no-flow time, chest compressions should be continued while applying and charging the paddles or self-adhesive pads (if the size of the child's chest allows this). Chest compressions should be briefly paused once the defibrillator is charged to deliver the shock. The ideal energy dose for safe and effective defibrillation in children is unknown, but animal models and small paediatric case series show that doses larger than 4 J kg^{-1} defibrillate effectively with negligible side effects.[29,37,48,49] Clinical studies in children indicate that doses of 2 J kg^{-1} are insufficient in most cases.[13,42,50] Biphasic shocks are at least as effective and produce less post-shock myocardial dysfunction than monophasic shocks.[36,37,49,51–53]

Therefore, for simplicity and consistency with adult BLS and ALS guidance, a single-shock strategy using a non-escalating dose of 4 J kg^{-1} (preferably biphasic but monophasic is acceptable) is recommended for defibrillation in children. Use the largest size paddles or pads that fit on the infant or child's chest in the antero-lateral or antero-posterior position without the pads/paddles touching each other.[13]

Airway

Cuffed tracheal tubes

Cuffed tracheal tubes can be used safely in infants and young children. The size should be selected by applying a validated formula.

Cricoid pressure

The safety and value of using cricoid pressure during tracheal intubation is not clear. Therefore, the application of cricoid pressure should be modified or discontinued if it impedes ventilation or the speed or ease of intubation.

Capnometry

Monitoring exhaled carbon dioxide (CO_2), ideally by capnography, is helpful to confirm correct tracheal tube position and recommended during CPR to help assess and optimize its quality.

Titration of oxygen

Based on increasing evidence of potential harm from hyperoxaemia after cardiac arrest, once spontaneous circulation is restored, inspired oxygen should be titrated to limit the risk of hyperoxaemia.

Rapid response systems

Implementation of a rapid response system in a paediatric inpatient setting may reduce rates of cardiac and respiratory arrest and in-hospital mortality.

New topics

New topics in the 2010 guidelines include channelopathies (i.e., the importance of autopsy and subsequent family testing) and several new special circumstances: trauma, single ventricle pre- and post-1st stage repair, post-Fontan circulation, and pulmonary hypertension.

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 a child within 4 weeks of age. An *infant* is a child under 1 year of age, 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.[54]

A. Paediatric basic life support

Sequence of actions

Rescuers who have been taught adult BLS and have no specific knowledge of paediatric resuscitation may use the adult sequence, as outcome is worse if they do nothing. 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 approximately 1 min of CPR before they go for help (see adult BLS guideline).

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

1. Ensure the safety of rescuer and child.
2. Check the child's responsiveness:
   - Gently stimulate the child and ask loudly: are you all right?

3A. If the child responds by answering or moving:
   - Leave the child in the position in which you find him (provided he is not in further danger).
   - Check his condition and get help if needed.
   - Re-assess him regularly.

3B. If the child does not respond:
   - Shout for help.
   - Turn carefully the child 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.
     - 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:
   - **Look** for chest movements.
   - **Listen** at the child's nose and mouth for breath sounds.
   - **Feel** for air movement on your cheek.

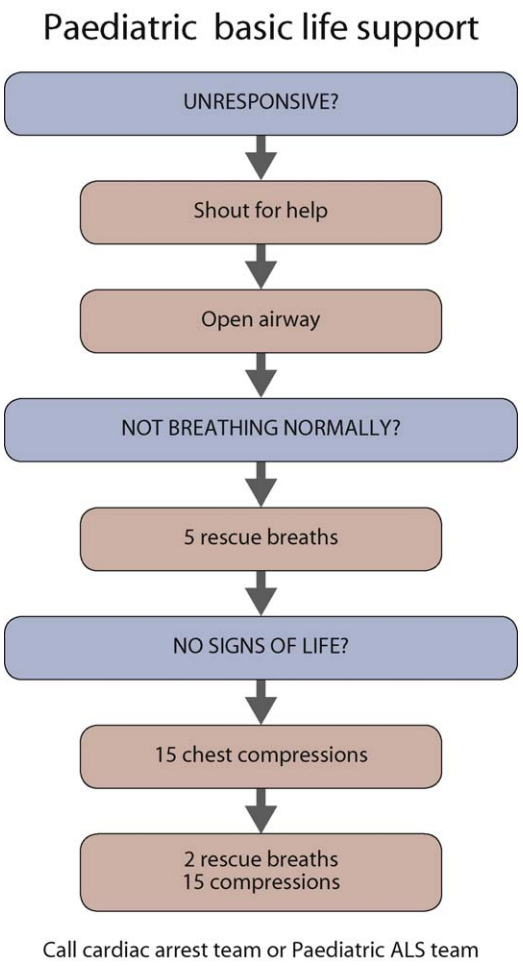

Fig. 6.1. Paediatric basic life support algorithm for those with a duty to respond to paediatric emergencies.

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).
   - Send or go for help – call the local emergency number for an ambulance.
   - 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 a child over 1 year of age (Fig. 6.2):

- 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 month to open, but maintain chin lift.
- Take a breath and place your lips around the mouth, making sure that you have a good seal.

Fig. 6.2. Mouth-to-mouth ventilation – child.

- Blow steadily into the mouth over about 1–1.5 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.

Rescue breaths for an infant (Fig. 6.3):

- Ensure a neutral position of the head (as an infant's head is usually flexed when supine, this may require some extension) 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 over 1–1.5 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.

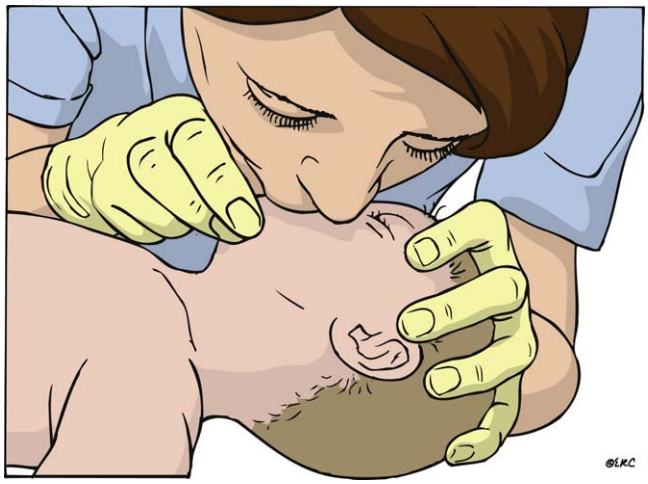

Fig. 6.3. Mouth-to-mouth and nose ventilation – infant.

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.
- 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 (not abnormal gasps or infrequent, irregular breaths).
     If you check the pulse, ensure you take no more than 10 s.
     In a child over 1 year – feel for the carotid pulse in the neck.
     In an infant – feel for the brachial pulse on the inner aspect of the upper arm.
     The femoral pulse in the groin, which is half way between the anterior superior iliac spine and the symphysis pubis, can also be used in infant and children.

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 to his side (into the recovery position) if he remains unconscious.
   - Re-assess the child frequently.

7B. If there are no signs of life, unless you are CERTAIN you can feel a definite pulse of greater than 60 beats min^{-1} within 10 s:
   - Start chest compressions.
   - Combine rescue breathing and chest compressions:

Chest compressions:

For all children, compress the lower half of the sternum: To avoid compressing the upper abdomen, locate the xiphisternum by finding the angle where the lowest ribs join in the middle. Compress the sternum one finger's breadth above this; the compression should be sufficient to depress the sternum by at least one third of the depth of the chest. Don't be afraid to push too hard: "Push Hard and Fast". Release the pressure completely and repeat at a rate of at least 100 min^{-1} (but not exceeding 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. The best method for compression varies slightly between infants and children.

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 the rest of both hands with the fingers together to encircle the lower part of the infant's rib cage with the tips of the fingers supporting the infant's back. For both methods, depress the lower sternum by at least one third of the depth of the infant's chest.

Chest compression in children over 1 year of age (Figs. 6.5 and 6.6): Place the heel of one hand over the lower half of the sternum (as above). Lift the fingers to ensure that pressure is not applied over the child's ribs. Position yourself vertically above the victim's chest and, with your arm straight, compress the sternum to depress it by at least one third of the depth of the chest. In larger children or for small rescuers, this is achieved most easily by using both hands with the fingers interlocked.

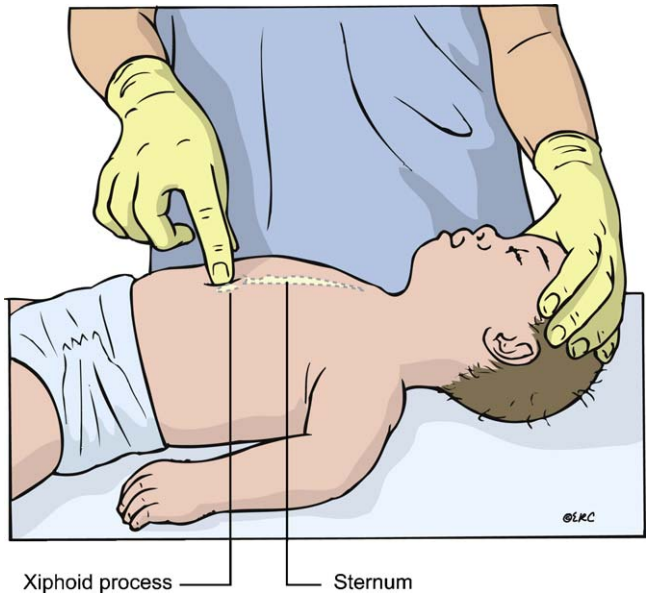

Fig. 6.4. Chest compression – infant.

8. Do not interrupt resuscitation until:
   - The child shows signs of life (starts to wake up, to move, opens eyes and to breathe normally or a definite pulse of greater than 60 min^{-1} is palpated).
   - Further qualified help arrives and takes over.
   - You become exhausted.

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.
- If only one rescuer is present, undertake resuscitation for about 1 min before going for assistance. To minimise interruption in CPR, it may be possible to carry an infant or small child whilst summoning help.

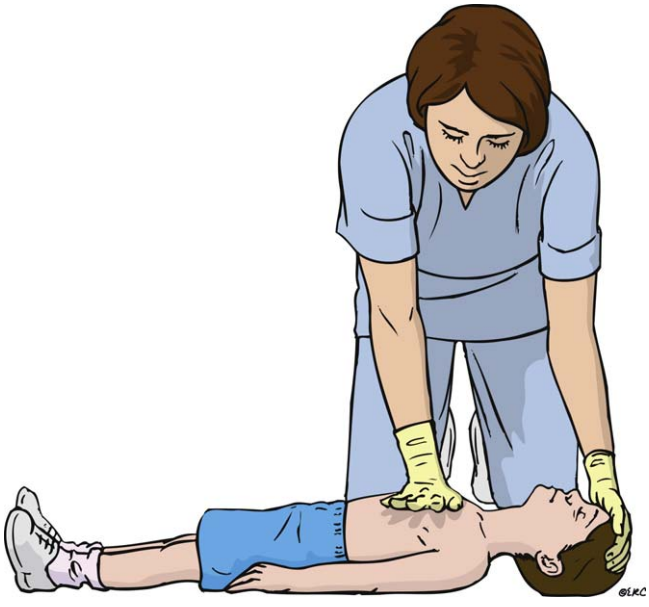

Fig. 6.5. Chest compression with one hand – child.

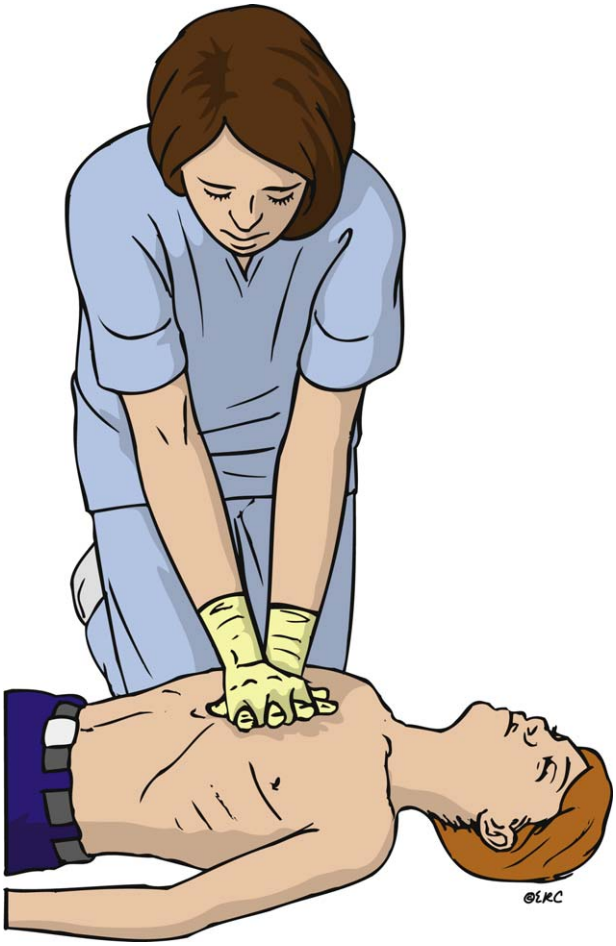

Fig. 6.6. Chest compression with two hands – child.

- The only exception to performing 1 min of CPR before going for help is in the case of a child with a witnessed, sudden collapse when the rescuer is alone. In this case, cardiac arrest is likely to be caused by an arrhythmia and the child will need defibrillation. Seek help immediately if there is no one to go for you.

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.

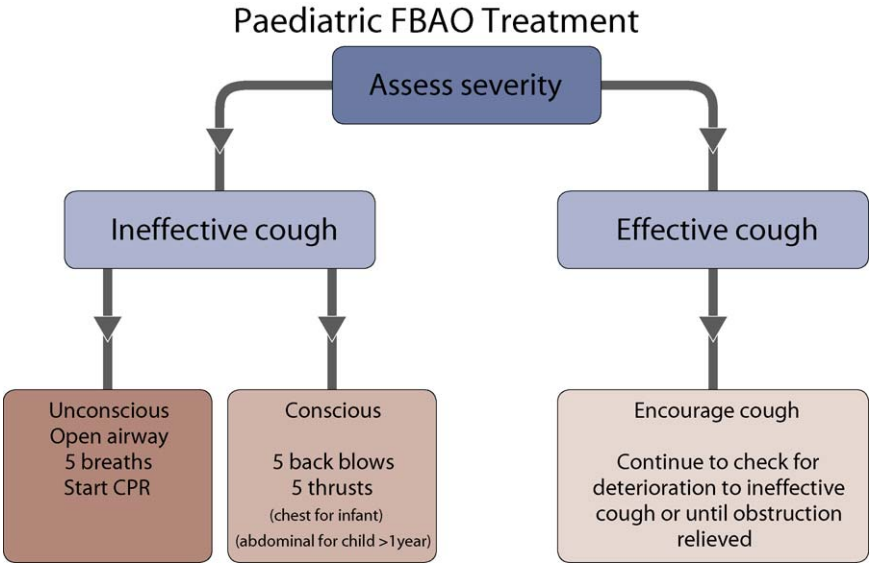

Fig. 6.7. Paediatric foreign body airway obstruction algorithm.

- 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

No new evidence on this subject was presented during the 2010 Consensus Conference. Back blows, chest thrusts and abdominal thrusts all increase intrathoracic pressure and can expel foreign bodies from the airway. In half of the episodes more than one technique is needed to relieve the obstruction.[55] 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.

The foreign body airway obstruction (FBAO) algorithm for children was simplified and aligned with the adult version in 2005 guidelines; this continues to be the recommended sequence for managing FBAO (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 because of the horizontal position of the ribs, which leaves the upper abdominal viscera much more exposed to trauma. 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 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)

1. Safety and summoning assistance

Safety is paramount: rescuers must not place themselves in danger and should consider the safest treatment of the choking child.

If the child is coughing effectively, no external manoeuvre is necessary. Encourage the child to cough, and monitor continually.

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

2. 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.

Table 6.1
Sign 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	

Back blows in 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 exacerbate 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 too relieve the obstruction with each blow rather than to give all five.

Back blows in 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.
- 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 the 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 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, re-assess 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.[5]

3. 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 can impact the object more deeply 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 before summoning the EMS (if this has not already been done by someone else).
- When the airway is opened for attempted delivery of rescue breaths, look to see if the foreign body can be seen in the mouth.
- If an object is seen, 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 conscious level whilst awaiting the arrival of the EMS.

B. Paediatric advanced life support

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.[56–61] So-called asphyxial arrests or respiratory arrests are also more common in young adulthood (e.g., trauma, drowning, poisoning).[62,63] The outcome from cardiopulmonary arrests in children is poor; identification of the antecedent stages of cardiac or respiratory failure is a priority, as effective early intervention may be life saving.

The order of assessment and intervention for any seriously ill or injured child follows the ABC principles.

- A indicates airway (Ac for airway and cervical spine stabilisation for the injured child).
- B indicates breathing.
- C indicates circulation (with haemorrhage control in injured child).

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. 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.[64–69] This team should include at least one paediatrician with specific knowledge in the field and one specialised nurse, and should be called to evaluate a potentially critically ill child who is

not already in a paediatric intensive care unit (PICU) or paediatric emergency department (ED).

Diagnosing respiratory failure: assessment of A and B

Assessment of a potentially critically ill child starts with assessment of airway (A) and breathing (B). Abnormalities in airway patency or gas exchange in the lungs can lead to respiratory failure.

Signs of respiratory failure include:

- *Respiratory rate* outside the normal range for the child's age – either too fast or too slow.
- Initially increasing *work of breathing*, which may progress to inadequate/decreased work of breathing as the patient tires or compensatory mechanisms fail, additional noises such as stridor, wheeze, 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 best evaluated by pulse oximetry.

There may be associated signs in other organ systems that are either affected by inadequate ventilation and oxygenation or act to compensate the respiratory problem. These are detectable in step C of the assessment and include:

- Increasing tachycardia (compensatory mechanism in an attempt to increase oxygen delivery).
- Pallor.
- Bradycardia (ominous indicator of the loss of compensatory mechanisms).
- Alteration in the level of consciousness (a sign that compensatory mechanisms are overwhelmed).

Diagnosing circulatory failure: assessment of C

Circulatory failure (or shock) is characterised by a mismatch between metabolic demand by the tissues and delivery of oxygen and nutrients by the circulation.[70] Physiological compensatory mechanisms lead to changes in the heart rate, in the systemic vascular resistance (which commonly increases as an adaptive response) and in tissue and organ perfusion. Signs of circulatory failure include:

- Increased *heart rate* (bradycardia is an ominous sign of physiological decompensation).
- Decreased systemic *blood pressure*.
- Decreased *peripheral perfusion* (prolonged capillary refill time, decreased skin temperature, pale or mottled skin).
- Weak or absent peripheral pulses.
- Decreased or increased *intravascular volume*.
- Decreased urine output and metabolic acidosis.

Other systems may be affected, for example:

- Respiratory frequency may be increased initially, in an attempt to improve oxygen delivery, later becoming slow and accompanied by decompensated circulatory failure.
- Level of consciousness may decrease because of poor cerebral perfusion.

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.[71,72] If cardiac arrest is suspected, and in the absence of signs of life, rescuers (lay and professional) should begin CPR unless they are certain 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.[72–75] If personnel skilled in echocardiography are available, this investigation may help to detect cardiac activity and potentially treatable causes for the arrest.[76] However, echocardiography must not interfere with 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 early and effective intervention in children with respiratory and circulatory failure to prevent progression to full arrest.

Airway and breathing

- Open the airway and ensure adequate ventilation and oxygenation. Deliver high-flow oxygen.
- Establish respiratory monitoring (first line – pulse oximetry/SpO_2).
- Achieving adequate ventilation and oxygenation may require use of airway adjuncts, bag-mask ventilation (BMV), use of a laryngeal mask airway (LMA), securing a definitive airway by tracheal intubation and positive pressure ventilation.
- 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 by peripheral intravenous (IV) or by intraosseous (IO) cannulation. 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) as required.
- Isotonic crystalloids are recommended as initial resuscitation fluid in infants and children with any type of shock, including septic shock.[77–80]
- Assess and re-assess the child continuously, commencing each time with the airway before proceeding to breathing and then the circulation.
- 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.

Airway

Open the airway using basic life support techniques. Oropharyngeal and nasopharyngeal airways adjuncts can help maintain the airway. Use the oropharyngeal airway only in the unconscious child, in whom there is no gag reflex. Use the appropriate size (from the incisors to the angle of the mandible), to avoid pushing the tongue backward and obstructing the epiglottis, or directly compressing the glottis. The soft palate in the child can be damaged by insertion of the oropharyngeal airway – avoid this by inserting the oropharyngeal airway with care; do not use any force. 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 but must be re-assessed after insertion. These simple airway adjuncts do not protect the airway from aspiration of secretions, blood or stomach contents.

Laryngeal mask airway (LMA)

Although bag-mask ventilation remains the recommended first line method for achieving airway control and ventilation in children, the LMA is an acceptable airway device for providers trained in its use.[81,82] It is particularly helpful in airway obstruction caused by supraglottic airway abnormalities or if bag-mask ventilation is not possible. The LMA does not totally protect the airway from aspiration of secretions, blood or stomach contents, and therefore close observation is required. Use of the LMA is associated with a higher incidence of complications in small children compared with adults.[83,84] Other supraglottic airway devices (e.g., laryngeal tube), which have been used successfully in children's anaesthesia, may also be useful in an emergency but there are few data on the use of these devices in paediatric emergencies.[85]

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 is preferable during resuscitation. Oral intubation is quicker and simpler, and is associated with fewer complications than nasal placement. In the conscious child, the judicious use of anaesthetics, sedatives and neuromuscular blocking drugs is essential in order to avoid multiple intubation attempts or intubation failure.[86–95] The anatomy of a child's airway differs significantly from that of an adult; hence, intubation of a child requires special training and experience. Clinical examination and capnography must be used to confirm correct tracheal tube placement. The tracheal tube must be secured and vital signs monitored.[96] It is also essential 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 prehospital tracheal intubation of children. Prehospital tracheal intubation of children may be considered if:

(1) the airway and/or breathing is seriously compromised or threatened;
(2) the mode and duration of transport require the airway to be secured early (e.g., air transport); and
(3) if the operator is adequately skilled in advanced paediatric airway management including the use of drugs to facilitate tracheal intubation.[97]

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

	Uncuffed	Cuffed
Neonates*premature*	Gestational age in weeks/10	Not used
Neonates *Full term*	3.5	Not usually used
Infants	3.5–4.0	3.0–3.5
Child 1–2 years	4.0–4.5	3.5–4.0
Child >2 years	Age/4 + 4	Age/4 + 3.5

Rapid-sequence induction and intubation

The child who is in cardiopulmonary arrest and/or deep coma does not require sedation or analgesia to be intubated; otherwise, intubation must be preceded by oxygenation (gentle BMV is sometimes required to avoid hypoxia), rapid sedation, analgesia and the use of neuromuscular blocking drugs to minimise intubation complications and failure.[98] The intubator must be experienced and familiar with drugs used for rapid-sequence induction. The use of cricoid pressure may prevent or limit regurgitation of gastric contents[99,100] but it may distort the airway and make laryngoscopy and intubation more difficult.[101] Cricoid pressure should not be used if either intubation or oxygenation is compromised.

Tracheal tube sizes

A general recommendation for tracheal tube internal diameters (ID) for different ages is shown in Table 6.2.[102–107] 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 measured by resuscitation tapes.[108]

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., when lung compliance is poor, airway resistance is high or if there is a large air leak from the glottis.[102,109,110] The use of cuffed tubes also makes it more likely that the correct tube size will be chosen on the first attempt.[102,103,111] 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.[109,110,112] 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.[112]

Confirmation of correct tracheal tube placement

Displaced, misplaced or obstructed tubes occur frequently in the intubated child and are associated with increased risk of death.[113,114] No single technique is 100% reliable for distinguishing oesophageal from tracheal intubation.[115–117]

Assessment of the correct tracheal tube position is made by:

- laryngoscopic observation of the tube passing beyond the vocal cords;
- detection of end-tidal CO_2 (by colorimetry or capnometry/-graphy) 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, confirm tracheal tube position by direct laryngoscopy. After correct placement and confirmation, secure the tracheal tube and re-assess 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.[118] 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:

Displacement of the tracheal tube.
Obstruction of the tracheal tube or of the heat and moisture exchanger (HME).
Pneumothorax.
Equipment failure (source of gas, bag-mask, ventilator, etc.).
Stomach (gastric distension may alter diaphragm mechanics).

Breathing

Oxygenation

Give oxygen at the highest concentration (i.e., 100%) during initial resuscitation. Once circulation is restored, give sufficient oxygen to maintain an arterial oxygen saturation (SaO_2) in the range of 94–98%.[119,120]

Studies in neonates suggest some advantages of using room air during resuscitation (see Section 7).[11,121–124] In the older child, there is no evidence of benefit for air instead of oxygen, so use 100% oxygen for initial resuscitation and after return of a spontaneous circulation (ROSC) titrate the fraction inspired oxygen (FiO_2) to achieve a SaO_2 in the range of 94–98%. In smoke inhalation (carbon monoxide poisoning) and severe anaemia however a high FiO_2 should be maintained until the problem has been solved because in these circumstances dissolved oxygen plays an important role in oxygen transport.

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 poorer survival rates in animals and adults.[125–131] Although normoventilation is the objective during resuscitation, it is difficult to know the precise minute volume that is being delivered. A simple guide to deliver an acceptable tidal volume is to achieve modest chest wall rise. Use a ratio of 15 chest compressions to 2 ventilations and a compression rate of 100–120 min^{-1}.[125] Once ROSC has been achieved, provide normal ventilation (rate/volume) based on the victim's age and, as soon as possible, by monitoring end-tidal CO_2 and blood gas values.

Once the airway is protected by tracheal intubation, continue positive pressure ventilation at 10–12 breaths min^{-1} without interrupting chest compressions. Take care to ensure that lung inflation is adequate during chest compressions. When circulation is restored, or if the child still has a perfusing rhythm, ventilate at 12–20 breaths min^{-1} to achieve a normal arterial carbon dioxide tension ($PaCO_2$). Hyperventilation and hypoventilation are harmful.

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 prehospital setting or in an emergency department.[114,132–135] Assess the effectiveness of BMV by observing adequate chest rise, monitoring heart rate and auscultating for breath sounds, and measuring peripheral oxygen saturation (SpO_2). Any healthcare provider with a responsibility for treating children must be able to deliver BMV effectively.

Prolonged ventilation

If prolonged ventilation is required, the benefits of a secured airway probably outweigh the potential risks associated with tracheal intubation. For emergency intubation, both cuffed and uncuffed tracheal tubes are acceptable.

Monitoring of breathing and ventilation

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 the child.[136–139] 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.[140–143]

Capnography may also provide information on the efficiency of chest compressions and can give an early indication of ROSC.[144,145] Efforts should be made to improve chest compression quality if the $ETCO_2$ remains below 15 mmHg (2 kPa). 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,[146–150] or after the use of sodium bicarbonate when there may be a transient increase.[151] Current evidence does not support the use of a threshold $ETCO_2$ value as an indicator for the discontinuation of resuscitation efforts.

Oesophageal detector devices

The self-inflating bulb or aspirating syringe (oesophageal detector device, ODD) may be used for the secondary confirmation of tracheal tube placement in children with a perfusing rhythm.[152,153] There are no studies on the use of the ODD in children who are in cardiopulmonary arrest.

Pulse oximetry

Clinical evaluation of the oxygen saturation of arterial blood (SaO_2) is unreliable; therefore, monitor the child's peripheral oxygen saturation continuously by pulse oximetry (SpO_2). Pulse oximetry can be unreliable under certain conditions, for example, if the child is in circulatory failure, in cardiopulmonary arrest or has poor peripheral perfusion. Although pulse oximetry is relatively simple, it is a poor guide to tracheal tube displacement. Capnography detects tracheal tube dislodgement more rapidly than pulse oximetry.[154]

Circulation

Vascular access

Vascular access is essential to enable drugs and fluids to be given, and blood samples obtained. Venous access can be dif-

ficult 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.[155–157] In any case, in critically ill children, if attempts at establishing intravenous (IV) access are unsuccessful after 1 min, insert an intraosseous (IO) needle instead.[155,158]

Intraosseous access

Intraosseous access is a rapid, safe, and effective route to give drugs, fluids and blood products.[159–168] The onset of action and time to achieve adequate plasma drug concentrations are similar to that achieved via the central venous route.[169,170] Bone marrow samples can be used to cross match for blood type or group[171] for chemical analysis[172,173] and for blood gas measurement (the values are comparable to central venous blood gases if no drug has been injected in the cavity).[172,174–176] However samples can damage autoanalysers and should be used preferably in cartridge analyser. Flush each 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. Intraosseous access can be maintained until definitive IV access has been established. The benefits of semi-automated IO devices remain to be seen but preliminary experiences show them to be rapid and effective for obtaining circulatory access.[167,168,177,178]

Intravenous access

Peripheral IV access provides plasma concentrations of drugs and clinical responses equivalent to central or IO access.[156,157,179–181] Central venous lines provide more secure long-term access but, compared with IO or peripheral IV access, offer no advantages during resuscitation.[156,179–181]

Tracheal tube access

Intraosseous or IV access should be definitely preferred to the tracheal route for giving drugs.[182] Drugs given via the trachea have highly variable absorption but, for guidance, the following dosages have been recommended:

Adrenaline	100 $\mu g\,kg^{-1}$
Lidocaine	2–3 $mg\,kg^{-1}$
Atropine	30 $\mu g\,kg^{-1}$

The optimal dose of naloxone is not known.

Dilute the drug in 5 ml of normal saline and follow administration with five ventilations.[183–185] Do not give non-lipid soluble medications (e.g., glucose, bicarbonate, calcium) via the tracheal tube because they will damage the airway mucosa.

Fluids and drugs

Volume expansion is indicated when a child shows signs of circulatory failure in the absence of volume overload.[186] Isotonic crystalloids are recommended as the initial resuscitation fluid for infants and children with any type of circulatory failure.

If 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 every bolus, re-assess the child's clinical state, using ABC, to decide whether a further bolus or other treatment is required.

There are insufficient data to make recommendations about the use of hypertonic saline for circulatory failure associated with head injuries or hypovolaemia.[187,188]

There are also insufficient data to recommend delayed fluid resuscitation in the hypotensive child with blunt trauma.[189] Avoid dextrose containing solutions unless there is hypoglycaemia.[190–193] Monitor glucose levels and avoid hypoglycaemia; infants and small children are particularly prone to hypoglycaemia.

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).[194] It is safe because 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. Give adenosine rapidly, followed by a flush of 3–5 ml of normal saline.[195] 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 is placed prominently 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 VF, so increasing the likelihood of successful defibrillation.

The recommended IV/IO dose of adrenaline in children for the first and for subsequent doses is 10 $\mu g\,kg^{-1}$. The maximum single dose is 1 mg. If needed, give further doses of adrenaline every 3–5 min. Intratracheal adrenaline is no longer recommended,[196–199] but if this route is ever used, the dose is ten times this (100 $\mu g\,kg^{-1}$).

The use of higher doses of adrenaline via the IV or IO route is not recommended routinely as it does not improve survival or neurological outcome after cardiopulmonary arrest.[200–203]

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, compromising extremity, mesenteric, and renal blood flow. High-dose adrenaline can cause severe hypertension and tachyarrhythmias.[204]

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.[205]

Amiodarone

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. Except when given for the treatment of refractory VF/pulseless VT, amiodarone must be injected slowly (over 10–20 min) with systemic blood pressure and ECG monitoring to avoid causing hypotension. This side effect is less common with the aqueous solution.[206] Other rare but significant adverse effects are bradycardia and polymorphic VT.[207]

Atropine

Atropine accelerates sinus and atrial pacemakers by blocking the parasympathetic response. It may also increase AV conduction. Small doses (< 100 μg) may cause paradoxical bradycardia.[208] In

bradycardia with poor perfusion that is unresponsive to ventilation and oxygenation, the first line drug is adrenaline, not atropine.

Atropine is recommended for bradycardia caused by increased vagal tone or cholinergic drug toxicity.[209–212]

Calcium

Calcium is essential for myocardial function[213,214] but routine use of calcium does not improve the outcome from cardiopulmonary arrest.[215–217]

Calcium is indicated in the presence of hypocalcaemia, calcium channel blocker overdose, hypermagnesaemia and hyperkalaemia.[218–220]

Glucose

Data from neonates, children and adults indicate that both hyper- and hypo-glycaemia are associated with poor outcome after cardiopulmonary arrest,[221–223] but it is uncertain if this is causative or merely an association.[224] 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. Avoid hyper- and hypo-glycaemia following ROSC. Strict glucose control has not shown survival benefits in adults when compared with moderate glucose control[225,226] and it increases the risk of hypoglycaemia in neonates, children and adults.[227–231]

Magnesium

There is no evidence for giving magnesium routinely during cardiopulmonary arrest.[232] Magnesium treatment is indicated in the child with documented hypomagnesaemia or with torsades de pointes VT regardless of the cause.[233]

Sodium bicarbonate

Do not give sodium bicarbonate routinely during cardiopulmonary arrest or after ROSC.[220,234,235] 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, produce hypokalaemia, hypernatraemia, hyperosmolality, and inactivate catecholamines.

Lidocaine

Lidocaine is less effective than amiodarone for defibrillation-resistant VF/pulseless VT in adults[236] and therefore is not the first line treatment in defibrillation-resistant VF/pulseless VT in children.

Procainamide

Procainamide slows intra-atrial conduction and prolongs the QRS and QT intervals. It can be used in SVT[237–239] or VT[240] resistant to other medications in the haemodynamically stable child. However, paediatric data are sparse and procainamide should be used cautiously.[241,242] Procainamide is a potent vasodilator and can cause hypotension: infuse it slowly with careful monitoring.[243–245]

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).[246] 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.[247–258]

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.[255–257,259,260] Two paediatric series suggested that terlipressin could be effective in refractory cardiac arrest.[258,261]

These drugs could be used in cardiac arrest refractory to several adrenaline doses.

Defibrillators

Defibrillators are either automatically 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 preset 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.[13,262,263]

Recommended sizes are:

- 4.5 cm diameter for infants and children weighing <10 kg.
- 8–12 cm diameter for children >10 kg (older than 1 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. Do not use ultrasound gel, saline-soaked gauze, 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.[264,265] In practice, this means that the paddles should be applied firmly.

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

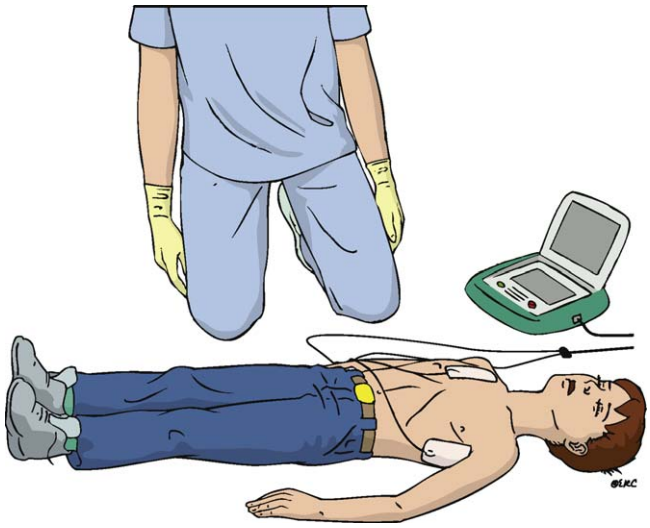

Fig. 6.8. Paddle positions for defibrillation – child.

shocks.[36,49,51–53,266] Animal models show better results with paediatric doses of 3–4 J kg^{-1} than with lower doses,[49] or adult doses.[38] Clinical studies in children indicate that doses of 2 J kg^{-1} are insufficient in most cases.[12,38,42] Doses larger than 4 J kg^{-1} (as much as 9 J kg^{-1}) have defibrillated children effectively with negligible side effects.[29,48] 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.[31,32,267] The AED should be equipped with a dose attenuator which decreases the delivered energy to a lower dose more suitable for children aged 1–8 years (50–75 J).[34,37] If such an AED in not available, use a standard AED and the preset adult energy levels. For children above 8 years, use a standard AED with standard paddles. Although the evidence to support a recommendation for the use of AEDs (preferably with dose attenuator) in children less than 1 year is limited to case reports,[39,40] it is acceptable if no other option is available.

Advanced management of cardiopulmonary arrest (Fig. 6.9)

ABC

Commence and continue with basic life support
Oxygenate and ventilate with BMV

- Provide positive pressure ventilation with a high inspired oxygen concentration
- Give five rescue breaths followed by external chest compression and positive pressure ventilation in the ratio of 15:2
- Avoid rescuer fatigue by frequently changing the rescuer performing chest compressions
- Establish cardiac monitoring

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 μg kg^{-1}) and repeat every 3–5 min.
- Identify and treat any reversible causes (4 Hs and 4 Ts) (Fig. 6.10).

Shockable – VF/pulseless VT

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

- Charge the defibrillator while another rescuer continues chest compressions.
- Once the defibrillator is charged, pause the chest compressions, ensure that all rescuers are clear of the patient. Minimise the delay between stopping chest compressions and delivery of the shock – even 5–10 s delay will reduce the chances of the shock being successful.[268,269]
- Give one shock.
- Resume CPR as soon as possible without re-assessing the rhythm.
- After 2 min, check briefly the cardiac rhythm on the monitor.
- Give second shock (4 J kg^{-1}) if still in VF/pulseless VT.
- Give CPR for 2 min as soon as possible without re-assessing the rhythm.
- Pause briefly to assess the rhythm; if still in VF/pulseless VT give a third shock at 4 J kg^{-1}.
- Give adrenaline 10 μg 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[270] if still in VF/pulseless VT after the fifth shock.

If the child remains in VF/pulseless VT, 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 (4 Hs and 4 Ts) remembering that the first 2 Hs (hypoxia and hypovolaemia) have the highest prevalence in critically ill or injured children (Fig. 6.11).

If defibrillation was successful but VF/pulseless VT recurs, resume CPR, give amiodarone and defibrillate again at 4 J Kg^{-1}. Start a continuous infusion of amiodarone.

Reversible causes of cardiac arrest

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

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

Sequence of events in cardiopulmonary arrest

1. When a child becomes unresponsive, without signs of life (no breathing, cough or any detectable movement), start CPR immediately.
2. Provide BMV with 100% oxygen.
3. Commence monitoring. Send for a manual defibrillator or an AED to identify and treat shockable rhythms as quickly as possible.

In the less common circumstance of a witnessed sudden collapse, early activation of the emergency services and getting an AED may be more appropriate; start CPR as soon as possible.

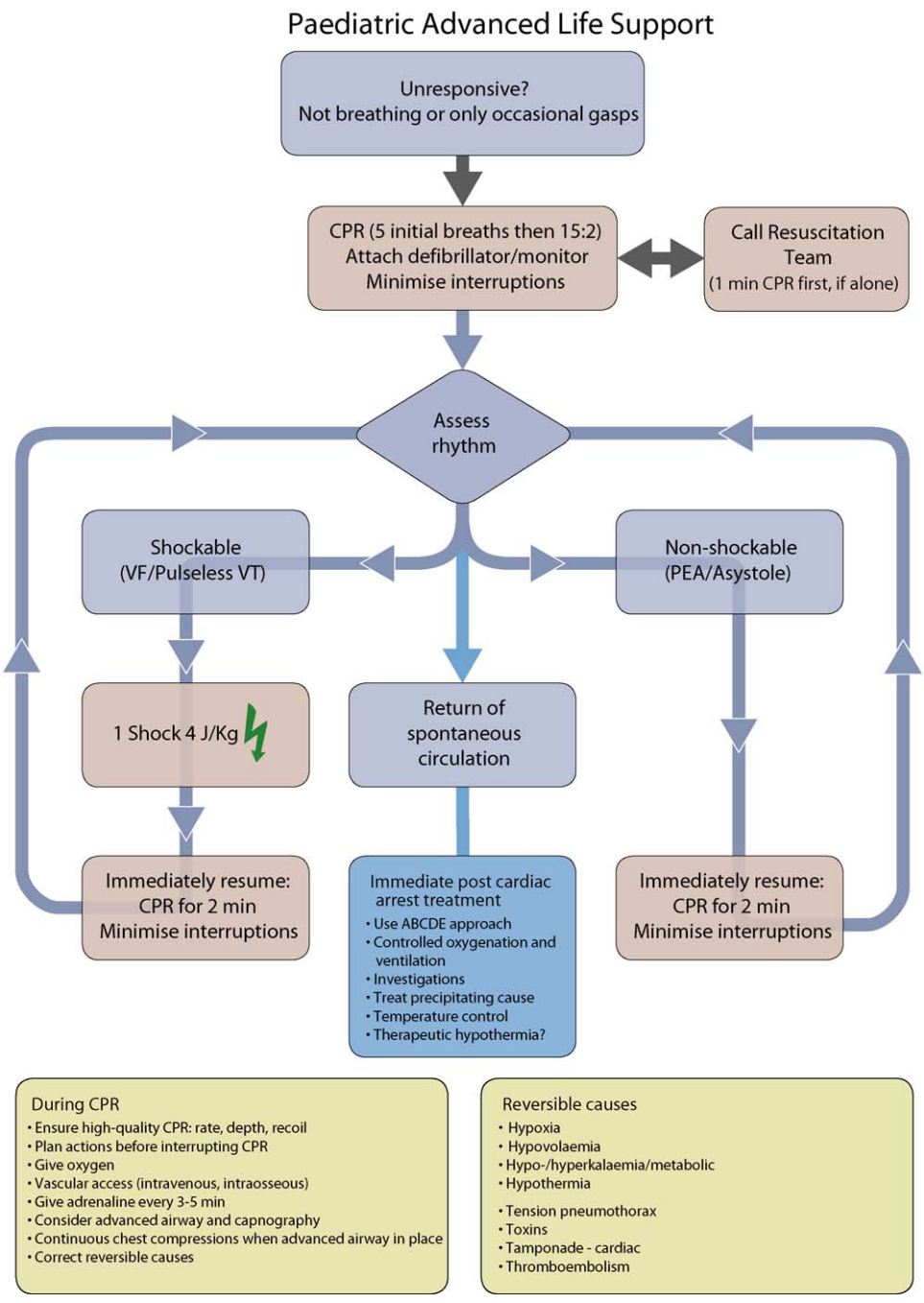

Fig. 6.9. Paediatric advanced life support algorithm.

Cardiac monitoring

Position the cardiac monitor leads or defibrillation paddles as soon as possible to enable differentiation between a shockable and a non-shockable cardiac rhythm. Invasive monitoring of systemic blood pressure may help to improve effectiveness of chest compression[271] but must not delay the provision of basic or advanced resuscitation.

Shockable rhythms are pulseless VT and VF. These rhythms are more likely after sudden collapse in children with heart disease or adolescents.[41–43] 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.

Echocardiography may be used to identify potentially treatable causes of cardiac arrest in children. Cardiac activity can be rapidly visualised[76] and pericardial tamponade diagnosed.[272] However, appropriately skilled operators must be available and its use should be balanced against the interruption to chest compressions during examination.

Non-shockable rhythms

Most cardiopulmonary arrests in children and adolescents are of respiratory origin.[54,58,273–275] 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.[17,276]

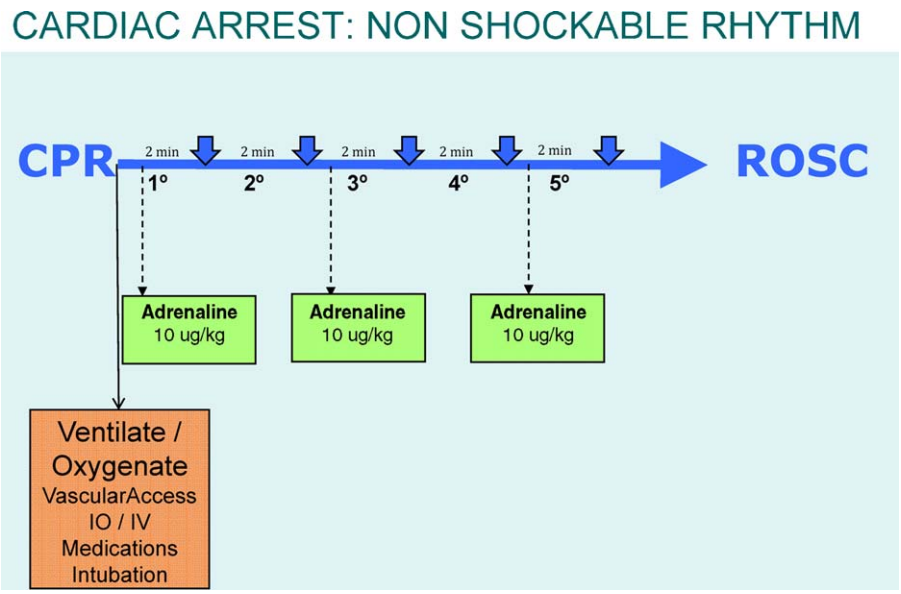

Fig. 6.10. Paediatric algorithm for non-shockable rhythm.

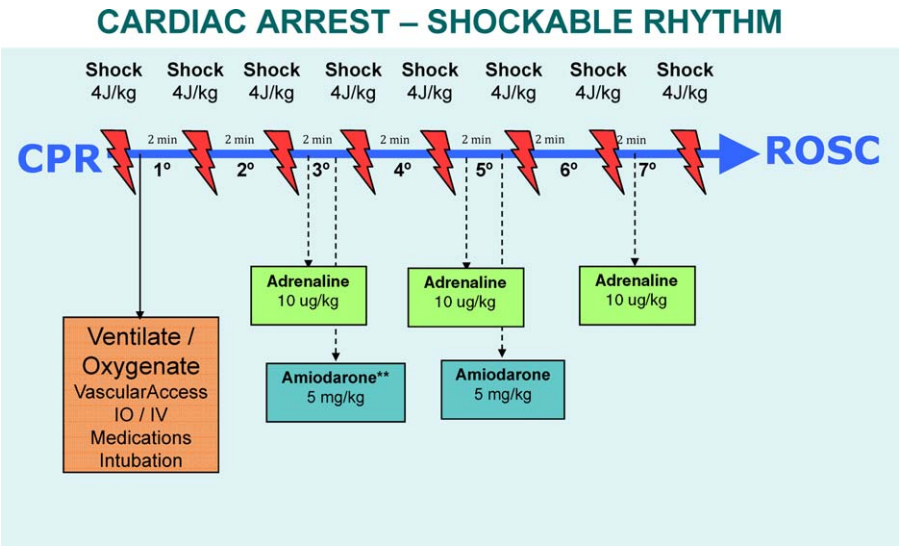

Fig. 6.11. Paediatric algorithm for shockable rhythm.

Bystander CPR is associated with a better neurological outcome in adults and children.[277–279] The most common ECG patterns in infants, children and adolescents with cardiopulmonary arrest are asystole and PEA. PEA is characterised by organised, wide or narrow complex electrical activity, usually (but not always) at a slow rate, 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 4 Hs and 4 Ts) that led to a sudden impairment of cardiac output.

Shockable rhythms

Primary VF occurs in 3.8–19% of cardiopulmonary arrests in children.[13,41–43,60,274,275,277] The incidence of VF/pulseless VT increases with age.[267,280] The primary determinant of survival from VT/pulseless VT 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%. Survival after more than 12 min of VF in adult victims is <5%.[281] Cardiopulmonary resuscitation provided before defibrillation for response intervals longer than 5 min improved outcome in some studies,[282,283] but not in others.[284]

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.[43]

Drugs in shockable rhythms

Adrenaline (epinephrine)

Adrenaline is given every 3–5 min by the IV or IO route in preference to the tracheal tube route.

Amiodarone in VF/pulseless VT

Amiodarone is indicated in defibrillation-resistant VF/pulseless VT. Experimental and clinical experience with amiodarone in children is scarce; evidence from adult studies[236,285,286] demonstrates increased survival to hospital admission, but not to hospital dis-

charge. One paediatric case series demonstrates the effectiveness of amiodarone for life-threatening ventricular arrhythmias.[287] Therefore, IV amiodarone has a role in the treatment of defibrillation refractory or recurrent VF/pulseless VT in children.

Extracorporeal life support

Extracorporeal life support should be considered for children with cardiac arrest refractory to conventional CPR, if the arrest occurs in a highly supervised environment and available expertise and equipment 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 poorly perfused child has a heart rate <60 beats min^{-1}, and they do not respond rapidly to ventilation with oxygen, start chest compressions and give adrenaline. If the bradycardia is caused by vagal stimulation (such as after passing a nasogastric tube), atropine may be effective.

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.[288]

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.[289] If the child is unstable with a depressed conscious level, attempt synchronised electrical cardioversion immediately.

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 is too haemodynamically unstable, 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 0.5–1 J kg^{-1} and the second dose is 2 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.[270,287,290–297] 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.[298,299] 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.[300] 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 a pulse. 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,[291] although cardiovascular side effects are common.[270,287,292,297,301]

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. Amiodarone may be considered as a treatment option if this fails or if the diagnosis of VT is confirmed on an ECG. Procainamide may also be considered in stable SVT refractory to vagal manoeuvres and adenosine,[239,302–304] and in stable VT.[239,240,305,306] Do not give procainamide with amiodarone.

Special circumstances

Channelopathy

When sudden unexplained cardiac arrest occurs in children and young adults, obtain a complete past medical and family history (including a history of syncopal episodes, seizures, unexplained accidents/drownings, or sudden death) and review any available previous ECGs. All infants, children, and young adults with sudden, unexpected death should, if possible, have an unrestricted, complete autopsy, performed preferably by pathologists with training and expertise in cardiovascular pathology.[307–316] Consideration should be given to preservation and genetic analysis of tissue to determine the presence of a channelopathy. Refer families of

patients whose cause of death is not found on autopsy to a health care provider/centre with expertise in cardiac rhythm disturbances.

Life support for blunt or penetrating trauma

There is a very high mortality associated with cardiac arrest from major (blunt or penetrating) trauma.[317–320] 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.[321–325]

Single ventricle post-stage 1 repair

The incidence of cardiac arrest in infants following single ventricle stage 1 repair is approximately 20%, with a survival to discharge of 33%.[326] There is no evidence that anything other than routine resuscitative protocols should be followed. Diagnosis of the pre-arrest state is difficult but it may be assisted by monitoring the oxygen extraction (superior vena caval $ScvO_2$) or near infrared spectroscopy (cerebral and splanchnic circulations).[327–329] Treatment of high systemic vascular resistance with alpha-adrenergic receptor blockade may improve systemic oxygen delivery,[330] reduce the incidence of cardiovascular collapse,[331] and improve survival.[332]

Single ventricle post-Fontan

Children in the pre-arrest state who have Fontan or hemi-Fontan anatomy may benefit from increased oxygenation and an improved cardiac output by instituting negative pressure ventilation.[333,334] Extracorporeal membrane oxygenation (ECMO) may be useful rescue for children with failing Fontan circulations but no recommendation can be made in favour or against ECMO in those with hemi-Fontan physiology or for rescue during resuscitation.[335]

Pulmonary hypertension

There is an increased risk of cardiac arrest in children with pulmonary hypertension.[336,337] 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.[338] Resuscitation is most likely to be successful in patients with a reversible cause who are treated with intravenous epoprostenol or inhaled nitric oxide.[339] 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.[340] Right ventricular support devices may improve survival.[341–344]

Post-arrest management

After prolonged, complete, whole-body hypoxia-ischaemia ROSC has been described as an unnatural pathophysiological state, created by successful CPR.[345] Post-arrest management 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.[345–348] Vasoactive drugs (adrenaline, dobutamine, dopamine and noradrenaline) may improve the child's post-arrest haemodynamic values but the drugs must be titrated according to the clinical condition.[349–359]

Temperature control and management

Hypothermia is common in the child following cardiopulmonary resuscitation.[360] Central hypothermia (32–34 °C) may be beneficial, whereas fever may be detrimental to the injured brain. Mild hypothermia has an acceptable safety profile in adults[361,362] and neonates.[363–368] Whilst it may improve neurological outcome in children, an observational study neither supports nor refutes the use of therapeutic hypothermia in paediatric cardiac arrest.[369]

A child who regains a spontaneous circulation, but remains comatose after cardiopulmonary arrest, may benefit from being cooled to a core temperature of 32–34 °C for at least 24 h. The successfully resuscitated child with hypothermia and ROSC should not be actively rewarmed unless the core temperature is below 32 °C. Following a period of mild hypothermia, rewarm the child slowly at 0.25–0.5 °C h^{-1}.

There are several methods to induce, monitor and maintain body temperature in children. External and/or internal cooling techniques can be used to initiate cooling.[370–372] Shivering can be prevented by deep sedation and neuromuscular blockade. Complications can occur and include an increased risk of infection, cardiovascular instability, coagulopathy, hyperglycaemia and electrolyte abnormalities.[373–375]

These guidelines are based on evidence from the use of therapeutic hypothermia in neonates and adults. At the time of writing, there are ongoing, prospective, multicentre trials of therapeutic hypothermia in children following in- and out-of-hospital cardiac arrest (www.clinicaltrials.gov; NCT00880087 and NCT00878644).

Fever is common following cardiopulmonary resuscitation and is associated with a poor neurological outcome,[376–378] the risk increasing for each degree of body temperature greater than 37 °C.[376] There are limited experimental data suggesting that the treatment of fever with antipyretics and/or physical cooling reduces neuronal damage.[379,380] Antipyretics and accepted drugs to treat fever are safe; therefore, use them to treat fever aggressively.

Glucose control

Both hyper- and hypo-glycaemia may impair outcome of critically ill adults and children and should be avoided,[228–230,381–383] but tight glucose control may also be harmful.[231,384] Although there is insufficient evidence to support or refute a specific glucose management strategy in children with ROSC after cardiac arrest,[225,226,345] it is appropriate to monitor blood glucose and avoid hypoglycaemia as well as sustained hyperglycaemia.

Prognosis of cardiopulmonary arrest

Although several factors are associated with outcome after cardiopulmonary arrest and resuscitation[41,60,385–389] there are no simple guidelines to determine when resuscitative efforts become futile.

After 20 min of resuscitation, the resuscitation team leader should consider whether or not to stop.[273,390–394] The relevant considerations in the decision to continue the resuscitation include the cause of arrest,[60,395] pre-existing medical conditions, age,[41,389] site of arrest, whether the arrest was witnessed,[60,394] the duration of untreated cardiopulmonary arrest ('no flow'), number of doses of adrenaline, the $ETCO_2$ value, the presence of a shockable rhythm as the first or subsequent rhythm,[386,387] the

promptness of extracorporeal life support for a reversible disease process,[396–398] and associated special circumstances (e.g., icy water drowning,[277,399,400] exposure to toxic drugs).

Parental presence

In some Western societies, the majority of parents prefer to be present during the resuscitation of their child.[401–410] Parental presence has neither been perceived as disruptive[403,411–415] nor stressful for the staff.[401,403,412] Parents witnessing their child's resuscitation believe their presence to be beneficial to the child.[401–403,410,414–417] 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.[402–404,414,415,417,418]

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.[411] However in out-of-hospital resuscitation, some EMS providers may feel threatened by the presence of relatives or are concerned that relatives may interfere with their resuscitation efforts.[419] Evidence about parental presence during resuscitation comes from selected countries and can probably not be generalised to all of Europe, where there could be different socio-cultural and ethical considerations.

Family presence guidelines

When relatives are allowed in the resuscitation room, a dedicated member of the resuscitation team should be present with the parents to explain the process in an empathetic manner, ensuring that the parents do not interfere with or distract the resuscitation process. If the presence of the parents 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.[411,420–423]

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.

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