10   Paediatric Advanced Life Support

Introduction

There is concern that resuscitation from cardiac arrest is not performed as well as it might because the variations in guidelines for different age groups cause confusion to providers, and therefore poor performance. As in 2005, most of the changes in paediatric guidelines for 2010 have been made for simplification and to minimise differences between adult and paediatric protocols. It is hoped that this will assist teaching and retention.

There remains a paucity of good quality evidence on which to base the resuscitation of infants and children. Most conclusions have had to be drawn from extrapolated adult studies and from experimental work.

In children, secondary cardiopulmonary arrests, caused by either respiratory or circulatory failure, are more frequent than primary arrests caused by arrhythmias.[276] So-called asphyxial arrests or respiratory arrests are also more common in young adulthood (e.g. trauma, drowning, poisoning). The outcome from cardiopulmonary arrests in children is poor[21] and 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 ABCDE 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).
- **D** indicates disability (level of consciousness and neurological status).
- **E** indicates exposure to ensure full examination (whilst respecting dignity and temperature conservation).

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.[84] This team should include at least one paediatric specialist 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).
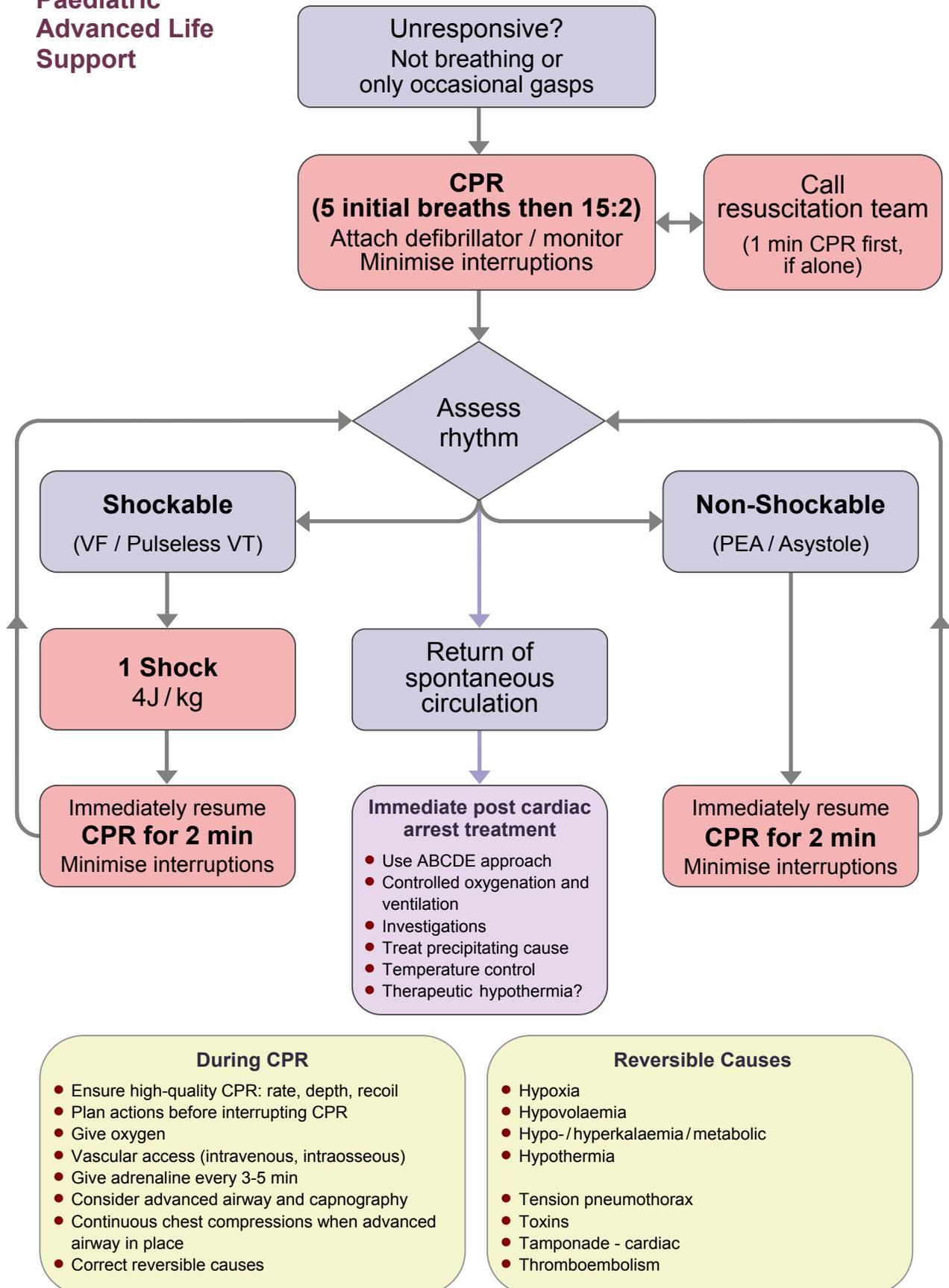
Guideline changes

- Adrenaline is given after the third shock for shockable rhythms and then during every alternate cycle (i.e. every 3-5 min during CPR). Adrenaline is still initially given as soon as vascular access is available in the non-shockable side of the algorithm.

- Amiodarone is given after the third shock for shockable rhythms. The dose is repeated after the fifth shock, if still in ventricular fibrillation/pulseless VT (VF/VT).

- Bag-mask ventilation remains the preferred method for achieving airway control and ventilation. If this fails, the laryngeal mask airway (or possibly other supraglottic airway device) is an acceptable alternative for suitably trained providers.

- Once spontaneous circulation has been restored, delivered oxygen should be titrated to limit the risk of hyperoxaemia.

- CO_2 detection (preferably with capnography) is even more strongly encouraged, not only to confirm placement of tracheal tubes but also to aid decision making during cardiopulmonary resuscitation (CPR) and management of ventilation after return of spontaneous circulation (ROSC).

- Post-resuscitation care should include consideration of induced hypothermia.

Sequence of actions

1. **Establish basic life support (see paediatric BLS chapter).**

2. **Oxygenate, ventilate, and start chest compression:**

   - Provide positive-pressure ventilation with high-concentration inspired oxygen.

   - Provide ventilation initially by bag and mask. Ensure a patent airway by using an airway manoeuvre as described in the paediatric basic life support chapter.

   - If it can be performed by a highly skilled operator with minimal interruption to chest compressions, the trachea should be intubated. This will both control the airway and enable chest compression to be given continuously, thus improving coronary perfusion pressure.

   - Take care to ensure that ventilation remains effective when continuous chest compressions are started.

   - Use a compression rate of 100 - 120 min^{-1}

   - Once the child has been intubated and compressions are uninterrupted, use a ventilation rate of approximately 10 - 12 min^{-1}.

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Paediatric Advanced Life Support

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┌─────────────────────────────┐
│      Unresponsive?          │
│    Not breathing or         │
│  only occasional gasps      │
└─────────────────────────────┘
              │
              ▼
┌─────────────────────────────┐      ┌──────────────────┐
│           CPR               │      │      Call        │
│ (5 initial breaths then 15:2)│◄───►│ resuscitation team│
│ Attach defibrillator / monitor│    │  (1 min CPR first,│
│   Minimise interruptions    │      │    if alone)     │
└─────────────────────────────┘      └──────────────────┘
              │
              ▼
        ◇ Assess ◇
        ◇ rhythm ◇
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Shockable
(VF / Pulseless VT)

Non-Shockable
(PEA / Asystole)

1 Shock
4J / kg

Return of spontaneous circulation

Immediately resume
CPR for 2 min
Minimise interruptions

Immediate post cardiac arrest treatment
- Use ABCDE approach
- Controlled oxygenation and ventilation
- Investigations
- Treat precipitating cause
- Temperature control
- Therapeutic hypothermia?

Immediately resume
CPR for 2 min
Minimise interruptions

During CPR
- Ensure high-quality CPR: rate, depth, recoil
- Plan actions before interrupting CPR
- Give oxygen
- Vascular access (intravenous, intraosseous)
- Give adrenaline every 3-5 min
- Consider advanced airway and capnography
- Continuous chest compressions when advanced airway in place
- Correct reversible causes

Reversible Causes
- Hypoxia
- Hypovolaemia
- Hypo- / hyperkalaemia / metabolic
- Hypothermia

- Tension pneumothorax
- Toxins
- Tamponade - cardiac
- Thromboembolism

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Sequence of actions (continued)

3. **Attach a defibrillator or monitor:**

- Assess and monitor the cardiac rhythm.

- If using a defibrillator, place one defibrillator pad or paddle on the chest wall just below the right clavicle, and one in the mid-axillary line.

- Pads or paddles for children should be 8 - 12 cm in size, and 4.5 cm for infants. In infants and small children it may be best to apply the pads or paddles to the front and back of the chest if they cannot be adequately separated in the standard positions.

- If used, place monitoring electrodes in the conventional chest positions.

4. **Assess rhythm and check for signs of life:**

- Look for signs of life, which include responsiveness, coughing, and normal breathing.

- Assess the rhythm on the monitor:
  - Non-shockable (asystole or pulseless electrical activity (PEA)) **OR**
  - Shockable (VF/VT).

5A. Non-shockable (asystole or PEA):

This is the more common finding in children.

- **Perform continuous CPR:**
  - Continue to ventilate with high-concentration oxygen.
  - If ventilating with bag-mask give 15 chest compressions to 2 ventilations.
  - Use a compression rate of 100 - 120 min^{-1}.
  - If the patient is intubated, chest compressions can be continuous as long as this does not interfere with satisfactory ventilation.
  - Once the child has been intubated and compressions are uninterrupted use a ventilation rate of approximately 10 - 12 min^{-1}.

Note: Once there is ROSC, the ventilation rate should be 12 - 20 min^{-1}. Measure exhaled CO_2 to monitor ventilation and ensure correct tracheal tube placement.

- **Give adrenaline:**
  - If venous or intraosseous (IO) access has been established, give adrenaline 10 mcg kg^{-1} (0.1 ml kg^{-1} of 1 in 10,000 solution).
  - If there is no circulatory access, attempt to obtain IO access.
  - If circulatory access is not present, and cannot be obtained quickly, but the patient has a tracheal tube in place, consider giving adrenaline 100 mcg kg^{-1} via the tracheal tube. This is the least satisfactory route (see routes of drug administration).

- **Continue CPR, only pausing briefly every 2 min to check for rhythm change.**

- Give adrenaline 10 mcg kg^{-1} every 3 to 5 min (i.e. every other loop), while continuing to maintain effective chest compression and ventilation without interruption.

- **Consider and correct reversible causes:**
    - o **H**ypoxia
    - o **H**ypovolaemia
    - o **H**yper/hypokalaemia (electrolyte disturbances)
    - o **H**ypothermia

    - o **T**ension pneumothorax
    - o **T**oxic/therapeutic disturbance
    - o **T**amponade (cardiac)
    - o **T**hromboembolism

- **Consider the use of other medications such as alkalising agents.**

5B. Shockable (VF/VT)

This is less common in paediatric practice but may occur as a secondary event and is likely when there has been a witnessed and sudden collapse. It is commoner in the intensive care unit and cardiac ward.

- **Continue CPR until a defibrillator is available.**
- **Defibrillate the heart:**
    - o Charge the defibrillator while another rescuer continues chest compressions.
    - o Once the defibrillator is charged, pause the chest compressions, quickly ensure that all rescuers are clear of the patient and then deliver the shock. This should be planned before stopping compressions.
    - o Give 1 shock of 4 J kg^{-1} if using a manual defibrillator.
    - o If using an AED for a child of less than 8 years, deliver a paediatric-attenuated adult shock energy.
    - o If using an AED for a child over 8 years, use the adult shock energy.

- **Resume CPR:**
    - o Without reassessing the rhythm or feeling for a pulse, resume CPR **immediately,** starting with chest compression.
    - o Consider and correct reversible causes (4Hs and 4Ts).

- **Continue CPR for 2 min, then pause briefly to check the monitor:**
  - If still VF/VT, **give a second shock** (with same energy level and strategy for delivery as the first shock).

- **Resume CPR:**
  - Without reassessing the rhythm or feeling for a pulse, resume CPR **immediately,** starting with chest compression.

- **Continue CPR for 2 min, then pause briefly to check the monitor:**

- **If still VF/VT, give a third shock** (with same energy level and strategy for delivery as the previous shock).

- **Resume CPR:**
  - Without reassessing the rhythm or feeling for a pulse, resume CPR **immediately,** starting with chest compression.
  - Give adrenaline 10 mcg kg^{-1} and amiodarone 5 mg kg^{-1} after the 3rd shock, once chest compressions have resumed.
  - Repeat adrenaline every alternate cycle (i.e. every 3-5 min) until ROSC.
  - Repeat amiodarone 5 mg kg^{-1} one further time, after the 5th shock if still in a shockable rhythm.

  Continue giving shocks every 2 min, continuing compressions during charging of the defibrillator and minimising the breaks in chest compression as much as possible.

Note: **After each 2 min of uninterrupted CPR, pause briefly to assess the rhythm.**

  - **If still VF/VT:**
    - Continue CPR with the shockable (VF/VT) sequence.
  - **If asystole:**
    - Continue CPR and switch to the non-shockable (asystole or PEA) sequence as above.
  - **If organised electrical activity is seen,** check for signs of life and a pulse:
    - If there is ROSC, continue post-resuscitation care.
    - If there is **no** pulse (or a pulse rate of < 60 min^{-1}), and there are no other signs of life, continue CPR and continue as for the non-shockable sequence above.

If defibrillation was successful but VF/VT recurs, resume the CPR sequence and defibrillate. Give an amiodarone bolus (unless 2 doses have already been given) and start a continuous infusion.

Important note

Uninterrupted, good-quality CPR is vital. Chest compression and ventilation should be interrupted only for defibrillation. Chest compression is tiring for providers. The team leader should continuously assess and feed back on the quality of the compressions, and change the providers every 2 min.

Explanatory notes

Shockable rhythm sequence

The change in timing of administration of adrenaline and amiodarone has been in response to the change in the adult algorithm. There is no evidence that the treatment of VF should differ fundamentally from adult practice except that seeking and treating the reversible causes is particularly important in children because arrhythmias are unlikely to be due to coronary artery disease.

Shock energy level

The ideal energy level for safe and effective defibrillation in children is unknown. The recommendation of 2 - 4 J kg^{-1} in Guidelines 2000 was based on a single historical study of effective outcomes. Extrapolation from adult data and experimental studies shows that biphasic shocks are at least as effective as monophasic shocks and produce less post-shock myocardial dysfunction. Clinical studies have shown that an initial monophasic or biphasic shock level of 2 J kg^{-1} has a low success rate in paediatric VF.[277-279] Paediatric case series have reported that shock levels of more than 4 J kg^{-1} (up to 9 J kg^{-1}) have effectively defibrillated children less than 12 years of age with negligible adverse effects. In experimental studies, high energy levels cause less myocardial damage in young hearts than in adult hearts.

A single 4 J kg^{-1} shock strategy improves first shock success rate and minimises interruption in chest compressions.

Tracheal tubes

Recent studies continue to show no greater risk of complications for children less than 8 years when cuffed, rather than uncuffed, tracheal tubes are used in the operating room and intensive care unit. Cuffed tracheal tubes are as safe as uncuffed tubes for infants (except neonates) and children if rescuers use the correct tube size and cuff inflation pressure, and verify tube position. The use of cuffed tubes increases the chance of selecting the correct size at the first attempt. Under certain circumstances (e.g. poor lung compliance, high airway resistance, and large glottic air leak) cuffed tracheal tubes may be preferable.

Alternative airways

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. 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. Other supraglottic airway devices (e.g. laryngeal tube), which have been used successfully in children's anaesthesia, may also be useful, but there are few data on the use of these devices in paediatric emergencies.

Capnography

Monitoring end tidal CO_2 ($ETCO_2$) (preferably with capnography) reliably confirms tracheal tube placement in a child weighing more than 2 kg with a perfusing rhythm, and its use is strongly recommended after intubation, and during transport of an intubated child. 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 with CPR. Capnography does not rule out intubation of a bronchus. The absence of exhaled CO_2 during CPR does not guarantee tube misplacement because a low or absent end tidal CO_2 may reflect low or absent pulmonary blood flow.

Capnography may also provide information on the efficiency of chest compressions and a sudden rise in exhaled CO_2 can give an early indication of ROSC. Efforts should be made to improve chest compression quality if the $ETCO_2$ remains below 2 kPa as this may indicate low cardiac output and pulmonary blood flow. Care must be taken when interpreting $ETCO_2$ values after the administration of adrenaline or other vasoconstrictor drugs when there may be a transient decrease in values, or after the use of sodium bicarbonate when there may be a transient increase. Current evidence does not support the use of a threshold $ETCO_2$ value as an indicator for stopping the resuscitation attempt.

Routes of drug administration

Although atropine, adrenaline, naloxone, lidocaine and vasopressin are absorbed from the tracheobronchial tree, much lower blood concentrations result than if the same dose were given intravascularly. Conversely, good quality evidence in both adults and children show that intraosseous (IO) access is safe and effective and this route is therefore far preferable to tracheal administration, which should be used only if there is no alternative. Semi-automated devices for inserting IO needles are available. Although there are few data to support their use in children during CPR, reports of their use in other circumstances have shown them to be effective.

Drugs used in CPR

Adrenaline

This is an endogenous catecholamine with potent alpha, $beta_1$, and $beta_2$ adrenergic actions. Although it is central to the treatment algorithms both for non-shockable and shockable cardiac arrest rhythms, a prospective randomised adult study of the use of drugs (including adrenaline) in CPR showed an improvement in ROSC but not in long-term neurologically intact survival.[144] Adrenaline induces vasoconstriction, increases coronary perfusion pressure, enhances the contractile state of the heart, stimulates spontaneous contractions, and increases the intensity of VF so increasing the likelihood of successful defibrillation.

The recommended IV/IO dose of adrenaline in children is 10 mcg kg^{-1}. Subsequent doses of adrenaline should, if needed, be given every 3-5 min. Higher doses of intravascular adrenaline should not be used routinely in children because this may worsen outcome.

Amiodarone

Amiodarone is a membrane-stabilising anti-arrhythmic drug that increases the duration of the action potential and refractory period in atrial and ventricular myocardium. Atrioventricular conduction is also slowed, and a similar effect is seen in accessory pathways. Amiodarone has a mild negative inotropic action and causes peripheral vasodilation through non-competitive alpha-blocking effects. The hypotension that occurs with IV amiodarone is related to the rate of delivery and is due more to the solvent (Polysorbate 80 and benzyl alcohol), which causes histamine release, than the drug itself.

In the treatment of shockable rhythms, give an initial IV bolus dose of amiodarone 5 mg kg^{-1} after the third shock. Repeat the dose after the fifth shock if still in VF/VT. If defibrillation was successful but VF/VT recurs, amiodarone can be repeated (unless two doses have already been injected) and a continuous infusion started. Amiodarone can cause thrombophlebitis when injected into a peripheral vein and, ideally, should be administered via a central vein. If central venous access is unavailable (likely at the time of cardiac arrest) and it has to be given peripherally, it should be flushed liberally with 0.9% sodium chloride or 5% glucose.

Atropine

Atropine is effective in increasing heart rate when bradycardia is caused by excessive vagal tone (e.g. after insertion of nasogastric tube). The dose is 20 mcg kg^{-1} and a minimum dose of 100 mcg should be given to avoid a paradoxical effect at low doses. There is no evidence that atropine has any benefit in asphyxial bradycardia or asystole and its routine use has been removed from the ALS algorithms.

Magnesium

This is a major intracellular cation and serves as a cofactor in many enzymatic reactions. Magnesium treatment is indicated in children with documented hypomagnesemia or with polymorphic VT (torsade de pointes), regardless of cause.

Calcium

Calcium plays a vital role in the cellular mechanisms underlying myocardial contraction, but high plasma concentrations achieved after injection may be harmful to the ischaemic myocardium and may also impair cerebral recovery. The routine administration of calcium during cardiac arrest has been associated with increased mortality and it should be given only when specifically indicated, for example in hyperkalaemia, hypocalcaemia, and overdose of calcium-channel-blocking drugs.

Sodium bicarbonate

Cardiac arrest results in combined respiratory and metabolic acidosis, caused by cessation of pulmonary gas exchange, and the development of anaerobic cellular metabolism respectively. The best treatment for acidaemia in cardiac arrest is a combination of effective chest compression and ventilation (good quality CPR). Administration of sodium bicarbonate generates carbon dioxide, which diffuses rapidly into the cells, exacerbating intracellular acidosis if it is not rapidly cleared via the lungs. It also has the following detrimental effects:

- It produces a negative inotropic effect on an ischaemic myocardium.
- It presents a large, osmotically active, sodium load to an already compromised circulation and brain.
- It produces a shift to the left in the oxygen dissociation curve further inhibiting release of oxygen to the tissues.

The routine use of sodium bicarbonate in cardiac arrest is not recommended. It may be considered in prolonged arrest, and it has a specific role in hyperkalaemia and the arrhythmias associated with tricyclic antidepressant overdose.

Fluids for resuscitation

Hypovolaemia is a potentially reversible cause of cardiac arrest. If hypovolaemia is suspected, infuse intravenous or intraosseous fluids rapidly (20 ml kg^{-1} boluses). In the initial stages of resuscitation there are no clear advantages in using colloid solutions, whatever the aetiology, so use isotonic saline solutions for initial volume resuscitation. Do not use dextrose-based solutions for volume replacement – these will be redistributed rapidly away from the intravascular space and will cause hyponatraemia and hyperglycaemia, which may worsen neurological outcome.[222, 232, 280]

Post-resuscitation care

Oxygen

There is increasing evidence that hyperoxaemia can be detrimental and studies in neonates suggest some advantages in using room air during initial resuscitation (see Newborn Life Support).[270] In the older child there is no evidence for any such advantages, so 100% oxygen should be used for initial resuscitation. After ROSC, inspired oxygen should be titrated, using pulse oximetry, to achieve an oxygen saturation of 94 - 98%.[281, 282] In situations where dissolved oxygen plays an important role in oxygen transport such as smoke inhalation (carbon monoxide poisoning) and severe anaemia, maintain a high inspired oxygen (FiO_2).

Therapeutic hypothermia

Hypothermia is common in the child following cardiopulmonary resuscitation.[231] 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 and neonates and, although it has been shown to improve neurological outcome in adults after VF arrest, an observational study neither supports nor refutes the use of therapeutic hypothermia in paediatric cardiac arrest.[283]

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 rewarmed actively 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}.

Complications of mild therapeutic hypothermia include increased risk of infection, cardiovascular instability, coagulopathy, hyperglycaemia, and electrolyte abnormalities such as hypophosphataemia and hypomagnesaemia.

Hyperthermia is associated with a poorer outcome,[230, 284, 285] so infants and children with core temperatures over 37.5°C should be cooled actively to a normal level.

At the time of writing, there are ongoing, prospective, multicentre trials of therapeutic hypothermia in children following in and out-of-hospital cardiac arrest. (See the US National Institutes of Heath Clinical Trials studies NCT00880087 and NCT00878644). The results from these may change this advice.

Blood glucose control

Neonatal, child and adult data show that both hyper- and hypo- glycaemia are associated with poor outcome after cardiopulmonary arrest but it is uncertain if this is causative or merely an association. Plasma glucose concentrations should be monitored closely in any ill or injured child, including after cardiac arrest. Do not give glucose-containing fluids during CPR except for treatment of hypoglycaemia.

Hyper- and hypo- glycaemia should be avoided following ROSC but tight glucose control has not shown survival benefits when compared with moderate glucose control in adults and increased the risk of hypoglycaemia in neonates, children and adults.

Parental presence

Many parents would like to be present during a resuscitation attempt; they can see that everything possible is being done for their child. Reports show that being at the side of the child is comforting to the parents or carers, and helps them to gain a realistic view of attempted resuscitation and death.[286] Bereaved families who have been present in the resuscitation room show less anxiety and depression several months after the death.

Parental presence in the resuscitation room may also encourage healthcare providers' professional behaviour and facilitate their understanding of the child in the context of his family.

A dedicated staff member should be present with the parents at all times to explain the process in an empathetic and sympathetic manner. They can also ensure that the parents do not interfere with the resuscitation process or distract the resuscitation team. If the presence of the parents is impeding the progress of the resuscitation, they should be gently asked to leave. When appropriate, physical contact with the child should be allowed.

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